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MICHIGAN STATE UNIVERSITY

POTENTIAL IMPACT OF DIGITAL TECHNOLOGY SOLUTIONS ON THE NEW SOO LOCK

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INTRODUCTION

The St. Marys River, the border between Michigan's Upper Peninsula in the United States and the Province of Ontario, Canada, allows marine traffic to navigate between Lake Superior and Lake Huron. The challenge is that Lake Superior is 21 feet higher than Lake Huron, with the St. Marys Rapids between them. There have been navigation locks around the rapids for two centuries, but the current navigation system has only a single lock that can accommodate the largest 1000-foot bulk ships ("lakers") that transport taconite, grain, and scrap from Lake Superior to the other Great Lakes. Since the current Poe Lock is over 50 years old and there is no redundancy that can accommodate the current lakers, the US Army Corps of Engineers (USACE) with the support of the governments of the U.S. and the State of Michigan has allocated resources to build a second identically sized lock to provide additional redundancy and capacity. The rationale for the duplication is to preserve redundancy by not allowing the carriers to build larger ships for the second lock. The new lock's target date to be operational is 2028.

This research, which is being completed by the Axia Institute of Michigan State University under the sponsorship of the Conference of Great Lakes St. Lawrence Governors and Premiers (GSGP) is designed to assess the navigation activity levels through the locks, capacity, capabilities and performance characteristics of the current lock, and the potential for new technology applications at the second lock system. The goal is to provide GSGP stakeholders with insight regarding resource priorities and policy applications as the second lock is constructed and operationalized in order to maximize the new lock system's value to the regional and national economies. The specific research questions include:

1. Considering the marine tracking data, what are the current activity characteristics of commercial vessel traffic through and around the Soo Locks over the past six years?
2. Considering the interviews with representatives of the marine sector (shippers, carriers, government agencies, and the USACE), what are the perceptions regarding congestion, extended navigation, lock operations, activity levels and potential for changes in lock operating policies and technologies?
3. Considering the current lock activity levels and performance enhancements experienced at other locations with enhanced policies and technologies, should these be applied as the second lock is completed? The specific policies and technologies being considered include: 1) Extended or optimized daily operations during winter; 2) Increased decision support for traffic management; 3) Hands-free mooring; and 4) Maintenance scheduling.

The following section describes the Soo Locks operating environment, the activity levels in the current environment, observations from the interviews with the lock stakeholders, data analysis regarding the application of new technologies for the locks and recommendations for future action.

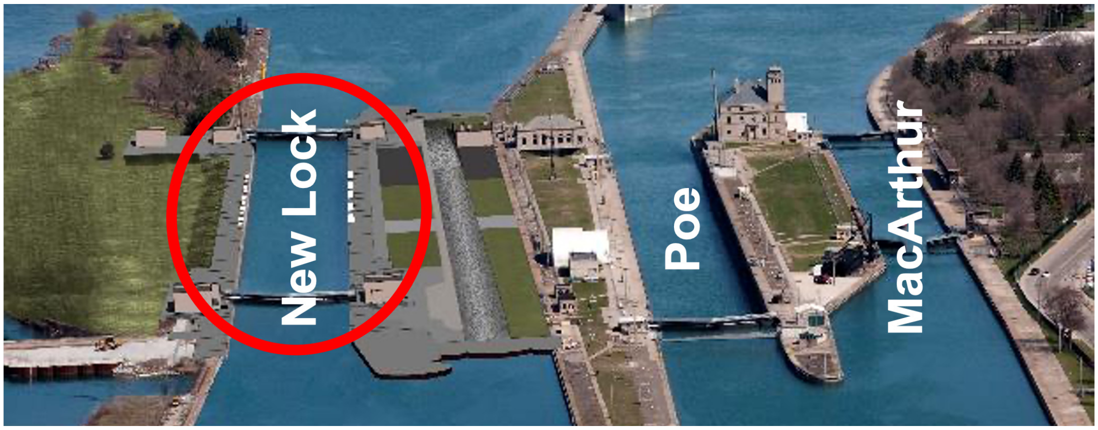
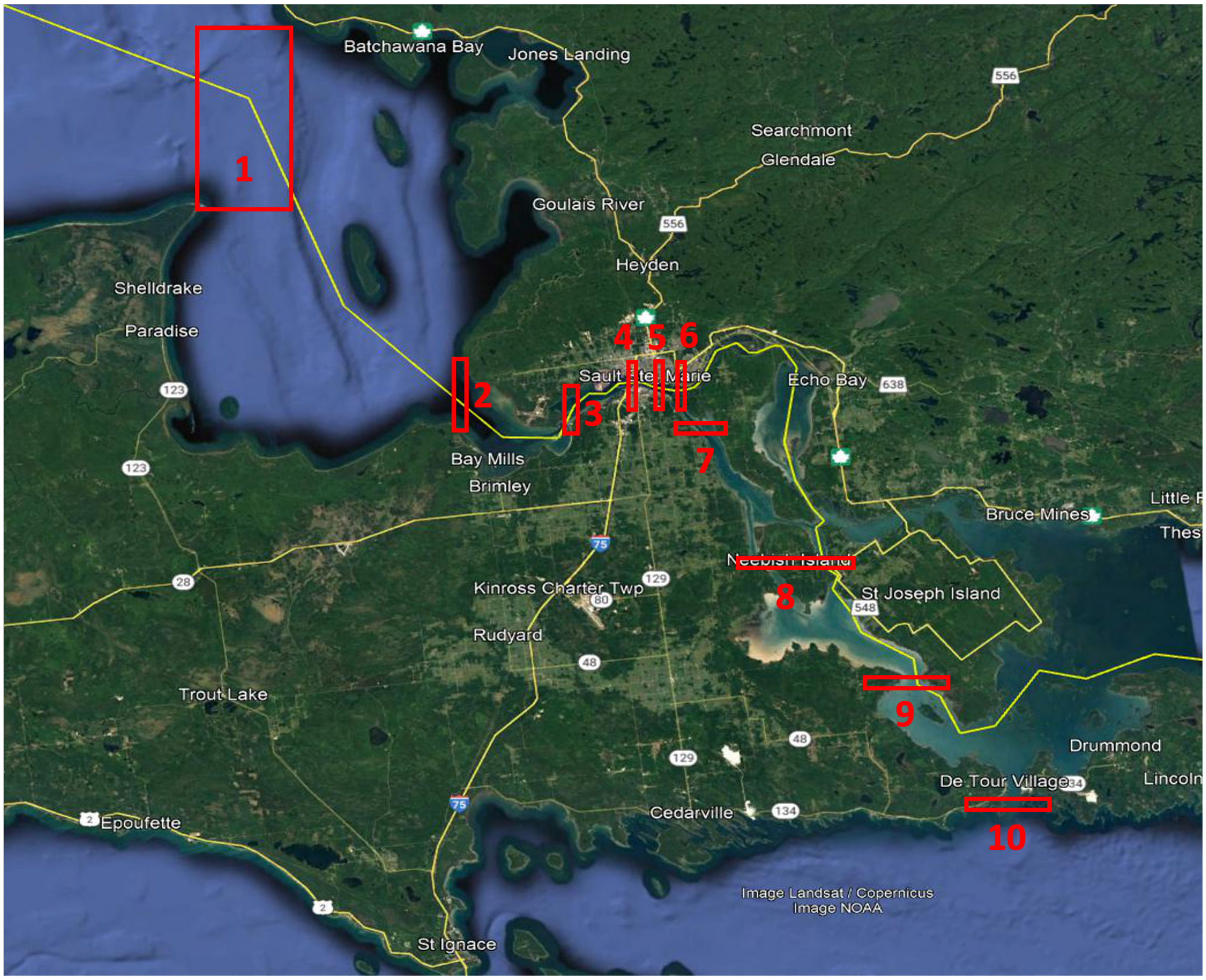


Image courtesy of the USACE

SAULT STE. MARIE LOCKS OPERATING ENVIRONMENT

The St. Marys River is a 70-mile-long connecting channel between the eastern end of Lake Superior and northern Lake Huron near its confluence with Lake Michigan. Water flows from Lake Superior through Whitefish Bay and forms the headwaters of the St. Marys River at Sault Ste. Marie where the Soo Locks allow maritime traffic to traverse a 21-foot hydraulic drop that naturally existed through shallow rapids. Figure 1 illustrates the waterway and other features that are natural bottlenecks to navigation when passing between the lakes. Zones 1 and 2 are the northwest and southeast limits of Whitefish Bay, respectively. Zone 5 is the Soo Locks while Zones 4 and 6 are the western and eastern limits of the piers used to guide vessels into the locks. Zones 8 and 9 are the rock cuts west and east of Neebish Island. Zone 10 is the southern limit of the St. Marys River. St. Marys River navigation is controlled by Vessel Traffic Service (VTS) St. Marys River which is operated by the U.S. Coast Guard (Soo Control). Documentation regarding St. Marys River operations is provided by Vessel Traffic Service St. Marys River User Manual.[1] The Captain of the Port (COTP) Sault Sainte Marie directs all vessel traffic and monitors the VHF call sign of "Soo Traffic." Due to the limitations in channel width at some locations in the St. Marys River, there are one-way traffic areas where meeting, turnarounds and over-taking are prohibited. Two-way traffic is allowed in some areas of the river but there can never be more than two vessels abreast.

Figure 1: St. Marys River and bottlenecks to navigation



Current Activity Levels

Global marine traffic is tracked using location data exchanged between vessels and the Automatic Identification System (AIS) satellites. AIS is required on all passenger vessels and on cargo ships larger than 300 gross tons. The AIS data include vessel name, origin, destination and other characteristics along with location generally updated in one-minute temporal resolution. While these systems are primarily intended for vessel safety and collision avoidance, historical records are publicly available for research purposes through the government website, Marine Cadastre.[2]

Historical AIS data records vessel movement and lock activity which provide a baseline for marine traffic through the St. Marys River and locks. Historical AIS data, downloadable in daily files, contain records for vessels globally. This study used the subset of the data for the years from 2015 to 2021 for key portions of the St. Marys River (Figure 1). The master file was organized to evaluate activity by Great Lakes navigation years, defined as March 25th through January 15th. Within each of the zones shown in Figure 1, multiple records reflect the movement of each vessel. The first record (minimum timestamp) for each voyage through each zone was recorded and later used to assess transit times. The times between the ten zones were calculated as the difference between the first time that a vessel shows up in a zone and the first time it shows up in a previous zone. Time spent in the lock was determined as the difference between the entry and exit of Zone 5. Transit times are calculated as the time difference between records for each vessel. The calculated time delta reflects the travel time between zones.

This resulted in a dataset with 312,462 records including 1,442 vessels over the six-year period. To assess transit times, the study further subset this data to only include passenger, cargo, and tanker vessels (Cargo codes 60-89) and excluded, for example, pleasure craft, rescue vessels, and fishing boats. The subset AIS data therefore included 330 vessels with 118,642 records, representing approximately 10,500 voyages through the waterway.

As is typical for transit times, data reflect a minimum transit time skewed to the right for delayed traffic. Accordingly, median values more accurately represent the expectant transit times as the mean is skewed by long tails. Figure 2 illustrates this for vessel traffic moving through the locks, calculated between Zones 4 and 6. While the mean time from pier-to-pier through the locks was 90 minutes, the median time minimizing the impact of the skewness resulting from the delays was 75 minutes.

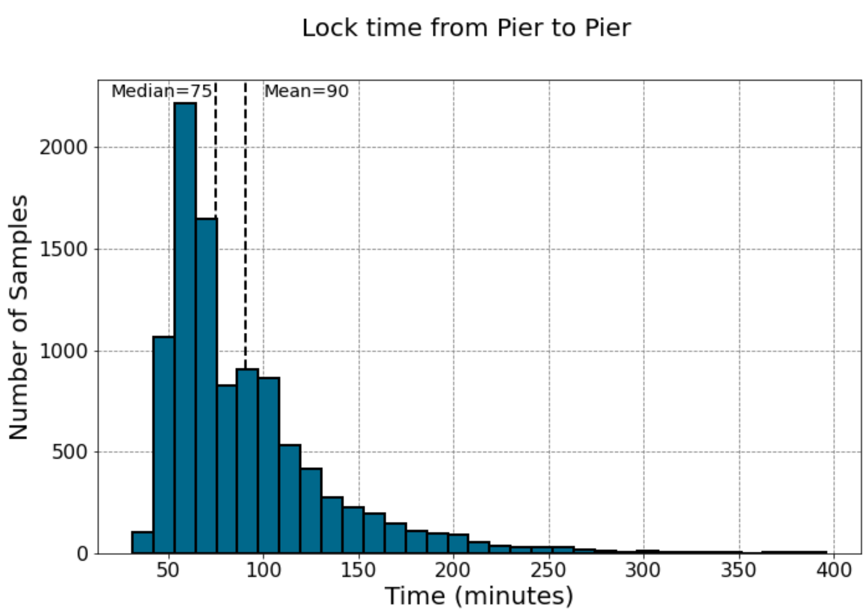


Figure 2: Transit times between approach piers (Zones 4 and 6) through the Soo Locks.

Statistics regarding commercial vessels are summarized in Table 1 for transits through major sectors of the lock system. Median values and standard deviation represent the expected values and uncertainty for transit times. The analysis concludes that the median time in the lock was 41 minutes and the median time from pier-to-pier was 75 minutes. The median total time from Northwest Whitefish Bay to South St. Marys was 10 hours, of which 3 hours was from NW Whitefish to the locks and 4 hours was from South St. Marys to the locks. Another way to assess the degree of uncertainty is the coefficient of variation (CV). CV is the ratio of the standard deviation to the median for the lane. The greater the CV for a lane, the greater the uncertainty and relative magnitude of delays. As shown in Table 1, the time through the locks had a low CV (0.25), while the CV from North St. Marys to the locks (0.42), CV from NW Whitefish Bay to S St. Marys (0.50), and the CV time through the locks (0.51) were moderate. The CVs for S St. Marys to the locks (0.95), NW Whitefish to the locks (1.20), and Mid St. Marys to the locks (1.24) were the largest and demonstrated the most significant variation or uncertainty relative to the median value. This implies that these voyage segments had the largest relative uncertainty. A comparison of the CVs indicates that there was relatively low variability in close proximity to the locks even though the movement from entering the St. Marys River to the locks may have demonstrated significant variability. Specifically, there was high variability from NW Whitefish Bay to the locks, S St. Marys to the locks, and Mid St. Marys to the locks. These results indicate that most of the uncertainty occurred when the vessels were queuing and sequencing into the locks.

Image courtesy of the USACE

Table 1: Operating statistics through major portions of the channel

Lane	Zones	Sample Size	Mean	Median	Standard Deviation	Coefficient of Variation
NW Whitefish Bay to S St. Marys	1-10	10,350	12 hrs	10 hrs	6 hrs	0.50
Through Locks (Pier-to-pier)	4-6	10,009	90 min	75 min	46 min	0.51
Through Locks (Gate-to-gate)	5	9,951	44 min	41 min	11 min	0.25
NW Whitefish to Locks	1-4	10,404	5.6 hrs	3.0 hrs	6.7 hrs	1.20
North St. Marys to Locks	2-4	9,183	100 min	87 min	42 min	0.42
S St. Marys to Locks	6-10	10,360	5.9 hrs	4.0 hrs	5.6 hrs	0.95
Mid St. Marys to Locks	6-8	10,255	2.5 hrs	2.0 hrs	3.1 hrs	1.24

The impact of seasonal variations is assessed by comparing the transit times through the locks and channels with the expectation that winter months, with ice floes, would exhibit longer delays. Winter months are defined as March and April--months when the locks are operational and when ice conditions are most persistent in the waterway. The data indicate that expected winter transit times were only slightly longer than in summer, but variations were greater. For example, transits through the entire channel had the same median time of 11 hours in winter and summer, but the standard deviation was much higher in winter. Longer transit times through the locks in wintertime, reflected in pier-to-pier statistics, exhibited a 15 percent delay likely due to ice blockages. Table 2 indicates that the median time and CV were not significantly different for gate-to-gate operations for summer and winter operations. However, the summer-winter transit time between the piers and between Whitefish Bay and the S St. Marys demonstrated an approximately 15 percent difference in mean and standard deviation. The result was that the season did not make much difference in the time between the piers, but vessels were slower between piers and in overall time during the winter.

Table 2: Transit time comparison for summer (May-Jan) and winter (Mar-Apr) months

Lane	Zones	Sample Size	Mean	Median	Standard Deviation	Coefficient of Variation
Summer Locks (Gate-to-gate)	5	8,916	44 min	41 min	11 min	0.25
Winter Locks (Gate-to-gate)	5	1,038	45 min	41 min	12 min	0.27
Summer Locks (Pier-to-pier)	4-6	9,015	89 min	74 min	44 min	0.49
Winter Locks (Pier-to-pier)	4-6	1,044	102 min	85 min	56 min	0.55
Summer Whitefish Bay to St. Marys	1-10	9,237	11.8 hrs	11.0 hrs	5.9 hrs	0.50
Winter Whitefish Bay to St. Marys	1-10	1,095	13.9 hrs	11.0 hrs	6.9 hrs	0.50

The U.S. operates two locks at Sault Ste. Marie. The largest lock is the Poe Lock which was re-built in 1968 and is 1,200 feet long and 110 feet wide. The Poe Lock is the only lock that can accommodate the 1,000-foot lakers. The MacArthur Lock was built in 1943 and is 800 feet long and 80 feet wide. While the MacArthur Lock can accommodate the smaller commercial vessels, such as the "Salties" that must navigate the Welland Canal (bypassing Niagara Falls), it cannot accommodate the 1000-foot lakers.

The analysis next compared the transit times through the Poe and MacArthur Locks by segregating traffic at latitude 46.5027 N. The Poe lock, which handles 85 percent of marine traffic, exhibited longer transit times, likely due to larger vessel size, increased traffic level and the volume of water needed to operate the larger chamber. The results indicate that the difference between the mean and median time between the Poe and MacArthur Locks was about 5 minutes (11%) and the difference in standard deviation was 1 minute, or 10 percent. While there is a large difference in the number of transits (8,290 for Poe and 1,625 for MacArthur), an 11 percent time difference is still significant. The difference is probably due to two factors. The first is congestion at the entry piers which are relatively near the entrance to both locks. The second, and probably more significant, is the water volume of the lock. The Poe Lock has about 2.24 times the water volume of the MacArthur Lock. While the Poe Lock has larger tunnels moving the water into and out of the lock, it is still much slower to fill and empty resulting in more of a delay.

Table 3: Transit time comparison for Poe and MacArthur Locks

Lane	Zones	Sample Size	Mean	Median	Standard Deviation
Poe Lock (Gate-to-gate)	5	8,290	45 min	42 min	11 min
MacArthur Lock (Gate-to-gate)	5	1,625	39 min	37 min	10 min

As U.S. and Canadian vessels represent the majority of vessel traffic, the analysis compares statistics for the two countries with the expectation that Canadian vessels that can operate both on the lakes and in the ocean ("Salties") would exhibit longer transit time due to a lack of bow and thruster control resulting in reduced maneuverability. While not all "Salties" are Canadian, many are. There are also Canadian lakers which were treated the same as U.S. lakers in the analysis since both use the larger Poe Lock. Vessels from the two countries exhibited identical median transit times through the channel, but Canadian vessels had a 19 percent higher variance and therefore longer average travel times than U.S. vessels. Further investigation of key segments in the waterway revealed that delays were most concentrated in the upstream portions of the waterway, particularly Whitefish Bay. These results suggest that Canadian vessels took 25 percent less time pier-to-pier and had standard deviations that were 25 percent less. The rationale for this difference is likely that Canadian or other "Salties" can use the MacArthur Lock which is less congested. However, when one measures the time between Whitefish Bay – S St. Marys, Whitefish Bay - pier, St. Marys, and Whitefish Bay, time for Canadian vessels ranged from 6 – 59 percent greater with the mean difference of 30 percent. The conclusion is that Canadian vessels have an advantage through the locks likely due to their ability to use the MacArthur Locks but have a disadvantage in all other movements from Whitefish Bay to S St. Marys.

Table 4: Transit time comparison between U.S. and Canadian flagged vessels.

Lane	Zones	Sample Size	Mean	Median	Standard Deviation
U.S. Locks (Pier-to-pier)	4-6	6,057	101 min	93 min	49 min
Canada Locks (Pier-to-pier)	4-6	2,693	76 min	64 min	37 min
U.S. Whitefish Bay to St. Marys	1-10	6,174	11.7 hrs	10.2 hrs	5.1 hrs
Canada Whitefish Bay to St. Marys	1-10	3,008	13.8 hrs	10.0 hrs	7.9 hrs
U.S. Whitefish Bay	1-4	6,391	5.1 hrs	3.5 hrs	5.7 hrs
Canada Whitefish Bay	1-4	3,041	8.1 hrs	3.7 hrs	8.6 hrs
U.S. St. Marys	6-10	6,201	6.2 hrs	4.9 hrs	5.6 hrs
Canada St. Marys	6-10	2,826	6.6 hrs	4.7 hrs	6.1 hrs
U.S. Whitefish Bay	1-2	6,243	3.4 hrs	2.0 hrs	5.6 hrs
Canada Whitefish Bay	1-2	3,563	4.7 hrs	2.0 hrs	7.3 hrs

Year-to-year changes in vessel traffic may also affect waterway delays. For example, traffic through the Poe Lock changed considerably in recent years when demand declined during the Covid-19 pandemic and then surged in 2021 when traffic returned.

Table 5: Cargo ship lockages by year.

Year	Poe Lockages	Mac Lockages	Total
2015	1,444	325	1,769
2016	1,336	257	1,593
2017	1,215	233	1,448
2018	1,159	174	1,333
2019	907	196	1,103
2020	410	143	553
2021	2,495	600	3,095

2020 and 2021 represent abnormally low and high maritime traffic periods, respectively. While one might expect high traffic years to result in higher transit times due to longer wait times and queuing in the connecting channel, a comparison of transits through the entire waterway, and those from pier-to-pier at the Soo locks, show otherwise. Median times for both populations were nearly identical for the two years, however, median transit times in 2021 through the entire system were longer due to higher variance in that year. This is likely reflective of higher congestion and longer queuing in the approach channels as vessels adjust speed in the channel prior to entering the locks. The results indicate that mean and median transit times are about 10 percent greater due to the higher vessel volumes in 2021. Table 6 also illustrates that the 2021 standard deviation is almost double that of the 2020 performance demonstrating the impact of volume on delays.

Table 6: Transit time comparisons for high and low traffic years.

Lane	Zones	Sample Size	Mean	Median	Standard Deviation
2020 Whitefish Bay to S St. Marys	1-10	542	11 hrs	10 hrs	3.2 hrs
2021 Whitefish Bay to S St. Marys	1-10	2,969	12 hrs	10 hrs	6.2 hrs
2020 Through Locks (Pier-to-pier)	4-6	552	82 min	68 min	45 min
2021 Through Locks (Pier-to-pier)	4-6	2,898	89 min	73 min	43 min

Image courtesy of the USACE

Interview Perceptions

The second stage of the research used interviews to identify stakeholder perceptions of congestion and technology applications. The interviews included one-hour discussions with USACE personnel, contractors for lock maintenance and construction, carriers, mooring firms, and pilots. There were a total of eight interviews involving eleven individuals. The majority of the interviewees represented senior management or staff for lock design and construction, operations, carriers and USACE. Two of the interviews involved individuals who are involved in hands-on operations at the locks. The following summarizes the observations from the interviews.

Congestion

The first interview focus concerned congestion in the approach channels to the locks and in the St. Marys River. While the performance data suggested that there is some congestion, the interview responses indicated that they did not think it was a major problem. The reason interviewees did not consider this to be a problem was their belief that there was no way to make significant changes to the existing system. The rationale for this position is that the channels into the locks, particularly from S St. Marys, are narrow which makes passing difficult. The COTP reviews the vessel when it is beginning its approach to the locks, either from the north or the south, and determines whether a trailing vessel should pass the one in front of it to take advantage of its speed so that there is not a queue of vessels following a slower one. According to the interviewees, it is not common to shift vessel sequence once they have entered the River. This is similar to a slower-moving truck on a narrow two-lane road where there are a number of faster trucks that cannot pass. Since the slower-moving truck limits the speed of all the vehicles, it effectively creates a queue at the next processing resource such as a stop light, toll booth, weigh station or lock.

The U.S. Coast Guard limits the vessel speed on the St. Marys River to 8-14 miles per hour, with lower speeds imposed as the vessel approaches navigation hazards and as the vessel approaches the locks. Maximum vessel speed is also reduced by 2 miles per hour during the winter navigation season. As a result, vessel speed and passing are limited when vessels are between the NW Whitefish Bay and S St. Marys. Congestion is also caused by the “Salties” which must have pilots and do not have bow thrusters, causing them to be less maneuverable and operate at slower speeds, particularly near the locks. The combination of slower speed and inability to pass results in systemic congestion without any obvious means to resolve it.

A major source of congestion are the delays incurred due to lock mechanical and maintenance issues. To estimate the magnitude of these delays, the research considered the time spent in the locks (Zone 5) and at the gates (Zones 4 and 6). The median time spent in the lock was 41 minutes, and the standard deviation was 11 minutes. The analysis assumed that any vessels that remained in the lock or at the gate for more than the median (41 minutes) plus two standard deviations (2 * 11 = 22 minutes), for a total of 63 minutes or more, likely resulted from mechanical or maintenance problems. Using this limit, 245 vessels took more than 63 minutes to get through the lock during the six years. This represented about 2.45 percent of the vessels, or 41 vessels per year. Considering the winter closure, this amounts to about one mechanical delay per week.

The next question concerned whether there was a difference between U.S. and Canadian vessels transiting the locks. The interviewees had mixed perceptions. For the most part, the U.S. shippers and carriers did not believe there was a significant difference between U.S. and Canadian transit times. However, the

Canadian shippers and carriers felt that the Canadian vessels were disadvantaged in the sequencing. In general, the Canadian vessel times are less than the U.S. vessel times in terms of the median and standard deviations for pier-to-pier. However, in virtually all other cases, the Canadian mean, median, and standard deviations are greater than the U.S. times. There are two likely reasons for this difference. First, there are a number of Canadian ore ships that load taconite at Algoma Steel which is just above the locks in Sault Ste. Marie, Ontario. Once these vessels pull away from the loading dock, they are queued to go downbound through the locks. As a result, these vessels can bypass most of the distance from NW Whitefish Bay to the locks. The second reason is that many of the Canadian vessels are smaller than the lakers so they can fit through the MacArthur Lock. With these two exceptions in the immediate area of the locks, U.S. vessels have a shorter mean, median and standard deviation. In general, the conclusion is that Canadian vessels take additional time except for the pier-to-pier moves.

Seasonal navigation

The second interview focus considered seasonal navigation restrictions and operations. The ice in the channels and locks limit the shipping season to March 25th through January 15th. While the season could theoretically be extended on the margins depending on the weather, there are currently no guarantees as the heavy lock maintenance is scheduled during the winter down time and it is typically not possible to open and close the locks to respond to breaks in the weather. While the season could be further extended through the use of icebreakers, the interviewee's perceptions are that an extended season is neither necessary nor economically viable.

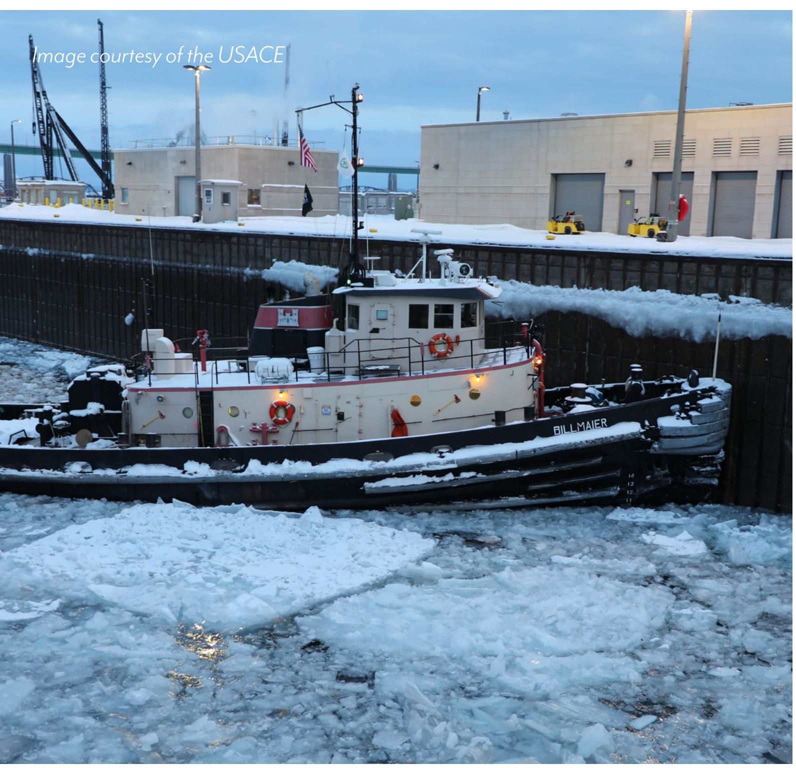


Image courtesy of the USACE

Winter operations using icebreaking capabilities are named "Operation Taconite." Interviewees believe that substantial winter operations are not necessary because the mines, mills, and port operators have used stockpiling to accommodate seasonal operations. Stockpiling refers to the building up of taconite, grain, scrap, or other commodities at the shipping and receiving ports in anticipation of winter season shutdowns. Stockpiling at the source provides a buildup of material so it is ready to be loaded into vessels when the navigation season begins. Stockpiling at the destination provides inventory for the mills to process during the winter season.

Extended winter navigation would require a significant increase in icebreaking capacity. With nine large icebreakers on the northern lakes (often with 2-3 in maintenance), it is common for lakers to get stuck on the lakes or in the channels causing delays and possibly vessel damage. While the vessels often move in convoys led by an icebreaker in the winter, changes in temperature, wind and weather can bring the convoy to a stop for days or even a week when the ice becomes too thick or when an icebreaker is not available.

In terms of economic viability, another winter challenge results from the removal of summer navigation buoys that are replaced with less effective winter buoys which do not include comparable electronics and are not as accurate. There is also an increased probability that a buoy might be missing or out-of-location due to ice. Another solution is electronic buoys (virtual buoys) that can be used in the channels during the winter. However, there is some reluctance to use virtual buoys when visibility is low which is often the case during the winter.

In sum, the interviews suggested that there is no economic benefit of extended winter operations for either the lakers or the "Salties." The lakers would not benefit as they currently move the annual demand for taconite, grain, and other commodities in the ten months of the current shipping season. While they could haul an additional two months with seasonal extension, due to stockpiling there is no demand for the additional two months of volume and the vessel assets could not be reduced since the vessels have such a long life cycle. In the case of "Salties," season extension would not provide any economic benefit as their access to and from the ocean is already restricted due to ice in the Welland Canal and St. Lawrence River.

Technology Applications

The interviews also considered the application of advanced technologies for the second lock and potentially for the Poe Lock as well. Specific technologies that were considered include vessel management decision support, Hands-free Mooring (HFM), and the use of one-way locks. The interviewees' observations regarding each technology are discussed below.

Vessel Traffic Flow Management (VTFM) refers to the use of information technology-based decision support systems to aid in the guidance and sequencing of vessels based on direction, traffic volume, weather and the position of other vessels. Currently, vessel traffic management is controlled by the COTP and Soo Traffic who monitor all vessel traffic from NW Whitefish Bay to S St. Marys based on experience, judgment and communications using radio, telephones and the Internet. Since maritime traffic management is similar to the routing and sequencing methods used for air and land transportation and is sometimes used for marine applications, the thought is that sequencing algorithms might be useful for vessels on the Lakes and in the channels.

Developed beginning in 2017, a VTFM system is now used in the St. Lawrence Seaway to enhance forecasts of near-term traffic, develop more sophisticated traffic management tools for Seaway vessel traffic, and disseminate additional information to stakeholders/users. The specific VTFM vision is to:

1) Predict vessel transit times, forecast queues and delays;
2) Share long-range traffic forecasts with users in exchange for voyage data; and,
3) Provide strategic and tactical tools to traffic managers and carriers.

The specific benefits provided by a VTFM include predictability for:

1) Voyage planning;
2) Lock availability;
3) Berth availability;
4) Pilot availability; and
5) Lift bridge availability.

The arguments for a VTFM on the Upper Great Lakes of Erie, Huron, Michigan and Superior are to provide consistent decision support throughout the entire Great Lakes St. Lawrence system and to provide vessel captains insight regarding traffic, speed, perception of increased navigation sophistication and resource availability, particularly when in constrained areas such as channels and locks. The counterargument, however, is that there is enough room on the Lakes for the captains to use existing technologies such as telecommunications, radar, GPS, and the Internet to access the required information with enough accuracy in all but the most constrained areas (i.e., The Soo Locks). The stakeholder interviews suggested that technology-assisted VTFM might not result in any substantial reduction in transit time, but there could be benefits for voyage planning as well as lock, berth, and pilot availability.

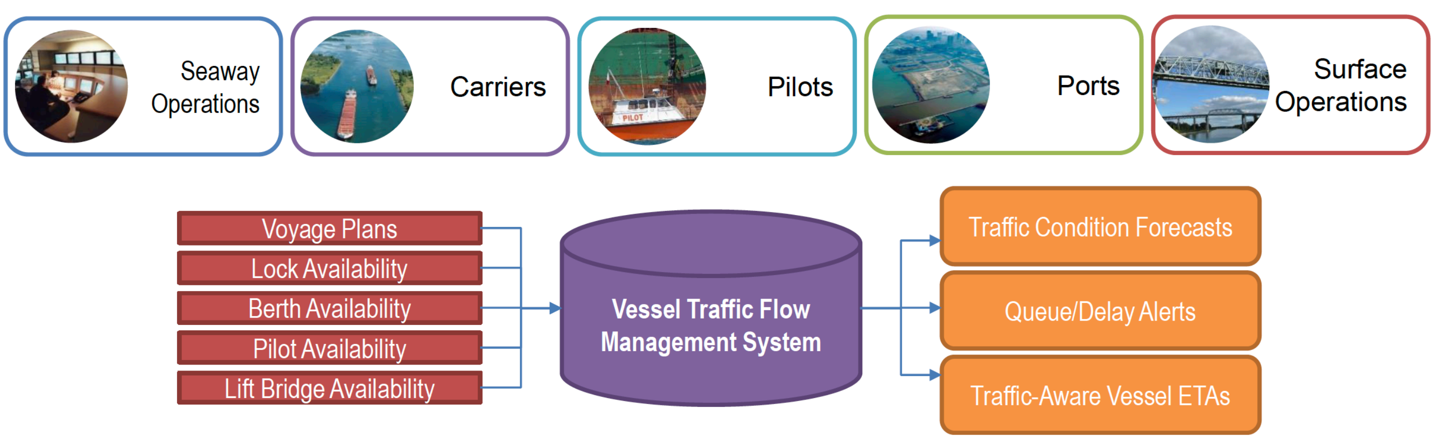


Image courtesy of the GLS

The primary rationale for the perceived lack of potential improvement through the use of VTFM is that the vessel speed is restricted once vessels are in the channel from NW Whitefish Bay to S. St. Marys, and limited passing is allowed due to the narrowness of the channels. While there could be an argument for a VTFM in the St. Marys River due to the constraints and congestion, the benefits would probably not be significant due to speed and passing limitations. While a VTFM system may assist in resource (locks, berths, pilots) allocation, it is important to provide the captains with significant flexibility when considering the course, speed, wind, weather, and traffic. In any case, most vessel captains would likely rely on their radar and their judgment to navigate on the Lakes unless there is an expected constraint such as in the St. Marys River or at the locks.

Hands-free Mooring (HFM) is another technology discussed during the interviews. Instead of traditional mooring lines which must be handled manually, HFM uses a combination of articulating arms built into the side of the lock chamber attached to vacuum pads. These articulating arms are connected to the sides of the lock chamber using rails that allow the pads to move up and down with the vessel as the water level in the lock changes. When the vessel is in the lock, the arm moves the pad to the side of the vessel where it locks to the vessel using suction. The vessel is then held in place with 8-10 mooring arms. Figure 3 illustrates a hands-free mooring system. A review of the literature and discussions with the interviewees indicates that HFM could benefit the locks (both the Poe and the second lock) by reducing labor staffing, reducing fuel and emissions during mooring operations, and increasing safety, particularly in windy and icy weather. HFM also reduces fuel consumption and emissions by allowing the vessel to reduce its power level since the vessel does not need engine power to hold itself in place. While HFM presents challenges in winter due to icing on the pads and for "Salties" due to vessel design, interviewees reported that the benefits for the lakers are substantial enough to justify the installation. HFM systems have already been installed and used successfully in the St. Lawrence Seaway locks, so similarly installing them at the Soo locks creates the added benefit of consistent technology throughout the Great Lakes St. Lawrence system.

The safety advantages of HFM include the reduction in the number of personnel to handle the lines around the lock. As the vessel moves through the locks, it must be attached to the side of the lock so that the vessel does not hit the side of the lock or the gate. In addition, the lines must be adjusted as the vessel moves, rises and declines with the water in the lock. Two other safety issues that must be considered are the water on the lock and vessel deck which results in slippery decks and cables. While the problem is more significant in colder weather due to icing, water from waves and wet cables makes the decks slippery throughout the year. The wet decks increase the danger that the line handler might slip and be injured. The other danger results from the cable tension when a cable is connected to the lock and the vessel. This tension increases the possibility that the cable could snap or a line handler could be caught. While neither of these are common, they are a safety risk.

The operational advantages include the economic benefits of HFM, including reduced deck crew, faster passage through the locks, reduced fuel utilization and fewer greenhouse gas emissions. Specifically, benefits include efficiency, saving time and resources, as the maneuver is faster than mooring manually with cables, with fewer crewmembers needed for the procedure; safety, with appreciable improvements for personnel safety both ashore and onboard since incidents with mooring cables are prevented; and stable vessel remains in position during the lockage. The experience in the Welland Canal is that HFM reduces time in the lock by 40-45 minutes which is projected to increase annual vessel cycles by one. This would be a substantial reduction in lock time for the Soo.

The commercial advantages of HFM include facilitating more bulk cargo volume through the locks with additional vessel cycles. HFM also facilitates the passage of more "Salties" with other cargo types such as machinery, windmills, and other project cargo. While these types of commodities have been shipped through the lower lakes, there has not been a substantial volume moved to Lake Superior ports so HFM could facilitate a broader range and greater number of commodities to markets around Lake Superior. The use of HFM should also raise the perception of the technological sophistication of Great Lakes navigation.

HFM should also be retrofitted in the Poe Lock as it goes through its major maintenance following the opening of the second lock. The rationale for retrofitting the Poe Lock with HFM are:

1) Consistency of operational procedures between the two

locks;

2) Increased operational safety;

3) Reduced operating costs due to less labor;

4) Increased operational consistency with the St. Lawrence Seaway; and,

5) Increased appearance of technical sophistication to attract more vessel traffic to Lake Superior. The only real negative of retrofitting the Poe Lock with HFM is the cost but Axia believes that the long-term increases in consistency and safety are worth the investment.

Another technology considered in the interviews was one-way locking. In essence, one lock would be used for downbound (Lake Superior to Lake Huron) traffic, and the other lock would be used for upbound traffic. The thought is that this approach would simplify directions getting into the locks and reduce congestion. The general perception of the stakeholders is that a one-way system would not enhance operations at the Soo Locks. They believe that one-way locking would not be effective due to the relatively narrow channels which often make it impossible for two vessels to pass each other and because it takes more time for the lock chambers to fill and empty. It would add about 30 minutes to transit times to cycle the lock between ships going one way, which would translate to an increased average lock time of about 70 minutes (From 41 minutes).

Where twin locks exist, such as in the Panama Canal and on the Ohio River, except in cases of heavy congestion the locks do not tend to be operated simultaneously due to "chamber interference." Chamber interference is caused by the hydraulic dynamics that occur when there is both a vessel exiting a lock and water being discharged from the second lock at the same time. The result is that the entering or exiting vessel would be difficult to control. The most efficient way to operate a lock is to open one gate, allow one vessel to enter the chamber, close the gate, allow water to flow into or from the lock (depending on whether the vessel is being lowered or raised), open the gate and allow the vessel to exit the lock. Once the vessel that was in the lock clears, another vessel going in the opposite direction from the one that was in the lock moves into the lock. There are challenges if a ship is waiting at a second lock door adjacent to the lock that has just been opened due to the volume of water that has just been released and the close proximity to the ship that is leaving the first lock. As a result, ships would have to queue further away from the locks which would be inefficient and require careful coordination to avoid collisions.

Figure 3. Illustration of Hands-free Mooring from the St. Lawrence Seaway (Image courtesy of the GLS)

CONCLUSIONS

A synthesis of the Soo Locks activity data and the interviews suggests the following conclusions.

Redundancy

The principal benefit of a second lock is redundancy. In the case of an unexpected closure of one lock, which has happened in the case of ship collisions with the lock or lock wall, the other lock can continue to operate. With the addition of a second lock, USACE can schedule one lock to be open for passage while the other is being maintained. This will substantially reduce unexpected maintenance delays. As discussed above, the analysis estimates that a maintenance shutdown occurs about once per week during the shipping season and this should be reduced to essentially zero with the availability of the second lock. From a strategic perspective, investment in redundancy demonstrates the willingness of the U.S. government to make a substantial commitment to infrastructure that will enhance supply chain performance and reduce supply chain risk.

Congestion

The skewness and standard deviations for many of the reported vessel movements demonstrate how much travel times vary for many of the transits. Movement from gate-to-gate within the locks has a relatively low coefficient of variation, indicating that this is a minor source of uncertainty. Movement from NW Whitefish Bay to S St. Marys and pier-to-pier reflect a moderate amount of variation. This indicates that downbound moves have a moderate amount of uncertainty. The greatest amount of variation is evidenced in the upbound movements, which demonstrated twice the variation of the downbound movements. It appears that the major source of congestion is the delay in vessels sequencing as they move into the locks from S St. Marys.

There was some belief that one-directional locking might be useful for reducing congestion. The potential of one-way locking was discussed with the stakeholders in the interviews and while the stakeholders understood the potential, they did not think that it would be viable for the Soo Locks. The major reason why one-way locking would not likely be viable at the Soo is the narrowness of the channels, particularly for upbound transits.

Seasonal Extension

One change under consideration with the construction of the second lock is the possibility of extending the season by delaying the current closing and opening the locks earlier. The redundancy of the second lock would reduce the risk of potential damage due to ice or other navigational challenges. A major reason for the seasonal shut-down is to provide time for extensive maintenance. A second lock would provide much more flexibility as one lock could be shut down for maintenance while the other could be used for extended operations. While it might be possible to extend the season with the second lock, the general feeling of the stakeholders is that seasonal extension was neither useful nor viable. The stakeholders also felt that extended operations would require additional icebreaking capacity. Another concern with extended season operations is the removal of navigation buoys, particularly in the St. Marys River, which are removed in the winter to protect them from ice.

Sequencing and Scheduling

Sequencing and scheduling refers to the practice of queuing or otherwise coordinating vessel movements to optimize vessel speed and to ensure the availability of the locks or other key infrastructure upon the vessel's arrival. This is a common practice in transportation to make effective use of a constrained channel in a land or marine environment. While this is a basic principle of transportation, it is not an appropriate application for the Soo Locks. To be effective, scheduling and sequencing must allow for vessels to pass in the channel. Since vessel speed is limited and there is limited room to safely pass in the channel, particularly below the locks, scheduling and sequencing would not be a very effective option.

Another strategy to enable more efficient sequencing and scheduling would be the use of a vessel traffic flow management (VTFM) system. Use of VTFM on the Upper Great Lakes would provide consistent decision support throughout the entire Great Lakes St. Lawrence system and provide vessel captains insight regarding traffic, speed, perception of increased navigation

Image courtesy of the USACE

sophistication and resource availability, particularly when in constrained areas such as channels and locks. However, there is enough room on the Lakes for the captains to use existing technologies to access the required information with enough accuracy in all but the most constrained areas. VTFM might not result in any substantial reduction in transit time through the Soo Locks, but there could be benefits for voyage planning as well as coordinating lock, berth, and pilot availability.

Hands-Free Mooring

Hands-free mooring (HFM) offers many advantages to lock operations for both the second lock and a retrofit for the current Poe Lock. These include safety advantages, operational advantages, and commercial advantages.


Image courtesy of the USACE

RECOMMENDATIONS

- Move forward with the construction and opening of the second lock to provide the critical redundancy and sustainability of Soo Lock operations. The need for a redundant lock is obvious to provide for a backup in case of lock, gate or pier damage, or terrorist incident. The second lock also allows for optimized maintenance to ensure that one lock remains operational at all times;
- Implement Hands-free Mooring (HFM) for both the new lock and the Poe Lock. The HFM systems should be compatible between these two locks and with the system in place in the St. Lawrence Seaway;
- Consider the application of a Vessel Traffic Flow Management (VTFM) system consistent with that used in the St. Lawrence Seaway. The system should focus on voyage planning as well as lock, berth, and pilot availability. The VTFM will make the upper Great Lakes more attractive for "Salties" with a wider range of commodities.
- Utilize only one of the major locks at a time (Poe and second). One lock should be used for moving vessels (downbound and upbound) while the other is either being maintained or in a holding status;
- Further Investigate the source of variability as vessels move closer to the locks from either Lake Superior or the lower St. Marys River. While the pier-to-pier time and the lock times are relatively consistent, there is significant variation from NW Whitefish Bay to the locks and from the S St. Marys and Mid St. Marys to the locks. It would be useful to find out the reason for such variation to help identify potential improvements;
- Investigate the impact of significant increases in vessel volume through the locks. This investigation should include the use of simulation to understand the dynamics of vessel volume and uncertainty on lock operating capacity; and
- Reduce the focus on seasonal extension. While extensions might be useful on the margin, winter operations are difficult and dangerous and there is not a strong economic argument.

In summary, this research has demonstrated that there is significant congestion in the channels moving into the locks both northbound and southbound. The channel width and other marine hazards result in relatively slow vessel movement through the St. Marys River. The second lock and HFM will facilitate movement through the locks due to less time in the lock (HFM), reduced delays (redundancy and better maintenance), and increased use of the MacArthur Lock for smaller vessels. A systematic use of these technologies and practices will yield better performance at the Soo Locks.

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