

# Management Systems for Inland Waterway Traffic Control, Volume II: Vessel Tracking for Managing Traffic on the Upper Mississippi River



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# **MANAGEMENT SYSTEMS FOR INLAND WATERWAY TRAFFIC CONTROL, VOLUME II: VESSEL TRACKING FOR MANAGING TRAFFIC ON THE UPPER MISSISSIPPI RIVER**

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## **EXECUTIVE SUMMARY**

### **Genesis, Evolution, and Structure of the Report**

In February 2003, the Center for Transportation Studies at the University of Missouri-St. Louis released a white paper produced for the Institute for Agriculture and Trade Policy (IATP) entitled: “Upper Mississippi River and Illinois Waterways: How to Reduce Waiting Times of Vessels While Using the Current Infrastructure.” The white paper recommended investigating an appointment system and revisiting some other low cost measures previously identified but rejected by the U.S. Army Corps of Engineers as a means of reducing the congestion that occurs periodically at locks in the Upper Mississippi River and Illinois Waterway (UMR-IW).

Based on that recommendation, the Center for Transportation Studies initiated a project in March 2004 designed to (1) improve the management of and reduce the operational costs of inland water transportation assets and (2) identify and evaluate specific traffic management measures for implementation on the Upper Mississippi River and Illinois Waterway segment of the inland water transportation system. This project was funded by the Midwest Transportation Consortium with matching funds from the University of Missouri-St. Louis. The Institute for Water Resources (IWR) of the U.S. Army Corps of Engineers provided lock operations data. The IATP was to also contribute to the project, but withdrew because of financial considerations that fiscal year.

In June 2004, the IWR agreed to fund a companion project at the Center for Transportation Studies that would investigate the potential use of vessel tracking systems primarily as an aid in implementing lockage and traffic management policies. Funding this companion project also made the Corps a full partner in the original study. The “vessel tracking” companion project included: (1) an investigation of automatic vessel tracking applications and related geographic information systems for inland waterway transport on the Upper Mississippi River (UMR) system, (2) the documentation of appropriate technologies necessary to implement a vessel tracking system, and (3) the development of a prototype vessel tracking geographic information system.

Consequently, this report is structured in two distinct but related volumes. Volume 1, “Identification and Evaluation of Alternatives for Managing Lock Traffic on the Upper Mississippi River,” focuses on identifying and evaluating traffic management alternatives for possible implementation and Volume 2, “Vessel Tracking for Managing Traffic on the Upper Mississippi River,” focuses on the feasibility of using vessel tracking systems to provide real time or near-real time data on tow positions in support of new lockage or traffic management policies. A summary of each volume follows.

### **Volume 1 Summary**

This volume examines and evaluates alternative traffic management policies designed to improve the efficiency of lockage operations in an intermittently congested segment of the UMR navigation system. The traffic management alternatives examined and evaluated range from lock



appointment systems, to re-sequencing tows for processing at a lock or a series of locks, to the complete scheduling of vessel movements on the waterway.

A detailed statistical analysis of U.S. Army Corps of Engineers 2000-2003 OMNI data compiled for the UMR navigation system is presented which indicates that the UMR system segment bounded by Lock 20 upstream and Lock 25 downstream experiences some periodic traffic congestion, is subject to intra-seasonal changes in demands for service, and operates as a interconnected system in that Locks 20-25 share a large amount of common and interrelated commercial tow traffic. The statistical analysis considers the role of many diverse factors in the operation of the UMR such as: the different types of vessels using the system; the different types of lockages required by different vessels; the night or day movements of vessels in the pools connecting the locks, the night or day lockages of vessels; and differing river flow characteristics that affect tow movements, to determine their impact on lockage times and transit times between locks. Equations produced by the statistical analysis are then employed in a new simulation model used to evaluate the results of implementing scheduling and sequencing rules designed to manage queues and vessel traffic more efficiently at Locks 20-25.

The discrete event simulation model is presented, validated against known UMR traffic flows, and used for investigating the effects of these traffic management alternatives. The simulation model extends earlier inland navigation simulation models of systems of locks by explicitly incorporating seasonal and interdependent traffic demands for specific origin and destination trips into the model. The simulation model is calibrated with historic data and shown to accurately represent the overall operation of the system including the periodic seasonality of the demand for lock use evident in the U.S. Army Corps of Engineers OMNI data.

## **Volume 2 Summary**

This volume examines the feasibility of vessel tracking systems for better managing lockages on the UMR navigation system. Vessel tracking systems are widely available and can be used to improve waterway operations and to enhance safety, security and environmental protection in many settings. This volume describes current vessel tracking applications and technologies and presents a prototype vessel tracking geographic information system for the UMR. A description of automatic vessel tracking and related applications that have been developed for a variety of purposes worldwide and may be relevant to the UMR is presented first. This includes satellite-based vessel tracking systems, automatic identification systems (AIS), vessel traffic services, and vessel traffic management systems. The volume then discusses ongoing efforts to develop comprehensive inland waterway traffic management systems that exploit technological developments to provide stakeholders with information to support better waterway decision-making.

Next, the volume describes technologies necessary to implement a vessel tracking system on the UMR, including methods for acquiring dynamic data for vessels, and for communicating this data to a geographic information system (GIS) for visual display. Important issues in position reporting, communications, and data integration, as well as key organizational issues involving responsibility and authority associated with vessel tracking on the UMR are highlighted.

Finally, a prototype vessel tracking GIS is presented that provides static displays and an example of dynamic vessel tracking to demonstrate the functionality possible from vessel tracking on the UMR. The prototype is built using the Arc Map 9.0 GIS with the Tracking Analyst extension for managing the dynamic display.

## **Conclusion**

Our analyses reveal that, as a consequence of the low commercial traffic levels currently evident in the UMR navigation system, implementing an alternative traffic management policy does not appear to yield sufficient benefits relative to its costs to warrant the market disruptions its implementation would create. However, the implementation of a vessel tracking system could be designed to provide the additional benefits of enhancing homeland security, improving navigation safety, protecting environmentally sensitive river habitats. It may also provide a basis for implementing future traffic management policies should traffic levels significantly increase or the operational characteristics of the UMR navigation system significantly degrade.

## **Recommendations**

1. New traffic management policies such as appointment and scheduling systems should not be implemented on the UMR at this time because of the small economic benefits they would create relative to their costs at existing traffic levels and the potential disruptions they would create in existing water transportation markets.
2. New traffic management policies such as appointment and scheduling systems should be evaluated under conditions of both significantly increased traffic levels and significantly degraded operating characteristics of the locks comprising the UMR navigation system in order to ascertain the effectiveness of alternative management policies in those circumstances.
3. Vessel tracking systems for lockage or traffic management on the UMR should be designed in concert with the selection of a potential lockage or traffic management alternative.
4. Responsibility and legal authority for lockage and traffic management on the UMR should be clarified before implementing larger scale lockage and traffic management systems.
5. Opportunities to partner with other agencies and private organizations in developing vessel tracking on the UMR should be explored; one area for special attention is to strengthen linkages with the Coast Guard regarding the implementation of AIS.

## INTRODUCTION

Vehicle or vessel tracking with geographic positioning systems is used to improve operations and to enhance safety, security and environmental protection in many transportation systems. Vessel tracking technologies allow real or near-real time tracking of watercraft at remote locations. Geographic information systems (GIS) provide a visual display of location-based data integrated with descriptive attribute information. Integrating vessel tracking with GIS can help improve waterway system operations by visually presenting vessel positions and movements on electronic maps that display infrastructure and other relevant features, along with associated static and dynamic descriptive information. Current technologies for finding real time locations and for mobile communications allow data to be collected and displayed efficiently in real or near-real time. This enhanced visibility and knowledge can lead to better management of limited waterway transportation resources and constrained infrastructures.

The project, “Geographic Information Systems for Tracking Vessels on the Inland Waterways” (USGS award No. 04HQGR0145 REVISED), investigated the feasibility of vessel tracking for better managing of lockages on the Upper Mississippi River (UMR). The major activities of the project were to

- Describe automatic vessel tracking applications and related geographic information systems for inland waterway transport on the Upper Mississippi River system;
- Document appropriate technologies necessary to implement a vessel tracking system; and
- Develop a prototype GIS to display dynamic vessel locations, lock locations and operating conditions, river features, and important shore elements, with relevant attribute data.

Each of these activities is addressed in the following sections of this document.

This project complements a companion project of the Center for Transportation Studies (CTS) at the University of Missouri/St. Louis that examined traffic management alternatives for the UMR. That project detailed in Volume 1 investigated how intelligent appointment or scheduling systems that better manage tows and barges for passage through the locks on the UMR might reduce congestion at the locks. A GIS-based vessel tracking system might support more effective and more efficient lockages and river traffic management by providing relevant individuals (e.g., a river “traffic manager”) with a single information source including dynamic display of vessel locations and attribute information. Such a system could supplement the lockmaster’s existing “mental map” of tow locations.

A vessel tracking system coupled with intelligent rules for managing lockages could provide opportunities to improve locking operations and reduce total throughput times at locks on the UMR. This would benefit inland waterway shippers and carriers through decreased costs and increased reliability from more efficient lock operations. A vessel tracking system on the UMR might also provide benefits in other areas, including homeland security, by providing information on where individual tows and barges are located within the waterway system, their

recent and not so recent past travels, as well as relevant data such as ownership, cargo, and their location relative to various structures within and along the waterway.

## Background

The U.S. Army Corps of Engineers (Corps) is responsible for the maintenance and development of the locks along the inland waterways in the United States. The Corps is involved with 10,867 miles of the fuel-taxed inland waterway, including 171 lock sites and 214 lock chambers. The UMR includes 29 lock and dam facilities as shown in Figure 1. See Volume 1 of this report for details of the UMR navigation system.



Figure 1. Map of the UMR navigation system  
(Source: U.S. Army Corps of Engineers)

Lockages on the UMR are currently controlled by the lockmaster at each individual lock. Under most conditions (without excessive congestion) tows are locked through in the order of arrival at the lock. This produces a “first come, first served” (FCFS) or “first in, first out” service policy at each lock. Lockmasters maintain radio communications with tows in their vicinity and can also access static real time tabular displays of the tows in each pool and each lock queue; for example, the U.S. Army Corps of Engineers Navigation Information Connection displays current information at: <http://www2.mvr.usace.army.mil/NIC2/vesselinfoqueue.cfmtows>.

As an example, Tables 1, 2, and 3 provide information on the vessels queued at Lock 22, the vessels in Pool 22 (above Lock 22), and the vessels in Pool 24 (below Lock 22) in the afternoon of May 31, 2005, respectively. (Note that Locks 22 and 24 are adjacent, as there is no Lock 23.) The Queue List for Lock 22 (Table 1) shows two tows in the queue. The ROBERT GREENE is currently (at 3:18:23 pm) locking (since starting at 3:00 pm) and is downbound with 15 barges. The LEXINGTON is first in the queue (since arriving at 12:18 pm) and is upbound with 13 barges. Both of these tows are double cut lockages (i.e. the tow is too long to fit into the 600-foot lock chamber, so it must be separated into two “cuts”, each no more than 600-feet long, for passage through the lock).

**Table 1. Queue list at lock 22, run on 5/31/2005 at 3:18:23 p.m.**  
(Source: <http://www2.mvr.usace.army.mil/NIC2/Reports/lockqm22>)

Vessel Name	Vessel Number	Datetime	Chamber	Direction Up or Down	Total Barges	Lockage Type	Vessel Type	Number of Cuts
<b>Lock 22</b>								
ROBERT GREENE	619977	SOL 05-31-05 15:00 CDT	1	D	15	S	T	2
LEXINGTON	508204	ARR 05-31-05 12:18 CDT	1	U	13	S	T	2

**Table 2. Vessels in pool 22, run on 5/31/2005 at 3:16:44 p.m.**  
(Source: <http://www2.mvr.usace.army.mil/NIC2/Reports/lockm22>)

Vessel Name	Vessel Number	Datetime	Status	Total Barges
<b>Pool 22 Up Bound</b>				
RAYMOND GRANT ECKSTEIN	633152	EOL 05-31-05 15:00 CDT	Done	14
TOM TALBERT	536790	EOL 05-31-05 13:11 CDT	Done	14
<b>Pool 22 Down Bound</b>				
ROBERT GREENE	619977	SOL 05-31-05 15:00 CDT	Locking	15
Total Vessels = 3		Up-Bound = 2	Down-Bound = 1	

Table 2 shows three vessels in Pool 22 (above Lock 22). The RAYMOND GRANT ECKSTEIN completed locking at Lock 22 at 3:00 p.m. and is now upbound in Pool 22 with fourteen barges. The TOM TALBERT completed locking at Lock 22 at 1:11 p.m. and is now upbound in Pool 22 with fourteen barges. The ROBERT GREENE is locking at Lock 22 with fifteen barges having started its lockage at 3:00 p.m. as shown in the queue list for Lock 22 in Table 1).

**Table 3. Vessels in pool 24 on 5/31/05 at 3:18:07 p.m.**  
 (Source: <http://www2.mvr.usace.army.mil/NIC2/Reports/lockm24>)

Vessel Name	Vessel Number	Datetime	Status	Total Barges
<b>Pool 24</b>	<b>Up Bound</b>			
LEXINGTON	508204	ARR 05-31-05 12:18 CDT	Arrived	13
KELLEY LEE	564520	EOL 05-31-05 14:50 CDT	Done	3
<b>Pool 24</b>	<b>Down Bound</b>			
THOMAS K	645394	EOL 05-31-05 10:30 CDT	Done	15
Total Vessels = 3	Up-Bound = 2	Down-Bound = 1		

Table 3 shows three vessels in Pool 24, below Lock 22. The LEXINGTON arrived at Lock 22 with thirteen barges at 12:18 p.m. and is in the queue (as also shown in Table 1). The KELLEY LEE was upbound in Pool 24 with three barges, having completed locking at Lock 24 at 2:50 p.m. The THOMAS K is downbound in Pool 24 with fifteen barges, since completing lockage at Lock 22 at 10:30 am.

Tables 4, 5, and 6 provide the Datetime, Lockage Type, and Vessel Type codes shown in Tables 1, 2, and 3.

**Table 4. Datetime codes**  
 (Source: [http://www.mvr.usace.army.mil/mvrimi/omni/webbrpts/omni\\_vl/Datetime.htm](http://www.mvr.usace.army.mil/mvrimi/omni/webbrpts/omni_vl/Datetime.htm))

Datetime—the date and time shown are based on the event code	
Event Code	Description
ARR	ARR (Arrival)—The datetime that the vessel arrived
SOL	SOL (Start of Lockage)—The datetime that the vessel started locking through the chamber. In the case of a lock stoppage, the datetime is the time the lock stoppage started
EOL	EOL (End of Lockage)—The datetime that the vessel ended its lockage

**Table 5. Lockage type codes**(Source: [http://www.mvr.usace.army.mil/mvrirmi/omni/webbrpts/omni\\_vl/Lockage%20Types.htm](http://www.mvr.usace.army.mil/mvrirmi/omni/webbrpts/omni_vl/Lockage%20Types.htm))

<b>Code</b>	<b>Description</b>
O	Open pass – The vessel traverses the lock with no lock hardware operation/chambering. The vessel goes straight through the chamber with both sets of gates open. This may occur at tidal locks.
F	Fast double (Multi-chamber) – The towboat and possibly some of its barges are separated from the remaining barges and are locked through a different chamber from the remaining barges.
J	Jack knife – The tow is rearranged, usually from two barges wide to three, by breaking the face coupling on at least one barge and knockout of the tow.
K	Knockout – The towboat alone is separated from its barges and moved alongside the barges for lockage..
N	Navigable pass – The vessel traverses the dam instead of the lock. The vessel actually navigates outside the lock walls.
S	Straight – The tow is not broken up for lockage.
T	Barge transfer – Barges are placed in the lock chamber by one towboat, removed and continued on their journey with another towboat.
V	Setover – The towboat and one or more of its barges are separated as a unit from the remaining barges to be “set over” for service.
Z	Other (remarks) – Any type of lockage not defined by one of the above.
	None

**Table 6. Vessel type codes**(Source: [http://www.mvr.usace.army.mil/mvrimi/omni/webrrpts/omni\\_vl/Vessel%20Types.htm](http://www.mvr.usace.army.mil/mvrimi/omni/webrrpts/omni_vl/Vessel%20Types.htm))

Type of Vessel	Vessel Code	Description
Commercial	C	Dry Cargo Vessel [self-propelled]—A self-propelled vessel carrying dry cargo.
Other	J	Dredge Vessel [self-propelled]—A self-propelled vessel designed to remove material from a dredge site.
Commercial	E	Liquid Cargo Vessel (i.e. Tanker) [self-propelled]—A self-propelled vessel carrying liquid cargo.
Other	K	Crewboat (doesn't include boat crew) [self-propelled]—A self-propelled vessel used primarily for transporting commodities and/or personnel, excluding people required to operate the crewboat (supply boats/utility vessels).
Other	M	Commercial Non-cargo Vessel—Vessel owned and/or operated by commercial industry, but does not carry cargo or passengers for a fee, i.e., vessel owned/used by business only for business purposes.
Other	N	Non-federal Government Vessel (i.e. state or local govt.)—Any government vessel, other than a federal government vessel, i.e., state, local, etc.
Commercial	F	Fishing Vessel (commercial)
Other	G	Federal Government Vessel
Other	L	Lightboat
Commercial	P	Passenger Boats & Ferry (commercial)
Recreation	R	Recreational Vessel
Commercial	T	Towboats (Commercial)
Other	U	Federal Government Contractor Vessel
	X	Lock Stoppage—This code can be used for a non-vessel that is locking through the lock. Also, this code is used when the lock is down and unable to service boats.
Other	Z	Other (Remarks)
		None

From the static information in Tables 1, 2, and 3 one can form a “mental map” of the river segment. Based on the reported destinations, the reported times for completing lockage at the upstream and downstream locks, and the expected speeds of tows upbound and downbound, one can estimate the positions of the tows and the arrival times at the locks. (Note that Tables 1, 2, and 3 show only a single tow headed towards Lock 22 that has not already arrived: the KELLEY LEE. The other tows upbound in Pool 24 and downbound in Pool 22 are in the queue list for Lock 22.) However, until the lockmaster makes visual contact with the tow, he/she cannot precisely locate the tow. Even when a tow calls in and indicates its location (e.g., at a call-in point), the lockmaster cannot be certain that the reported position is the actual location of the tow. Under congested conditions, tows may call in early (prior to reaching the designated call-in point) to establish their position in the queue.

While an attentive lockmaster (or other individual) may develop a fairly accurate mental map of tow locations on a segment of the waterway, because the data is reported only for lockages, the activities of the commercial tows between the locks are uncertain. For example, tows may stop, reverse direction, pick up barges or drop off barges at various docks or terminals in the pools. Thus, an interpolation of tow location based on the previous lockage and the expected vessel



speed is likely to be inaccurate. In addition, the arrival of recreation vessels for locking can be difficult to predict in detail in advance.

The lower (southernmost) five 600 foot long locks of the UMR navigation system, Locks 20, 21, 22, 24 and 25 (there is no Lock 23) were selected as the study site for the companion project evaluating traffic management alternatives for the UMR. These locks are the most heavily utilized 600 foot long locks on the UMR and are among the most congested of all locks in the inland navigation system. These locks experience periodic traffic congestion and strong seasonal variation in demands for service. They also tend to operate as a system in that they share a large amount of common interrelated commercial tow traffic. The prototype GIS-based vessel tracking system is developed for the portion of the UMR covering these five locks.

To familiarize ourselves with the operating environment we made site visits to all five Lock and Dam facilities in the study region (Lock & Dam 20, 21, 22, 24 and 25). During each visit we met with the lockmaster on duty, described our project, and discussed traffic conditions and special operating procedures unique to that lock. We also sought suggestions on ways to improve lockage operations, especially through traffic management measures, feedback on our proposal, willingness to implement alternative traffic control measures, and indications of potential utility for GIS-based vessel tracking systems. The individual lockmasters had somewhat different practices regarding managing lockages for their particular lock, depending on a range of conditions. Some of the key findings are as follows:

- Safety is a paramount concern.
- There is a wide range of willingness and desire to implement traffic control measures; some lockmasters expressed limited initiative for making changes; others seemed enthusiastic about increased flexibility to manage traffic.
- Issues of legality, authority and responsibility must be clarified before implementing traffic management measures.
- Graphical map displays could provide a useful depiction of vessel locations, and would provide visibility into the actions of tows between locks.
- Given the current practice in which lockmasters do not take actions until a tow calls in, there is little incentive or reason to monitor tows that are not in the vicinity of a lock.
- There was a range of views on the incremental benefit from implementing vessel tracking technology for managing lockages, though most individuals expected small benefits at best; some stated that GIS-based displays would add little to their knowledge of vessel locations, especially with low levels of traffic; others stated that vessel tracking and display might have some benefit, especially if more active traffic management measures were to be implemented.

In addition to the lock visits we had numerous discussions and visits with inland waterway practitioners and researchers to collect relevant information for our study. The information gleaned from these activities is reflected in the following sections as appropriate. A brief summary of these activities are as follows:

- A visit to the Volpe National Transportation Center in Cambridge, Massachusetts (in September 2004) to learn of their experiences with vessel tracking and GIS
- A visit with the Commanding Officer of the Marine Safety Office St. Louis and Captain of the Port St. Louis of the U.S. Coast Guard, and several of her staff in March 2005
- A tour of the U.S. Coast Guard's Inland Rivers Vessel Movement Center (IRVMC) in St. Louis in March 2005
- A visit to the St. Lawrence Seaway Development Corporation and the St. Lawrence Seaway traffic control center in Massena, New York in May 2005
- Attending the 2004 National Waterways Conference in St. Louis in September 2004
- Numerous discussions with personnel of the U.S. Coast Guard and U.S. Army Corps of Engineers regarding the availability of electronic and GIS data
- Discussions and meetings with numerous barge industry representatives and vendors of vessel tracking systems and vessel traffic management systems

## **GIS AND VESSEL TRACKING APPLICATIONS**

Vessel and vehicle tracking technologies are well developed for a wide variety of transportation applications, in both the public and private sector. For example, air traffic control systems have long been used to manage air transportation, primarily for reasons of safety (though security concerns have become prominent more recently). Public transit and public works agencies often track vehicles in real time with global positioning system (GPS) receivers to improve operations. Private sector firms in the rail and motor carrier industry also track vehicles, and have developed extensive information and decision support systems based on dynamic real and near-real time locational data. Vessel tracking systems have also been implemented in a variety of applications worldwide for both maritime (deep-sea) and inland water transportation.

A geographic information system (GIS) integrates spatial or geographic data that is static (e.g., lock locations) or dynamic (e.g., tow locations) with attribute data that provides relevant descriptive information. A GIS may be viewed as a collection of hardware and software for capturing, managing, manipulating, integrating, analyzing, and displaying geographically referenced information. A GIS provides tools to support data collection, analysis, and decision making for a particular environment. Vessel tracking systems may use a GIS for visual display of location-based data on an electronic map. Integrating vessel tracking with GIS can help improve waterway system operations by visually presenting vessel positions and movements on electronic maps that display relevant features in and along the waterway, along with associated static and dynamic descriptive information. This enhanced visibility and knowledge can lead to better management of limited waterway transportation resources and constrained infrastructures.

Static geographic information systems are used by a variety of organizations for a wide range of analyses involving the UMR. Examples include systems primarily focused on navigation, flood

protection, safety and security, and environmental protection. Users of such systems include federal, state and local governmental agencies (including the U.S. Army Corps of Engineers and the U.S. Coast Guard), a variety of non-governmental organizations (NGOs), especially environmentally-focused organizations, tow operators, and educational institutions. However, static GIS do not include dynamic movements of tows or focus on lockage operations.

The variety of GIS-based systems that have been developed to help in managing various aspects associated with the inland waterways have not been designed for research purposes related to managing lockages, tracking vessels or managing traffic. However, some recent research that does integrate GIS with other models, especially simulation models, and that better addresses tow vessel activities includes Dobbins and Abkowitz (2002), Bilbrey (2004), Biles and Sasso (2004) and Martin et al. (2004).

Current technologies for finding real-time locations and for mobile communications allow data to be collected and displayed efficiently in real or near-real time. Small handheld GPS units can be purchased for under \$100 and vehicle tracking systems for land, marine and air vehicles are readily available. Vessel tracking systems require determining the location of the vessel and communicating that information (along with other relevant information) to a central location capable of receiving and managing the locational information.

Vessel tracking applications generally have one of the following primary motivations: safety and security, compliance, and operational improvements related to traffic management. However, there is often some overlap between these categories, and technologies implemented for one purpose (e.g., safety) may have applications in other areas (e.g., traffic management). Private firms generally implement vehicle tracking to aid in dispatching, routing, or recovery following lost or stolen vehicles. The primary goals are to improve efficiency, accountability and productivity. Vessel tracking systems have more commonly been required for reasons of safety, security and compliance; for example to ensure safe navigation, to prevent or respond to disasters, and to ensure compliance with regulations on travel in restricted areas.

While the U.S. Army Corps of Engineers OMNI database does maintain a record of tows in each lock queue and in the pools between locks, the Corps is not presently engaged in real or near-real time tracking of tows on the UMR. A system for tracking tows on the UMR would provide more accurate locations of the tows to the Corps personnel at the locks. This might help the Corps better manage lockages in support of an appointment or scheduling system at the locks, or support even broader traffic management measures. A tow tracking system might also provide collateral benefits in the areas of safety, security, environmental protection and operations.

The technology for tracking tows in real time or near-real time is well developed, and the larger barge companies operating on the UMR have implemented vessel tracking for their own fleets of towboats. Furthermore, the U.S. Coast Guard has recently implemented the tracking of tows carrying hazardous cargos on inland waterways, including the UMR. However, neither the individual operators nor the Coast Guard share their tow position data with the Corps. Thus, in the pools between the locks, the Corps is generally unaware of the exact location of the tows. The remainder of this section describes important vessel tracking and related applications. This includes vessel tracking by tow operators and the U.S. Coast Guard on the UMR, as well as other

relevant applications in the U.S. Coast Guard vessel traffic services (VTS) centers, along the St. Lawrence Seaway and the Panama Canal, on European inland waterways, for port and harbor security and for fisheries enforcement activities.

## Tow Operator Tracking Systems

The larger tow operators on the UMR have implemented real or near-real time tracking for their own fleets of towboats or barges on the UMR and on other inland waterways. Position information can be used for a variety of strategic and operational purposes within the firm, and the tracking systems may be linked to a variety of other software tools to assist in activities such as sales, accounting, dispatch, maintenance, compliance, etc. Such tools may be developed in-house by the waterway operators, by third parties, or by the vessel tracking system vendors.

Several companies provide tow locations, and other tow information via the web, in some cases on publicly accessible sites. For example, Figure 2 displays boat positions for Memco Barge Line, which are shown as river miles on the various rivers (OHR = Ohio River; LMR = Lower Mississippi River, etc.).

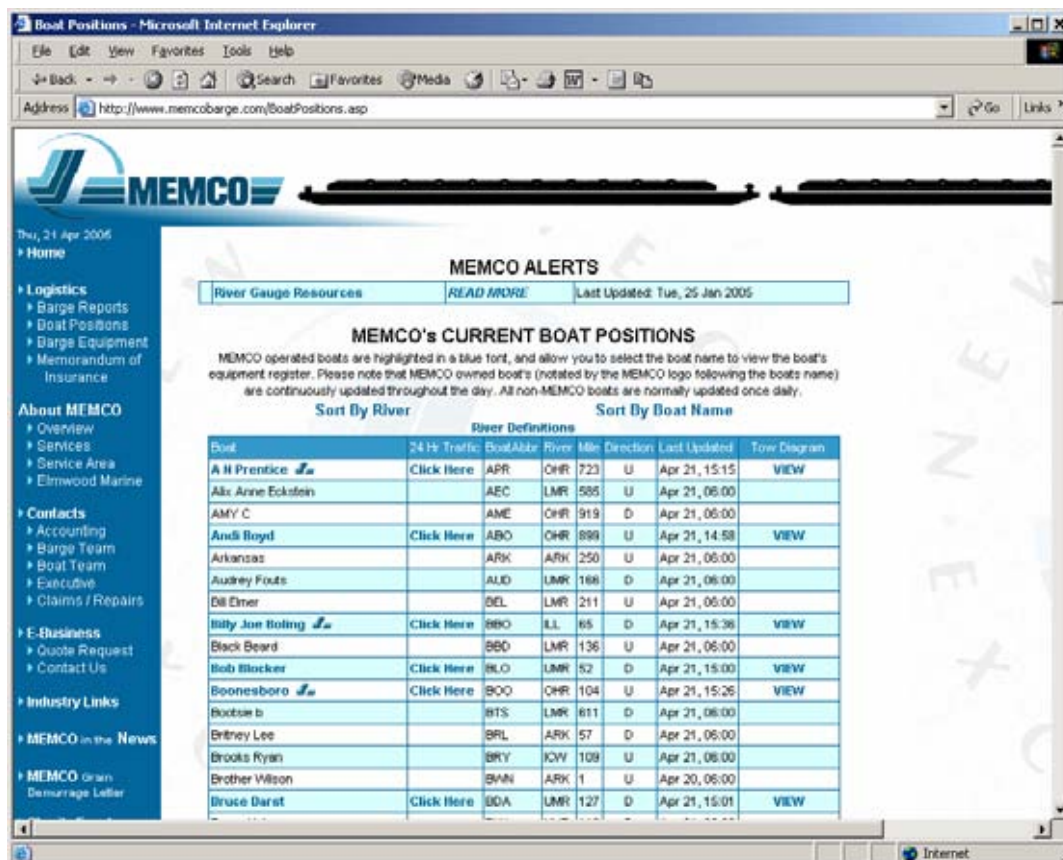
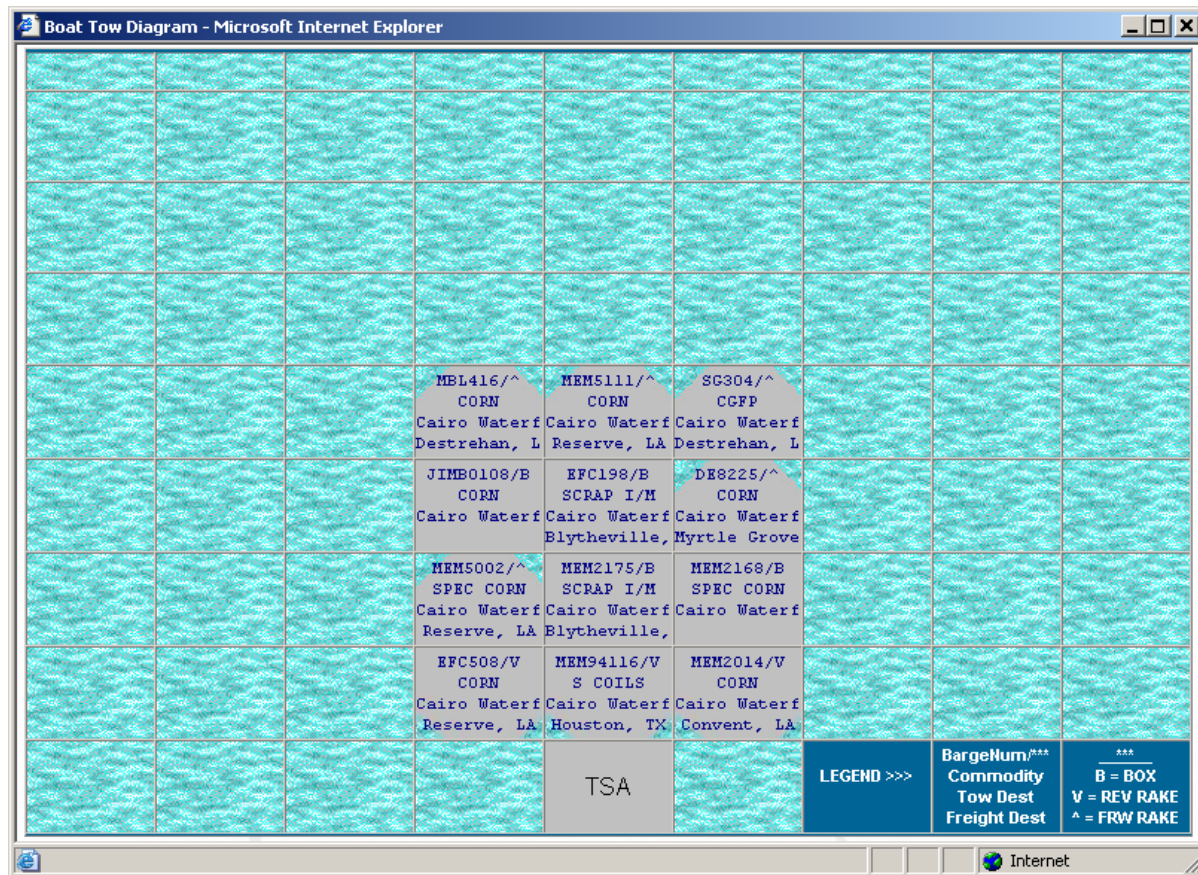


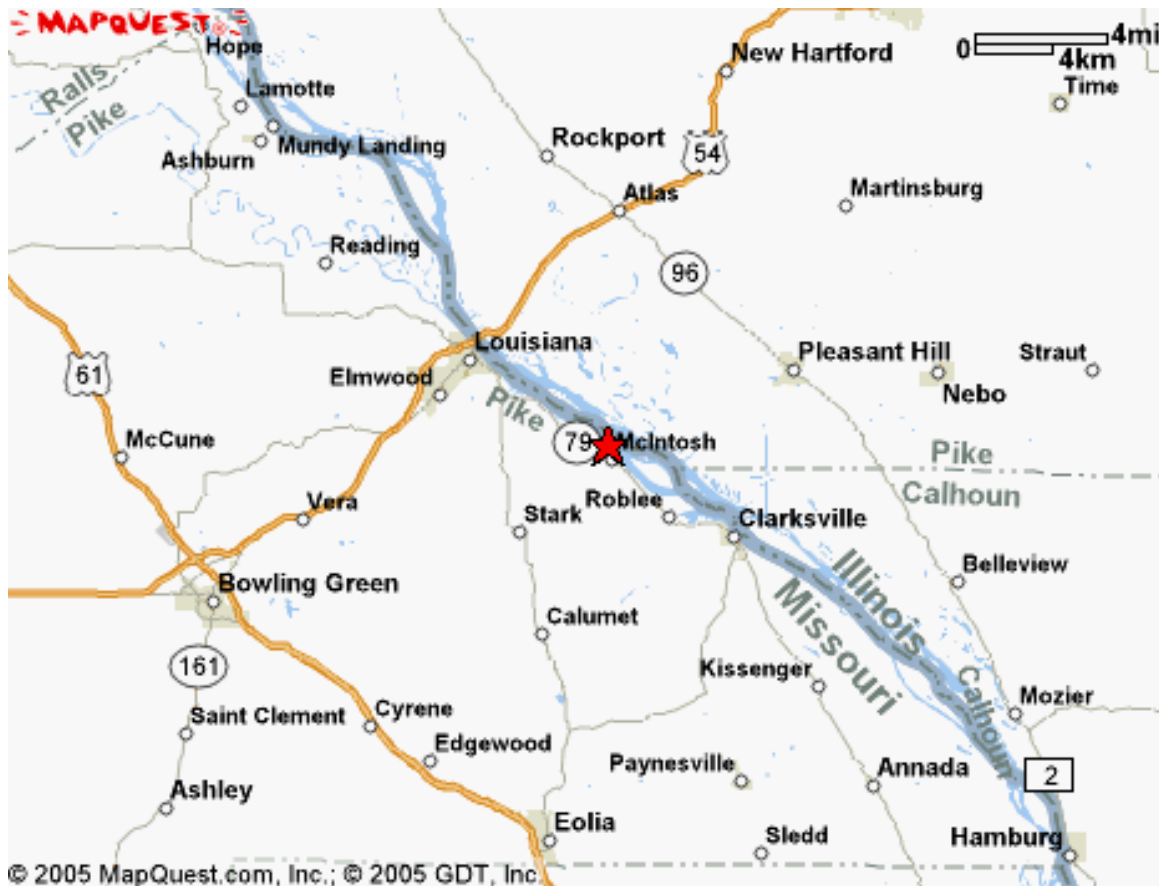
Figure 2. Memco boat positions  
(Source: [www.memcobarage.com/BoatPositions.asp](http://www.memcobarage.com/BoatPositions.asp))



**Figure 3. Memco tow diagram**  
(Source: [www.memcobarge.com/BoatPositions.asp](http://www.memcobarge.com/BoatPositions.asp))

Figure 3 provides a tow configuration for one of the Memco tows. This type of information is generally not available to the lockmasters; nor would it be used in managing lockages under current operating practices. Ingram Barge Company provides tow locations as river miles on the web and even uses MapQuest to provide a visual image of the tow's location on a map of the appropriate geographic region.





**Figure 4. Internet map of a towboat location for Ingram Barge Company**  
 (Source: [http://www.ingrambarge.com/barge\\_positions.asp](http://www.ingrambarge.com/barge_positions.asp))

Figure 4 shows such a map of the location of one of the Ingram's towboats (represented by a star) on the UMR. Figure 5 provides a zoomed-in view of this same towboat location, which now appears to be outside the river and atop a rail line! Such positional inaccuracy may have several sources, including calculation of an inaccurate position for the vessel (e.g., due to the inherent level of accuracy of the selected geographic positioning system), an inaccurate map of the riverbanks, or data errors (e.g., in collection or transmission). However, note that for purposes of traffic management and use in a lock scheduling or appointment system, a high level of positional accuracy would not likely be required. In contrast, for many navigational purposes, a high level of positional accuracy may well be essential.



**Figure 5. Towboat location for Ingram Barge Company**  
 (Source: [http://www.ingrambarge.com/barge\\_positions.asp](http://www.ingrambarge.com/barge_positions.asp))

Ingram Barge Company has also developed a variety of GIS applications internally, including one to automatically identify large queues (e.g., in excess of specified sizes) based on the Corps OMNI data. This then allows the firm to contact tows that may be affected by the large queues to make operational changes (e.g., to alter speeds). Other waterway operators have proprietary vessel tracking systems that are often linked with other management support tools. For example, American Commercial Barge Line LLC (ACBL) has the proprietary River-Trac system that includes tow tracking and display on a map.

One popular commercial vessel tracking system in use on the UMR and on other inland waterways in the U.S. is Boatracs®. Boatracs® is the marine version of the OmniTRACS system (from QUALCOMM, Inc.) for vehicle tracking and communications. This system provides automatic vessel positions at periodic intervals (e.g., hourly or every quarter hour) and whenever the vessel sends or receives a message. Boatracs® is a satellite-based system that provides positional accuracy generally within approximately 100 meters (Paul 2005, U.S. Coast Guard 1998b). It also provides secure communications between the vessel and the shore station.

The customers of Boatracs® include over 400 commercial fleets covering over 800 inland workboats, including major inland waterway operators such as Ingram Barge Company, Kirby

Inland Marine, Inc., and Memco Barge Line (Paul 2005). Boatracs® provides a network operations center that operates twenty-four hours a day and seven days a week. In 2003, Boatracs® participated in a Transportation Security Agency (TSA) sponsored security exercise on the Columbia River designed to test vessel tracking and communications. Boatracs® is also used by fishing fleets and VMS applications. In late 2004, Boatracs® was purchased by the Canadian telematics firm AirIQ, Inc.

Land-based (rather than satellite-based) systems can also be used for locating and communicating with tows on the UMR. Watercom is an established communications method that has been in use on the inland waterways for several decades. The Watercom system provides ship-to-shore voice, data, and telecommunication services using cellular radio communications throughout the U.S. inland waterways (and along the Gulf Coast) via a network of radio towers. Current users include a variety of commercial, government and recreational vessels. Watercom was purchased by Mobex Network Services, LLC in September 2000 (from American Commercial Lines, Inc.).

In 2003, Mobex/Watercom announced a partnership with StarTrak LLC to sell a barge tracking product called BargeTrak. This product is initially targeted at tank barge fleets, but may be easily extended to other types of barges. BargeTrak is solar powered and it includes two way communications via satellite or cellular radio, GPS for positioning, and a variety of sensors (for example, to automatically detect leaks, draft, load status, etc.). BargeTrak also provides “geofencing” that creates automated alerts when a barge reaches a specified location as indicated within the GIS. Position and sensor information is sent to the networks operations center and then to the customer via the Internet. Capability is also provided to communicate via pager, fax, or cell phone in the event of an exception or emergency condition.

A variety of other land or satellite-based systems are capable of tracking vessels on inland waterways, including systems based on Argos and Inmarsat. Argos is a multinational joint project of the French space agency (CNES), several U.S. government agencies, and other Japanese and European agencies. Inmarsat is an international consortium that provides maritime voice, facsimile and data services nearly worldwide using a combination of owned and leased satellites. Examples of these types of systems include: (1) the ShipLoc systems from CLS, a subsidiary of the French Space Agency, which uses Argos to provide vessel tracking anywhere in the world to within 300 meters; and (2) Meridian’s Vessel Management System (MVM) which provides GPS-based vessel tracking with multiple data communications mediums, including radio, cellular or satellite technologies (Meridian 2005). Other examples of satellite-based vessel tracking include products from Mobex Network Services Ltd., Satamatics Ltd., EMMI Network, S.L., Pole Star Space Applications Ltd., Mobile Satellite Ventures, MariTEL, Inc., Information Technology Systems, LLC., IntelliTrans, LLC., TransCore and SASCO INC.

### **Inland Rivers Vessel Movement Center (IRVMC)**

The Inland Rivers Vessel Movement Center (IRVMC) was established by the U.S. Coast Guard in St. Louis, Missouri in April 2003 to track transportation of certain dangerous cargoes (CDCs) on all inland waterways, including the UMR. For details on IRVMC, see U.S. Coast Guard (2004). The CDCs of concern to IRVMC include explosives and blasting agents, poisonous



liquids and gases, ammonium nitrate and certain fertilizers, radioactive materials, bulk liquefied chlorine gas, and other liquefied gases. This is one example of tow tracking by a public agency on the UMR. Last year, IRVMC tracked over 36,000 barge transits on over 10,300 miles of inland rivers (Department of Homeland Security 2005). However, since only a small fraction of barges and tows on the UMR are moving CDCs, relatively few vessels are currently tracked by IRVMC on the UMR.

The owners and operators of barges hauling CDCs are required to report their position and other information to the IRVMC at a number of specified points along the river and when performing specified activities. Reports may be made electronically or manually via toll-free telephone, fax, or email. The data that must be reported to the IRVMC includes the following:

- Name of barge and towboat
- Name of loading, fleeting and terminal facilities
- Estimated time of arrival at loading, fleeting and terminal facilities
- Estimated time of arrival at 148 designated reporting points (including at departure from Lock and Dam 21 and Lock and Dam 25)
- Planned route
- Estimated time of departure from facilities
- Any significant departure from previously reported information

The timing of the reporting to IRVMC is as follows:

- 4 hours prior to loading CDCs
- 4 hours prior to getting underway with CDCs
- 4 hours prior to dropping off and picking up CDCs from a fleeting area
- At entry into, and departure from, the covered geographic area
- Upon arrival at the final destination if within the reporting area
- At any time the estimated time of arrival (ETA) varies by 6 hours from the previously reported ETA
- When directed by the Coast Guard

The IRVMC tracks vessels in near-real time based on either reports directly from the tows or reports from a terrestrial source, such as the owner or a vessel tracking service provider. Reports from towing firms and vessel tracking service providers are generally provided via electronic data transfer. Tow locations are displayed in the IRVMC facility in St. Louis on a simple electronic map (covering the U.S.). IRVMC provides information on CDC barges to the Captains of the Ports on inland rivers, who may then schedule security boarding and escorts, as warranted.

The focus of IRVMC is homeland security and their mission is “to ensure public safety, prevent sabotage or terrorists acts, and facilitate the efforts of emergency services and law enforcement officers responding to terrorist attacks” (U.S. Coast Guard 2004). IRVMC coordinates activities such as inspections of barges and escorts of tows with CDCs through certain areas. Note that due to the slow speeds on the river and the limited directions for travel, real time vessel tracking (e.g., minute-by-minute) is not needed. IRVMC has selected near-real time tracking (e.g., every

hour) and reporting requirements at specified points (before entering areas of special interest) to fulfill its mission efficiently, without requiring an excessive amount of data or communications from the tows.

### **Vessel Traffic Services (VTS) Areas**

Vessel traffic services centers provide another example of vessel tracking by the U.S. Coast Guard, in some cases on inland waterways. The Coast Guard has defined VTS areas in heavily congested waterways, primarily harbors and ports. The purpose of a VTS is to provide “active monitoring and navigational advice for vessels in particularly confined and busy waterways” (U.S. Coast Guard 2003a). VTS systems originally focused on safety, efficiency, and environmental protection. This included prevention of collisions and groundings, especially in bad weather, as well as traffic management activities “to expedite ship movements” and “increase transportation system efficiency” (U.S. Coast Guard 2003a). More recently security concerns have become paramount, and VTS provides an important component of programs for port and harbor security. For background on VTS centers, see the reports by the Committee on Maritime Advanced Information Systems (1996, 1999).

VTS centers integrate data from several sources to provide a complete and coherent view of vessel traffic in a specified, usually congested, area. These are primarily located at major U.S. ports, including: St. Mary’s River, Michigan; Berwick Bay, Louisiana; Los Angeles/Long Beach, California; Prince William Sound, Alaska; Houston-Galveston, Texas; New York, New York; Puget Sound, Washington; and San Francisco, California. There is also a high-water VTS area at Louisville, Kentucky covering a thirteen mile stretch of the Ohio River. (This is a part-time service to assist vessels near the falls of the Ohio. In recent years it has operated for 45 days on average.)

A VTS center combines data broadcast from vessels (including identification, position, course, speed, etc.) with data from a network of land-based and/or vessel-based sensors (e.g., radar, VHF radio, infrared and closed circuit television). Information from the sensors is fed to a traffic monitoring and control center for managing the traffic. The traffic center relies on a sophisticated software system to integrate multiple data streams and to provide operators with GIS-based electronic map displays of the waterways with dynamic tracking of vessels. VTS systems also allow users to electronically establish geographic regions of interest with automated alarms when vessels travel in or out of the region. Such geo-fencing capabilities can assist in safe navigation and security operations. VTS systems can be expensive to establish because of the need for shore-side facilities, hardware, software and communications. Automation of data collection activities has been a priority and an important goal has been to collect the needed data without unduly burdening the operators of the vessels.

VTS may be viewed as providing a service analogous to that of air traffic control in congested waterways. Vessels traveling in VTS areas report their positions (and related information) and receive similar information from other vessels, as well as navigational safety information from the VTS center. Better real time knowledge of vessel locations and behaviors can improve operations, decrease congestion, and reduce the likelihood of injuries, casualties and

environmental damage. VTS centers can also provide extensive traffic surveillance capabilities that are more essential for maintaining safety and security activities, than for improving lockages.

A recent development that facilitates the work of VTS centers is the requirement for vessels to use AIS (Automatic Identification Systems). AIS is a shipboard broadcast system that automatically and continuously does two things: 1) transmits specified information including a vessel's identification, type, position, speed, course, and other safety-related information; and 2) receives this information from other such devices. The information broadcast by AIS can be received by appropriately equipped shore stations (e.g., VTS centers), as well as by vessels, and aircraft. An AIS device includes a global navigation satellite system (GNSS) receiver (e.g., a GPS unit), a VHF radio transceiver and a microprocessor.

AIS was developed by the IMO (International Maritime Organization) to improve maritime safety, enhance environmental protection and improve VTS operations. AIS is required on nearly all vessels on international voyages, and the U.S. Maritime Transportation Security Act of 2002 requires ship-board AIS on certain domestic vessels operating in VTS areas. These include the following:

- Self-propelled vessels of 65 feet or more in length, engaged in commercial service or on international voyages
- Towing vessels of 26 feet or more in length and more than 600 horsepower
- Vessels of 100 gross tons or more carrying one or more passengers for hire
- Tankers regardless of tonnage
- Passenger vessels certified to carry 150 or more passengers for hire
- Passenger vessels of 150 gross tons or more

AIS is not currently required on the UMR, though AIS is on many tow boats on the Lower Mississippi River that traverse a VTS area. The U.S. Coast Guard is developing plans to use satellite monitoring to track ships more widely using AIS. Such a system may be easily extended to tracking AIS equipped vessels on the inland waterways.

Lockheed Martin Maritime Systems & Sensors has provided the VTS systems for nine U.S. ports, including one covering part of the Lower Mississippi River. This system covers vessels operating from the Gulf of Mexico up to Baton Rouge, a distance of approximately 300 nautical miles along the river. The vessel traffic control center is located in New Orleans, Louisiana. This particular VTS center was installed in October 1998, and it has been periodically updated to add new capabilities. This system uses AIS base stations, radar, closed circuit television, and VHF communications. The total cost was approximately \$2 million in 1998, which included several radars, vessel traffic control software, and connection with the vessel identification system in use at the time (a predecessor of AIS). Several years later the system was upgraded to add AIS capability (Kinsella 2005). For more information on VTS systems from Lockheed Martin, see Amadio (2001).

The U.S. Coast Guard has been upgrading VTS centers as part of its PAWSS (Port and Waterways Safety Systems) project. See U.S. Coast Guard (2003b) for more details. While this was originally focused more on monitoring vessels and assuring safe navigation, the heightened security concerns in recent years have shifted the focus to identifying and assessing vessel movements, and disseminating security information to appropriate personnel. Note that the U.S. Coast Guard has a statutory responsibility under the Ports and Waterways Safety Act of 1972 to ensure the safety and environmental protection of U.S. ports and waterways. The PWSA authorizes the Coast Guard to "...establish, operate and maintain vessel traffic services in ports and waterways subject to congestion." It also authorizes the Coast Guard to require the carriage of electronic devices necessary for participation in the VTS system.

While efforts continue in the U.S. to expand VTS areas and AIS coverage under the leadership of the Coast Guard, a number of other countries have already developed more extensive vessel tracking and navigation systems than has the U.S. Kenyon (2003) reports that the entire coastlines of Norway, Sweden and Finland are fully or nearly covered by AIS, and the major ports and coastal areas in a number of countries, including Great Britain, Chile, Japan, and Australia also are covered by AIS. For other international experiences in South Africa, Australia, the Netherlands, UK and Ireland, see Borgmann (1999), Fleming (2000), Gerretsen (2000), Jemesen (1999), and Ramm (2000).

### **The St. Lawrence Seaway**

The Great Lakes - St. Lawrence Seaway system stretches 2,342 miles between the U.S. and Canada, linking ports in the middle of North America and the Atlantic Ocean. The Seaway is managed with bi-national cooperation between the Saint Lawrence Seaway Development Corporation (SLSDC) in the United States and the St. Lawrence Seaway Management Corporation (SLSMC) in Canada. There are fifteen locks in the Seaway, with eight at the Welland Canal (managed by the SLSMC) connecting Lake Ontario and Lake Erie (avoiding Niagara Falls), and seven more between Montreal and Lake Ontario. Only two locks (Eisenhower and Snell) are managed by the SLSDC. In total, these locks raise vessels about 600 feet above sea level. The cost of the Seaway is shared between commercial carriers using the waterway and the two Seaway management corporations (St. Lawrence Seaway Development Corporation 2005b). The seaway opened to commercial traffic on April 25, 1959.

While the Seaway includes a sequence of locks, as on the UMR, the locks on the Seaway are longer than those on the UMR, and operations on the Seaway are rather different than on the UMR. The Seaway locks handle ships up to about 740 feet in length, 78 feet in width and 27 feet draft. Locks may raise or lower vessels about forty feet, and completing a lockage takes approximately forty-five minutes. Vessels traversing the Seaway are generally large ships (25,000 tons) and their lockages do not require multiple cuts.

A typical trip takes eight to ten days to go from Lake Superior to the Atlantic Ocean, with about one day required to travel between Lake Ontario and Montreal. The primary commodity movements consist of low cost, dry bulk products such as iron ore, grain, stone, coal and cement. In addition to the physical differences between locking on the seaway and other inland

waterways, a local pilot is required for all Seaway vessels. Like operations on the UMR, winter affects the Seaway, closing it for about three months each year.

Responsibility for the operations and maintenance of the navigational aspects of the Canadian portion of the Seaway (thirteen locks) resides with the SLSMC, a not-for-profit corporation, under a long-term management agreement with the Government of Canada. The Government of Canada owns all fixed assets of the Canadian Seaway. The two U.S. locks in the Seaway are operated and maintained by the SLSDC, a wholly owned government corporation within the U.S. Department of Transportation.

The Seaway navigation system is unique and relies upon the Seaway Traffic Management System (TMS). All vessels entering the system are inspected and entered into the TMS (often days before arrival at a U.S. port). The TMS provides a structured method of managing transits for all the vessels along the Seaway. TMS users can create and modify vessel transit records as needed. Vessel information is entered and stored in the database, and is used to populate the transit records. Vessel information consists of the vessel identification information (vessel number, IMO number, and full name), fleet, length, depth, beam, units, origin, and destinations beyond the Seaway. Other information maintained includes: pre-clearance status, inspection report date, fleet, vessel group and type, country of registry, agent, cellular number, and last transit date. Because the U.S. segment of the Seaway and the U.S. locks are located between Canadian locks, most information regarding vessels is entered into the TMS by the SLSMC prior to reaching the U.S. locks.

The Seaway TMS maintains plans for each transit and this information includes items such as lake course, load conditions (i.e., ballast), hazardous cargo, last location, calculated time of arrival, ultimate destination, origin, call in location, turning location, and fuel stops. Delays regarding vessel movements can be added, modified and deleted. The TMS allows all of the vessel traffic control centers in the Seaway to share a common vessel information database.

In 2002, the St. Lawrence Seaway implemented an AIS requirement and integrated it with the Seaway's TMS. This is claimed to be the first substantial use of AIS on an inland waterway (St. Lawrence Seaway Development Corporation 2005a). The project was completed by a team that included the U.S. SLSDC, the Canadian SLSMC, various marine transportation interests, and technical assistance from the U.S. Volpe Transportation Systems Center. AIS transponders are currently required on all commercial vessels transiting through the Seaway. To receive AIS signals from vessels, nine antennas were erected at base stations along the Seaway, and appropriate communication links were established to the traffic control centers. The nine base stations broadcast water levels, weather data and lockage order-of-turn information for each lock within the Seaway.

A vessel equipped with AIS continuously transmits its location to the Seaway's traffic control center, as well as to other ships on the Seaway. In the traffic control center the location of each vessel is continuously tracked and displayed on an electronic map of the Seaway, together with its speed and course. Complementing this information, the Seaway's TMS broadcasts (through AIS channels) pertinent data such as lock availability, local wind speed and direction, water levels and flows, ice conditions, and safety-related messages as dictated by circumstances. The

integration of AIS and traffic management produces a valuable navigation aid that enhances the ability of each ship captain or pilot to navigate the Seaway safely and efficiently. Traffic control centers also provide typical radio communications capabilities.

The Seaway operators claim that AIS greatly enhances safety, improves the efficiency of the traffic management and increases vessel security and emergency response capabilities. The cited benefits of AIS for the Seaway include providing more efficient vessel traffic management as a result of knowing the accurate location and speed of the vessels; monitoring vessel speeds especially for hazardous cargo and deeper draft vessels; and providing faster response time to vessels in case of security concerns and vessel accidents or incidents in any kind of weather.

The potential benefits to the carriers using the Seaway include the reduction of overall transit time because of better scheduling of lockages and other services, such as inspections and dispatching of pilots. The real-time position and behavior information for the vessel also allows the vessel's master or pilot to improve coordination of the meeting or overtaking of other vessels in critical reaches of the Seaway (EPA 2003). Aggregate potential savings for all transiting vessels are estimated at U.S. \$300,000 annually (St. Lawrence Seaway Development Corporation 2005b).

Through agreements with the Canadian Shipowners Association and the Shipping Federation of Canada, the cost of implementing AIS was shared between the commercial carriers, the SLSDC, and the SLSMC. The overall cost of the AIS development and implementation was approximately \$2 million over twelve years as shown in Table 7. Early activities from 1992-1996 were for conducting a feasibility study with prototype demonstrations (\$200,000). Activities in 1997-1999 included development of system requirements, a survey of AIS equipment and demonstration of integration with the Seaway TMS (\$150,000). The full implementation of the AIS-based vessel traffic services system in 2000-2002 included hardware and software installation for the AIS shore stations and full integration of AIS with TMS at two traffic control centers (\$1,565,000). Recent activities in 2003-2004 are primarily maintenance, updates and training (\$163,800). The Volpe Center provided technical assistance in all aspects of software development, hardware evaluation, and procurement, the installation of AIS shore base stations and the integration of AIS with the Seaway TMS.

**Table 7. Seaway AIS project costs**  
(Source: data prepared by S. Hung, 1999.9.17, revised 2005.5.31)

<b>Year</b>	<b>Total cost</b>	<b>SLSDC</b>	<b>SLSMC</b>	<b>Carriers</b>
1992-1996	\$200,000	\$200,000	\$0	\$0
1997-1999	\$150,000	\$75,000	\$75,000	\$0
2000-2002	\$1,565,000	\$500,000	\$500,000	\$565,000
2003-2004	\$163,800	\$78,900	\$78,900	\$6,000
Total	\$2,078,800	\$853,900	\$653,900	\$571,000

While the Seaway's TMS system does provide accurate positional information (via AIS), as well as estimated arrival times at relevant points, traffic management does not generally include re-sequencing vessels for lockages. Given that nearly all lockages move a single ship as a unit

(double cut lockages are extremely rare), there is little variability in lockage times, unlike on the UMR. Although the Seaway requires AIS, vessels are still required to report in at specified call-in points and traffic management on the Seaway still relies heavily on voice transmissions.

## **Panama Canal**

The Panama Canal is approximately eighty kilometers long, linking the Atlantic and Pacific Oceans through the Isthmus of Panama. Like the St. Lawrence Seaway, the Panama Canal uses a sequence of locks to raise and lower vessels, and it employs a vessel tracking and traffic management system. The canal's three sets of locks include a total of twelve chambers and all locks occur in side-by-side pairs. The Gatun Locks have three pairs of chambers in sequence; the Pedro Miguel Locks have a single pair of chambers and the Miraflores Locks have two pairs of chambers. Transit of the locks generally takes eight to ten hours.

The Panama Canal authorities have long used information systems for better managing transits through the canal (see Allard (2000) and Jument and Cattalani (1998) for details on vessel traffic management systems at the Panama Canal). A vessel tracking and traffic management system, known as the CTAN (Communications Tracking and Navigation) system was developed by the Panama Canal Commission (PCC) and the Center for Navigation at the Volpe National Transportation Systems Center (in Cambridge, Massachusetts). This was part of a larger effort to improve vessel traffic management at the Panama Canal and it needed to track not only transiting vessels, but also the PCC resources such as tugboats, launches, and land-based vehicles that support the transits. Tracking information was also to be used to support a scheduling system.

The CTAN system relies on differential GPS-based locations, along with radar at both ends of the canal. Requirements for a pre-arrival notice of 96 hours also facilitate tracking and scheduling. Vessel positions are integrated with other information and presented in a real-time electronic map display developed jointly by the Volpe Center and Panama Canal pilots.

Prior to transit, vessels can be provided by the PCC with light-weight mobile units that provide positioning and communications (as with AIS). These units include a differential GPS (DGPS) receiver, a laptop processor with a display monitor, and digital communications components. These mobile units offer the PCC pilots and shore-side personnel the information required for safe navigation of the vessels. This allows pilots to better plan and control meeting situations and to ascertain traffic conditions at any point of the Canal. Additionally, pilots have access to real-time information on the availability and readiness of support resources needed at critical points in the transit, such as the locks and the Gaillard Cut. This information also is provided to the Canal's shore-side traffic control center, where other PCC personnel can obtain, evaluate, and disseminate the information needed for traffic management in the waterway.

## **River Information Systems (RIS)**

Europe is developing a broad, integrated and unified approach to inland waterway information systems under the heading of River Information Services (RIS). RIS has evolved from a series of smaller-scale projects across Europe, and RIS was officially defined in 1998 by the European Commission as “a concept of harmonized information services to support traffic and transport management in inland navigation, including interfaces to other modes of transport.”

RIS uses common systems to link all relevant parties across the inland waterways:

- vessel pilots
- tow companies
- lock, harbor, and terminal operators
- RIS operators
- waterway authorities
- emergency responders

RIS is also used for law enforcement, statistical data collection, and assisting in assessing waterway charges and port fees.

RIS integrates inland waterway information services to support the planning and management of traffic and transport operations across Europe to improve safety, efficiency and security. Many economic and environmental benefits are expected from RIS, including the following:

- improved navigational operations for vessel operators
- improved transportation and logistics processes (leading to higher quality services at lower costs) for shipping companies, ports and logistics companies
- reduced waiting times at locks and ports
- reduced fuel consumption from better planning of voyages

The European Commission, Directorate General for Energy and Transport (2005) reported benefit/cost ratios for RIS in a demonstration project on the Rhine River as follows: 5 to 1 for society, 3.5 to 1 for waterway pilots, and 1 to 1 for waterway authorities. RIS is now being gradually implemented on inland waterways in several Member States of the European Union (EU). This section describes some of the key features of RIS. For additional information, see Buck Consultants International et al. (2004) and European Commission, Directorate General for Energy and Transport (2005).

Inland waterways have long played an important role in European transportation, and RIS is designed to operate across a broad geographic region including many different countries, languages and cultures. More than 35,000 kilometers of inland waterways connect hundreds of cities and industrial regions across eighteen countries in the EU. Eleven of these countries have an interconnected waterway network. The Rhine and the Danube Rivers form the backbone of the waterway system, with other important riverways concentrated in the Netherlands and parts of Belgium and France. River transport accounts for 7% of the total inland transport in the EU,



totaling 125 billion ton-km (77.5 billion ton-miles) in 2003 (Buck Consultants International et al. 2004). The most intense concentration of traffic is along the Rhine River corridor through Germany, Belgium and the Netherlands.

There is a large variation in the waterway infrastructure and the waterway vessels of Europe. European inland commercial fleets are primarily characterized by two types of vessels: single self propelled vessels and push boats with barges. The carrying capacity of self propelled vessels and pushed barges total about 7.5 and 6.4 million deadweight tons, respectively. Self propelled vessels are concentrated on the Rhine River, with barge tows dominating the traffic on the Danube and other waterways (Buck Consultants International et al. 2004).

Part of the impetus for the development of RIS is the increasing congestion for land transport modes, especially road transportation, in Europe. The European Commission (EC) views inland navigation as an attractive potential alternative to land transportation. The EC's White Paper on the European Transport Policy for 2010 (European Commission 2001) proposed the use of efficient navigational aids and information and communication technologies to make inland waterway transportation more reliable, accessible and competitive; and to help inland water transport carry more time sensitive goods and containers. One goal of RIS is to make inland waterway transport a key part of modern supply chain management. The improvement of inland waterway transport is also of special interest in light of the expansion of the EU to include Central and Eastern European countries.

The comprehensive view of RIS integrates information regarding the navigation conditions of the waterways, the actual traffic situation in the immediate vicinity of a vessel, and strategic traffic information for planning of voyages, including scheduling of locks, ports and terminals. It allows carriers and waterway facility operators to better manage fleets and freight flows by tracking vessels and shipments. Data on vessel identification, position, heading, speed, etc., as well as information related to the cargo, will be captured electronically and processed automatically. RIS can provide both operational benefits (e.g., real time navigational decisions) and strategic benefits (e.g., better resource planning) for the potential users, including waterway authorities, vessel pilots, terminal managers, lock masters, etc.

Given the size and complexity of the European inland waterway network, a key for optimal functioning of RIS is use of a common architecture. The compatibility and interoperability of RIS services and applications relies on common design guidelines, standards and protocols for data exchange, communication, equipment and frequencies. A wide range of organizational, legal, political and technological challenges must be overcome to create the envisioned seamless harmonized system crossing many borders. Furthermore, the inland river systems are designed to be compatible with the maritime systems to provide seamless service covering all waterborne traffic in the EU.

RIS is comprised of a collection of services: Fairway information services, Traffic information services, Traffic management services, Calamity abatement services, Transport logistics services, and Statistics and water charges services. Each of these areas is briefly described below.

*Fairway information services* provide geographical, hydrological and administrative data on the infrastructure and navigation conditions of the waterways for use by pilots and fleet managers to plan, execute and monitor voyages. This includes dynamic and static information such as: forecasts of the water level, lock operating hours, maintenance activities for waterway infrastructure, accidents, temporary regulations, etc. This does not include information on vessels or their movements. Fairway information can be interactively displayed on an inland electronic chart display information system (ECDIS) onboard vessels and on shore. Traditionally, these services have been provided through paper charts, documents, TV and radio broadcasts, internet, e-mail and fixed telephones at locks.

*Traffic information services* include (1) tactical traffic information on real time vessel characteristics and movements on a limited part of the waterway and (2) strategic traffic information over a larger geographical area, including forecasts and analyses of future traffic situations. Tactical traffic information includes data such as the vessels' position, speed, and heading, which may be provided by remote sensing (e.g., radar), AIS, or other technologies. The information can be displayed on an Inland ECDIS and is used primarily for navigation decisions in the current traffic situation. Strategic traffic information provides a general overview of the traffic situation in a relatively large area and is used mainly for planning and monitoring activities. This provides information about intended voyages of vessels, dangerous (hazardous) cargo and times of arrival at defined points.

*Traffic management services* allow waterway authorities to facilitate safe navigation, to optimize the use of waterway infrastructure and to protect the environment. This includes local traffic management at VTS centers, navigational support (with vessel tracking), and lock and bridge management. Currently, vessel traffic services (VTS) centers are located at critical points along the European waterway network. These VTS centers receive data on vessels in their vicinity from shore based radar stations and/or AIS. VTS centers track vessels in their vicinity, provide navigational support and interact with the traffic as needed. RIS enhances and facilitates the work of existing VTS centers and permits traffic management on more of the European inland waterway network. Lock and bridge management services allow better planning by lock and bridge operators by sharing strategic and tactical traffic information. This allows better estimates of vessel arrival times and facilitates the flow of vessels through the locks and bridges. Lock operators can inform the individual pilots of the estimated time of availability, thereby enabling pilots to adjust their speed and possibly save fuel.

*Calamity abatement services* facilitate response to waterway emergencies. Relevant data is filed at the beginning of a trip and updated as necessary via ship reporting systems. In the event of an accident, the needed data is then available and appropriate responders can be provided with prompt and accurate information.

*Transport logistics services* include services for voyage planning, port and terminal management, and cargo and fleet management. Voyage planning services allow pilots and fleet managers to better plan vessel routes, drafts and arrival times based on fairway and traffic information. Voyage planning requires reliable information and forecasts on water levels and currents for an entire route from fairway information systems, along with accurate strategic and tactical traffic information. Port and terminal management services help improve resource planning and utilization for port and terminal operations. Better estimates of vessel arrival times and terminal availability help improve utilization of terminal and port facilities. This also allows negotiation of arrival times between vessels and terminals. Cargo and fleet management services allow better management of vessel fleets through real time tracking of loaded and empty barges and vessels. These services integrate information on cargoes being moved, cargoes at terminals waiting to be shipped, and available empty vessels.

*Statistics and waterway charges services* provide support for collecting and maintaining accurate data on the inland waterways, and for assessing appropriate charges. Automated electronic data collection will simplify the process for the data providers and the users, and can improve data quality. Waterway statistics may be used by waterway authorities, as well as by current and potential waterway users. RIS can also automate processes for assessing and collecting tolls and charges for infrastructure use and harbor activities.

RIS also creates new opportunities by exploiting the vast and disparate data being collected. For example, electronic marketplaces may allow better matching of carriers and shippers on the waterways and may facilitate more inter-modal operations. Vessel and cargo tracking and tracing allows fleet managers and logistics service providers to optimize utilization of transport capacities and infrastructures.

RIS has evolved from a wide variety of national stand-alone projects and services that have been developed across Europe since the late 1980s. Table 8 provides a brief summary of some of these major initiatives throughout Europe.

**Table 8. European waterway information system projects**

<b>Project</b>	<b>Country</b>	<b>Summary</b>
ARGO	Germany	Provides real time data on fairway conditions and water levels
BICS	Netherlands, Germany and others	Voyage and cargo reporting system to assist the pilot and fleet operator, especially for hazardous cargo
BIVAS	Belgium	Flemish internet-based virtual marketplace for barge transportation that links barge operators and shippers
DORIS	Austria	System to automatically generate tactical traffic information for pilots and waterway authorities using AIS. To be implemented on the Danube River in Austria in 2005
ELWIS	Germany	Provides a variety of fairway information services
IBIS	Belgium	A Flemish email-based system to share information between authorities and vessels
GINA	Belgium	A reporting application for Wallonia, especially for assessing waterway fees and collecting statistics
GWS	Belgium	System for waterways data exchange, including traffic support and automated infrastructure management
IVS90	Holland	Vessel reporting system for assisting waterway authorities with lock planning, VTS, calamity abatement and collecting statistics
MIB/MOVES	Germany	Vessel reporting system for incorporating several waterway services. Operational since 2001
NIF	Germany	System to transmit a variety of waterway messages regarding navigation and safety
VNF2000	France	System to invoice tolls and produce traffic statistics

A major challenge in implementing RIS is to integrate these various services and systems into a single unified concept. Two key recent projects focused on this integration are INDRIS and COMPRIS.

The INDRIS (Inland Navigation Demonstrator for River Information Services) project, which lasted from 1998 until 2002, was the major starting point for the development of the European RIS concept. INDRIS defined the concepts, functions and scale of RIS for all potential users. It also developed a methodology and guidelines to harmonize communications and reporting procedures across Europe and successfully demonstrated the technical aspects of RIS and many of its elements. Achievements of INDRIS included: 1) incorporation of new technologies in inland navigation (AIS transponders and inland ECDIS), 2) development of a framework for European cooperation on RIS, and 3) development of user-oriented applications for value-added services to the transport industry. INDRIS was a joint venture between national public authorities, the water transport industry, and research institutes from Austria, Germany, Belgium, France and the Netherlands.

The COMPRIS (Consortium Operational Management Platform River Information Services) project was launched in September 2002 and is planned for completion by the end of 2005. The COMPRIS consortium consists of forty-four active partners from eleven European countries. COMPRIS aims to finalize development of the technical, organizational and functional

architectures for RIS on a pan-European level. COMPRIS also seeks to enhance standards and applications for information exchange to prepare for implementation of RIS on European waterways. For details on the COMPRIS project see the website: <http://www.euro-compris.org>.

COMPRIS includes applications and systems for navigational support, vessel traffic management, optimum use of locks and infrastructure, accessing information by logistics service providers, facilitating cross-border transportation. It also includes testing of the system in various countries to demonstrate feasibility. Successful completion of the demonstrations provides the basis for full implementation of RIS across Europe. One key aspect of COMPRIS is the development of architectures for RIS that provide a framework for individual systems and services. These architectures covers four building blocks: 1) a reference model for enhanced inland navigation, 2) a functional and information architecture, 3) a physical, communication and data architecture, and 4) an organizational architecture. The feasibility for practical implementation of this framework will be assessed and validated during a trial phase of the project.

Because of the multiplicity of countries, languages and cultures in Europe, implementing RIS across Europe faces many challenges, especially in integrating disparate systems, facilitating border crossings, and managing cultural differences. RIS projects are careful to ensure compatibility and interoperability between current and new RIS systems in Europe and to integrate the different information services on the waterways. A pan-European approach also encourages suppliers of equipment to produce hardware and software for RIS at reasonable and affordable costs and to view RIS technology as a market opportunity. Because border crossing and international shipments can create added complications in transportation, RIS has been careful to address such issues in system design. Electronic data collection and transmission (including AIS) can facilitate these activities and can also help reduce language barriers.

The information services that comprise RIS are supported by a wide range of technologies. Technological innovations that have been introduced on the inland waterways during the last decade include electronic navigation charts (ENC) and inland ECDIS, internet applications (e.g., for notifying pilots), electronic ship reporting systems for cargo and voyage-related data, and vessel tracking and tracing technologies (including AIS). Satellite positioning technology can also be integrated into RIS using new European satellite systems.

RIS is expected to provide four types of strategic benefits, including increased competitiveness for waterway users, optimized use of infrastructures, improved safety and security, and increased environmental protection. RIS can lead to better planning of voyages and more reliable transportation. This in turn can lead to

- better use of limited resources and infrastructure by terminal and lock operators,
- reduced fuel consumption,
- reduced congestion and waiting times at locks and terminals,
- improved fleet management and better use of personnel,
- a more agile transportation system that better responds to disruptions, and

- creation of a more competitive transportation mode, thereby shifting cargo off roads and reducing vehicle emissions and noise.

RIS also improves safety and security by facilitating better navigational decisions (leading to a reduction in incidents, injuries and fatalities) and by more detailed monitoring of dangerous goods. The information sharing and vessel and cargo tracking aspects of RIS also contribute to enhanced security of transport operations. Finally, by linking together all members of the supply chain, including other modes of transport, RIS helps make inland water transport a better partner in a pan-European intermodal transportation system.

### **Vessel Identification and Positioning System (VIPS)**

The Vessel Identification and Positioning System was developed by the Volpe National Transportation Center in Cambridge, Massachusetts and has been implemented in a variety of locations for safety, security and environmental compliance. VIPS has been deployed for security applications such as protecting U.S. forces and assets in domestic and foreign ports, or protecting Boston Harbor during the 2004 Democratic National Convention. It also has been used for improving harbor security during transits of vessels such as LNG (liquid natural gas) tankers.

VIPS uses GPS technology, custom transponders and encryption to ensure accuracy and security. VIPS can incorporate AIS to allow vessels to identify themselves, but its main focus is on identifying potentially threatening vessels that would not be broadcasting their positions. VIPS is designed to integrate data from both shore-based and vessel-based sensors (e.g., radar) to identify any unknown vessels. VIPS leverages technologies the Volpe Center developed for applications at the Panama Canal and the St. Lawrence Seaway.

VIPS uses the TransView (TV32) GIS software for real time display. This allows real-time tracking of vessels as well as automated alarms when vessels enter or leave specified geographic regions. VIPS is primarily a system for port security and it includes considerable functionality that would be of interest for detailed identification and monitoring of vessels.

### **Vessel Monitoring Systems (VMS)**

Vessel Monitoring Systems (VMS) are required by the National Marine Fisheries Service (NMFS) for tracking fishing vessels in certain offshore fishing areas for compliance purposes. In 1988, the National Oceanographic and Atmospheric Administration (NOAA) Fisheries Office for Law Enforcement (OLE) began a satellite-based vessel monitoring program to locate high-seas drift-net fishing vessels and to monitor compliance with various restrictions in the North Pacific Ocean. These fisheries are managed by regional councils that prescribe the equipment and procedures for complying with the VMS requirements. According to NOAA (2005), this allows OLE to monitor compliance, track violators and provide evidence for prosecution while maintaining the integrity of the individual fisherman's effort. This original project has been expanded to other fisheries, and in 2003 there were 1,528 fishing vessels equipped with VMS.

As the number of international agreements increases, the requirement to utilize more-cost effective enforcement measures and the expansion of VMS-equipped vessels will increase.

Since most of the fisheries selected for VMS tracking lie well off the U.S. shore, satellite-based vessel tracking systems are generally used. A variety of systems have been approved for use by NOAA, and many commercial vendors are in the market. Billing for VMS is separated between accounts for the vessel owner and OLE. VMS position reports and vessel-initiated messaging are paid for by the vessel owner. Messaging initiated from the OLE operations center is paid for by OLE (NOAA 2003). Polling for vessel locations generally occurs in one hour intervals, but can be increased when required. Communication charges vary based on the service provider and communications plan chosen.

### **SmartLock**

SmartLock is a tool being developed for the Port of Pittsburgh that uses differential GPS to assist tow pilots in operations at a lock. Unlike VTS systems, SmartLock is a lock navigation aid for the tow pilot and the goal is to allow safe lockages even in zero visibility. SmartLock provides tow pilots with very accurate real time information on their position relative to the lock infrastructure, as well relevant information on river and weather conditions. The information is received through a wireless network at the lock and displayed on an electronic navigation chart on the vessel.

The SmartLock project started as a collaborative effort between the Port of Pittsburgh Commission, U.S. Army Corps of Engineers and students from Carnegie Mellon University. The Pittsburgh Port District, which covers 200 miles of commercially navigable waterway in Southwest Pennsylvania, currently loses about 11 days of operations annually due to fog. A software firm has been hired to develop the system and a test it at a lock on the Ohio River. According to James (2003), estimated savings are \$50,000 per boat.

### **Summary and Discussion**

This section describes existing vessel tracking applications that may be relevant to the situation on the UMR. Key findings are as follows:

- Tow tracking is in use on the UMR by operators and to a lesser extent by the U.S. Coast Guard
- Vessel traffic management systems are well established in the U.S. (and worldwide), though primarily at ports
- Vessel tracking and traffic management systems exist for some waterways with sequences of locks (e.g., the St. Lawrence Seaway and the Panama Canal), but the UMR is unique with its combination of tows, lock chambers and river conditions
- Comprehensive inland waterway traffic management is being advanced in Europe, more so than in the U.S.
- Recent events have shifted the focus of waterway authorities to security (as opposed to efficiency) in the U.S.

The requirements for tracking vessels for the purposes of managing lockages are somewhat different than those for other applications, such as navigational safety, security, or fisheries enforcement. Given the slow speeds of vessels on inland waterways and the limited options (directions) for vessel travel as compared to a more open deep water or harbor environment, real time vessel tracking and traffic monitoring is not essential for managing lockages. Furthermore, highly accurate positioning systems (e.g., differential GPS) are not required for implementing appointment or scheduling systems for lockages. However, such detailed systems may have uses for ensuring navigational safety or security, especially in poor weather conditions.

While sophisticated vessel tracking and traffic management systems exist, such as along the St. Lawrence Seaway, the primary motivation for such systems is related more to issues of navigational safety and security, than to managing lockages for improved efficiency. Existing inland waterway vessel tracking on the UMR (by operators or the U.S. Coast Guard's IRVMC) seems to operate satisfactorily with positional updates on approximately an hourly basis. Thus, an expensive and comprehensive real-time vessel tracking system is probably not advisable on the UMR solely for purposes of managing lockages.

However, a vessel tracking system designed and implemented for one purpose may well be easily extendible to other purposes, and the development of multiple overlapping vessel tracking systems seems inefficient. The systems for the St. Lawrence Seaway provide an indication of the current state-of-the-art in vessel tracking and vessel traffic management. The example in Europe with the development of comprehensive and integrated River Information Services (RIS) systems indicates the near-future state-of-the-art and it may provide a worthwhile model for future developments in the U.S.

While the U.S. Coast Guard's IWS (Intelligent Waterways Systems) initiative (U.S. Coast Guard 2003c) does provide a vision of a more unified and comprehensive inland waterway information system, this project seems smaller in scope, both in terms of services provided and agencies involved, than with RIS in Europe. With regard to implementing AIS nationwide, the GAO (2004) recommended that partnerships between the U.S. Army Corps of Engineers, the U.S. Coast Guard and other relevant public and private agencies could be most beneficial. An expansion of this recommendation for partnerships between the Corps, the Coast Guard, waterway carriers and other relevant private entities could be most beneficial in designing and implementing an efficient and effective version of RIS in the U.S. that expands on current projects to address the needs of all relevant participants.

A comprehensive vessel tracking system for the UMR, including lockage management, could benefit greatly from the experiences of the St. Lawrence Seaway and the European RIS initiative, which have developed over many years and through many different projects. These systems are maintaining or pushing the state-of-the-art and their experiences in integrating different technologies and functionalities into a comprehensive system, in environments more challenging than on the UMR (e.g., multi-national, multi-cultural, etc.), provide a base map deserving of more study for possible future actions on the UMR.



## **TECHNOLOGIES TO IMPLEMENT VESSEL TRACKING ON THE UMR**

The key functions of a vessel tracking system for managing lockages on the Upper Mississippi River (UMR) are: 1) finding the geographic position of the tow, 2) communicating the tow position to an information system, and 3) integrating the information into an electronic display for use in managing lockages. The geographic position of a tow can be readily and economically determined either by position sensing equipment onboard the tow (e.g., using standard GPS technologies) or by remote sensing technologies (e.g., radar). For use in managing lockages or traffic control, the tow positions need to be communicated from the vessels to the lockmaster or traffic controller. Tow position information can be linked with associated tow identification information (e.g., name of vessel, number of barges, cargoes, etc.) and displayed on an electronic map of the relevant geographic region using a geographic information system (GIS). Tow position information could also be used as input for an automated lock management information system (LMIS). Such a system might provide the lockmaster (or river traffic controller) with a suggested lockage sequence or suggested lockage appointment times based on current tow positions along the waterway (and other relevant data).

This section describes relevant technologies for vessel tracking on the UMR, including methods for acquiring dynamic (real or near-real time) location and attribute data of vessels, and for communicating this data to an information system for visual display. This includes vessel location technologies embedded in commercial vessel tracking systems and communication options from ship-to-shore and on to the LMIS. This section also highlights key issues in position reporting, communications, and integration of data into a LMIS, as well as organizational issues including responsibility and authority associated with vessel tracking on the UMR.

### **Determining Tow Locations**

There are a variety of technologies that could be used to determine the geographic position of a tow on the UMR. These range from automated systems that use satellites and ground stations for precise positioning, to manual systems where tow pilots report their position at specified locations along the river. However, for vessel tracking to be effective, tow positions must be determined repetitively at a great enough frequency to construct a realistic travel path for the vessel.

Positional data on tows may be collected at various locations and at various time intervals as needed by the application. For example, the U.S. Coast Guard's Inland Rivers Vessel Movement Center (IRVMC) and the St. Lawrence Seaway require vessels to report their arrival at specified points along the waterway. On the other hand, many commercial vessel tracking systems provide periodic positional reports at specified time intervals (e.g., hourly). Some systems, such as AIS, provide essentially continuous positional reporting. Besides reporting current positions at specified points in space or time, vessels may need to be continuously available for polling to determine their current location (and perhaps other relevant data).

Manual self-reporting of tow positions to the Corps is currently used on the UMR as the tows radio ahead to the lockmaster at the upcoming lock in their journey when they reach specified call-in points. Once a vessel calls in to indicate it has arrived and is ready for lockage, it can be placed in the lock queue. However, manual self-reporting systems are subject to inaccuracies as tows may call in prior to reaching the designated point. Currently, lockmasters cannot determine a tow's location without visual confirmation.

Another example of self-reporting of tow positions on the UMR is the tracking of certain dangerous cargoes (CDCs) by the IRVMC. Tow operators are required to report their position and some associated information to IRVMC at various locations along the river and when specified activities occur. This information may be provided electronically from the tow operator's traffic management center, or by the individual tow pilot using email, fax or phone.

While self-reporting of tow positions can be effective and efficient, it may be inaccurate (intentionally or not), unreliable and expensive if large numbers of vessels are providing manual reports. An automated vessel tracking system could provide accurate tow locations automatically, even in poor weather conditions. Automated vessel positioning technologies allow tow locations to be readily and economically determined using equipment onboard the tow. Vessel positions are calculated based on triangulation using the distances to several known locations, which may be satellites or terrestrial antennas. Generally, using a greater number of known locations increases the accuracy of the position calculations.

The common method for finding vessel positions is to use a global navigation satellite system (GNSS). These are collections of satellites that have been designed to provide accurate locations nearly anywhere on (or near) the earth's surface. The only fully functional GNSS currently in use is the U.S. global positioning system (GPS), operated by the U.S. Department of Defense. This uses a constellation of 24 satellites in six orbital planes in circular 20,200 km orbits. The GPS satellites provide high frequency radio signals that allow GPS receivers to calculate their position and velocity. GPS receivers need to view at least four satellites to compute an accurate position. Other GNSSes include the Russian system GLONASS, which is currently being renovated, and the European GALILEO system, currently under development. The GALILEO system is planned to provide capabilities for supporting River Information Services (RIS), as discussed in the previous section.

The GPS system originally included an intentional degradation of signals to limit the accuracy for civilian and commercial uses, but this feature was removed in 2000. Standard GPS receivers, which are available in various sizes and packages from many commercial vendors, typically have positional accuracy of about 15 meters (depending on the conditions). Much greater accuracy can be achieved with differential GPS, which uses stationary land based GPS receivers at known locations to reduce the positional error (measuring GPS accuracy is a statistical exercise beyond the scope of this report).

In addition to GPS, there are a number of commercial telecommunications satellite systems that can also be used for determining vessel positions. However, the positional accuracy with such systems is generally less than that with GPS, since they were not designed for positioning objects

(positioning accuracy depends on the number of satellites in the system and their orbits, among other factors).

Since GPS does not provide communications capabilities for transmitting vessel positions to another location, commercial vessel tracking systems integrate vessel positioning and communications, so that the vessel locations and associated identification and performance information (e.g., speed, heading, etc.) can be transmitted together. This can be broadcast from a vessel, as with AIS, or sent via secure or non-secure communications to private organizations, such as carriers or vessel tracking service providers, or waterway authorities. Large tow operators in the UMR currently track their tows with commercial or proprietary vessel tracking systems that provide tow locations and other information automatically at regular intervals.

### *Satellite-based Systems*

There are several providers of satellite-based telecommunications systems and any of these communications systems could be used in conjunction with geographic positioning technologies (e.g., GPS) to implement vessel tracking systems. A number of commercial vendors have developed vessel tracking packages (equipment + software) that integrate vessel positioning and communications using several different satellite systems, with services provided by private satellite communications firms such as Orbcomm, Iridium, and Inmarsat, or by public systems such as Argos.

#### **Boatrac<sup>®</sup>**

Boatrac<sup>®</sup> is a tow tracking system in use on the UMR that provides positioning and two-way satellite-based data transmission within the continental U.S. and up to several hundred miles offshore (U.S. Coast Guard 1998b). Boatrac<sup>®</sup> does not use GPS for positioning, but instead uses triangulation with commercial telecommunications satellites to provide an accuracy of approximately 100 meters. Boatrac<sup>®</sup> has been in use since 1989 and is currently owned by AirIQ, Inc. of Canada.

Boatrac<sup>®</sup> is a full service integrated solution (hardware, software and service) that combines positioning and secure communications. It is the maritime version of the Qualcomm OmniTRACS<sup>®</sup> vehicle tracking service, and like OmniTRACS<sup>®</sup> it uses transponders on existing satellites. The Boatrac<sup>®</sup> network includes two ground stations in San Diego, California and Las Vegas, Nevada, and all communications between the terminals on the vessels and the ground station are at Ku-band and are secure, unlike other options such as AIS. Boatrac<sup>®</sup> has a large installed maritime customer base of over 400 fleets and it provides a range of management systems, solutions and communications services. In addition to use on the UMR, Boatrac<sup>®</sup> was tested by the U.S. Coast Guard's Eighth District along the Gulf of Mexico and the lower Mississippi River in 1998 (U.S. Coast Guard 1998b) and by the Transportation Security Agency on the Columbia and Snake Rivers in 2003.

Generally, Boatrac<sup>®</sup> provides updated positions hourly and with every message sent from the vessel. The hardware cost for Boatrac is approximately \$3500-\$5000 per boat (Paul 2005; U.S. Coast Guard 1998a; Sheffield 2003). Current costs for vessel positioning alone

are approximately \$55/month for hourly positioning. Additional charges for messaging are assessed by message and by character and typically average approximately \$100/month per boat (Paul 2005).

### **Argos**

Argos is satellite-based system for positioning, data collection and communications with global coverage that has a primary focus on environmental applications. It was established in 1978 in a joint initiative of the U.S. and France and is currently a joint project of the French and Japanese space agencies (CNES and NASDA, respectively), the U.S. National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA), and the European Meteorological Satellite Organization (EUMETSAT). Argos includes several earth stations in the U.S. and France for communicating with its satellites, along with data processing centers in Europe, the U.S., Japan, Peru and Australia. Argos is operated by the French firm CLS, a majority of which is owned by CNES.

Argos uses NOAA polar orbiting environmental satellites and can provide positions with an accuracy of approximately 150 meters. Argos also allows GPS to be integrated in the system to improve positional accuracy. Argos is often used for environmental data collection applications (e.g., tracking weather from buoys or monitoring an animal's health in the wild), but it also supports vessel monitoring systems (VMS) for fisheries that incorporate vessel tracking with GPS. CLS also supplies vessel monitoring control centers for fisheries that include the necessary hardware and software systems for monitoring and tracking fishing vessels worldwide using GIS. Many commercial firms provide Argos transmitters/receivers and Argos has a large customer base with thousands of active users (Argos 2004).

### **Inmarsat**

Inmarsat is the international maritime satellite organization and it provides satellite-based communications and positioning for mobile users, primarily for maritime safety. Inmarsat began service in 1981 and now includes a range of services for different types of data and a wide variety of users. Inmarsat uses four satellites to provide global coverage except in Polar Regions (above 70 degrees north or south) and Inmarsat systems are heavily used for ocean carriers and fishing fleets. Inmarsat operates its own satellites and is currently launching the fourth generation Inmarsat-4 satellites which will expand the capabilities and speed of communications. (The first of three new Inmarsat-4 satellites is now operational.) Inmarsat has its headquarters and satellite control center in London, with tracking and control stations in Canada, China, and Italy.

Inmarsat provides vessel tracking through use of integrated GPS receivers in the Inmarsat C, mini C and D+ services. These systems support text messaging and compressed data reports, but differ in their size and functionalities. Inmarsat C and mini-C meet maritime requirements for global maritime distress and safety system (GMDSS) and ship security alert systems (SSAS) required by the International Maritime Organization (IMO) (Digital Ship 2004). Receivers using Inmarsat C and D+ have been approved by NOAA as a satellite-based VMS for fisheries (NOAA 2003, 2004) and several commercial system and service providers are using Inmarsat satellites to deliver vessel tracking systems, including

Satamatics Ltd., Land Sea Systems, Inc., PoleStar Space Applications Limited, EMMI Network, and GPS Danmark.

### **Orbcomm**

Orbcomm is a satellite communications system owned by a partnership of Orbital Sciences Corporation and Teleglobe, Inc of Canada that began service in 1999. Orbcomm is used for sending and receiving short text messages, monitoring remote equipment, and tracking mobile units. Orbcomm has a network of approximately thirty satellites, with a control center in Dulles, Virginia and numerous earth stations to link customers together. An Orbcomm system has been approved by NOAA as a satellite-based VMS for fisheries (NOAA 2003, 2004) and commercial vessel tracking systems have been developed that use Orbcomm for communications. In June 2004 Orbcomm received a U.S. Coast Guard contract to provide satellite-based AIS capability (Sternstein 2004).

Communications using Orbcomm may experience some delays due to the nature of the satellite system. Orbcomm satellites are low earth orbit satellites (unlike Inmarsat which uses higher geostationary orbits to provide continuous broad geographic coverage) and both the user and a gateway earth station must be within the footprint of the same satellite in order to communicate in real time. There is no inter-satellite communication with Orbcomm, so a satellite may store data until it passes over a gateway when it can send the data forward. In testing by the U.S. Coast Guard (1999) this created coverage gaps of up to two hours. System availability can also be affected by a satellite or gateway failure, or by removal of a satellite from the system for testing.

### *Non-satellite Based Technologies*

Tow positions can be determined automatically by non-satellite (e.g., terrestrial or airborne) remote sensing technologies, such as radar or radio frequency identification (RFID) technologies. However, remote sensing of vessels with radar requires additional efforts and communications to identify the vessel and to link to the relevant identification data with the vessel position, before the information can be displayed in a GIS. Long range RFID systems have been developed for the military with the ability to identify RFID tags on mobile targets at ranges measuring several miles (Sellers et al. 1998). While these technologies seem feasible to adapt for tracking tows and barges on the UMR, the existing technologies and vessel tracking services seem more than adequate for the purposes of managing lockages on the UMR.

### **Automatic Identification Systems (AIS)**

Automatic Identification Systems (AIS) is a standardized technology for providing vessel positions and identification, as well as ship-to-ship, ship-to-shore and shore-to-ship communications. AIS was developed by the IMO to improve maritime safety, enhance environmental protection and improve vessel traffic services (VTS) operations. It is now required on nearly all vessels on international voyages, including nearly all large commercial passenger and towing vessels. The U.S. Maritime Transportation Security Act of 2002 requires ship-board AIS on all vessels subject to the Safety of Life at Sea (SOLAS) convention and on

certain domestic vessels operating in VTS areas and in Vessel Movement Reporting Service (VMRS) areas monitored by the U.S. Coast Guard.

AIS is a shipboard broadcast system operating in the VHF maritime band using a communications protocol developed under the aegis of the IMO, the International Telecommunication Union (ITU) and the International Electrotechnical Commission (IEC). AIS units automatically broadcast static, dynamic, and voyage related data that can be received by other vessels and land-based stations. Every ten seconds while underway, and every three minutes while anchored, the AIS broadcasts the following information: MMSI (the unique Maritime Mobile Service Identity code); navigation status; rate of turn; speed over ground; position accuracy; longitude; latitude; course over ground; true heading and a time stamp. Every six minutes the AIS broadcasts the following: MMSI; IMO number (unique identifier related to the vessel's construction); radio call sign; name; type of ship; dimensions of ship; location of ship; type of position fixing device; draft of ship; destination and estimated time of arrival (U.S. Coast Guard 2005a). AIS units also automatically receive the AIS broadcasts from other vessels and from shore stations.

According to U.S. Coast Guard (2005a), AIS is capable of handling over 4,500 reports per minute and updates as often as every two seconds. AIS uses a designated part of the frequency spectrum now known as AIS 1 and AIS 2, that correspond to VHF Channels 87B (161.975 MHz) and Channel 88B (162.025 MHz), respectively. It uses Self-Organizing Time Division Multiple Access (SOTDMA) technology to meet this high broadcast rate and ensure reliable operation. However, AIS has not replaced voice reports and sailing plan reports, deviation reports, and final reports are still required in ports (U.S. Coast Guard 2005b).

Each AIS system consists of a central processing unit (CPU), a global navigation satellite system (e.g., GPS) receiver for positioning, associated antennas, cable, four radios, (one VHF transmitter and three VHF receivers), and a standard marine electronic communications link to shipboard display and sensor systems. Position and timing information is normally derived from an integral or external global navigation satellite system receiver that may be a differential GPS receiver for precise positioning when needed (e.g., in coastal inland waters).

The AIS transponder works in an autonomous and continuous mode. Each station transmits and receives over two radio channels to avoid interference problems. A position report from one AIS station fits into one of the 2250 time slots established every sixty seconds. Synchronization is continuous to avoid overlap of slot transmissions (U.S. Coast Guard 2005b). The cost of an AIS transponder varies among manufacturers and with the options selected by the user, and basic prices range from \$4,500 to \$20,000 (Furuno 2005). Depending on the height of the antenna, system coverage range is similar to VHF marine applications, which is about twenty nautical miles at sea. Repeater stations can be used to extend the coverage distance.

The primary purpose of AIS is to improve navigational safety, and the integration of AIS with radar and charting displays has proven to be extremely valuable according to Morris (2005). Because AIS broadcasts can be received by a land-based antenna (e.g., at a traffic control center), these can be used to provide centralized dynamic vessel display and tracking. For

example, AIS information is captured and used for traffic management on the St. Lawrence Seaway and in VTS areas.

The benefits of AIS include improved safety and security, better environmental protection and better emergency response. Improved efficiency can result from reduced transit times, better scheduling of lockages and vessel tie-ups, and better scheduling of inspections and piloting services. Some of the current limitations of AIS identified by Morris (2005) include: difficulty in reading displays, distractions from pilot navigation duties, lack of training, and integration problems in some brands of AIS transceivers. Morris (2005) supports expanding AIS with software for charting and forecasting, integrating AIS with radar for verification, and requiring all vessels to be equipped with AIS.

The U.S. Coast Guard maintains a strong interest in AIS and it is an integral part of their Intelligent Waterways System (IWS) project, which is designed to automatically collect, manage and distribute information to benefit the entire marine transportation system. IWS proposes a Waterway Information Network (WIN) to tie together AIS, automated data distribution services and advanced navigation systems to facilitate the collection and sharing of relevant information. See Spaulding, et al. (2002), and U.S. Coast Guard (2003c) for more information.

The U.S. Coast Guard is currently implementing plans to use satellite monitoring to track ships with AIS using an Orbcomm commercial satellite (Sternstein 2004). While the primary impetus for such a system is to extend the Coast Guard's vision well beyond the U.S. coast, such a system may be extendable to tracking AIS equipped vessels on the inland waterways.

AIS is not currently required on the UMR; however, it is required on many vessels on the Lower Mississippi River that traverse a VTS area. The U.S. Coast Guard has asked carriers the two following questions about possible future implementation of AIS on the inland waterways (Department of Homeland Security 2003):

1. "Recognizing that AIS may ultimately be required on all navigable waters, what particular waterways or ports should be implemented before others?"
2. "Are there particular waterways where the AIS requirements should be waived? Why?"

The response to these questions from The American Waterways Operators (AWO) (2003a) indicated that they did not support extension of AIS for security purposes on inland rivers north of Baton Rouge, including the UMR, and further that AIS should not be required on non-self propelled vessels such as barges. AWO (2003a, 2003b) also expressed concerns about standardizing AIS requirements, better integration of AIS and electronic charting, limited space onboard towing vessels for AIS antennas, and the need for expensive land-side infrastructure to support AIS. Other responses from towing companies operating on the UMR regarding the extension of AIS to inland waterways provided the following opposing views:

- "AIS requirements should be waived for all inland waterways...and for all vessels engaged solely on domestic voyages on those waterways, because there is no safety or

security benefit...” and “AIS will provide no practical benefit for the mariner navigating narrow inland waterways.” (Southern Towing Company 2003)

- “Commercial watercraft, regardless of size or service, should be required to comply with AIS requirements.” and “...the Illinois River should have a relatively high priority [for implementing AIS], followed by the Ohio, Upper Mississippi, and Arkansas.” (American Commercial Barge Lines, LLC 2003).

## **Data Communications**

Communication of the tow locations to an information system relies on standard communication channels and technologies. The most common data communication media used in maritime transmissions and communications are radio (HF, UHF, VHF, trunk, radio or microwave link), cellular or satellite telephone, or satellite communications. These transmissions may be secure (as with some private providers and military organizations) or non-secure (as with AIS). When considering alternatives for communications, the following must be taken into consideration: transmission medium; coverage area; availability; accuracy; interoperability (ease of integration with other system requirements); reliability; level of security; and cost (including systems, installation, maintenance, and usage). The Federal Communications Commission (FCC) regulates and manages communications and frequencies for terrestrial and satellite systems.

Radios have long been used for communications along the inland waterways, and smaller towing firms may rely exclusively on radio for tow communications. Radio (and other terrestrial transmissions such as television) generally operates in the lower portion of the communications frequency spectrum, with VHF radio operating at frequencies of 138-152 MHz. The advantage of radio communications is that once the radio link is set up the calls are free of charge. However, radio may not be dependable in poor weather or a variety of other situations, and radio communications generally lack confidentiality. In addition, there can be complications with signal strength and range that are site specific and must be considered on a case-by-case basis.

Cellular phones can be used in many places for voice and data communications with commercial (and recreational) boats. While cellular phone systems are relatively simple to use, they may be more expensive than other communications systems. In addition, coverage on the waterways for cellular phone service is limited because the networks were designed around roadways for automobile and motor carrier use, not waterways. Cell phones are actually radios and generally operate at frequencies in the range 800-1900 MHz. Watercom is a cellular radio phone service using a network of radio towers located along major U.S. rivers that has been used for several decades. Watercom users incur a connection charge as well as a per-minute usage charge, based on where the vessel is operating. Some gaps in availability have been noted for cellular phone service due to “dead spots” for cell phone coverage on the river and the unreliability and length of time for communications (Sheffield 2003).

Satellite telephone systems, which are becoming more common, provide wider coverage than cellular phone service, but often at an increase in cost. Satellite communications systems are now becoming widespread and satellite communications alternatives were reviewed by the U.S. Coast Guard (1998a). Some providers of satellite communications operate their own satellites, while other providers use satellites operated by third parties. Satellite communications generally use



higher frequencies than terrestrial communications systems, and uplink and downlink frequencies may differ. For example, Inmarsat uses L band transmissions at frequencies between 1.5 and 2.7 GHz, and Boatracs® uses Ku-band transmissions at frequencies between 11.7 and 17.8 GHz. Generally these higher frequencies in satellite communications are less affected by atmospheric and weather conditions, compared to the lower frequencies used by terrestrial systems. However, sunspot activity can be a source of interference.

### **Integrating Data into a Vessel Tracking Lockage Information System**

Commercial vessel tracking systems that combine positioning and communications technologies generally provide for display of vessel positions on an electronic map using a GIS. This is a fundamental capability and it could be used on the UMR to verify tow positions as reported by the pilot and to improve the lockmaster's mental map of the river segment with which he or she is concerned. Such a display might also expand the geographic scope of the lockmaster's mental map by providing a dynamic adjustable visual display (using panning and zooming tools) of tow traffic on the river. By seeing more of the river a lockmaster might be able to anticipate problems leading to congestion earlier and to respond better. Electronic mapping of dynamic vessel positions using a historical database of vessel positions might also have applications for enforcement and security, though greater positional accuracy may be required in some cases.

While technologies for vessel tracking, electronic mapping, and optimizing lockages exist, we are not aware of a vessel tracking system that includes functionality for managing lockages. Such a system would require integration of vessel location and identification data into a lockage management information system (LMIS). Integrating tow locations into such a system requires collection and verification of the relevant tow and lock data in real (or near-real) time, and communication of the data to the LMIS.

Depending on the type of lockage management desired, the LMIS might provide simply a coherent display of tows and related attribute information (e.g., number of barges, destination, etc.) on an electronic map – or it might include a lockage optimization decision support module that incorporates a tow scheduling or sequencing algorithm to provide a suggested sequencing of tows for lockage or suggested lockage appointment times. This would require development of software to implement a lockage management alternative (e.g., including a lockage optimization algorithm) and to provide an interface between the vessel tracking system and the lockage optimization software for both input and output. The input data needed from the vessel tracking system (e.g., tow locations and associated attribute data) depends on the type of lockage management alternative desired, as outlined in Volume 1 of this report. Outputs would also depend on the type of lockage management alternative desired, as well as the needs of the user (e.g., lockmasters).

While a sophisticated LMIS with complex decision support algorithms and functionalities similar to those at a VTS installation or the traffic management system on the St. Lawrence Seaway is certainly feasible, it would be an expensive system that could be best used to support a wide range of functions in addition (and well beyond) managing lockages. The cost of such a system, as with VTS systems, depends on the geographic area involved, the type of technologies employed (radar, AIS, video, radio communications, etc.), and the infrastructure (towers, roads,

equipment shelters, etc.) required at each site. (Kinsella 2005) indicated that VTS installations can differ in cost by a factor of 100 depending on the site specifics.)

## **Summary and Discussion**

This section has described technologies that may be relevant for implementing vessel tracking on the UMR for use in improving management of lockages. Key findings include the following:

- Technologies for tow tracking are mature and commercial vessel tracking systems using a range of technologies are widely available for many applications.
- Satellite-based automatic vessel tracking and communications technologies are becoming more common.
- Real time and near-real time tow tracking is certainly feasible on the UMR – and is in use by many carriers and with the U.S. Coast Guard’s IRVMC.
- Dynamic vessel location data for the UMR could be acquired automatically or by manual self-reporting from tows.
- AIS might provide an opportunity for cost effective data collection if it was required on the UMR.
- Integration of tow tracking and lock scheduling is feasible, but not yet in place.
- Costs of a lock management information system, including vessel tracking, cannot be estimated accurately until a lockage management alternative and system is specified, and a geographic region for implementation is selected.

There are a variety of methods that could be used to find tow positions on the UMR and to communicate those locations to a GIS or a lockage management information system (LMIS). Both automatic and manual reporting by the carriers to the IRVMC are currently in place on the UMR. Other marine vessel tracking systems exist and could likely be adapted to the UMR. However, the key issue driving the choice of a vessel tracking system is the nature of the need for vessel position data. Systems that use manual reporting at specified call in points are very different from those that use automated reporting at periodic intervals. However in either case, there are important questions. In the first case, the number and locations of the call in points must be determined. In the second case, the frequency of position reporting must be determined. These decisions are driven by the amount of positional and temporal accuracy needed for the selected method of managing lockages on the UMR. Since the cost increases with the positional and temporal accuracy (more call in points or more frequent updates), this issue deserves careful consideration.

The question of what type of vessel tracking is best depends on the particular situation. Important issues for vessel tracking include how and when to find and communicate tow locations. Some key questions about these issues include the following:

- How much positional accuracy is needed?
- How frequently should positions be updated given the slow speeds on the river?
- How much does real time or near-real time vessel tracking add for reducing congestion?

- Are there opportunities to partner with other relevant parties, such as the U.S. Coast Guard or individual carriers?
- Will AIS soon be required on the UMR?
- Will non-commercial (recreational) craft be tracked? If so, how?

Dynamic vessel location data can be displayed on an electronic map to improve the visibility of a lockage for a traffic manager, or it may be used within an LMIS for decision support. The type of LMIS needed and the types of information it requires depend on the type of traffic and the type of lockage management desired. A simple LMIS might do little more than display tow locations and identifying data on an electronic map, while a sophisticated LMIS could include more complex decision support and functionalities similar to those at a VTS installation. The geographic scope for such a system ranges from a single lock and adjacent pools, to multiple locks and pools, to the entire riverway. The vessel location data to be used in such systems could range from existing data (as in the OMNI database) to near-real time locations (e.g., every hour) to real time locations (e.g., as with AIS).

There is a range of alternatives for managing lockages (as outlined in Volume 1 of this report) and tow tracking at different levels of detail can be associated with each alternative. Increasingly detailed vessel tracking may provide little or no benefits in terms of improving lockages, though it would likely entail added costs for data collection. For example, one traffic management option would be to re-sequence vessels in lock queues using the existing (OMNI) data for vessel tracking (e.g., vessel positions are known only at the locks). Or, instead, one could use more detailed near-real time positional data reported at specified locations or time intervals by the vessel or carrier (as with IRVMC) to support the traffic management policy. The same re-sequencing approach could also be supported by a more comprehensive tow tracking system using real time technologies (e.g., AIS) with traffic management centers (as on the St. Lawrence Seaway).

Some important issues for identifying the type of vessel tracking appropriate for interfacing with an LMIS include the following:

- How do different levels of detail and precision in tow locations affect different lockage management alternatives?
- How does incomplete vessel tracking in which not all tows are located affect different lockage management alternatives?
- Should tows receive a benefit (e.g., higher priority for lockage) from providing positional information?
- How are recreational craft to be handled?
- What are the management implications if no recreational craft are tracked?

The use of vessel tracking technologies can raise a series of organizational and legal issues regarding how such use can be mandated and how the data collected could be used. There are a variety of stakeholders in the inland waterways (including the UMR) who could be affected, including the Corps, the Coast Guard, carriers, shippers, recreational user and the public at large. A key issue is to clarify who has the legal authority and responsibility for managing traffic on the UMR, including vessel lockages. The U.S. Coast Guard has significant safety and security

responsibilities for the inland waterways and they have been granted broad powers under the Maritime Transportation Security Act of 2002, including the ability to require AIS for security purposes. The responsibility and authority related to requiring private operators to carry vessel tracking equipment or participate in vessel tracking systems for lockage and traffic management needs to be clarified. Legal issues related to vessel tracking can be quite complex and challenging, though experiences in a difficult multinational environment in Europe suggest the challenges can be overcome (Molenaar and Tsamenyi 2000).

In the U.S. the inland waterway transportation system operates quite differently than the air transportation system and developing an inland waterway traffic control system analogous to that for air traffic control for commercial and general aviation would be a daunting task—perhaps more from a legal and organizational perspective, than from a technological perspective. However, the potential benefits from vessel tracking and from better management of traffic on the inland waterways can be quite broad, including improved safety and security, and better environmental protection. These benefits extend well beyond the narrow focus on better managing lockages, which are quite dependent on the level of traffic under management.

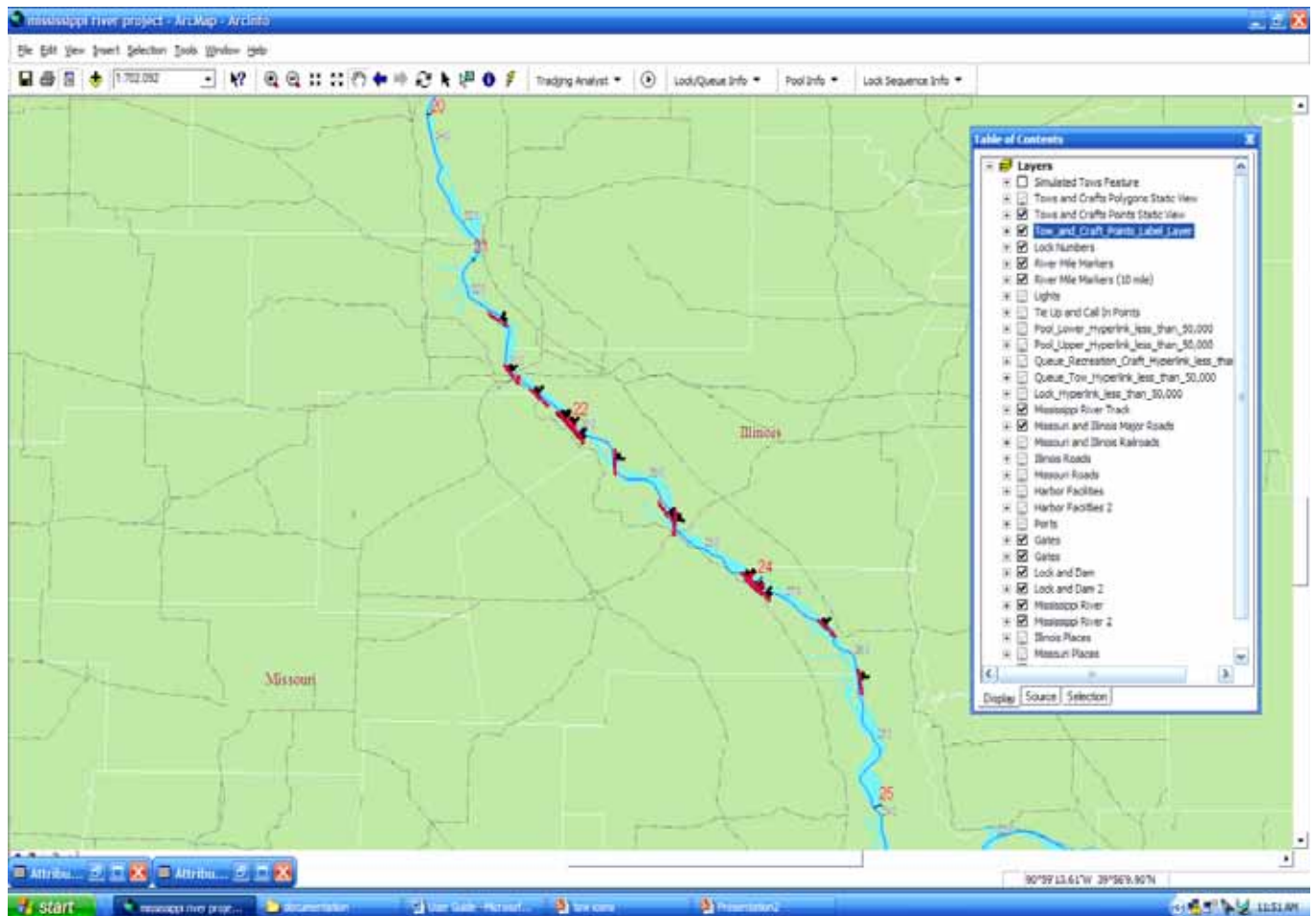
## **PROTOTYPE VESSEL TRACKING GIS**

We have developed a prototype vessel tracking geographic information system (GIS) to provide sample displays and an example of vessel tracking to demonstrate the functionality possible from vessel tracking on the UMR. The prototype includes static views to demonstrate display of geographic and attribute (tabular) data, along with dynamic views to show tows moving on the UMR. Static data may include lock locations and operating conditions, river features, and important shore elements, with relevant attribute data. A User's Guide for the prototype system is included as Appendix A to this Volume. The User's Guide includes details on how to acquire the data files needed for the prototype application described below.

The prototype system is built using the ArcMap 9.0 geographic information system (GIS) with the Tracking Analyst extension for managing the dynamic tow locations (both are software products of ESRI, Inc.). ArcMap 9.0 is a multi-functional program that has been used in a wide variety of fields, including transportation management, environmental analysis, economic impact analysis, water management, housing and community development, demographic analysis and forecasting, etc. ArcMap allows for the visualization of spatially based data, as well as in-built and custom-made applications for analysis of data. Tracking Analyst allows for both the static display of sequenced spatial data, like tow positions, as well as connectivity in a more dynamic set-up with streamed spatial data. In the prototype, the Tracking Analyst extension relies upon simulated tow positions created using past location data available from the Corps OMNI system.

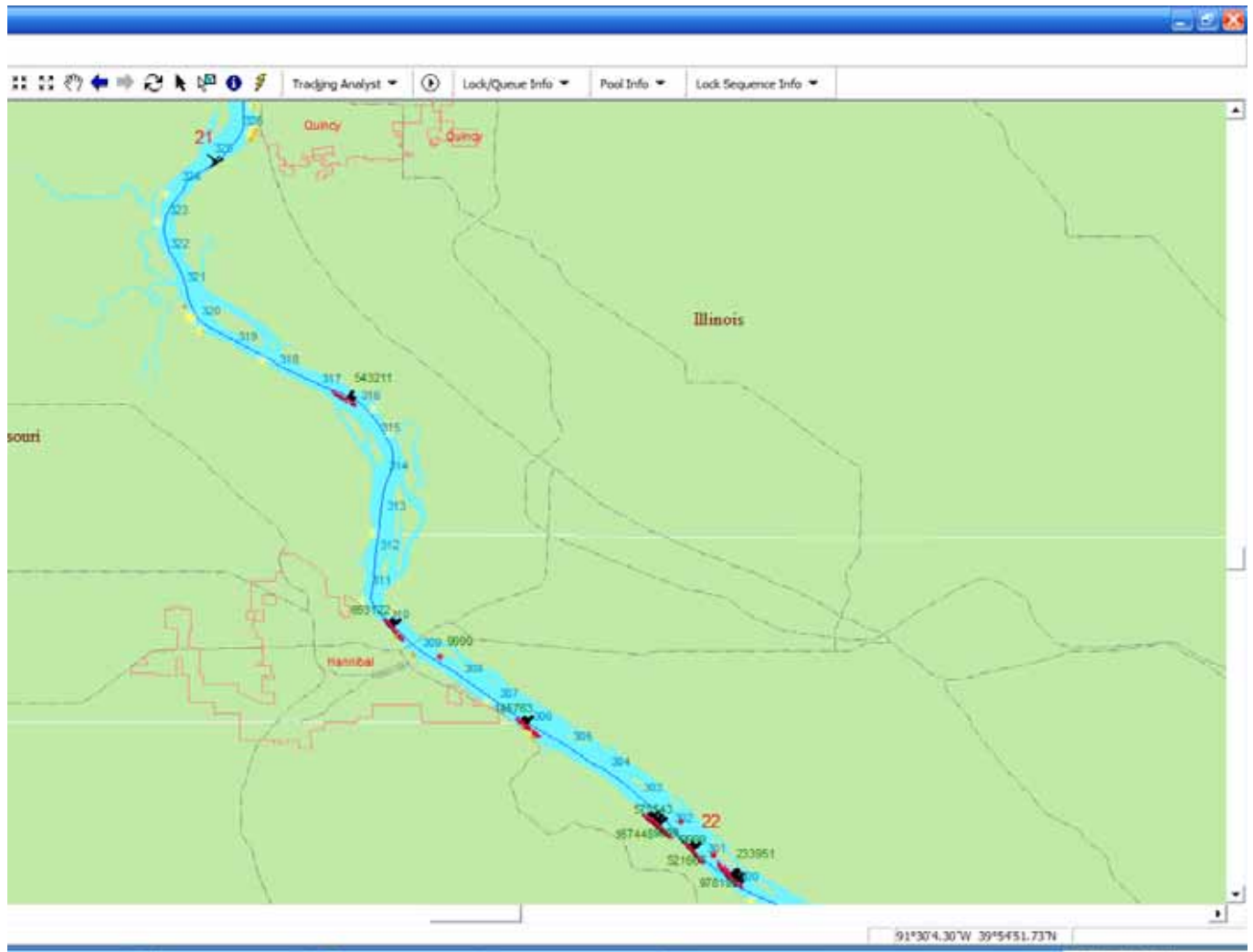
Creation of the electronic base maps of the study area for the prototype GIS required collecting and cleaning a variety of spatial data sets for the river and shore features, as well as the lock and dam infrastructure, and developing the associated attribute information. To demonstrate the vessel tracking capabilities, we created input files for dynamic display of tow locations for a set of sample voyages along the UMR derived from actual tows trips as represented in the OMNI database.

The appropriate geographic scope of the prototype displays depends on the selected traffic management alternative. This might range from a local focus and span of control at just a single lock (several miles upstream and downstream) to a regional or system focus incorporating multiple locks and pools (up to ~100 miles). With panning and zooming tools the GIS display can be adjusted as desired to best focus on the region of interest.



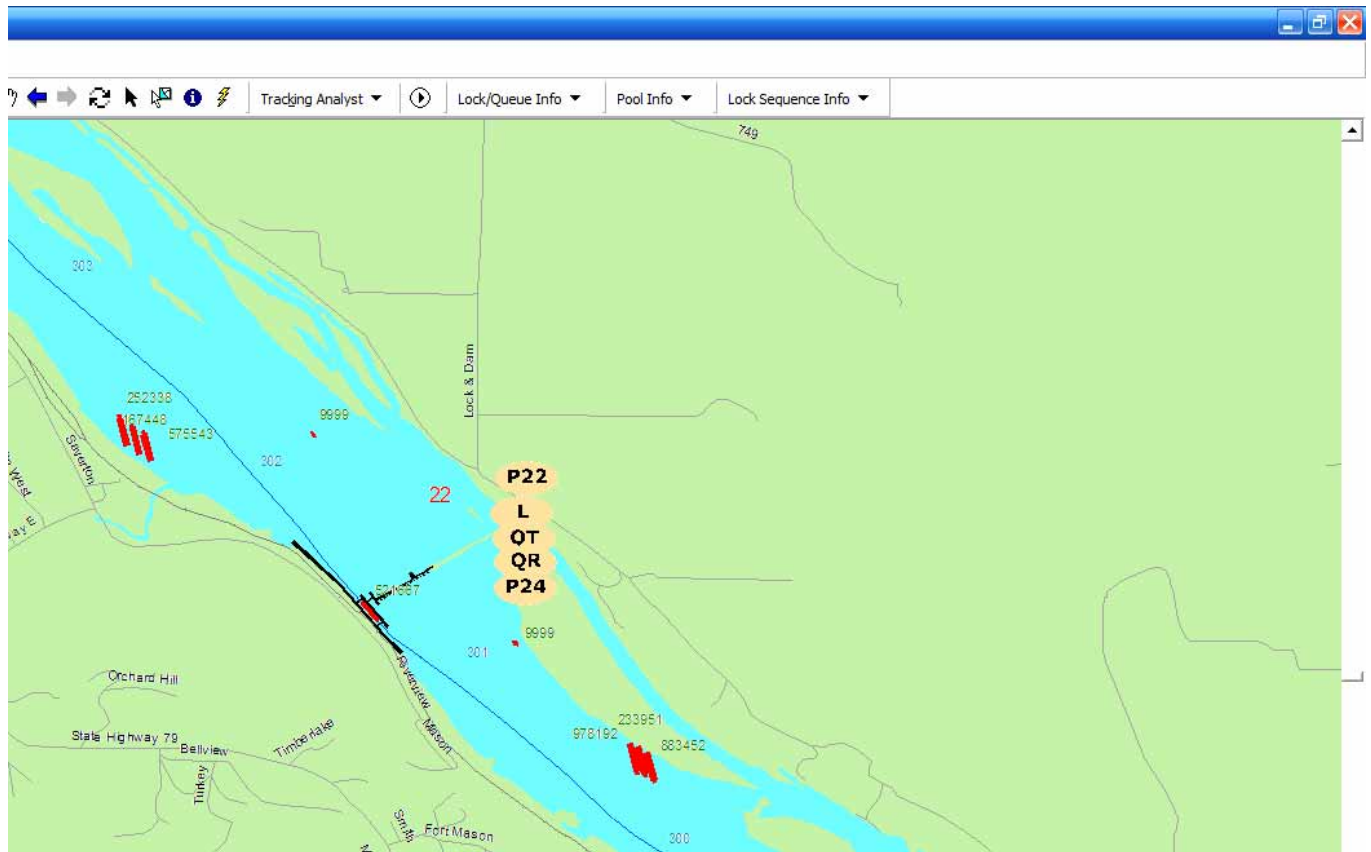
**Figure 6. Prototype vessel tracking GIS screenshot of pool 22, miles 240-340**

Figure 6 is a screen capture from the prototype vessel tracking GIS display of the study region between UMR Lock 20 (near the top) and UMR Lock 25 (near the bottom). This shows a number of tows heading upstream or downstream as boat icons, along with red dots representing recreational vessels. The small numbers along the river from 240 near the bottom of the display to 340 near the top of the display are the river miles along the UMR as measured upstream from the mouth of the Ohio River. The Table of Contents in Figure 6 displays the data layers available in the prototype GIS. The layers shown in the map display in Figure 6 are only those with a check mark.



**Figure 7. Prototype vessel tracking GIS screenshot of pool 22, miles 300-326**

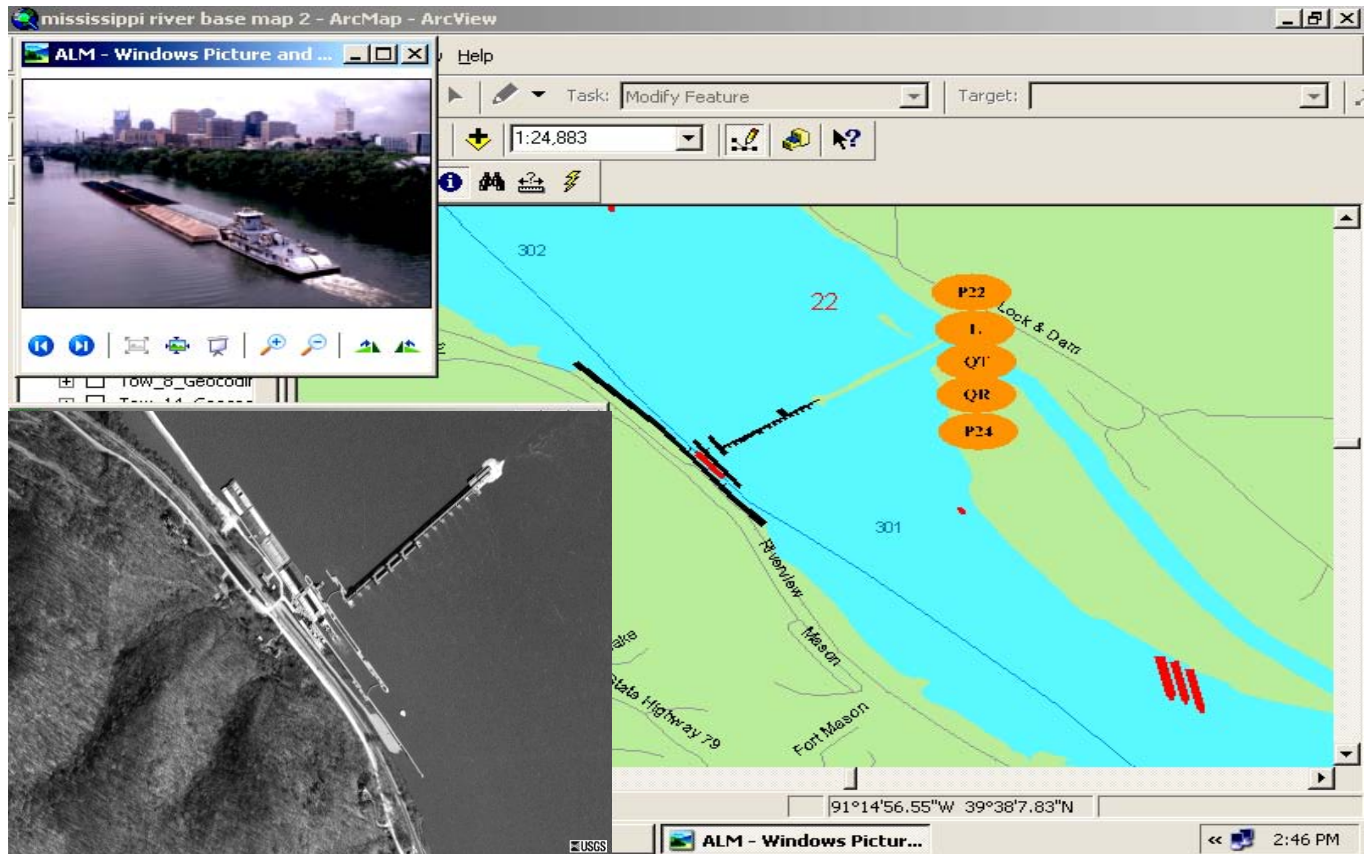
Figure 7 is a screen capture from the prototype vessel tracking GIS display of Pool 22 from river mile 300 to 326. This shows several tows queued above and below Lock 22 near the bottom of the display (overlapping boat icons) and three tows nearer the middle of the pool at river miles 306, 310 and 316.5.



**Figure 8. Prototype vessel tracking GIS screenshot of lock and dam 22**

Figure 8 is a screen capture from the prototype vessel tracking GIS display zoomed in on Lock and Dam 22. This shows more detail of the road network as well as seven tows: one tow in the lock chamber, three tows in queue (nosed into the shore) upstream of the lock (between river miles 302 and 303) and three tows in queue downstream of the lock (between river miles 300 and 301). The five oval icons above and to the right of the lock provide links to relevant attribute (tabular) data for: the upstream and downstream pools, Pool 24 and Pool 25 respectively (icons P24 or P25); the lock (icon L); and the queues of tows and recreational vessels (icons QT and QR, respectively). These oval icons are set to appear only at certain map scales so as not to create a cluttered display. (They do not appear in Figure 7, but the display can be adjusted so that they do appear at any desired level of resolution.)

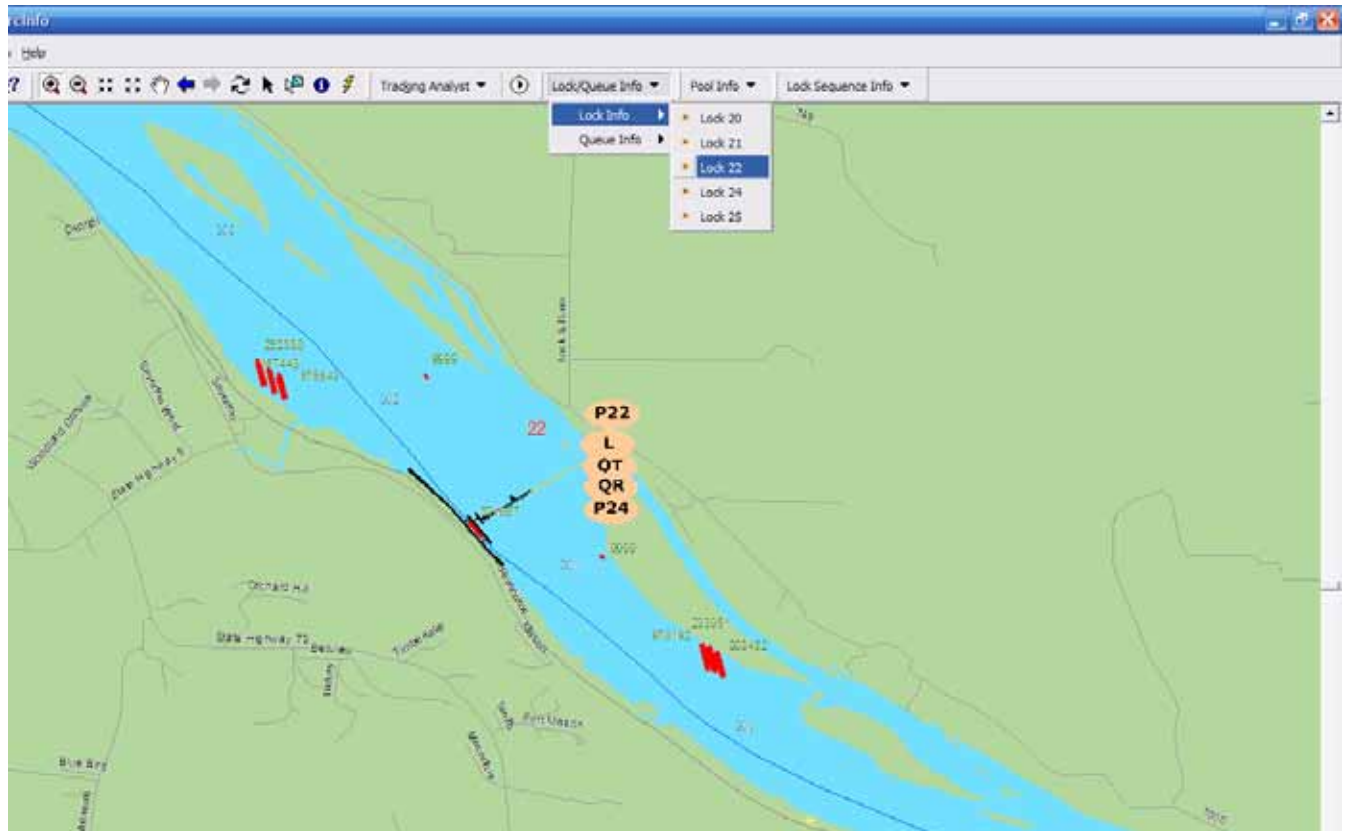




**Figure 9. Prototype vessel tracking GIS screenshot of lock and dam 22 with photos**

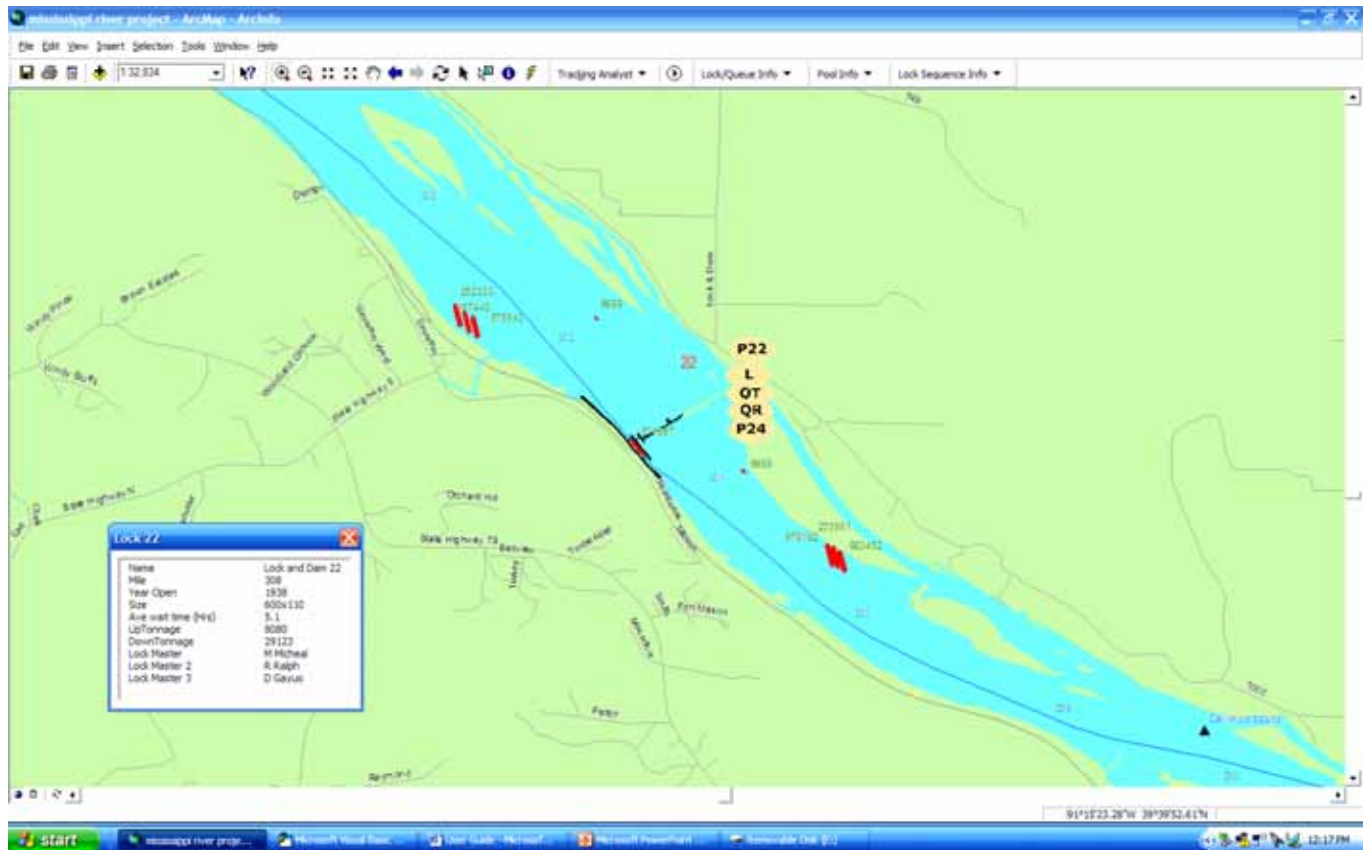
Figure 9 shows the same view zoomed-in even more, along with photos of the lock and dam and an individual tow. These photos can be linked to buttons or menus in the GIS. For example, closed circuit television could be used to provide images of a river section, a lock or of individual tows. Similarly, satellite or aerial photographs can be linked to the GIS.





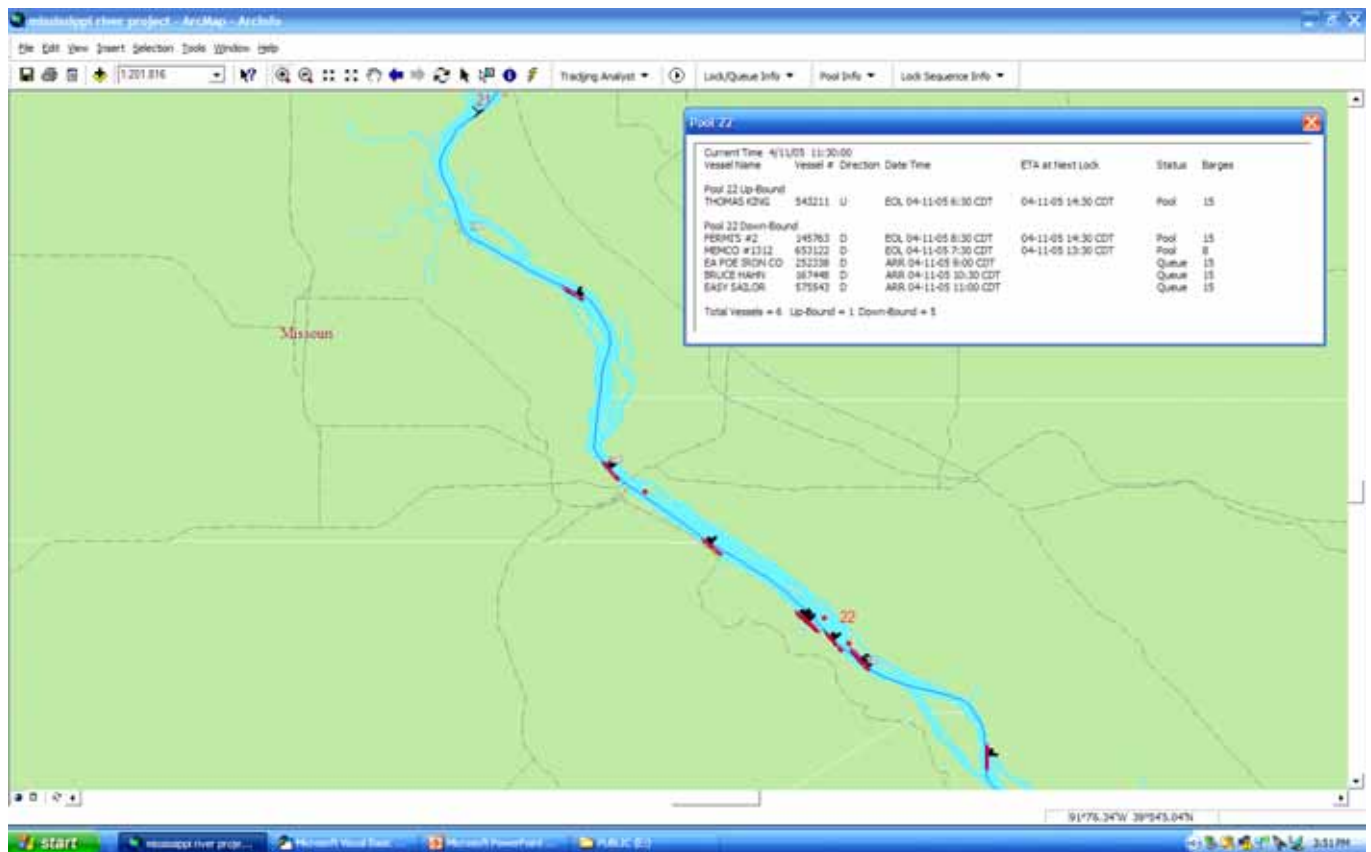
**Figure 10. Prototype vessel tracking GIS screenshot of lock and dam 22 with drop down menus**

Figure 10 is a screen capture from the prototype vessel tracking GIS display of the area around Lock and Dam 22 showing the drop down menus that contain lock and queue information (e.g., as currently available through the OMNI database).



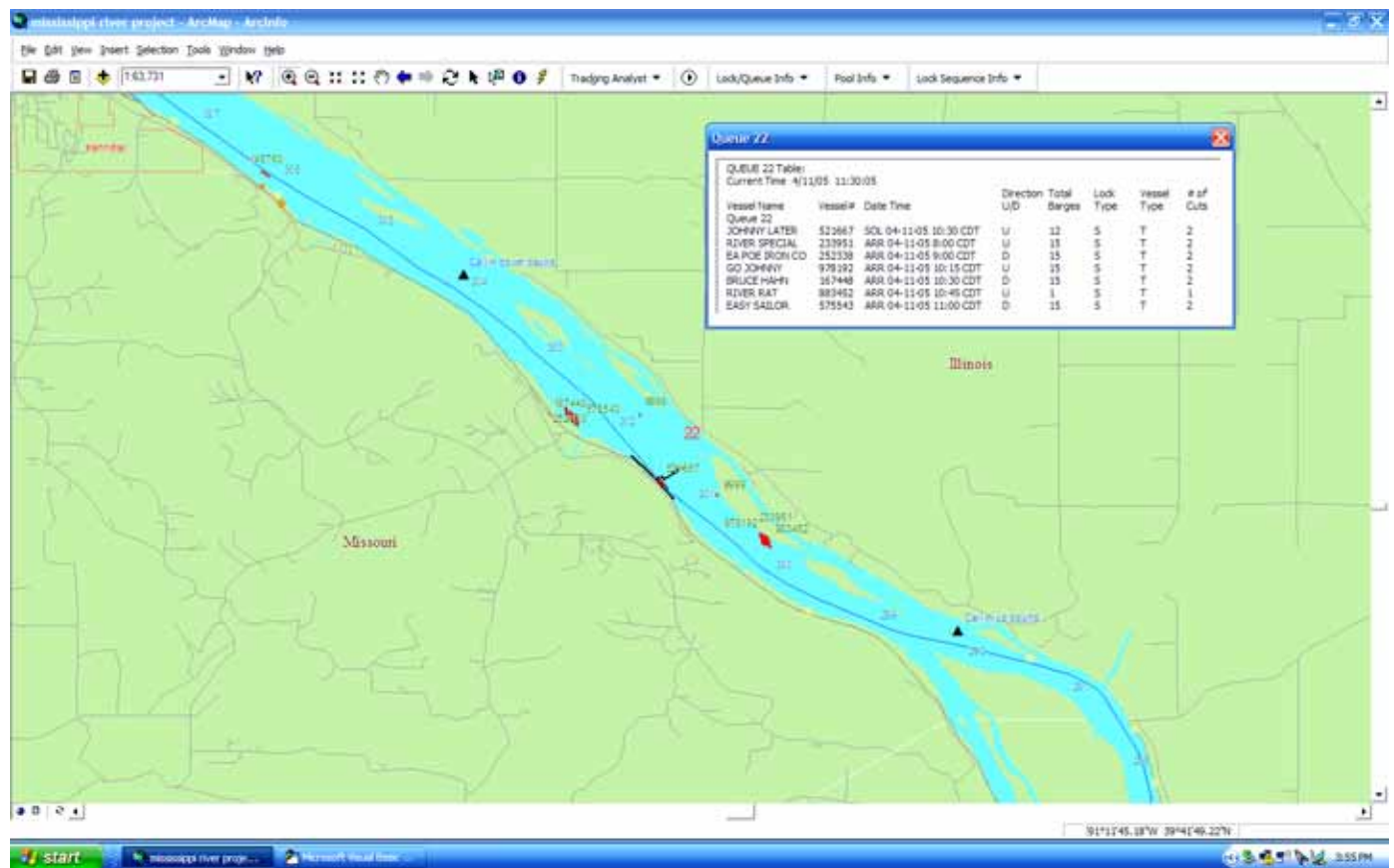
**Figure 11. Prototype vessel tracking GIS screenshot of lock and dam 22 with lock data**

Figure 11 is the same view as Figure 10, now with the lock data table. This table can display static or dynamic data about the lock. This information can also be accessed by clicking on the oval “L” icon near the lock.



**Figure 12. Prototype vessel tracking GIS screenshot of lock and dam 22 with pool data**

Figure 12 is screen capture from the prototype vessel tracking GIS display of Pool 22 with the pool data table. This displays the same data as currently viewed by the lockmasters from the OMNI database (as in Tables 2 or 3), but it could incorporate additional static or dynamic data as desired. This same information can also be accessed by clicking on the oval “P” icons near any lock, as shown in Figure 11. Note that three tows in this table (EA POE IRON CO, BRUCE HAHN, and EASY SAILOR) are shown with a “Date Time” of “ARR” indicated they have arrived at Lock 22 and are awaiting lockage. (See Tables 4, 5 and 6 for the codes used in these tables.) Two other downbound tows (FERMI’s #2 and MEMCO #1312) are traveling in Pool 22 on the way to Lock 22. The MEMCO #1312 is at river mile 306 in Figure 12 and the FERMI’s #2 is about one hour behind at river mile 310. The upbound tow at river mile 316.5 in Pool 22 is the THOMAS KING.



**Figure 13. Prototype vessel tracking GIS screenshot of lock and dam 22 with queue data**

Figure 13 is a screen capture from the prototype vessel tracking GIS display of Lock and Dam 22 with the queue data table for Lock 22. This can display the same data as currently viewed by the lockmasters from the OMNI database (as in Table 1), or it can incorporate additional static or dynamic data as desired. This can also be accessed by clicking on the oval “Q” icons near any lock, as shown in Figure 11.

The queue data table in Figure 13 shows one tow currently in the chamber at Lock 22 (JOHNNY LATER since “Date Time” = “SOL” in the queue data table) and six other tows that have arrived. These tows are listed in order of arrival time, with RIVER SPECIAL at the top of the queue. Note that the RIVER SPECIAL has waited 3.5 hours since it arrived at 8:00 CDT; the current time is shown as 11:30. Also, note that all these tows are double cut tows except the RIVER RAT.

As a demonstration of the linking of tow tracking with a lockage management decision support system, suppose the traffic management policy of “extended queues” is in effect with a re-sequencing rule that gives priority to single cut tows (i.e., those with 9 barges or less). With “extended queues” the re-sequencing possibilities include all vessels in the upstream and downstream pool that are headed towards a lock; not only just those that have already arrived at the lock. Thus, a downstream tow that has completed locking downbound at Lock 21, but has not yet arrived at Lock 22 is included in the extended queue for Lock 22, since that will be its next

lockage. However, this vessel cannot be placed in sequence for lockage before its estimated time of arrival.

Although only seven vessels have arrived at Lock 22 (as shown in the queue data table in Figure 13 and as overlapping symbols on the map), the extended queue for Lock 22 includes two additional vessels from Pool 22. These are the FERMI's #2 and the MEMCO #1312 (see the pool data table in Figure 12), both of whom are headed downstream towards Lock 22. The other tow in Pool 22 (the THOMAS KING; see the pool data table in Figure 12) is headed upstream away from Lock 22. Figure 6 shows these three tows in Pool 22, along with three more tows in Pool 24, one of whom is headed upstream towards Lock 22. Suppose this upstream tow is known to have a destination in Pool 24 before Lock 22, so that it is not included in the extended queue for Lock 22.

**Table 9. FCFS tow sequencing**

<b>Vessel Name</b>	<b>Arrival Time</b>	<b>Locking Time</b>	<b>Start of Lockage</b>	<b>Waiting Time</b>	<b>Number of cuts</b>
JOHNNY LATER	10:30	2:10	10:30	0:00	2
RIVER SPECIAL	8:00	2:00	12:40	4:40	2
EA POE IRON CO	9:00	2:00	14:40	5:40	2
GO JOHNNY	10:15	2:00	16:40	6:25	2
BRUCE HAHN	10:30	2:00	18:40	8:10	2
RIVER RAT	10:45	0:35	20:40	9:55	1
EASY SAILOR	11:00	2:00	21:15	10:15	2
MEMCO #1312	13:30	0:45	23:15	9:45	1
FERMI'S #2	14:30	2:00	24:00	9:30	2

If the nine tows in the extended queue for Lock 22 were processed in the order of arrival, then the sequence would be as shown in Table 9. This sequence is that of the queue data table in Figure 13 followed by the MEMCO #1312 and the FERMI'S #2 in sequence when they arrive. Suppose the arrival time of the MEMCO #1312 is estimated to be 13:30 and the arrival time of the FERMI'S #2 is estimated to be 14:30, given their current positions and the current time of 11:30 as shown in Figure 13. Using a FCFS sequence with the arrival times and locking times from Table 9 produces the waiting times shown in column five of Table 9, which total 64 hours and 20 minutes. (For ease of explanation, this simple demonstration assumes that lockages succeed one another immediately with no intervening time, and that lockage times are independent of the sequence. More complex interactions can easily be handled.)

If however, the tows were re-sequenced to move single cut tows to the front of the queue, then the RIVER RAT would be first after the JOHNNY LATER (currently in the chamber), since it is the only single cut tow that has arrived. The only other single cut tow in the extended queue is the MEMCO #1312, and it would be scheduled at the first opportunity after it arrives at 13:30. Table 10 provides the new lock sequence, along with start of lockage times and the waiting time with the re-sequencing, which now totals 53 hours and 40 minutes.

**Table 10. Re-sequencing of tows to process single cut tows first**

Vessel Name	Arrival Time	Locking Time	Start of Lockage	Re-sequencing Wait	Number of Cuts
JOHNNY LATER	10:30	2:10	10:30	0:00	2
1. RIVER RAT	10:45	0:35	12:40	1:55	1
2. RIVER SPECIAL	8:00	2:00	13:15	5:15	2
3. MEMCO #1312	13:30	0:45	15:15	1:45	1
4. EA POE IRON CO	9:00	2:00	16:00	7:00	2
5. GO JOHNNY	10:15	2:00	18:00	7:45	2
6. BRUCE HAHN	10:30	2:00	20:00	9:30	2
7. EASY SAILOR	11:00	2:00	22:00	11:00	2
8. FERMI'S #2	14:30	2:00	24:00	9:30	2

**Table 11. Comparison of sequences**

Vessel Name	Arrival Time	Locking Time	Re-sequencing Wait	FCFS Wait	FCFS Sequence	Savings
1. RIVER RAT	10:45	0:35	1:55	9:55	5	8:00
2. RIVER SPECIAL	8:00	2:00	5:15	4:40	1	-0:35
3. MEMCO #1312	13:30	0:45	1:45	9:45	7	8:00
4. EA POE IRON CO	9:00	2:00	7:00	5:40	2	-1:20
5. GO JOHNNY	10:15	2:00	7:45	6:25	3	-1:20
6. BRUCE HAHN	10:30	2:00	9:30	8:10	4	-1:20
7. EASY SAILOR	11:00	2:00	11:00	10:15	6	-0:45
8. FERMI'S #2	14:30	2:00	9:30	9:30	8	0:00
<b>TOTAL</b>			<b>53:40</b>	<b>64:20</b>		<b>10:40</b>

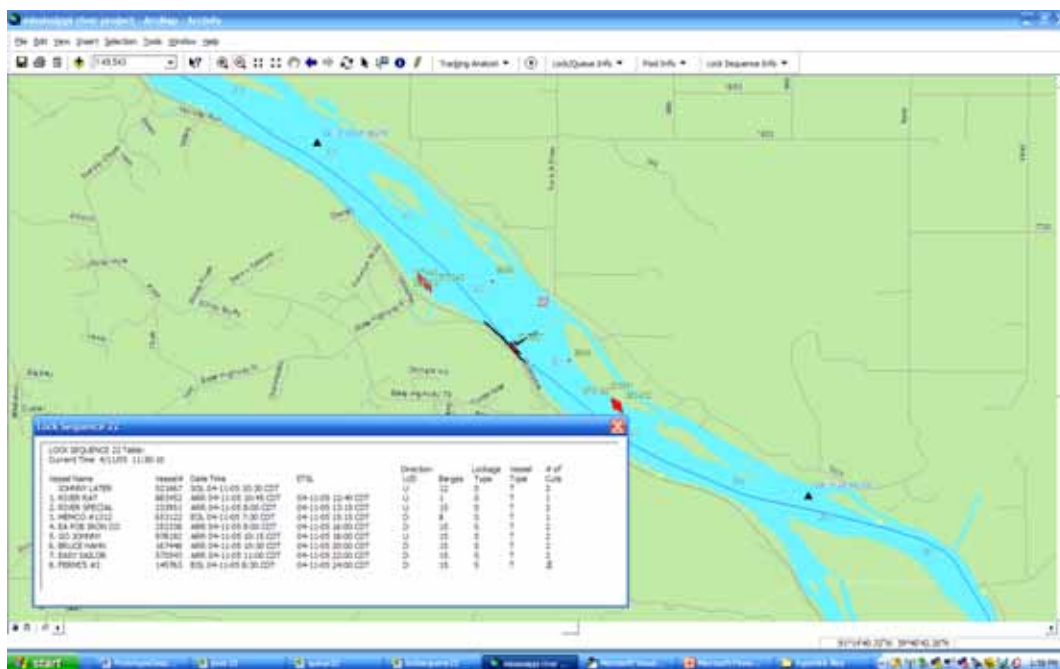
Table 11 provides a comparison of the waiting times for the FCFS sequence and the re-sequencing for the eight tows in the extended queue at Lock 22. (The tow in the chamber is not included in the comparison here). The “Savings” column contains the time saved by each tow in the re-sequencing, relative to the FCFS sequence. This indicates an overall savings of 10 hours and 40 minutes for the re-sequencing and it clearly shows how these savings accrue differentially to individual tows. The two single cut tows RIVER RAT and MEMCO #1312 save 8 hours each by moving to the front of the queue. The other (double cut) tows all have their waiting times increased between 35 and 80 minutes, except for the FERMI'S #2, which is processed last in both sequences and thus has no “savings”.

Table 11 demonstrates that while the elapsed time to complete all lockages is the same in both the FCFS sequencing of tows and the prioritized re-sequencing, the waiting times associated with the two policies are quite different. Moving the tows with shorter lockage times to the front of the queue reduces the total (cumulative) waiting time of all tows, though it may increase the waiting time (a little) for the majority of tows. Thus, large savings can accrue to a few tows moved up in the queue, while the other tows experience (small) increases in waiting time – but the net effect is a decrease in total tow waiting time.

A prioritized re-sequencing of tows (as in Table 10) could be accomplished by a lockage management decision support module as part of a lock management information system. The new sequence for lockages can be used to provide estimated start of lockage times for tows in the queue and these are shown in the column “ETSL” in Table 12. This information could then be provided on the GIS display, as shown for the prototype in Figure 14.

**Table 12. Lock sequence 22, current time 4/11/05, 11:30:10**

Vessel Name	Vessel#	Date Time	ETSL	Direction U/D	Number of Barges	Lock Type	Vessel Type	Number of cuts
JOHNNY LATER	521667	SOL 04-11-05 10:30 CDT		U	12	S	T	2
1 RIVER RAT	883452	ARR 04-11-05 10:45 CDT	04-11-05 12:40 CDT	U	1	S	T	1
2 RIVER SPECIAL	233951	ARR 04-11-05 8:00 CDT	04-11-05 13:15 CDT	U	15	S	T	2
3 MEMCO #1312	653122	EOL 04-11-05 7:30 CDT	04-11-05 15:15 CDT	D	8	S	T	1
4 EA POE IRON CO	252338	ARR 04-11-05 9:00 CDT	04-11-05 16:00 CDT	D	15	S	T	2
5 GO JOHNNY	978192	ARR 04-11-05 10:15 CDT	04-11-05 18:00 CDT	U	15	S	T	2
6 BRUCE HAHN	167448	ARR 04-11-05 10:30 CDT	04-11-05 20:00 CDT	D	15	S	T	2
7 EASY SAILOR	575543	ARR 04-11-05 11:00 CDT	04-11-05 22:00 CDT	D	15	S	T	2
8 FERMI'S #2	145763	EOL 04-11-05 8:30 CDT	04-11-05 24:00 CDT	D	15	S	T	2



**Figure 14. Prototype vessel tracking GIS screenshot of lock and dam 22 with locking sequence**



## SUMMARY

Vessel tracking using geographic positioning systems can be used to improve operations and to enhance safety, security and environmental protection on the inland waterways. Current technologies for finding real time locations and for mobile communications allow data to be collected, managed and displayed efficiently in real or near-real time. This enhanced visibility and knowledge can lead to better management of limited waterway transportation resources and constrained infrastructures.

This report provides results from the project “Geographic Information Systems for Tracking Vessels on the Inland Waterways” (USGS award No. 04HQGR0145 REVISED) that investigated the feasibility of vessel tracking for better managing lockages on the Upper Mississippi River (UMR). This report first describes automatic vessel tracking applications that may be relevant to tracking tows on the UMR, and then discusses the technologies necessary to implement a vessel tracking system. It also includes a description of prototype vessel tracking geographic information system (GIS) that was developed to provide sample displays and to demonstrate the functionality possible from vessel tracking on the UMR. A User’s Guide for the prototype vessel tracking system (included as an Appendix) includes details on how to acquire the data files for the prototype application.

This project complements a companion project of the Center for Transportation Studies (CTS) at the University of Missouri – St. Louis that examined traffic management alternatives for the UMR. That project described in Volume 1 of this report investigated how intelligent appointment or scheduling systems that better manage tows and barges for passage through the locks on the UMR might reduce congestion at the locks. A vessel tracking system might support more effective and more efficient lockages and river traffic management by providing relevant individuals (e.g., a lockmaster or river “traffic manager”) with a single information source including dynamic display of vessel locations and attribute information.

This research has found that tracking tows on the UMR is certainly feasible, though implementation of vessel tracking for all commercial tows may presents substantial challenges. These challenges are likely to be not so much technological, as organizational. While some limited lockage management does occur on the UMR with industry cooperation (e.g., use of an N up/M down sequence of lockages in response to large queues), lockage and traffic management schemes that are more disruptive will likely raise issues of authority and responsibility for traffic management on the inland waterways. However, any vessel tracking system for managing lockages should be driven by the data needs of the lockage and traffic management procedures and algorithms. A variety of systems could be implemented with widely differing levels of cost and positional accuracy; but in general, additional costs are incurred for acquiring additional spatial and temporal accuracy.



## RECOMMENDATIONS

1. A vessel tracking system for managing lockages on the UMR should not be selected or implemented prior to careful evaluation of the lockage and/or traffic management alternative.
2. The responsibility and legal authority for lockage and traffic management on the UMR should be clarified among all parties before implementing larger scale lockage and traffic management systems. A vessel tracking system could provide useful positional data on tows on the UMR. Such positional data could be of interest and of use to a variety of organizations outside the U.S. Army Corps of Engineers, including those with homeland security responsibilities. Such a system could provide information on where individual tows and barges are located within the waterway system, their recent and past travels, as well as relevant data such as ownership, cargo, and their location relative to various structures within and along the waterway.
3. Opportunities to partner with other agencies and private organizations in developing vessel tracking on the UMR should be explored. One area for special attention is to strengthen linkages with the Coast Guard regarding the implementation of AIS. A vessel tracking system coupled with intelligent rules for managing lockages could provide opportunities to improve locking operations and reduce total throughput times at locks on the UMR. This would benefit inland waterway shippers and carriers through decreased costs and increased reliability from more efficient lock operations. However, such benefits are likely to be small and to cause potentially significant markets disruption (see Volume 1 of this report). Therefore, an expensive and comprehensive real-time vessel tracking system is not advisable at this time on the UMR solely for purposes of managing lockages.
4. Vessel tracking on the UMR solely for managing lockages should not be implemented at this time.

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