

A Study of Real-Time Identification and Monitoring of Barge-Carried Hazardous Commodities

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Abstract— In response to increased terrorist threats related to hazardous material movements on the U.S. inland waterway system, towing vessel operators and fleet area managers, at specified reporting points, are required to notify the U.S. Coast Guard's Inland River Vessel Movement Center (IRVMC) of the movement of barges loaded with Certain Dangerous Cargo (CDC). The objective of this study is to develop and field test a prototype system that provides more accurate, uniform, and timely data on hazardous movements by barges, especially those certified as CDC, and to identify and report barges with potential security threats. The system being developed, namely TRACC, is expected to automatically track and monitor barges with CDC and communicate the real-time information to a data server. The event prediction and anomaly detection modules of the system will analyze the collected real-time data and other information to identify any potential security threats, and visually display locations and routes of suspicious barges. It will benefit homeland security community, first responders, local law enforcement personnel and business by providing timely and accurate barge information to make quick and right decisions in disasters involving CDC movement on the inland waterway.

Keywords- *information system; barge tracking; event prediction; anomaly detection; certain dangerous cargo*

I. INTRODUCTION

Eight hundred thousand daily shipments of hazardous materials are viewed as a significant threat to U.S. security because they can be easily used by terrorists as Weapons of Mass Destruction (WMD). About 24% of 3.9 billion tons of hazardous commodities is moved by water annually [1]. In response to increased terrorist threats, the U.S. Coast Guard (USCG), Eighth and Ninth Districts, has implemented rules for reporting the movements of Certain Dangerous Cargo (CDC) on the inland waterway system [2]. These rules establish Regulated Navigation Areas (RNAs) and the USCG Inland River Vessel Movement Center (IRVMC). Towing vessel operators are required to report to the IRVMC the movement of CDC barges at numerous points such as when entering the RNA, commencing a voyage within the RNA (4 hours prior), dropping off or picking up a CDC barge, transiting specified points in the RNA (certain locks and specified mile points), any

significant deviation or delay from the planned itinerary, and exiting the RNA. In addition, fleeting area managers must report daily to the IRVMC the inventory of CDC barges within a fleet area and any movement of barges within the fleet area. In 2005, over 40,000 CDC barge movements, more than 100 per day, were reported. [3].

Currently, the reporting system is an honor system and the IRVMC is accepting and “trusting” these cargo reports and position updates [4]. Because many reports are submitted by a manual process, the IRVMC has to keep enough manpower to take reports and update the database twenty-four hours a day and seven days a week. The IRVMC usually does not have real-time information on exact location of tows between two specified report points. In practice, towboat operators or fleeting managers may miss reporting or miss some required information in their reports. The analysis also shows inconsistent reporting practices among companies. Some operators provide their location information as frequently as once an hour while others may provide information once a day. The objective of this research is to develop and field test a prototype system that provides more accurate, uniform, and timely data on hazardous movements by barges, especially those certified as Certain Dangerous Cargo (CDC), and identify and report barges with potential security threats.

II. SYSTEM DESCRIPTION

The proposed barge tracking system, namely TRACC system (derived from its functionality including track the barge location, assess risks, detect anomalies and threats, anticipate consequences, and communicate to stakeholders), is expected to automatically identify CDC barges and their locations and communicate the collected information to a data server in a real-time fashion. Figure 1 shows the organization of the main components of the TRACC system including tracking devices, data acquisition software, database management system, anomaly detection module, location and anomaly prediction module, map generator, and report generators. The system has web-based interfaces with human users and with other computer systems. The major components are described as below.

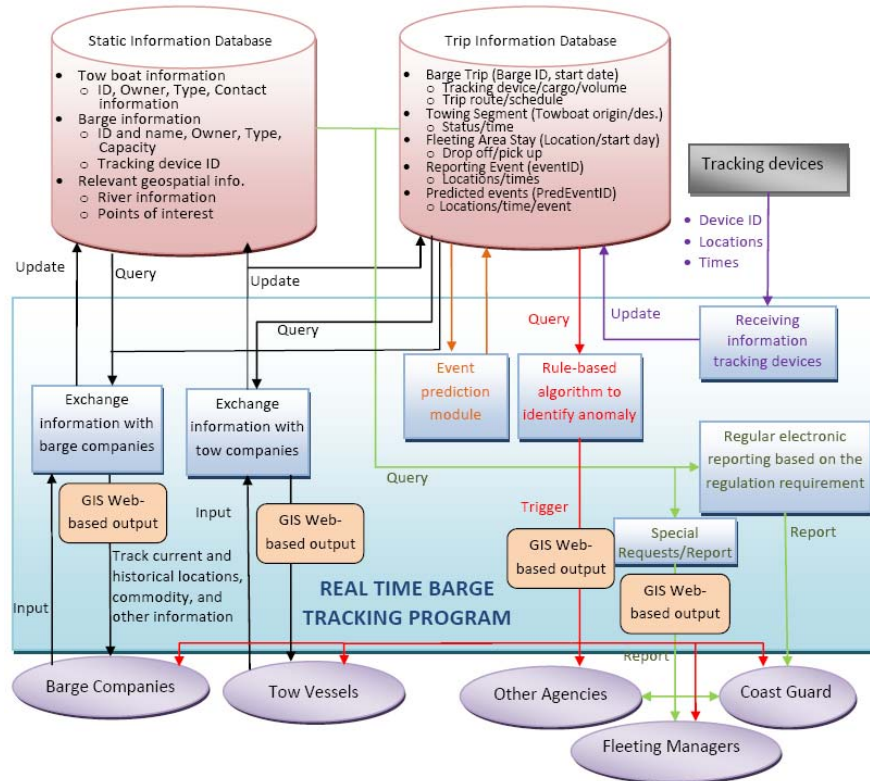


Figure 1. Framework of the TRACC system

A. The Databases

The static information and trip information databases are the foundation of the system. The static information database contains information on the river infrastructure, equipment inventory (barges and towboats), and points of interest (RNAs, locks, power plants, bridges, etc.). While some of these data may change on a longer temporal scale as equipment is bought and sold or new points of interest are established, the data are not expected to be as dynamic as the trip information database.

Trip information can be thought of as a hierarchy of information related to a barge trip. The trip is established by the shipper entering an origin and destination for a barge and the start and estimated-end dates. Within a trip, a barge may be moved by multiple towboats and reside in multiple fleeting areas. These towing segments and fleeting area stays form the next level of the hierarchy with the potential for multiple segments and stays per trip. Towing segments are identified by the towboat reporting a pick-up of the barge and ended by the drop-off. Fleeting area stays are identified by the drop-off at a fleeting area and the pick-up by another towboat.

The reporting events from the tracking device or from a user form another data set within the barge trip. They are indexed by the reporting device or user and the time of the report (not necessarily the time the message was received). The prediction module described below may also generate predicted events with an expected time or time range. These events will also be stored as a data set related to the barge trip.

B. Geographic Display

The geographic display system provides the capability to display locations of barges and points of interest on the waterway system. The system has an accurate display of the waterways and infrastructure near the waterway including cities and roadways. The system allows a user to zoom into a specified region and to see the locations of barge reports for which they have permission. The foundation data for the geographic display will be flexible enough to add other geospatial data over time as the functionality of the system expands. The geospatial display tool currently used is the Virtual Earth tool from Microsoft.

C. Tracking Devices

Another component of the TRACC is the tracking devices aboard barges. These devices will be attached to multiple barges in the test phase of the system and will report frequently via a cell phone connection. The proposed devices can report up to every 10 minutes if the sun is shining strongly enough to generate the required power. During cloudy periods and at night the devices will report every hour. Some of these reports may still be delayed by the lack of cell signals. The reports will be received by a commercial system and stored for TRACC retrieval. TRACC will use a web services interface to retrieve the data and will then process the reports to estimate the river location from the latitude and longitude, identify any apparent errors and update the trip information database.

D. Event Prediction Module

In order to allow users to be proactive in addressing risks, the system contains an event prediction module. This module uses recent location reports and historical link speeds to predict the locations of the tracked barge in the near future (4-6 hours). Using this predicted track for the barges, the system will predict future events that may be of interest such as entering an RNA, entering a port area, passing a point of critical infrastructure (bridges, power plants, etc.). Depending on parameters and rules set by the user, these events may be flagged as “events of interest.” For instance, entering a port region with a load of chlorine may be an event of interest if it occurs during a river festival. The identification of an “event of interest” could then be relayed to the appropriate users. As the system evolves, more real time information can be used to refine the predictions such as the incorporation of lock transit time estimates based on current queuing and delay experience.

E. Anomaly Detection Module

As reports come into the system from tracking devices, towboats, fleeting managers, and shippers, inconsistencies may be detected. These inconsistencies may indicate a missed report, an omitted report, a change in plans without a notification, or an accidental or intentional diversion of a barge. The anomaly detection process use a set of rules stored in a data structure that allow users, with appropriate permissions, to develop new rules for identifying anomalies. Rules would be triggered by a report or an event prediction or the elapse of a specified time period after a report is received.

F. Electronic Reporting to USCG

If a shipper, towboat operator or fleeting manager enters a report record in TRACC, the system will relay the report to the IRVMC system automatically. Since the USCG currently provides a web-based form for entering this data, there is a well-established format for exchanging the data with the IRVMC system (MISLE). The availability of this interface will keep users from having to enter data into the TRACC database and submitting the data to IRVMC. TRACC will have visibility over reports for tracked barges when those reports are entered into TRACC for forwarding to IRVMC.

III. SYSTEM IMPLEMENTATION

The TRACC system being developed uses a number of software components. This will be done to leverage the available capabilities of the software and to enable the system to operate within the world-wide-web environment.

The TRACC databases support spatial data and spatial functions. Latest version of Microsoft SQL Server is used in this research since it provides support for geographical data through the inclusion of new spatial data types, which can be used to store and manipulate location-based information. The spatial data types in latest SQL Server provide a comprehensive set of instance and static methods that one can use to perform queries and operations on spatial data. For example, SQL queries can express functions such as *Distance()* and *STIntersection()* to work with geographical data type. The function *Distance()* returns the distance to a location, route, or

route segment from another location; the function *STIntersection()* returns an object representing the points where a geography instance intersects another geography instance. Performance of queries against spatial data is further enhanced by the inclusion of spatial index support in the latest SQL Server. One can index spatial data with an adaptive multi-level grid index that is integrated into the SQL Server database engine. Spatial indexes consist of a grid-based hierarchy in which each level of the index subdivides the grid sector that is defined in the level above. The built-in spatial views also provide easy view of spatial query results.

The TRACC system has created an efficient network data structure for searching and analysis. The National Waterway Network from the Navigation Data Center, U.S. Army Corps of Engineers (NDC, USACE) is used as the source data. The National Waterway Network is a comprehensive network database of the navigable waterways of the United States. The majority of the information of this network database is at 1:100,000 with larger scales used in harbor/bay/port areas and smaller scales used in open waters. The National Waterway Network is comprised of a link database and a node database. Links are line strings, which consist of beginning and end points (nodes) with intermediate vertices (shape points). Links represent either actual shipping lanes (i.e., channels, Intracoastal Waterways, sealanes, rivers) or serve as representative paths in open water (where no defined shipping paths exist). Nodes may represent physical entities such as river confluence's, ports/facilities, and intermodal terminals, USACE nodes, or may be inserted for analytical purposes (i.e., to facilitate routing). In this research, links (polylines) are transformed into individual SQL Server database records for links and associated nodes. Those data allow the resulting GIS model to have a finer granularity of representation and make algorithms in TRACC more efficient by avoiding repetitive data.

The primary objective of the prediction model is to estimate the position of the barge based on updates from the onboard instruments and to predict the arrival of the barge at critical locations well in advance. The idea here is to utilize the maximum available information about the river, the barge and other important information and predict the location of the barge movement. A properly setup prediction model would be an attractive utility for authorities in coordinating and planning the movement of hazardous cargo in the inland river system while on the other hand help in tracking the barges for logistics purposes. The first step in setting up the prediction model is to establish the system dynamics that involve in the barge movement process. This requires defining the prominent elements involved in motion of a barge and then establishing their relationships. This would be a challenging task as there are multiple factors that would affect the system dynamics of a barge. A few of them could be highlighted as; the speed of river flow, the thrust given by the tow boat, direction of barge movement, number of barges in the assembly, barge depth on the river etc. However, it is important to note that most of these parameters can be obtained by analyzing previous data available on the same route. Training the system with the archived data would help establish the river and barge dynamics while the prior data from the same run would give a

good comparison between the existing conditions and the previous conditions. Using these parameters the system dynamics of the model can be updated.

The barge tracking and prediction problem is a time series forecasting problem. Therefore, time series forecasting techniques can be utilized in tackling the problem. Given a specific river, the barge location is determined as a linear value - mile marker. Thus, the challenge is to estimate the average speed of the barge's tow along various sectors of the river. The model implementation then will contain three stages: parameter estimation stage, prediction stage and update stage. The parameter estimation stage will use the training algorithm to estimate the prevailing conditions and update the system dynamics in the model. Using these updated system dynamics the prediction stage will predict the most likely location of the barge in next time step. Due to various errors in the measurements and approximations in the model setup this prediction will have a variance. Once a measurement is available the update stage of the prediction model re-estimates and minimizes this error variance that is involved in the prediction model and updates the model which would help in a better prediction.

Various rules have been developed for the TRACC anomaly and potential threat detection module. Some examples include:

- A tracking device reports a barge, which is not associated with a trip, beginning to move away from a fleeting area, and the towboat does not report a pickup within 30 minutes,
- Two barges belonging to the same tow are away from each other more than X miles,
- More than one tow vessel claims the same barge,
- A barge has Y mile deviation from its scheduled route,
- A tracking device reports a barge in a fleeting area and there has not been a drop-off report, or
- A tracking device has not reported for Z hours.

Rules are also developed to anticipate a risky situation such as:

- If two tows with CDC are predicted to pass in a highly populated area or near critical infrastructure (e.g., nuclear plant),
- If a large volume of CDC is predicted to be in one fleeting area or in a small geographic area,
- If tows with a large amount of CDC are predicted to wait for a long time in the queue at a lock, or

- If multiple tows with large amounts of CDC are expected to arrive at a port in a short period.

In the TRACC system, different users receive warnings and query data filtered by their role. Shipper or towing company enters data on shipments and status changes and view status and warnings for their shipments or equipment. Port authority view vessels in their region and receive alerts on inbound vessels or potential risks. Coast Guard has full visibility for the status and alerts.

IV. CONCLUSION

In response to increased terrorist threats related to hazardous material movements on the U.S. inland waterway system, this research intends to develop a real-time identification and monitoring system, namely TRACC, for tracking barge-carried hazardous commodities. The TRACC system being developed is expected to automatically identify CDC barges and their locations and communicate the collected information to a data server in a real-time fashion. The process can reduce errors caused by manual reports and provide uniform data to facilitate further analysis. The event prediction and anomaly detection modules of the system will analyze the collected real-time data and other information to identify any potential security threats. Analyzed results will be visually displayed in a GIS and communicated to different stakeholders. The TRACC system will benefit homeland security community, first responders, local law enforcement personnel and business by providing timely and accurate barge information to make quick and right decisions in disasters involving CDC movement on the inland waterways.

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