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16. Abstract

A MARAD/TSC team has been conducting a program to study navigation and communications systems on the Great Lakes and St. Lawrence River with the objective of defining technologies and systems which have the potential to increase economic benefits to the users, and support National Defense and National Strategic Goals. An outline of this program being conducted by TSC for MARAD is contained in Appendix G.

The first phase of this study identified shortcomings in existing systems, namely dependence on visual aids for navigation, congestion in the communications system, and lack of timely environmental data. This report contains the results of a project whose goal was to define requirements for: electronic navigation systems to supplement visual aids, additional communications capacity and a traffic information management system.

The next project in the program will be a state-of-the-art survey of equipment whose characteristics match the stated requirements.

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PREFACE

A principal objective of the Maritime Administration (MARAD) is to improve the efficiency and increase the use of the merchant marine transportation system, including inland waterway commerce on lakes, rivers, and canals. MARAD is conducting a Great Lakes and St. Lawrence River Navigation and Communications Program in response to expressed interests of U.S. Great Lakes ports and other parties in facilitating the flow of cargo through these ports via the greater Seaway system, which includes the Great Lakes, the international section of the Seaway, and the St. Lawrence River below Montreal. The goal of the program is to study and identify navigation and communications techniques which have the potential to improve maritime shipping from ports on the Fourth Seacoast to the Atlantic Ocean. The first phase of the program was an in-depth study of the system and the concerns of the user community, and resulted in Volume 1: Navigation and Communications System Study. This report documents the second phase of the program aimed at determining the requirements of a system that addresses the concerns of the users. These requirements will be matched against state-of-the-art technology in the next phase of the program.

The work reported here was performed under the sponsorship of the Office of Advanced Ship Development and Technology, Virgil W. Rinehart, Director. The program manager is W. Lloyd Fink. Data collection, analysis, and report preparation were performed by the Transportation Systems Center's (TSC) Center for Navigation: Chief, M.J. Moroney. F.D. MacKenzie is the Project Engineer directing a team of experts including W. Mohin of Applied Systems Technology, J. Powell* of B & M Technological Services Inc., G. LaQuadra** of Scientific Systems Inc., J. Sennott of Tracking and Imaging Systems, and S. Sheehy of System Development Corp.

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**Now with Intermetrics Inc.

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EXECUTIVE SUMMARY

National waterways are vital to U.S. commerical trade. The Great Lakes - St. Lawrence River system is one of the major U.S. waterways and provides an efficient means of moving commerce within the U.S., as well as to and from foreign countries. The proficient use of this natural resource underlies the economic health of the nation and makes a valuable contribution to national defense capabilities.

A MARAD/TSC team has been studying the problems of navigation and communications on the Great Lakes and St. Lawrence River since June 1983 with the goal of defining technologies or systems which would increase the efficiency and the capacity of marine transportation from, and into, the Fourth Seacoast ports through this inland water system.

In the first phase of this study MARAD/TSC teams visited 28 of the major U.S. ports on the Fourth Seacoast and interviewed representatives of 60 user organizations. The teams' mission was problem identification. Vessel riding teams made in situ inspections of areas identified by ship masters as most demanding on a navigator's skill. All connecting and constricting waterways were inspected from the bridge of a transiting vessel to document the use of visual cues by the master.

As a result, three major shortcomings in the waterway system were identified. There is too much reliance on visual aids such as buoys, lighthouses, and leading ranges, effectively restricting the movement of vessels to periods of good visibility. The present communications system is already congested in some geographic areas, therefore, additional capacity is required. A need exists for traffic information management on the inland waterway. Most of the information sought by the marine community is available but the distribution system is insufficient.

In this phase of the study inland waterway requirements are defined. The main emphasis in this section is on navigation requirements. Some of the communications, traffic information management, and display requirements are stated to illustrate the unity in a system approach.

The inland waterway requirements are grouped in four categories: open water, confluence zones, constricting channels, and areas with unique maneuvering needs (i.e., tug assistance, or line handling). The areas where tug assistance or line handlers are required were not included in the study.

Containment of a ship within its lane on open water at least 99 percent of the time has been established as a reasonable goal for the U.S. Coastal/Confluence Navigation System, and has been adopted for the Great Lakes. Using this criterion, an open water lane two miles wide has a track-keeping requirement of $\pm$0.6 miles.

The confluence zone connects the two mile wide open water land to the constricting channel. It is a tapering zone. The track-keeping requirements in the zone, where the width is one mile, are $\pm$0.3 miles. The navigation requirements for constricting channels include track-keeping, waypoint maneuvering, and tactical maneuvering.

In good visibility, defined as 1.5 mile or greater detection distance, all visual aids are available for use by the master. By alignment of the vessel with leading ranges, masters keep the vessel on the centerline or slightly to the right of center (this is an ingrained habit of some seafarers). Track-keeping accuracies of zero mean and 12 feet standard deviation have been confirmed empirically and theoretically. In poor visibility, defined as 0.25 mile detection distance, one can only see aids which are nearby and passing. In zero visibility the master is dependent on radar. In simulations of both of these situations, the mean values were still small, 6 feet; however, the standard deviation increased to 30 feet. This reflects the non-availability of the leading ranges as a visual cue.

Perturbing wind and current forces on a vessel and the pilot's reaction have been evaluated with the simulators. The disturbance of wind forces on a vessel depends on the sail area effects. In the one scenario, it was possible to compare the vessel's track with the influence of a 35 mph following wind, with one on the port quarter. Neither the mean position (on the centerline) nor the standard deviation (31 feet) differ significantly as a function of the change in wind direction. Apparently in the simulation, the helmsman and the pilot between them are able to compensate for the turning movement of the wind without causing changes in the track. In heavy winds, the vessel tracks were 100 feet from the centerline of an 800 foot wide channel - in the direction of the wind. The standard deviation was 90 feet. Pilots would use approximately half of the leeward side of an 800 foot channel under the heavy wind conditions studied.

Water currents cause similar displacements. With an 0.3 mph cross-current, the mean values of the vessels tracks were shifted an average of 85 feet in the down-current direction and the standard deviation increased to 56 feet. On the St. Lawrence River, Polly's Gut has a channel current of 3.2 mph with a current direction of 88 degrees. This is a difficult reach for maneuvering because of this water flow from the Long Sault Dam powerhouse.

Shallow water effects and thin ice cover effects tend to increase course stability. The turning performance is greatly reduced because of substantial stabilizing effects. Laker captains are familiar with the shallow water and thin ice cover effects. The effects on a superlaker have been modeled mathematically, simulated with a scale model and measured with full scale sea trails. Salty pilots must rely on first hand knowledge to get a "feel" of the vessel's performance. This appears to be a good strategy for similiar types of ships. A simulation of shallow water navigation with and without the pilot's knowledge of the ship's maneuverability had the following results for track-keeping in the 800 foot wide channel: the pilot familiar with the ship's shallow water maneuverability improved the ship's off-track deviation by 35 feet (from 96 to 61 feet). Improvements were also indicated for approach, entrance and waypoint operations.

The three operations in a waypoint maneuver are preparation, turn, and recovery of the centerline. Much of the data collected were from scenarios to evaluate the optimal number and favorable location of navigation buoys in a turn and on the straight reach. The influence of a heading change is determined by measuring the standard deviation of the vessel track before and following a waypoint maneuver. One mile on either side of the turn was selected as the measurement point. Data collected in simulation studies showed a standard deviation of 40 feet prior to a heading change of 35 degrees. The mean track was essentially on the centerline. The disturbance of the waypoint maneuver displaced the overall mean more than 50 feet to the right and doubled the standard deviation to 80 feet. The configurations and spacing of the buoys involved are representative of existing conditions on the inland waterway.

A relationship between track-recovery performance and information rate was determined. On pull-out, closer spaced buoys (high information rate) should permit better track-recovery performance (smaller standard deviation) than wide spaced buoys. The results of the simulation evaluation proved the opposite (i.e., the track-recovery was more erratic for closer spaced buoys). By examining the number of helm commands given by the pilot it was determined that the pilot was disposed toward overcontrol of the vessel when given a high rate of information. This effect was confirmed in another study of vessels using radar displays while approaching a deepwater port. Analysis showed that radar displays with high information rates were associated with more varied sailing strategies.

Visual cues used for waypoint maneuvers are side and turn markings. Leading ranges are not usable in a turn maneuver but will permit a quicker and smoother recovery toward the centerline. Pilots demonstrated that they were capable of compensating for cross wind forces of less than 12 mph following a turn - no significant increase in standard deviation. This effect was confirmed by at sea measurements in the Chesapeake Bay; the standard deviation was 60 feet. When the cross winds were greater than 12 mph, the standard deviation increased to 270 feet - three times larger than results from track-keeping statistics using the simulator. The large difference underscores the greater difficulty pilots have in estimating the vessel state and developing good vessel control inputs during waypoint maneuvers.

The most taxing of the tactical maneuvers is meeting a vessel while making a waypoint maneuver. This situation is avoided by pilots and traffic controllers alike. If it does occur it is a shiphandling problem not a navigation problem. A less taxing maneuver is meeting a vessel during the recovery operation. This is also avoided by pilots and traffic controllers.

Analysis of pilot performance by the riding teams determined that the largest of two vessels was reluctant to venture too far from the centerline.

The pilot would pick a track right of the centerline and let the smaller vessel determine the closet point of approach (CPA). At night the pilot kept his deck lights on to help define the abeam distance for the meeting vessel.

A communications system was specified to provide the rapid exchange of data (update one or two seconds) between meeting vessels in the inland waterway. A system of 28 transmitter sites (six are control stations) is recommended to provide 90 percent coverage. All transmitters would be collocated with the USCG VHF-FM transmitters. For total coverage additional sites would be needed in Canada.

A multiple frequency system in the aforementioned frequency range meets the update rate requirement. The total bit requirement per vessel is 770 bits (vessel identification, four characters; navigation data ship-to-shore, 38 characters; navigation data shore-to-ship, 35 characters; ASCII standard 10 bits/character).

Traffic information requirements consist of the following categories: vessel specific data, position, velocity, estimated time of arrival and ship identification; navigation data, other vessels' positions, estimated meeting maneuver location; scheduling data and system status (capacity situation); and environmental data including water depths, wave heights, wind and current velocity as well as marine weather forecasts tailored for specific areas.

Display requirements include a graphic display with an extended jack staff vector and predictor steering (suggested helm commands). The following features are needed for user acceptance: color for added information content, navigation aid locations, other vessel's position location, time-to-a-waypoint, and velocity.

The next phase of this study will be a state-of-the-art survey of candidate navigation, communications, traffic management and displays to match available technology against the stated requirements in this report.

1. INTRODUCTION

In the early part of the sixteenth century, Jacques Cartier, the French explorer, discovered and sailed up the St. Lawrence River. Seeking a passage to the Indies, he was stopped by the Lachine Rapids and established a trading post near the present city of Quebec. Thus began the utilization of the St. Lawrence River watershed and the Great Lakes by merchants, traders, explorers, adventurers, governments and industries. For 400 years this waterway system has played an important and dynamic role in the economic development of the United States and its neighbor Canada.

The first merchant vessel to sail on the Great Lakes was the Le Griffon in 1679. It was built on the Niagara River and sailed across Lake Erie, Lake Huron and Lake Michigan. The Le Griffon vanished on a return voyage from a fur trading post near the present site of Green Bay. While no trace of the vessel or its cargo was ever found, it was assumed that it was driven ashore and wrecked by a severe storm that came the night of its departure. Thus, it can be considered the first casualty of poor weather forecasting, primitive communications systems, and rudimentary navigation aids.

The Le Griffon, small by present standards, carried 50 tons of cargo. The modern superlaker is 1000 feet long and 105 feet wide, and can carry 60,000 tons. As the capacity of merchant vessels increased over the years, the ability to forecast weather changes has improved and new navigation and communications systems have been developed.

Even with 300 years of improvements, vessels still cannot safely navigate at all times and in all weather conditions because of their dependence on visual navigation techniques. During the winter months navigation on portions of the Great Lakes and the St. Lawrence River is impeded because floating, lighted-aids are removed from the channels lest they be moved, damaged or swept away by moving ice. Communications between vessels and vessel traffic advisors, ports, and owners, are not always reliable because of weather effects and interference from recreational boaters who share the common communications channel. Elimination or reduction of these limitations would greatly facilitate the expeditious movement by commercial operators. The Maritime Administration

(MARAD) has recognized for some time that these limitations sharply curtail increased productivity and have initiated programs, such as this study, to identify cost-effective electronic navigation and communications systems which could permit efficient movement in the Fourth Seacoast waterway in all types of weather, 24 hours each day during its 275-day season.

1.1 BENEFITS

The U.S. wants to maximize the benefits of its maritime transportation systems. The reasons typically cited are national defense, economic benefits, or both.

The requirement to support armed forces in a non-nuclear war with the movement of military supplies is critical. U.S. vessel requirements include small tankers and self-sustaining general cargo ships, break-bulk cargo vessels, roll-on/roll-off vessels, and containerships with their own cranes aboard. As important as the vessel requirements is the capability to move cargoes through national waterways and ports regardless of weather or other environmental constraints.

National strategic goals affect the waterborne movement of critical goods even during peacetime. Critical materials must be transported during peacetime to sustain strategic reserves and to supply the domestic economy. More than 96 percent of the dry bulk commodities imported by the U.S. are brought in by foreign-flag ships, since the U.S. dry bulk fleet (excluding those on the Great Lakes) is minimal.

Future shipping of bulk cargo and liner trades from and to America's heartland is a major determinant of the U.S. balance of trade and the economic health of half the States of the Union. Modernization and rehabilitation of key inland waterways is imperative to facilitate future waterborne commerce and to sustain the inherent economy of waterway transport.

Although a modern vessel is now operated with fewer than 30 people, and even though most bulk carriers are operated by a crew of 30 or more, many more jobs exist in shoreside vessel operations: longshoring, bunkering, ship supplies, etc.

Linkage exists between the merchant trade and other industries -- shipbuilding, ship repair, related supply industries (e.g., paint, steel, machinery), insurance, finance, and training of sea-going labor.

1.2 FEDERAL ROLE

The federal role in navigation and pollution control evolves from the intrinsically interstate and international character of much commercial shipping. The federal government traditionally promotes consistent international practices with regard to rules of the road, safety and navigational aids, and pollution prevention. A substantial federal role is assured so long as the U.S. interest in global commerce prevails.

The overall mission of MARAD, in accordance with the policies set forth in the Merchant Marine Act (1936, as amended) and related shipping statutes, is to promote the development and maintenance of an adequate, well-balanced, U.S. merchant marine industry, sufficient to move the nation's domestic waterborne commerce and a substantial portion of its waterborne foreign commerce, and capable of serving the civilian and military needs in time of war or national emergency.

Shipping organizations and firms on the Great Lakes-St. Lawrence River network, sometimes referred to as the Fourth Seacoast of the U.S., have expressed interest in the MARAD research program to identify and assess alternative navigation and communications systems which could expand the safe, efficient movement of the vessels on the network.

In response, MARAD requested the Department of Transportation, Transportation Systems Center (DOT/TSC) to investigate the problems mentioned. Under the terms of a General Working Agreement, TSC was tasked to determine the navigation and communications requirements of a system which would facilitate commercial vessel movements throughout the waterway from Duluth, MN through the Great Lakes to the deep waters of the Atlantic Ocean. In the next task TSC will identify and evaluate candidate systems capable of meeting those requirements, and make recommendations for viable options or necessary new developments.

The research methodology used to develop the requirements of the waterway system consisted of analyzing comments from the user community, previous

MARAD/TSC studies, related programs, and projects. In addition, the TSC reviewed the published documents from the Computer Aided Operations Research Facility (CAORF) and Eclectech Associates Inc. concerning vessel simulation experiments. Also analyzed were reports by Arctec Inc. and others dealing with vessel modeling and United States Coast Guard (USCG) reports pertaining to vessel track-keeping measurements on the St. Marys River and Chesapeake Bay.

A general literature search was made through the TSC Technical Reference Center and the National Maritime Research Center's (NMRC) Study Center at Kings Point, New York of the documents cited by the National Technical Information Service, Transportation Reseach Information System, Conference Papers Index, Oceanic Abstracts, Science Citation Index, and the Smithsonian Science Information Exchange. Reprints of all reports which dealt with Great Lakes-St. Lawrence River studies or with navigation or communications systems were reviewed.

2. PROBLEM DEFINITION

The MARAD/TSC objective is to develop techniques to increase the efficiency and capacity of the marine transportation system that serves the ports on the Great Lakes-St. Lawrence River waterway. The primary hindrance to increased capacity is economic in nature; the availability of vessels exceeds the demand for cargoes. This is a worldwide condition that is slowly improving. The world is recovering from one of the worst shipping and shipbuilding depressions ever known. The waterway is operating at less then one-half its capacity. However, a growth rate of only 10 percent per year will cause the system to be saturated in the mid-1990s. This long range view is based on 25 years of increased tonnage. The Lake Carriers' Association feels that the trend is away from saturation. The U.S. Coast Guard (USCG) and the St. Lawrence Seaway Development Corp. (SLSDC) are steadily improving both the visual navigation system and the electronic aids to navigation. A new traffic control system for the Welland Canal will be put in service in June 1986. The U.S. Army Corps of Engineers (COE) has studied the Soo, Eisenhower and Snell Lock Systems and has recommended modification for additional capacity, based on commodity forecasts for this waterway. (Ref. 1,2) MARAD/TSC's user study (Ref. 3) has indicated that a non-visual navigation system may be needed to expedite traffic before the system saturates and after the COE has completed its modifications.

However, a new navigation system is not a complete solution. Knowledge of each ship's position is not the total answer to guiding large vessels through narrow waterways. Information pertaining to other traffic and channel conditions, such as ice and currents, is equally important. The implication is that no stand alone positioning system, no matter how accurate, can be the total solution. One of the problems that exists today on the Great Lakes-St. Lawrence River is the lack of a system that combines navigation, communications, and traffic information management. This report addresses the system problem.

The following subsections define the navigation, communications, traffic information management, and display problems.

2.1 NAVIGATION/GUIDANCE PROBLEMS

Navigation on the Seaway system is normally constrained by the time required to process a vessel through the slowest lock. However, in times of low visibility or when the floating, lighted navigation aids are not available in specific channel reaches, the capacity constraints shift to those reaches. During periods of low visibility, the loss of visual cues causes many vessels to remain anchored, or if underway, to seek safe anchorage. In some cases, navigation will be prohibited by the responsible authorities. For example, navigation on the St. Marys River and St. Lawrence River is stopped when visibility is 1/4 nautical mile or less. Despite precautions, vessels still get caught in bad weather (fog, snow, heavy winds, and rain) in areas where there is no safe anchorage. On constricted waterways, radar is used in this situation to find safe anchorage. In the Great Lakes, RACON transponder systems, LORAN-C and radiobeacons are used for low visibility navigation, harbor entrance and anchorage.

At the beginning of each navigation season, the commissioning of floating lighted aids may be delayed up to four weeks due to ice in the river, which complicates setting buoys, and which may damage or move them off station. Toward the end of the season the floating, lighted aids must be decommissioned before ice prompts the close of navigation. Because of the early removal of aids in the fall and delay of their commissioning in the spring, navigation is restricted to daylight hours for a period of up to five weeks. This reduces capacity at a time when there is a rush to use the system (ore and coal shipping peaks at the beginning of the season; grain shipping peaks at the end).

2.2 COMMUNICATIONS PROBLEMS

An extensive research study was conducted by a MARAD/TSC team to determine the specific communications needs of the inland marine industry.

The study revealed a number of significant problems in the existing communications system: delays in exchanging communications; difficulty for agents and owners to communicate with vessels to control schedules, docks, etc; inability to communicate in some locations, even in emergencies; obsolete or old equipment; jam-up in communications during peak times; and the inability to transmit data back to the home office.

At the present time most communications on the Great Lakes-St. Lawrence River is provided by narrow band VHF-FM marine band radio. It is frequently congested, limited in capability, and does not provide total coverage of the waterway system. The shipowners are seeking solutions to their communications problems; the communications companies are looking at methods to improve the system.

If a navigation system is developed and vessel positions are transmitted to shore-based traffic information advisors, and if weather, wave height, water depth and other non-company data are sent to vessels, this data exchange could over-burden commercial communications systems. Therefore a supplemental communications system may be required for the Great Lakes-St. Lawrence River waterway. Some precise navigation systems require shore-based units that will provide corrections to the user to enhance navigation accuracies. If such a differential system is needed for the constricted waterways, the transmittal of correction data will saturate the existing communications network. A dedicated system will be necessary.

2.3 TRAFFIC MANAGEMENT PROBLEMS

Common problems mentioned during interviews with Great Lakes shippers and masters included scheduling difficulties and a need for up-to-date environmental data such as timely weather forecasts, water depths and visibility data. Many desire more information about ship movements. This need is particularly important when the ships approach certain locks in the system and when they enter or leave ports and rivers. Improvements in these areas could increase efficiency, capacity, and safety within the system.

Scheduling problems surfaced mainly in the Soo Locks, the St. Lawrence River Locks and in some dock operations. Locks are the primary constraint on inland waterway capacity. Lines of waiting vessels develop at locks when the arrival rate approaches the capacity limit. Vessel delays are directly proportional to arrival rates. The delays are costly, causing increased use of resources, additional inventory costs, and higher average cost per ton transported. Figure 2-1 shows how vessel delays increase with arrival rate. (Ref. 4) A lock is considered congested when the daily arrival rate reaches 80 percent of its physical capacity; attendant delay costs may prompt decisions to

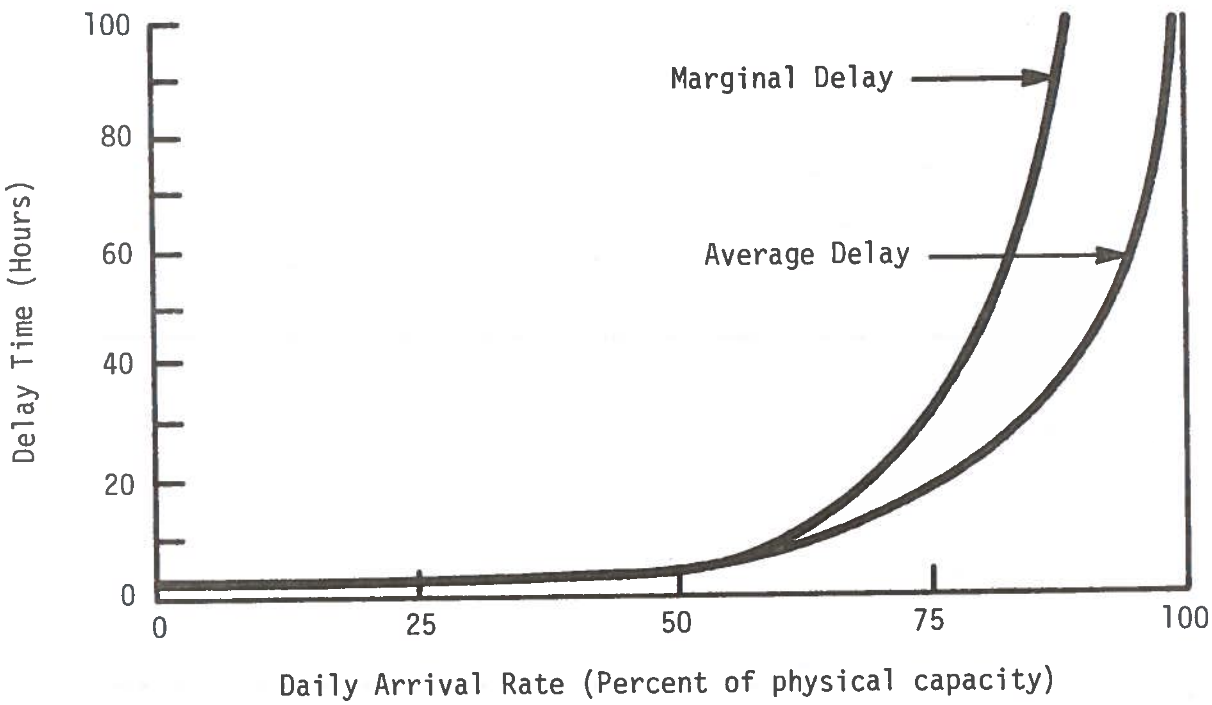


FIGURE 2-1. DELAY CURVES FOR LOCK TRANSIT

divert cargos to alternate transportation modes. Fleet operators report that lines of vessels are frequently seen waiting at the Soo Locks. As vessel size continues to expand, waiting times will increase because a greater percentage of the vessels will only be able to use the Poe Lock. The Welland Canal inaugurated an improved traffic information and control system in June 1986, its capacity cannot be further increased significantly by anything except physical improvements. At the Soo Locks, however, the masters have recommended that the "caravan" system be discontinued for downbound vessels and that MacArthur-sized vessels should be allowed to pass Poe-sized vessels. This type of vessel scheduling would be enhanced by a ship information system furnishing real time position and speed on all vessels approaching the locks. The COE also expressed a strong desire to have accurate position data and ship navigation performance data on all vessels in the St. Marys River channels and therefore includes a surveillance radar system in their expansion program. Scheduling at some docks is a large problem for dock operators. This is particularly true of "pocket" docks where the dock must be charged with the correct mixtures of ore pellets for the next ship scheduled to arrive. Poor ship movement data can cost many extra dollars in labor costs and ship delay time. Shipping agents also expressed a need for accurate, up-to-date vessel movement data to allow more efficient dock utilization and cargo handling.

The problem with current environmental data is that the weather forecasts are not focused on marine weather and are therefore neither sufficiently accurate nor timely for marine use. A traffic information system will not remedy this problem but if and when a Great Lakes weather office is opened there will be a need for a steady transfer of information from ship-to-shore and vice-versa which could easily fit into an overall management system. Inadequate up-to-date knowledge of current water depths and visibility in critical locations is another traffic problem. Current water depth information in the Vidal Shoals area and the St. Marys River would allow loading the vessel according to existing water depth, thus increasing system capacity and reducing the risks of groundings. A forecasting capability would need to develop to compensate for the 24 hour journey between the loading site and the Soo canal. Water depths in western Lake Erie and the Detroit River are important because of the large variations due to wind driven water movement. These variations can affect the safety of navigation in this area. Visibility data is desired for all restricted waterways especially those on the St. Lawrence and St. Marys Rivers. Vessels encountering reduced visibility in these channels must continue regardless of the visibility until a safe anchorage can be found. Both water depth and visibility data could be disseminated by a traffic information system once the sensors required for these measurements were in place.

The Detroit District of the COE publishes information twice a month on the Great Lakes and connecting channels' water levels and depths. The USCG monitors and reports (real-time) water depth in the Detroit River and Eastern Lake Erie. A summary of water level variations is given in Table 2-1.

TABLE 2-1. WATER FLUCTUATIONS

RIVER OR CHANNEL	MONTHLY MEAN DIFFERENCE (ft)	SHORT-TERM CHANGES (ft)
St. Marys River	±1	± 5 in 3 hrs, barometric pressure
St. Clair River	±1	± 2 short-term, wind
Lake St. Clair		± 1 in several hours
Detroit River (Lower Section)	±2	± 6 in 8 hrs, wind
St. Lawrence River	Constant	± 2 short-term, wind and power dam demand

In many areas information on ship movements were found to be lacking. Vessel pilots entering or leaving harbors such as Toledo, for example, with its long narrow channel, expressed a need to know: a) if another vessel is entering or leaving, b) where it is located, and c) what sort of vessel it is. The same sort of information is needed by the vessels leaving the Rouge River in Detroit, and in the St. Lawrence, St. Marys and Detroit/St. Clair River channels and is obtained from Sarnia Traffic, USCG, or by monitoring the reporting channels.

This information prepares the master or pilot for traffic and weather conditions ahead.

If a precision navigation system is installed on the restricted waterways of the Great Lakes system, a large amount of ship-to-shore information transfer will be required. This data would outstrip current communications systems and would naturally become part of an automated traffic information system.

2.4 DISPLAY PROBLEMS

As indicated in Appendix A the current visual aid to navigation system was not designed for the present vessel mix. It was primarily a system to be used by lakers with a forward bridge and guided by a master from a central position using the jack staff for alignment. The display of navigation information is suboptimal for superlakers and salties.

The USCG recognized from the beginning of their St. Marys River Project that the conventional method of electronic navigation would not suffice in high-precision applications. On a 1000-foot vessel, the conning officer is concerned about stranding in a 300-foot channel and has little time to read numbers from a receiver, interpolate lines of position from charts, and plot fixes to determine helm orders. To be useful in constricted waters, the receiver data must be processed in "real time" and the position fix and heading must be calculated automatically to present a continuous display of the ship's situation. As described in subsection 3.1.8.2 one could take advantage of the experience gained by repeated transits and display advisory helm orders to further free the master for the high-pressure task of waypoint and tactical maneuvering.

Experiments at CAORF (Ref. 5) determined that a display that included the vessel's position in the channel as well as a digital data block allowed a user to optimalize track-keeping performance over the use of a pure digital data display or a perspective display.

An additional problem when navigating on connecting waterways is the limited view from the bridge of a vessel which results from the number of waypoint maneuvers for which the master must prepare the vessel. (Ref. 6) Compounding this limited frontal view are environmental elements such as smoke, fog, snow, and dust.

3. SYSTEM REQUIREMENTS

3.1 NAVIGATION/GUIDANCE REQUIREMENTS

3.1.1 Traffic Survey

3.1.1.1 Vessel Categories - Vessel trades can be divided into two general categories: liner and bulk cargo. Manufactured and semi-processed goods are carried in liner vessels which run on a regular schedule and have published tariffs. Consequently, these cargoes provide what could be called a common carrier service. In contrast, oil, coal, grain, and ore usually are carried by bulk cargo vessels that publish neither schedules nor tariffs. These ships operate as either contract or private carriers. The U.S. is the only major industrialized nation in the world to mandate that its liner trades will be served by open conferences. Any liner firm is capable of joining an open conference at any time.

The Great Lakes-St. Lawrence River user community refers to the two types of vessels as salties and lakers. There are many other types of vessels on the waterway such as automobile and railcar carriers, dredges, tug boats, and military vessels. The most numerous vessel is the recreational boat; more are registered in the Ninth USCG District than any where else in the U.S. The scope of this report is limited to the ocean going vessels and lake carriers.

The types of vessels that sail on the Great Lakes-St. Lawrence River are shown in Figure 3-1.

3.1.1.2 Traffic Density - There is both a seasonal and geographic location variation in traffic density. The concentration of vessels is greater during the fall and spring season than during July and August. The grain harvest and industrial stockpiling for the winter are factors as is the rush of the salties to clear the system before it closes in December. In April the salties return and the depleted stockpiles are replenished by lakers. Traffic density is less on the open water than in the confluence areas leading to the constricted waterways. During peak periods the average traffic density varies from one

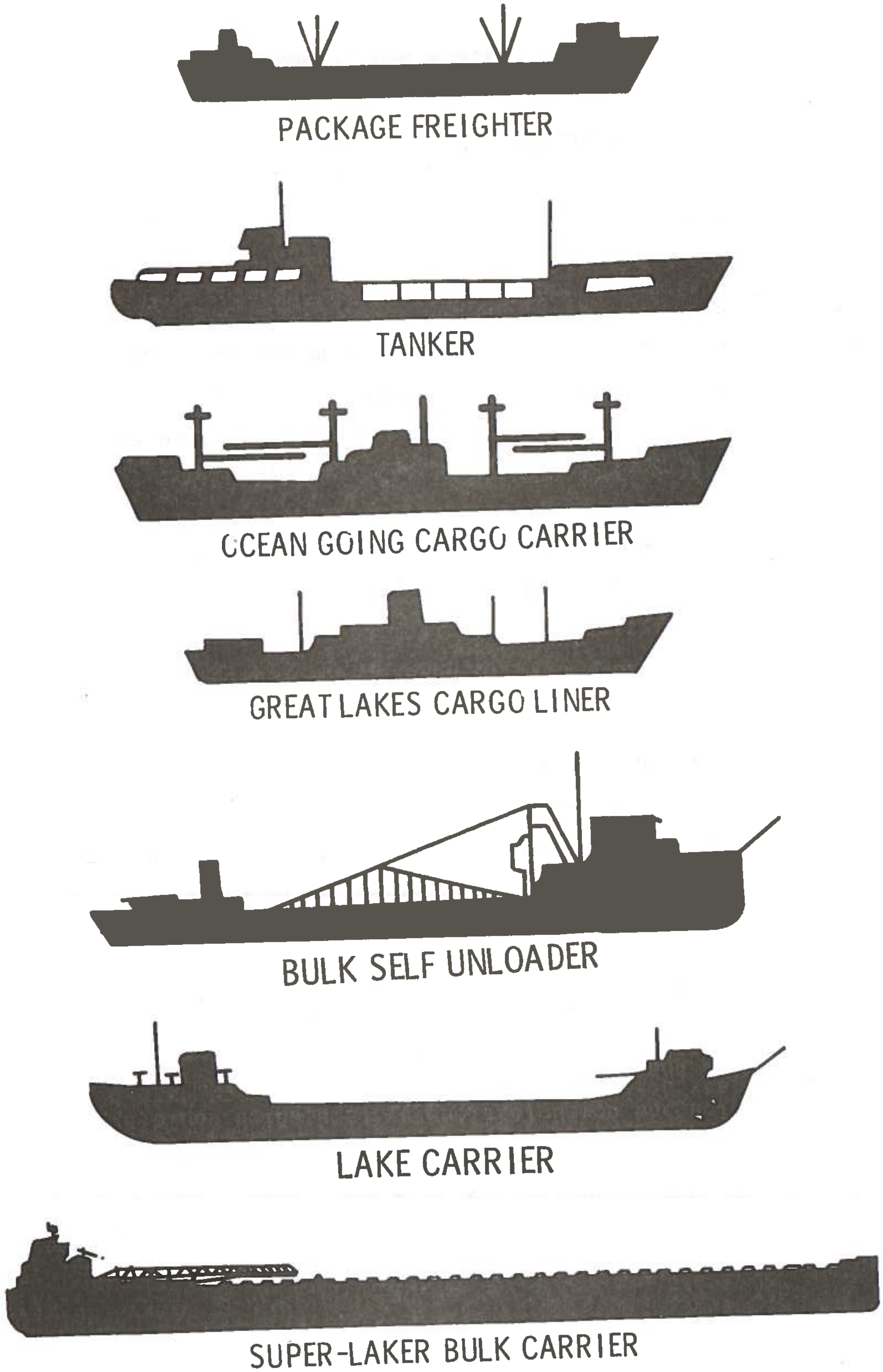


FIGURE 3-1. TYPES OF SHIPS THAT SAIL ON THE GREAT LAKES

vessel per three miles in the St. Marys River and St. Lawrence River to one vessel per five miles in the Welland Canal. These averages are based on all traffic traveling the allowable speeds. If a vessel is making a maneuver the pilot proceeds at slower speeds, reserving power to make course corrections if needed. This increases traffic density in turns. The slower speed of ships when entering and departing locks also increases traffic density in these areas. The number of heading changes per mile in a waterway determines the distribution of vessels along its length. There are 34 heading changes in 41.2 miles (.83 heading changes per mile) on the St. Clair River. This is the largest number of turns per mile on the entire system. The least is Lake St. Clair with .07 heading changes per mile (one heading change in 14.2 miles). The sailing lanes are wider on the open waters and therefore the traffic density is more uniform on the lakes than on the connecting waterways.

3.1.1.3 Critical Vessels - If navigation requirements are met for critical vessels, all non-critical vessels can be serviced by the same system. There are two critical types of vessels on the Great Lakes, the superlaker (1000 feet long and 105 feet wide) and the large salty (730 feet long and 76 feet wide). The superlaker is one of the critical types since vessel size has increased at a more rapid rate than the channel size in constricted areas. (Ref. 6) The salty is a critical type for a different reason: it is a single screw vessel, and has no bow thruster or stern anchor. In addition, the pilot (compulsary) may not have the opportunity to fully determine the maneuverability of the vessel, the adequacy of the radar, the degree of language compatibility between pilot, master, and helmsman, or the restrictions on the line of sight from the bridge to the navigation aids before entering the constricted waterway with the vessel. Simulation data in this report are for tankers of 30,000 and 80,000 deadweight - tons (dwt) and may apply to the critical saltwater vessel, but does not apply to the critical laker vessel.

3.1.1.4 Nominal Track Width - Containment of a vessel within its lane at least 99 percent of the time has been established as a reasonable goal of the Coastal/Confluence Navigation System. Using this criterion for the open water of the Great Lakes, the following nominal track widths and accuracy requirements are obtained, as can be seen in Figure 3-2 and Table 3-1.

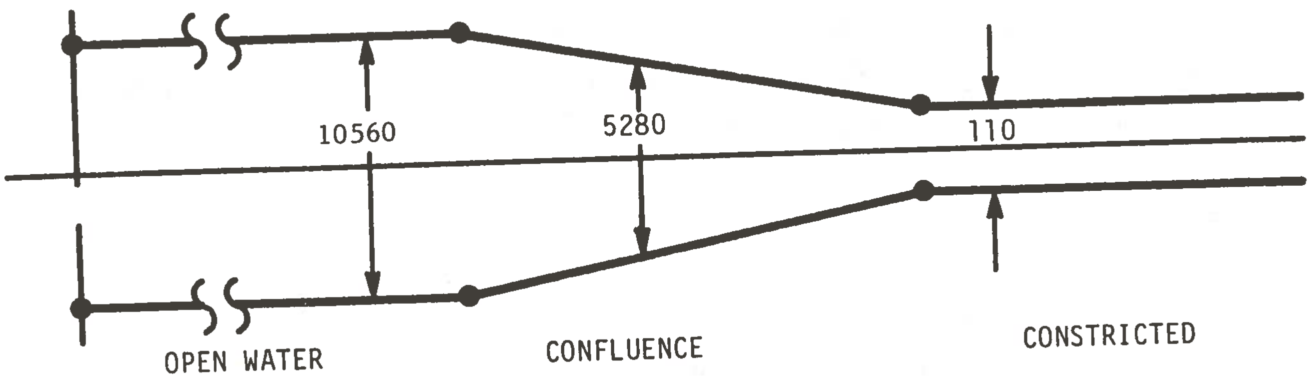


FIGURE 3-2. NOMINAL TRACK WIDTHS

TABLE 3-1. TRACK WIDTHS AND ACCURACY REQUIREMENTS

	Track Width (Feet)	Accuracy Requirement (Feet)
Openwater	10560	± 3168
Confluence Area	5280	± 1584
Constricted Water	110*	TBD**

*Width of Poe Lock
**To be determined

For constricted waterways the situation is more complex. When transiting constricted waterways the critical vessel is in one of three modes, track-keeping, waypoint maneuvering (course changes), or tactical maneuvering (preparing for or completing a course change for meeting or overtaking another vessel). The minimal track width is the 110-foot width of the Poe Lock. (The actual track width is described in Section 3.1.6.) For waypoint maneuvering the same nominal or theoretical track width is required. Vessels must maintain adequate separation when meeting or overtaking. At present there is insufficient information to determine an optimal separation distance based on ship size, speed, rudder activity, etc. However, a separation equal to half the combined beam of both vessels should provide a safe minimum distance (i.e., for two superlakers, 105 feet, for a superlaker and a salty, 92 feet).

3.1.1.5 Traffic Patterns - The superlaker, confined by the dimensions of the Welland Canal to the inner four lakes, travels through the St. Marys River, the Detroit and St. Clair Rivers, and the Straits of Mackinac. See Table 3-2. The largest number of transits are between Lake Superior and Lake Huron; second largest number of transits are between Lake Huron and Lake Erie. Most salties pass through both the St. Lawrence River and the Welland Canal and trade at all the Great Lakes ports. There is a grain flow pattern from west to east as well as ore, coal, and stone flow patterns (see Figure 3-3).

TABLE 3-2. RANKING OF WATERWAYS BASED ON PROJECTED TRAFFIC LEVELS FOR YEAR 2000[7]

WATERWAY	RANKING
St. Marys River	1
Welland Canal	2
Detroit/St. Clair River	3
St. Lawrence River	4
Straits of Mackinac	5

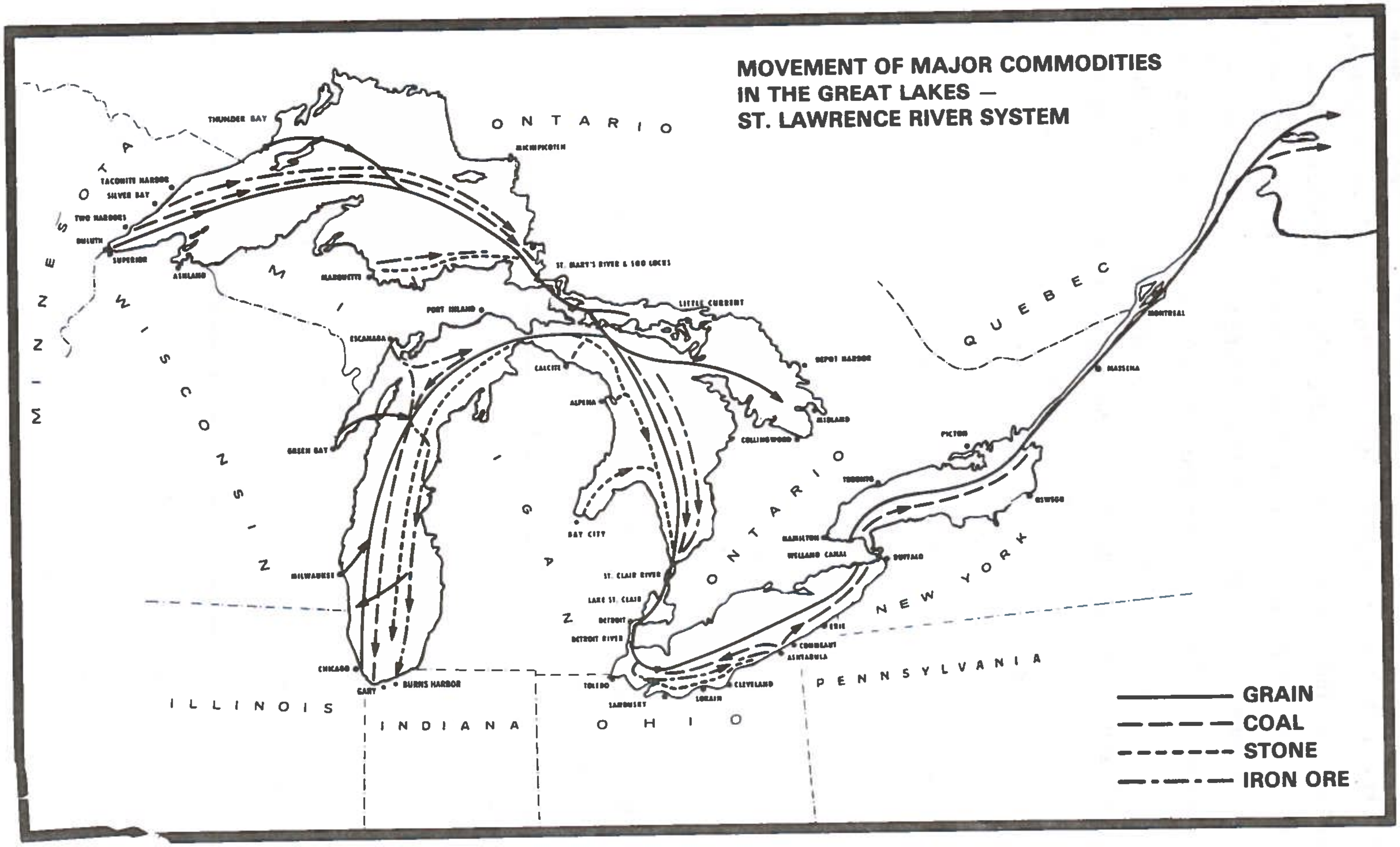


FIGURE 3-3. MOVEMENT OF MAJOR COMMODITIES IN THE GREAT LAKES-ST. LAWRENCE RIVER (9 YEAR PERIOD)

3.1.2 Waterway Description

3.1.2.1 Description of Great Lakes-St. Lawrence River System - From the Atlantic Ocean to Duluth, the Great Lakes-St. Lawrence River system is 2342 statute miles long. Over this distance 16 sets of locks are traversed that lift ships from sea level to an elevation of 602 feet in Lake Superior. These include seven locks on the St. Lawrence River, eight in the Welland Canal, and one set of locks at Sault Ste. Marie, Michigan. In terms of navigation and traffic management, it is the system of locks and connecting channels which are the most critical. These are:

a. St. Marys River, including the Soo Locks,

b. Straits of Mackinac,

c. St. Clair - Detroit River Systems,

d. Welland Canal, including locks,

e. St. Lawrence River, including locks.

The Great Lakes-St. Lawrence River system, including the connecting channels, is shown in Figure 3-4.

The St. Marys River connects Lake Superior to Lake Huron and contains the Soo Locks, located at Sault Ste. Marie, Michigan. A map of the region is shown in Figure F-1 in Appendix F. The Soo Lock system consists of four parallel locks, the MacArthur, Poe, Davis, and Sabin Locks. In addition to these four U.S. locks, an older lock is located on the Canadian side of the St. Marys River. Although this lock is small and shallow, it does relieve congestion at the American locks by handling passenger vessels, pleasure craft, and other small ships carrying cargo. The Soo Lock dimensions for all five locks are shown in Table F-1 in Appendix F.

The MacArthur Lock handles most of the downbound ships with dimensions of up to 750 feet in length and 75 feet in beam. The Poe Lock could handle ships up to 1100 feet long (with special procedures), but mostly handles 1000-foot vessels and any the MacArthur Lock cannot service. The Sabin and Davis Locks are identical in size and handle most of the upbound ships having a beam up to 75 feet and a length up to 826 feet (refer to Critical Vessels, Section 3.1.1.3).

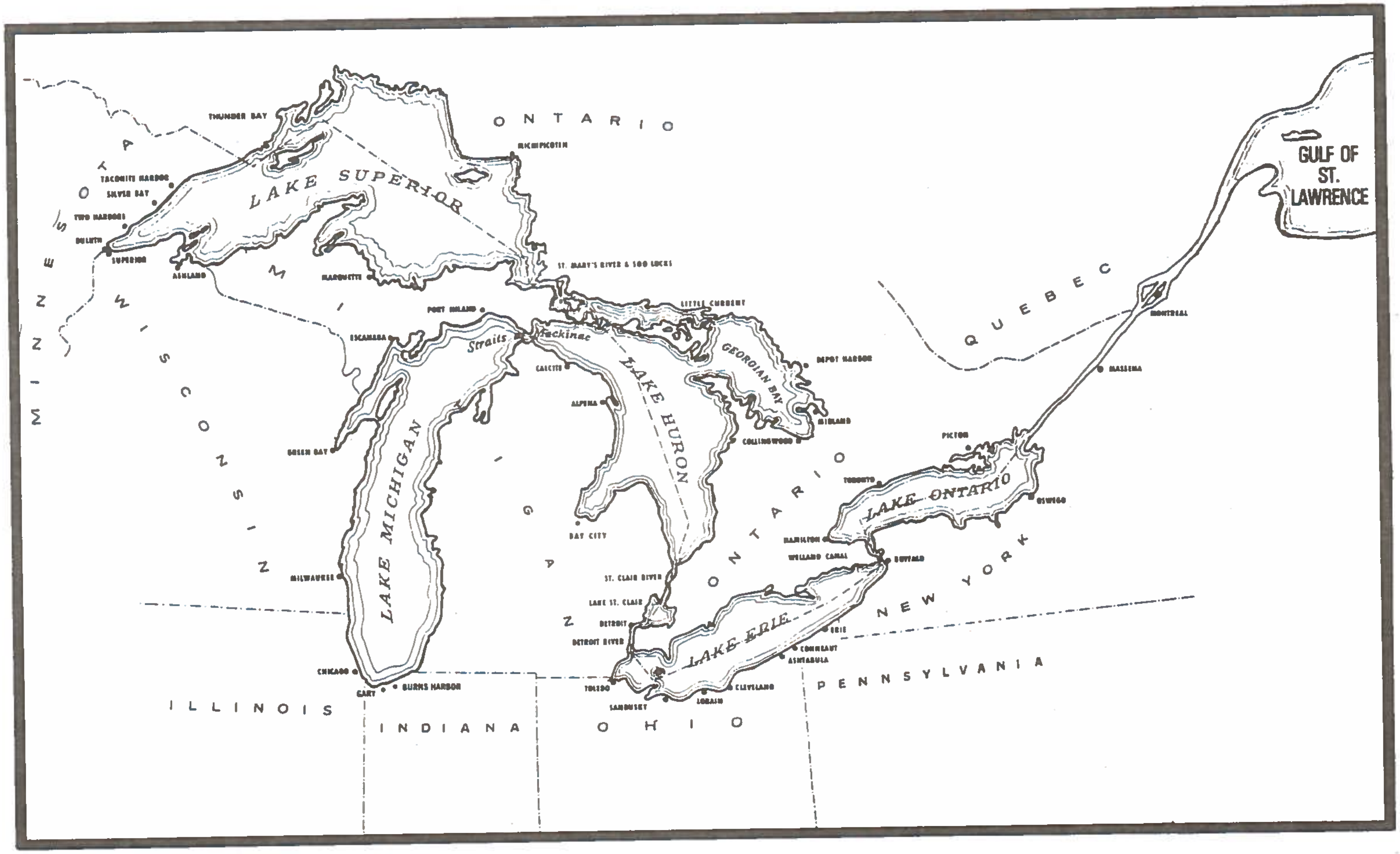


FIGURE 3-4. GREAT LAKES-ST. LAWRENCE RIVER SYSTEM

The Straits of Mackinac connect Lakes Michigan and Huron as shown in Figure F-2 in Appendix F. In most places, the channel in this strait is more than a mile wide and has a depth of over 50 feet. Two restricted sections are Round Island Passage (30 feet deep, 1250 feet wide) and Poe Reef Shoal (30 feet deep, approximately one mile wide).

The St. Clair-Detroit River System, including Lake St. Clair, is shown in Figure F-3 in Appendix F. It connects Lake Huron with Lake Erie. The St. Clair River has a minimum width of 600 feet at the Blue Water Bridge. The Detroit River has a minimum width of 300 feet. Lake St. Clair is shallow (channel depth 27.5 feet) and reacts quickly to wind conditions and temperature changes to form ice. (Environmental factors are discussed in Section 3.1.3.)

The Welland Canal, shown in Figure F-4 in Appendix F, is located approximately 20 miles west of the Niagara River and connects Lake Erie to Lake Ontario. The canal contains eight locks over a distance of 27 miles that provide a lift of 326 feet between Lake Erie and Lake Ontario. The lock dimensions are shown in Table F-2 in Appendix F.

The St. Lawrence River connects Lake Ontario to the Gulf of St. Lawrence. The system of seven locks is shown in Figure F-5 in Appendix F. These locks extend approximately 190 miles from St. Lambert Lock at Montreal to Lake Ontario. Of the seven locks, two are operated by the U.S.; the Snell and Eisenhower Locks located near Massena, NY. Five locks are operated by Canada; the St. Lambert and Cote Ste. Catherine Locks located near Montreal, the Upper and Lower Beauharnois Locks located in the Beauharnois Power Canal, and the Iroquois Lock located at Iroquois, Ontario. The dimensions of the seven locks are shown in Table F-3 in Appendix F.

3.1.2.2 Reach Description - The physical characteristics of the connecting waterways on the Great Lakes-St. Lawrence River are listed in Table F-4 in Appendix F. The St. Marys River and Welland Canal have minimum widths of 300 feet. The maximum heading change is 70 degrees on the St. Lawrence River. The density of traffic is greatest on the St. Marys River.

3.1.2.3 Channel Width - The St. Marys River lies between Canada and the U.S., separating the Province of Ontario from the upper peninsula of the State of

Michigan. This 65-mile waterway connects Whitefish Bay in Lake Superior to De Tour Passage in Lake Huron and serves as the only water shipping route connecting Lake Superior with the rest of the Great Lakes and the St. Lawrence River. The river, which has dredged channels as narrow as 300 feet, is traversed regularly by commercial iron ore vessels up to 1000 feet in length and 105 feet in beam. Although the Welland Canal, as seen in Table F-2, also has a minimum width of 200 feet, ships with beams wider than 76 feet are not permitted in the lock.

3.1.2.4 Channel Bottom Contours - The Great Lakes-St. Lawrence River system is a dredged system permitting passage of vessels drawing 26 feet (fresh water draft). The rocks in the area are part of the Canadian Shield and are noted for their hardness; the result is that bottom damage is generally more severe than that sustained in the river proper. Dredging plans are being reviewed by the COE review board to deepen portions of the upper St. Marys River to permit a maximum safe draft for downbound vessels of 26.5 feet at low water.

3.1.2.5 Turns - Two parameters govern the impact of heading changes on the smooth flow of traffic: the number of heading changes per mile of waterway and the largest heading change. Table F-4 in Appendix F describes these parameters. The St. Lawrence River has one heading change of 70 degrees; the remaining 106 are 43 degrees or less. The St. Marys River has a 65 degree turn and 24 others of less than 45 degrees. Lake St. Clair has one minor heading change of 7 degrees.

3.1.3 Environmental Factors

3.1.3.1 Wind - It was possible to make a comparison of the effect of wind using a simulator. (Ref. 8) In one leg, there was a following wind of 35 mph with gusts. At the end of the second leg, the wind was still 35 mph, now on the port quarter. There did not seem to be any effect of performance as a result of this crosswind: neither the overall mean 250 feet (centerline) nor the standard deviation 31 feet differ significantly as a function of the change. In the simulation, the helmsman and the pilot were able to compensate for the turning moment of the wind without affecting the ship's tracks.

Under heavy wind conditions (52 to 75 mph) pilots were shown to be capable of overcoming the wind-based perturbations on their vessels. (Ref. 9) In an 800-foot channel with winds up to 58 mph, tankers of 80K and 30K dwt would be found less than 100 feet from the centerline with a variability of 80 to 100 feet. With heavy wind forces of 75 mph the 80K dwt tanker would still be less than 100 feet from the centerline with a variability of 90 feet, while the 30K dwt tanker was 148 feet from the centerline with a variability of 110 to 120 feet. Pilots would use approximately half (200 to 250 feet) of the leeward side of an 800-foot channel under the heavy wind conditions studied.

3.1.3.2 Current - Variations in current were simulated (Ref. 8) and showed that in areas without a crosscurrent means were essentially at the centerline (250 feet) and standard deviations were small (30 feet). While in areas with a 0.3 mph crosscurrent, the means were shifted an average of 85 feet in the down current direction and the standard deviations increased to an average of 56 feet -- doubling in some conditions.

Wind and current affect the speed and maneuvering room requirements of vessels. The average channel current on the St. Lawrence River is 1.5 mph, ranging from 0.35 mph to 7.0 mph. There is a variable wind throughout the river and in some instances a crosstrack wind can pose a difficult situation.

Arctec Inc. conducted a study to review five years of St. Lawrence River weather data. (Ref. 10) Analysis of the data revealed some problem areas: "dynamic" reaches where the currents were not steady over the length of the reach, channel width varied, and winds could possibly vary due to changes in terrain contours. The study narrowed the problem areas down to three particular reaches, 1) St. Regis Island, 2) Polly's Gut, and 3) Copelands Cut. Polly's Gut with a channel current of 3.2 mph and a current direction of 88 degrees, is a difficult reach for maneuvering because of the crosscurrent from the Long Sault Dam powerhouse.

3.1.3.3 Bank Suction and Shallow Water Effect - Modifications of the channels to accommodate larger vessels would entail detailed investigations of the direct and indirect changes in the water levels and current flows of the system. The plans are generally aimed at determining the feasibility of increasing the presently maintained 26-foot draft in connecting channels to accommodate wider, longer, and deeper draft vessels. The St. Marys, St. Clair-Detroit, and St. Lawrence Rivers, along with Lake St. Clair and the Welland Canal, are designed to maintain 25.5-foot vessel draft. Navigable channels and Great Lakes depths are recorded in feet below "Low Water Datum" (LWD), which is a plane on each lake and a sloping surface on the connecting channels. LWD elevations are the average low levels rather than extreme lows. These navigation depths are generally equal to, or greater than, project depths -- except during the extreme low levels of the mid-1920s, 1930s, and early 1960s. During the critically high levels of the 1950s and 1970s, considerably deeper drafts were possible. Larger vessels would require dredging and possibly widening of the St. Marys, St. Clair/Detroit, and St. Lawrence Rivers and Lake St. Clair, as well as new lock systems for the St. Marys, Welland, and St. Lawrence locks systems.

In determining requirements for a navigation system, it is of interest to know whether bank effects supplement the aids in keeping the ship in the channel. The simulation results at CAORF suggest they do. Whether pilots understand the banks and use them or don't understand the banks and avoid them, bank effects keep ships in the channel. The banks present a cushioning barrier the ship must overcome to leave the channel, i.e., to strand, thus decreasing the possibility of a stranding. At the same time, the banks tend to force the ship away from the channel boundary and into any incoming traffic, thus increasing the chances for a collision. The fear of bank effects keep meeting vessels closer to the centerline and farther from the channel edge.

The risk of meeting traffic is described as the total risk of stranding and collision, although the tradeoff between the two risks is also meaningful. A set of conditions may result in a higher or lower total risk. They will also result in a more or less desirable tradeoff between the two risks. A traffic advisor who is evaluating a waterway with a dangerous bottom considers the total risk while an advisor evaluating a waterway with a soft bottom gives greater emphasis to the risk of collision.

The shallow water effect and the ice channel effect tend to increase course stability. The turning performance of a ship is greatly reduced because of substantial stabilizing effects. Pilots choose to rely on first hand experience to get the "feel" of the vessel's performance. This appears to be a fairly good strategy for similiar type ships, i.e., large and small salties. However, experience on one type of ship (salty) may not generalize to another (laker), particularly if the ships differ in hydrodynamic characteristics. A simulation of shallow water navigation with and without the pilot's knowledge of the vessel's maneuverability in shallow water had the following results for tankers: the off-track deviation when approaching a shallow water entrance with knowledge of the vessel's maneuverability ranged from 355 to 360 feet, as seen in Table 3-3. (Ref. 11) This was an improvement of 96 feet (closer to the trackline) over the pilot unfamiliar with the ship's maneuverability. In the channel the improvement was 118 feet; narrowing to 35 feet. During a waypoint maneuver of 90 degrees the improvement in off-track deviation was 50 feet.

TABLE 3-3. MANEUVERABILITY DATA

EXPERIENCE	DEEPWATER ONLY	SHALLOW WATER
OPERATION	OFF-TRACK DEVIATION (FEET)	
Approach	456	360
Entrance (1000')	279	161
Channel (800')	96	61
Waypoint (90o)	268	218

3.1.3.4 Visibility - Open water navigation continues during virtually all weather conditions. St. Marys River experiences delays of three to five hours because of fog problems. Other narrow waterways have similar visibility-caused delays. In some cases the loss of visibility is localized with no means of warning for a transiting vessel. In many areas a vessel must continue its transit once it has entered a reach. There may be no safe anchorage nearby if the weather changes unexpectedly while a vessel is transiting many parts of the waterways. All pilots, masters, and mates, who were interviewed, were trapped on at least one occasion in this type of an area when the visibility deteriorated without warning. With limited visual cues, the pilots continued the transits using radar until able to anchor in a safe area.

At night, some areas such as Green Bay have a different visibility problem. Lighted navigation aids blend with background lights. Experienced pilots develop special cues to identify the navigation aids. Radar and radar reflectors on buoys and aids also ameliorate this possible problem. More caution and a greater precision to the set of tracks at meeting reduces "risk" at night and shows a greater separation distance between the two ships. For some conditions this was combined with a lower standard deviation, the combination resulting in a lower measured risk of collision at night. For some conditions, the measured risk of stranding was lower at night as well. (See Section 3.1.4.2.)

3.1.3.5 Ice - The main impediment to winter transit has not been the inability of vessels to pass through the ice because modern icebreakers can provide open channels for merchant vessels under the severest conditions. (The Misener laker/ocean bulk carrier Canada Marquis made four voyages to Leningrad last winter, working in what was called one of the most severe Baltic winters in years.) The impediment has been the lack of navigation aids. Because ice will damage, sink or move buoys by which pilots judge the location of the shipping channel, at the onset of winter all lighted buoys are removed and stored ashore.

Vessels operating beyond the ice-free season encounter increased risks: ice causes the navigation channels to become narrow, lighted buoys are removed, and harbor channels are not maintained so that docking becomes difficult. Some channels with ice problems are managed for year-round operation: e.g. the Detroit River. Ice and winter weather periodically stop or slow down winter traffic for brief periods.

Winter ice also impedes lock operations: brash ice floats into the chambers, takes up space and must be locked through, thus reducing capacity. Ice also drifts into gate recesses and prevents gate closure.

Considerable effort has been made in recent years to set firm opening and closing dates for the navigation season. April 1 is the present opening date for the season, although vessels that do not need to pass through locks, such as the bulk liquid carriers that sail in Lake Michigan and Lake Huron, can go whenever ice conditions permit. In some cases, it is a function of where the wind has opened up the waterway. For example, ore was shipped from Escanaba to Burns Harbor in March of 1984. Wind and warm temperatures drove ice and slush from Lake Huron into the St. Clair River, building a shore-to-shore ice/slush jam and causing a three week delay for vessels sailing between Lake Huron and Lake Erie. At one time 86 vessels were trapped until the ice jam was broken on April 29, 1984. Losses were estimated at $1.6 million per day. The closing date varies on different areas of the system. (Refer to Table 3-4 for new dates.) The St. Lawrence River above Montreal usually freezes first, and in 1985 it closed on December 31. The target date was December 15. The Welland Canal usually closes next, followed by Sault Ste. Marie. On request from the Lake Carriers Association, Sault Ste. Marie may be kept open in any year until January 8, plus or minus one week. The St. Lawrence River from Montreal to open water has been in all year operation since 1958. The channel is kept open by icebreakers operating from Quebec City.

The St. Lawrence Seaway and the Welland Canal, which links Lake Ontario with Lake Erie, reopened April 3 for the 1986 navigation season, the U.S. Sault Ste. Marie canal, connecting Lake Superior with Lake Huron, April 1, and the Canadian Sault Ste. Marie canal April 14. In years past, this has benefited smaller bulkers; however, springtime openings have had significantly little impact on market sentiment. (Ref. 12)

3.1.4 Casualty Assessment

To summarize the most significant navigation problems, the results of a previously sponsored MARAD study are noted here. This study was performed in 1979 and ranked waterways of the Great Lakes-St. Lawrence River System. Great Lakes industry and government personnel were interviewed. The results of that study are shown in Figure 3-5 and Table 3-5. Figure 3-5 shows the number of collisions and groundings which occurred over a nine year period. (Ref. 6)

3.1.4.1 Critical Location - The Detroit River and Lake St. Clair, including western Lake Erie, experienced the largest number of groundings and collisions of any of the constricted waterways. The geographic area which includes the St. Marys River ranks second, and the area which includes the St. Clair River ranks third. One further conclusion which can be drawn from the data in Figure 3-5 is that the geographic areas containing the interconnecting waterways experience the largest number of groundings and collisions. The St. Marys River is the most critical location based on the number of accidents and its traffic density,

TABLE 3-4. ACTUAL OPENING AND CLOSING DATES OF NAVIGATION

	Montreal-Lake Ontario Section			Welland Canal Section		
Year	Opened	Closed	Days of Navigation	Opened	Closed	Days of Navigation
1959	April 24	December 3	223	April 6	December 15	254
1969	April 7	December 15	253	April 1	December 22	266
1979	April 2	December 22	265	March 28	December 29	277
1980	March 24	December 19	271	March 24	December 31	283
1981	March 25	December 20	271	March 25	December 27	278
1982	April 5	December 21	261	April 5	December 23	263
1983	March 31	December 19	264	April 5	December 27	267
1984	April 2	January 2	276	March 28	January 1	280
1985	April 2	December 31	274	April 1	December 31	275
1986	April 3			April 3		

ACTUAL DATES

OPENING - The date the system opened for commercial navigation.

CLOSING - The date the last commercial vessel cleared the system.

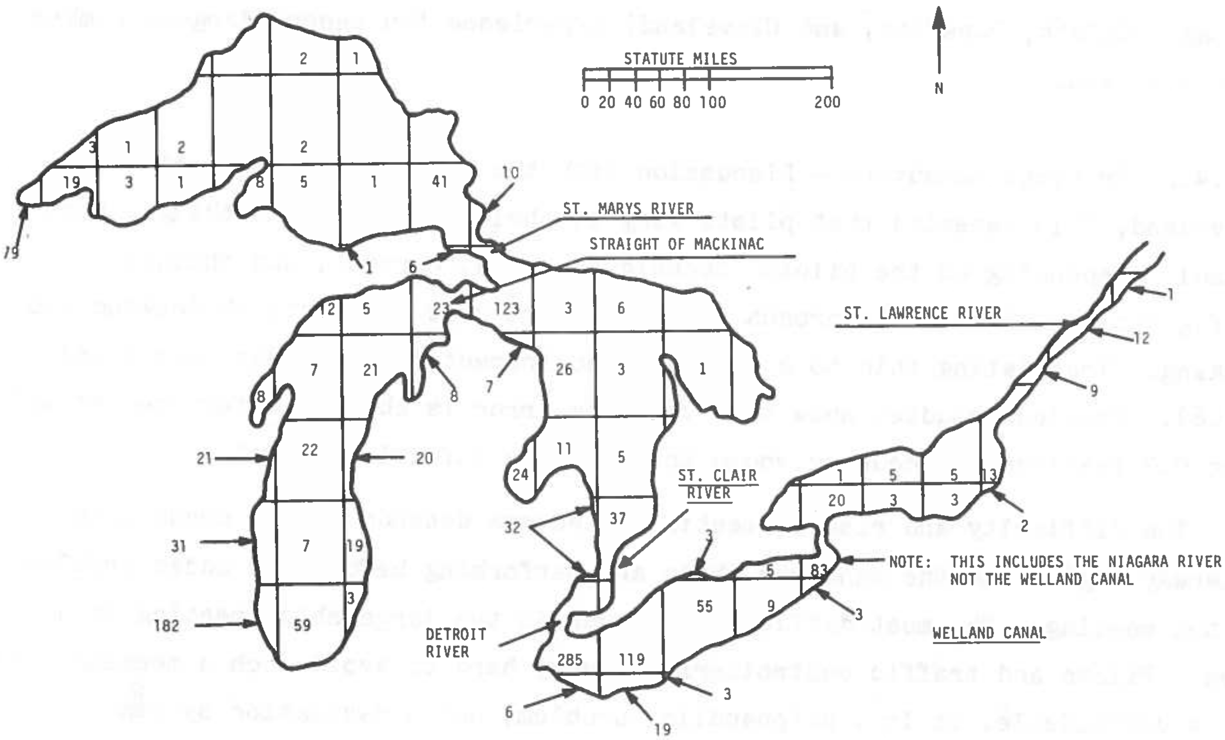


FIGURE 3-5. DISTRIBUTION OF COLLISIONS AND GROUNDINGS ON THE GREAT LAKES-ST. LAWRENCE RIVER (9 YEAR PERIOD)

TABLE 3-5. CASUALTY RANK FOR CONNECTING WATERWAYS

GEOGRAPHIC AREA	TOTAL GROUNDINGS AND COLLISIONS (9 YEAR PERIOD)	RANK
Detroit River and Lake St. Clair	285	1
St. Marys River	139	2
St. Clair River	69	3
St. Lawrence River	35	4
Straight of Mackinac	23	2

as shown in Table 3-1. Geographic areas containing major ports (such as Gary, Chicago, Duluth, Superior, and Cleveland) experience the second largest number of casualties.

3.1.4.2 Critical Maneuvers - Discussion with the Lake Carriers Association, Cleveland, Ohio revealed that pilots vary in their methods for docking a huge vessel. Depending on the pilots' techniques, wind, current, and channel configuration, different approach velocities are used to establish docking and locking. Translating this to a velocity requirement is difficult (see Section 3.1.6). Previous studies show that velocity error is about 0.8 feet/second and that 0.2 feet/second accuracy would therefore be sufficient. (Ref. 13)

The difficulty and risk of meeting maneuvers depends on the connecting waterway region and the maneuver ships are performing before the added problem of the meeting. The most difficult maneuver is two large ships meeting in a turn. Pilots and traffic controllers try very hard to avoid such a meeting. If it is unavoidable, it is a shiphandling problem, not a navigation system problem.

A simulation experiment did include evaluations of a meeting with one vessel still in the turn pullout 2000 feet from the apex, but with the second ship not yet committed to the turn. Pilots considered even this meeting very difficult, one they would try hard to avoid. Inspection of the baseline data shows that collision risk is considerably higher for such meetings than for meetings in a straightaway.

Another simulation had vessels of the same size meeting one mile beyond a turn and involves a day versus night comparison. The mean separation for the daylight manuever was 90.6 feet with a standard deviation of 15.3 feet; for the nighttime manuever the mean separation was 143.4 feet with a standard deviation of 25.2 feet. (Ref. 14, 15)

Results of a day-night meeting of vessels of different sizes have appeared in earlier experiments. In the aforementioned reports, a CAORF experiment found that pilots stayed farther away from a meeting ship at night when it was more difficult to see it. For day ships had a mean separation of 97.4 feet and standard deviation of 50.5 feet. For night one ship allowed the other more room with a mean separation of 106.1 feet and a standard deviation of 32 feet. The meeting point was one mile above the turn in both of the scenarios. (Ref. 14,15)

Analysis of pilot performance during meeting maneuver experiments conducted at CAORF indicate that the pilot concentrated on successfully maneuvering to a comfortable distance abeam an approaching ship of equal size or weight rather than concentrating on maneuvering to a particular position in the channel. This behavior resulted in a mean crosstrack position of his vessel during the maneuver to approximately one-sixth of the channel width to the right of centerline. In an 800-foot wide channel a superlaker would track 133 feet to the right of centerline. Separation distance for meeting vessels would be 161 feet. In a 500-foot wide channel a vessel would track 83 feet to the right of centerline. Two salties in a meeting maneuver in the 500-foot wide channel would have a separation distance of 90 feet.

When two different size tankers manuevered for a nighttime meeting during a simulation evaluation, there was a reluctance to venture off centerline in the 80K dwt tanker as compared to the 30K dwt tanker. Analysis of the standard deviation shows it to be a uniform tendency: that is, there was no significant difference in the standard deviations. However, the TSC riding teams reported that the largest or the more heavily loaded of two vessels would tend to meet traffic at a relatively constant crosstrack position letting the meeting traffic determine the abeam separation. Because an approaching ship presents a more certain boundary than a channel buoy, the uncertainty of stranding apparently overrode any potential for collision in the pilots' minds. The riding team noticed that the superlaker kept its deck lights on to enable meeting vessels to more clearly define the abeam distance.

3.1.4.3 Radar Assistance - Master and pilots rely on radar to supplement the visual navigation system. All floating aids and the majority of fixed aids have radar reflectors which identify these units on a radar screen. In addition, the USCG has - with the advice of a senior mariner group - installed RACONs to identify entrances to harbor and confluence areas. For a description of these aids see Appendix C.

On open water the radar is used for surveillance as well as supplemental navigation. In constricted areas, with the onset of unanticipated fog, the radar will be used as the sole means of locating a safe anchorage.

Radar can be used to examine an entire channel ahead for the pattern formed by the buoys, and experienced pilots are likely to notice if buoys have moved. When the buoys are removed in the fall some vessels leave reflectors on the fast ice to identify waypoints or turn points. The master will communicate with meeting vessels to inform them of the inplace reflector.

Laker captains use radar much more extensively than salty pilots. The latter must depend on the salty crew for the quality of the radar preventive maintenance. In addition, though pilots are familiar with all makes and models of radars, their radar training is usually more intensive on one system than on others.

Simulation studies have been conducted that compare track-keeping performance with and without the use of radar. Subjective analysis of track-keeping in the confluence area suggests that pilots using the ship's radar tend to keep closer to the designated track but at the expense of using more channel entrance and taking a longer time to settle down to the steered course. Once in the channel, the track-keeping with radar appears to be more erratic for the majority of pilots. More consistent track-keeping is achieved by visual assessment alone.

Statistically and numerically the differences of track-keeping accuracy and rudder usage with or without radar were found to be small. The off-track means are typically in the order of only 30 feet, and the variation in rudder usage is more a function of the specific helmsman's behavior than of the navigation available. When the pilot uses visual cues for assessing the distance of his ship's deviation from centerline he is more consistent and biased slightly to the starboard side of the channel, reflecting an ingrained habit to use the side of a channel rather than the center as if anticipating a meeting maneuver. As he proceeds down the channel the centerline is slowly approached. Where radar is available he makes his deviation zero in the vicinity of buoy sites. The accuracy is obtained at the expense of more centerline crossings (more helm orders). Track-keeping is a much more active process when radar assisted.

3.1.5 Critical Maneuvering Scenarios

3.1.5.1 General Maneuvering Scenarios - While navigating on the open waters of Great Lakes masters use both electronic and visual aids. The TSC riding team observed the use of LORAN-C signals to determine velocity over the ground and the use of the LORAN-C indicated position as a guard against large crosstrack errors while using the automatic pilot system. Radar and RACONs are used to identify the approaches to the connecting waterway.

A simulation of the impact of a heading change on track-keeping capabilities in constricted waterways was evaluated. The measurements selected were the maximum crosstrack standard deviation 5000 feet before and after the heading change of 35 degrees and the crosstrack mean at that point. These values were chosen on the assumption that they represent maximum track-keeping difficulty in the straight reach while values closer to the turn represent waypoint maneuvering capability. On the straight reach, the overall mean was essentially on the 250-foot line that is the center of the channel. The overall standard deviation was approximately 40 feet. The perturbation of a heading change of 35 degrees to the right displaced the overall mean more than 50 feet to the right and doubled the standard deviation to 80 feet. The configurations and spacing of the buoys involved are representative of existing conditions in U.S. channels.

Analysis of the performance over the length of a straight reach supports the inference that the pilots used a different strategy with staggered buoys. The mean of the crosstrack position of the transits shows a tendency to approach each buoy as it passes to the side. Pilots call this "zigzagging" or "buoy-hopping" when they describe doing it in the real world.

The results of a pullout following a heading change of 35 degrees was analyzed for differences in performance as a function of conditions. All the turns were the same in angle, radius, and number of turnmarkings. Therefore, differences in pullout performance are attributable only to straight channel buoy spacing (gated and spaced, .625 and 1.25 miles). The measures used to describe pullout performance in the different conditions were the crosstrack mean and standard deviation at 5225 feet beyond the apex of the turn. The standard deviation in the pullout ranged from 66 feet to 29 feet; the mean positions from centerline were 186 feet and 174 feet. (Ref. 8)

The condition with the best information did not seem to have the best performance; the more closely spaced buoys had the largest value of standard deviation. The possibility of too much buoy information leads to "over-control." This means the pilot tries too hard to achieve a precise track, giving a great many helm orders that result in frequent changes in the heading of the ship. Because of time lags between the giving of an order and the ship's response, the pilot's perception that the intended track has been overshot and his giving of a new order and then the ship's new response, such over-control would be expected to result in a greater standard deviation of crosstrack positions, even while achieving a better mean. Yet when the number of helm orders were analyzed, there were more rudder orders in the pullout for the closer spaced buoys. They were "over-controlling" in the pullout, resulting in a more precise mean and a larger standard deviation. However, this was true only for the pullout. For the rest of the straight run they still maintained a more precise mean but with no more, and perhaps fewer, helm orders and a lower standard deviation.

The heading change in the gated buoy condition presented the pilot with a situation in which there was a very high information rate and no restriction on pilot strategy (unlike the straight channel segments in which the pilot was instructed to stay on the centerline). The tracks are individual runs through the turn for the specific scenarios, each showing the outline of the 35-degree run in a 500-foot channel with the turn buoys indicated. They split into two different strategies: most went to the inside of the turn to allow for the current, while several made an ambitious attempt to stay at the centerline all the way through the turn. Such a relationship between a high information rate and high variability was also found in another study done for the USCG. An analysis of approach to a deepwater port found that radar displays with high information values were associated with more varied strategies.

The larger standard deviation in a high information rate condition should not be interpreted as relative uncertainty. Rather, the pilots were so certain of their position that, when they had the opportunity to demonstrate their expertise, they chose more difficult tracks for themselves and gave more helm orders to achieve those tracks. In those segments of the channel where the track was fixed, they were well able to maintain the track without extra effort and showed the precision of performance to be expected with high buoy information.

3.1.5.2 Specific Maneuvering Scenarios - To navigate a vessel the pilot must have information on the vessel's position and attitude relative to the intended course. This is particularly important in constricted waters such as the rivers and locks. The Detroit River is a constricted waterway which requires a high level of alertness on the part of a captain responsible for piloting a 1000-foot vessel through a channel that is 500-feet wide with rock sides and bottom. The river splits into upbound and downbound channels just north of the Detroit River Light, at Amherstburg, and represents one of the most dangerous areas of the river. The ship must make a right turn immediately followed by a left turn in a narrow channel, against an eight-foot-per-second current within 100 feet of the shore. These maneuvers are wholly dependent on the acute observation of the vessel's swing rate, concentration on turn bearings on selected shore objects, speed and accuracy of communication with the helmsman, and a great deal of experience. Based on a ranking of hazardous physical characteristics, the Detroit River is tied for second place with the Welland Canal and the St. Clair River. The St. Marys River is rated first. There, at Johnson Point, a sharp lefthand turn must be made into a 300-foot channel with no righthand markings but having good visual range. A vessel passes within 100 feet of land during this turn. This turn is made with full left rudder to get a large vessel turning and full right rudder to get it stopped. Also in the St. Marys River the Point of Woods range is crucial in aligning to the new channel and because the remainder of Munuscong Channel and Middle Neebish Channel are half channels (essentially all the upbound channels are half channels) and range lights are extremely important. Inability to see range lights in this whole section of the St. Marys River would make piloting extremely dangerous. Of all the visual navigation aids available to the pilot the ranges are the most accurate for determining crosstrack error on constricted waters. By steering a course which keeps these structures in line the pilot will remain within the confines of the channel (Figure 3-6). Other studies have identified the upbound middle Neebish

Channel as the critical location in the St. Marys River. This channel requires five heading changes averaging 53 degrees each. It is the most difficult section of the river in terms of turn severity.

3.1.6 Navigation Assessment

3.1.6.1 Great Lakes Accuracy Requirements - The ability of a ship to maintain its position within the confines of a given lane width is determined by the vessel's track-keeping capability. As the block diagram of Figure 3-7 shows, the track-keeping capability of a ship is influenced by (1) the inherent course stability, (2) the ship's trajectory and (3) the accuracy of the position fixing aid. (Ref. 16) Figure 3-8 illustrates this track-keeping ability as a time history of the ship's crosstrack errors as it leaves port, sails towards its destination, and periodically reestablishes its position with a fixing aid.

Since the accuracy of the position fixing aid is highly independent of the course stability and the trajectory of a ship, one can formulate the track-keeping ability of a ship by summing the variances of the individual error sources that contributes to the total track-keeping error, thus:

$$\text{track}^2 = \text{fix}^2 + \text{CS}^2 + \text{TR}^2$$

or

$$\text{track} = \left[\text{fix}^2 + \text{CS}^2 + \text{TR}^2\right]^{1/2}$$

where:

track = track-keeping error or requirement

fix = crosstrack error (or accuracy) of the position fixing device

CS = crosstrack error resulting from course stability

TR = crosstrack trajectory error

Thus, once the track-keeping requirements are established and the errors introduced by the inherent course stability and the trajectory of the ship are accounted for, then the accuracy required of the position fixing aid can be determined from

$$\text{fix} = \left[\text{track}^2 - \text{CS}^2 - \text{TR}^2\right]^{1/2}$$

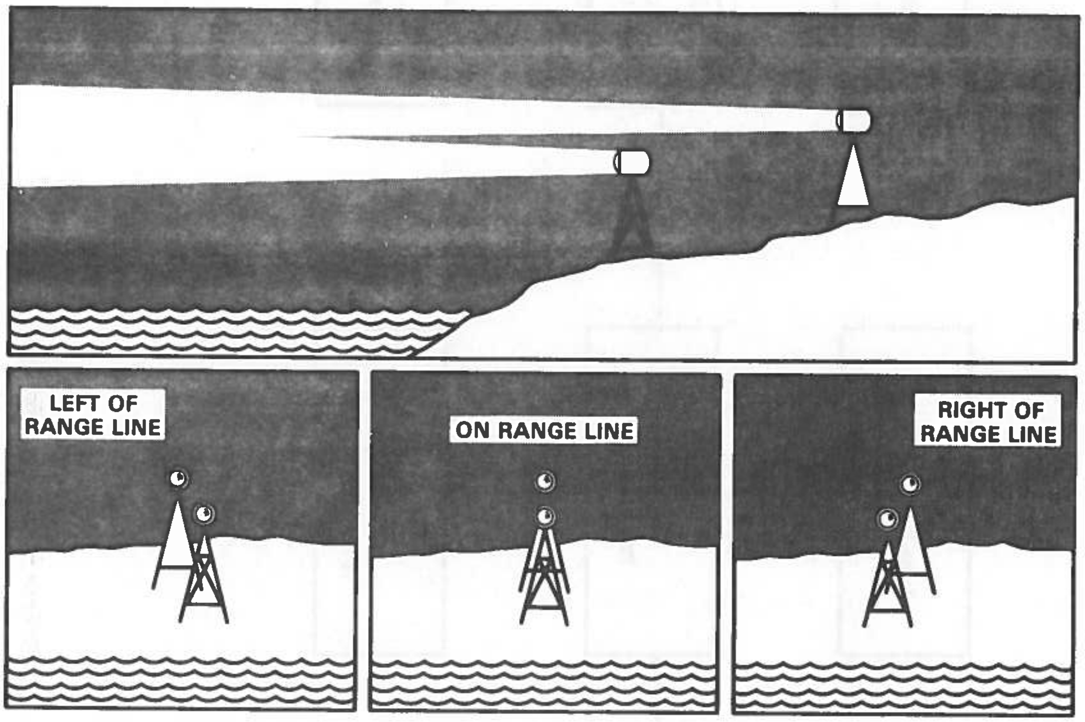


FIGURE 3-6. RANGE MARKERS AS NAVIGATIONAL AIDS

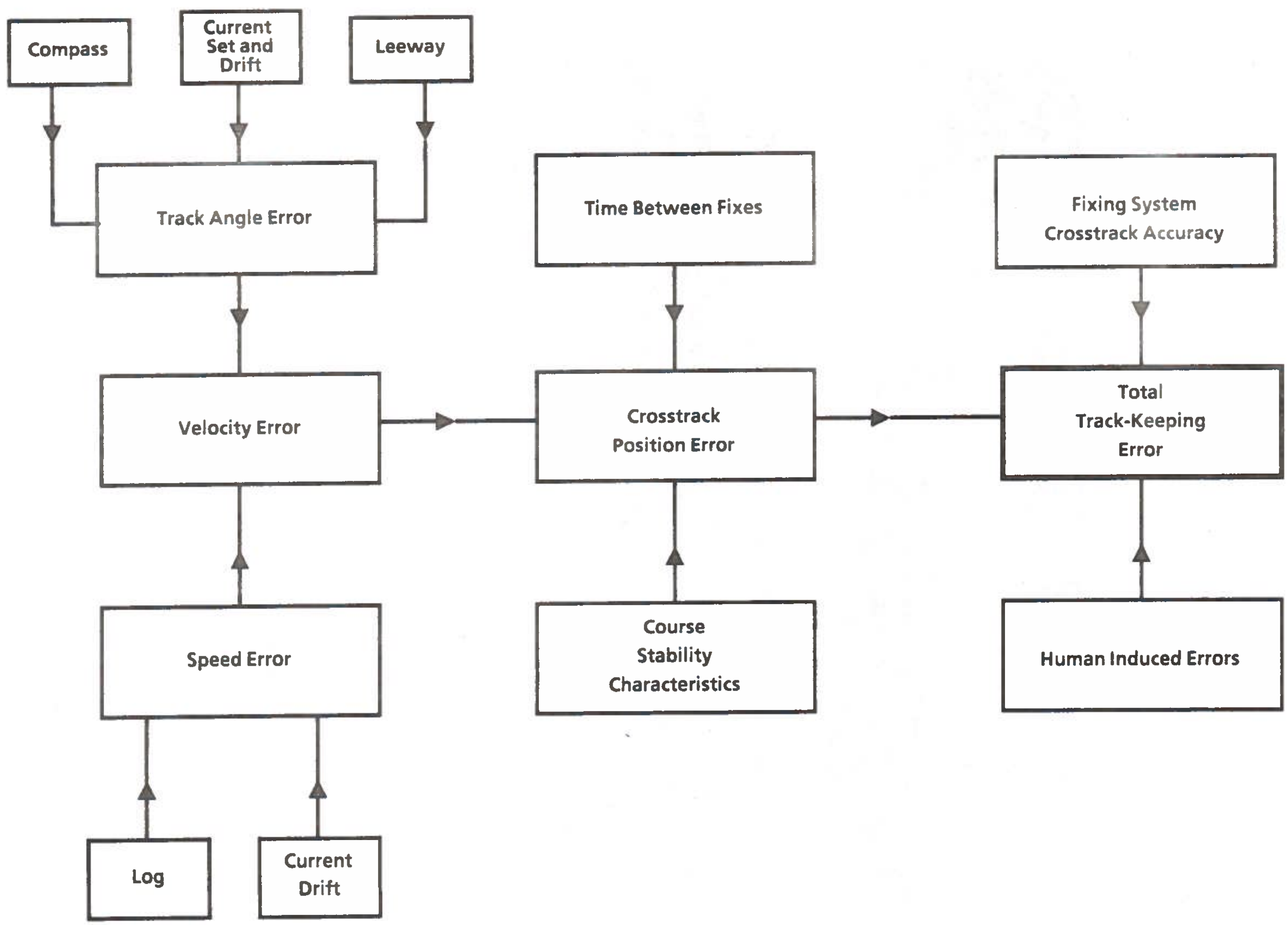


FIGURE 3-7. SHIP TRACK-KEEPING CAPABILITY

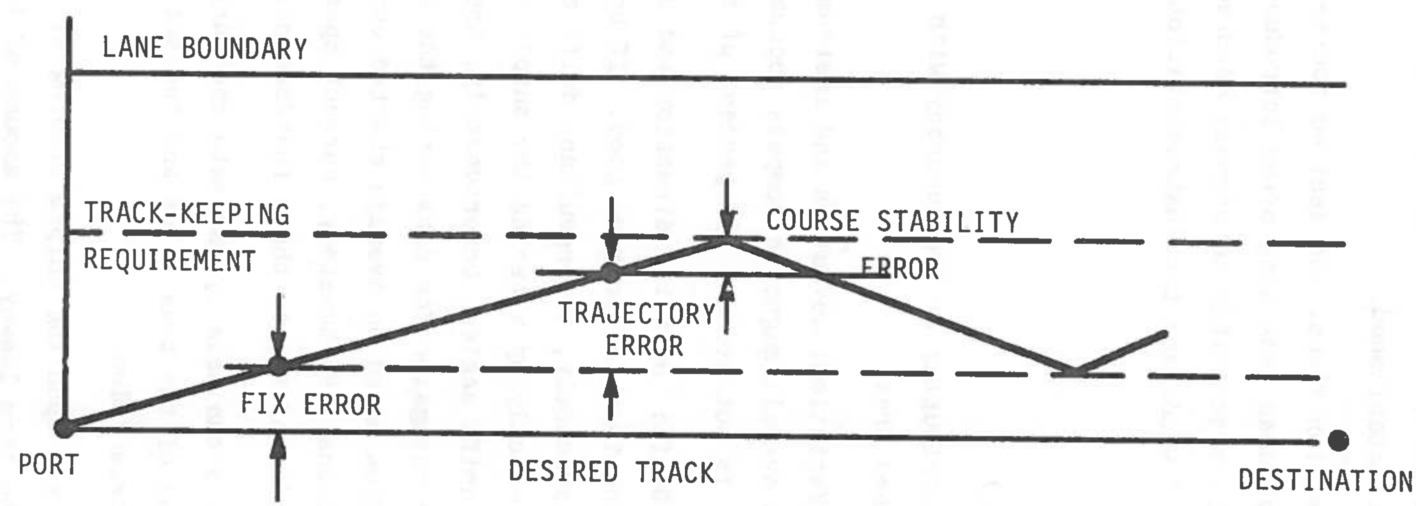


FIGURE 3-8. TIME HISTORY OF SHIP CROSSTRACK ERRORS

It should be noted that track variations resulting from human errors are not directly accounted for in this procedure, but are introduced indirectly when the track-keeping requirements are established.

Trajectory Error - Between position fixes, the desired course is maintained by dead reckoning. Unfortunately, dead reckoning often introduces errors into the ship's track. The technique is susceptible to compass accuracy limitations, unknown currents, influences of winds and the instrumentation limitations in the speed measuring device.

Trajectory Error Synthesis

1. Track Angle Error (θ_t)

   The major sources contributing to the accuracy with which the track angle can be determined are:

   a. Compass Error: Variation, deviation and instrumentation limitation contribute to an overall magnetic compass accuracy of approximately two degrees that is not exceeded 95 percent of the time.

   b. Current Set and Drift: Both the direction and speed of a sea current affect the track angle made good. If both the set and drift are known precisely, the resultant drift angle can be compensated for exactly by altering the ship's heading by an amount opposite to the drift angle. Unfortunately, the only means available to the navigator for determining the current set and drift is estimation based on average charted current values and the local sea conditions. Fortunately, current speeds are usually small, in the order of two to three feet/second.

      Skilled navigators can usually estimate the current speed to within a 0.4 feet/second of the true value and the set to within 10 to 15 degrees of its true value.

   c. Leeway: The effect upon the ship's heading of wind and sea are grouped under the term leeway. The amount of leeway produced in a given ship is a function of wind speed and direction, ship loading, super structure shape and height, type of waves and direction in which waves strike the vessel. These effects are in addition to those produced by the sea currents. Under moderate sea and wind conditions leeway for a powered vessel rarely exceeds a few degrees. Determination of the amount of leeway by the navigator is at best an estimate. To account for unapplied or estimated leeway corrections to the heading, a leeway error that will not be exceeded 95 percent of the time is assumed to be one degree.

The total track angle error (θ_t) resulting from independent error sources is obtained by summing the variances of the individual independent component errors.

Thus, for a 15-mph ship:

$$\theta_t^2 = \theta_c^2 + \theta_{s\&d}^2 + \theta_L^2$$

or, $$\theta_t^2 = 2^2 + 1^2 + 1^2$$

or, $$\theta_t = 2.5^o$$

2. Speed Error (dV)

Those major sources that introduce errors in determining the speed of the ship over the earth are:

a. Log: The log measures speed of the ship relative to the water motion. Calibration and resolution are such that 95 percent of the time the speed should be within 2.5 percent of the correct value for a quality log. For less expensive logs, the error may go as high as 5 to 10 percent. Fortunately, the crosstrack error is not significantly influenced by speed inaccuracies, even when they are in error by as much as 10 percent. For a 15-mph vessel, a 2.5 percent instrument accuracy results in a speed error of approximately $\pm$ 0.4 mph.

b. Current: The error in determining the speed of the water over the earth, as previously explained under track error, will be taken to be $\pm$ 0.29 mph.

For independent random error sources, the resultant probable error is determined by taking the sum of the variance of the independent error sources. Thus, for a 15-mph vessel:

$$dV^2 = 0.4^2 + 0.29^2$$

$$dV = 0.5 \text{ mph}$$

When a ship is on an incorrect heading and a maneuver is initiated to regain the required track, the ship at first will stray further from the desired track, increasing its crosstrack error. This error is the result of the fact that a ship has a finite turn radius and is affected by shallow water and ice coverings. Figure 3-9 shows the track of a ship under such a maneuver.

The crosstrack error increment resulting from the ship course characteristic is $XT = R(1-\cos\theta)$, where R is the radius of turn of the ship. This relationship is plotted in Figure 3-10. As the plot shows, even for large ships undergoing large course corrections (10 to 20 degrees) the resultant crosstrack error is small enough to ignore for the open lane problem.

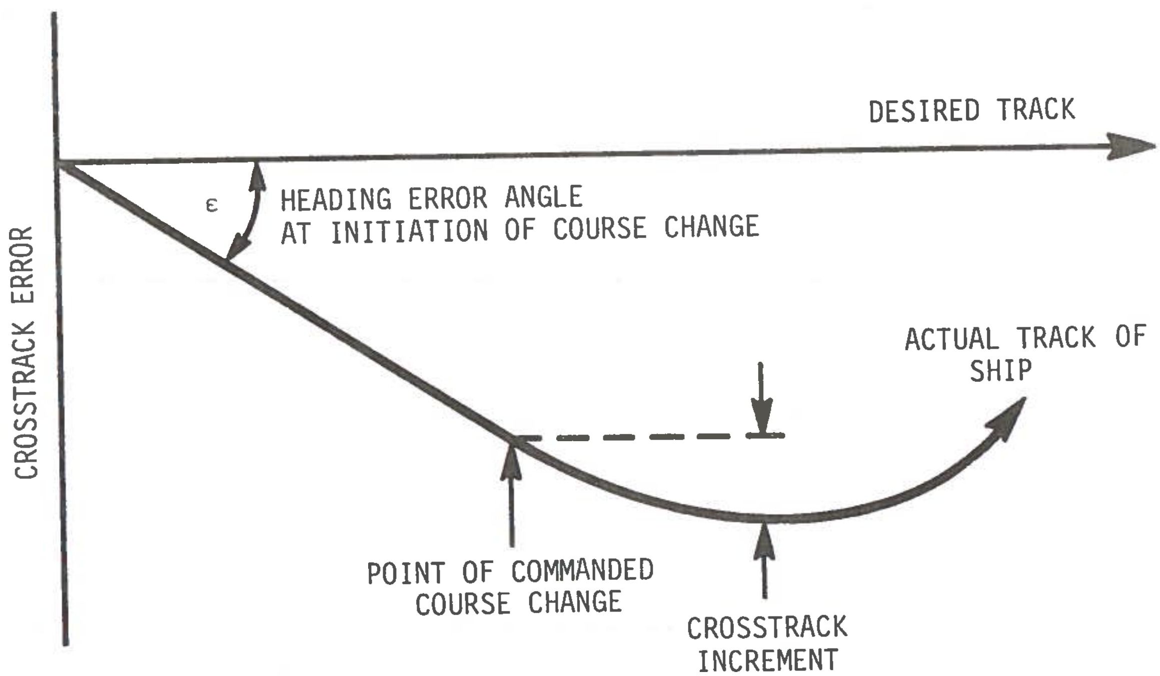


FIGURE 3-9. CROSSTRACK ERROR DUE TO COURSE STABILITY CHARACTERISTICS

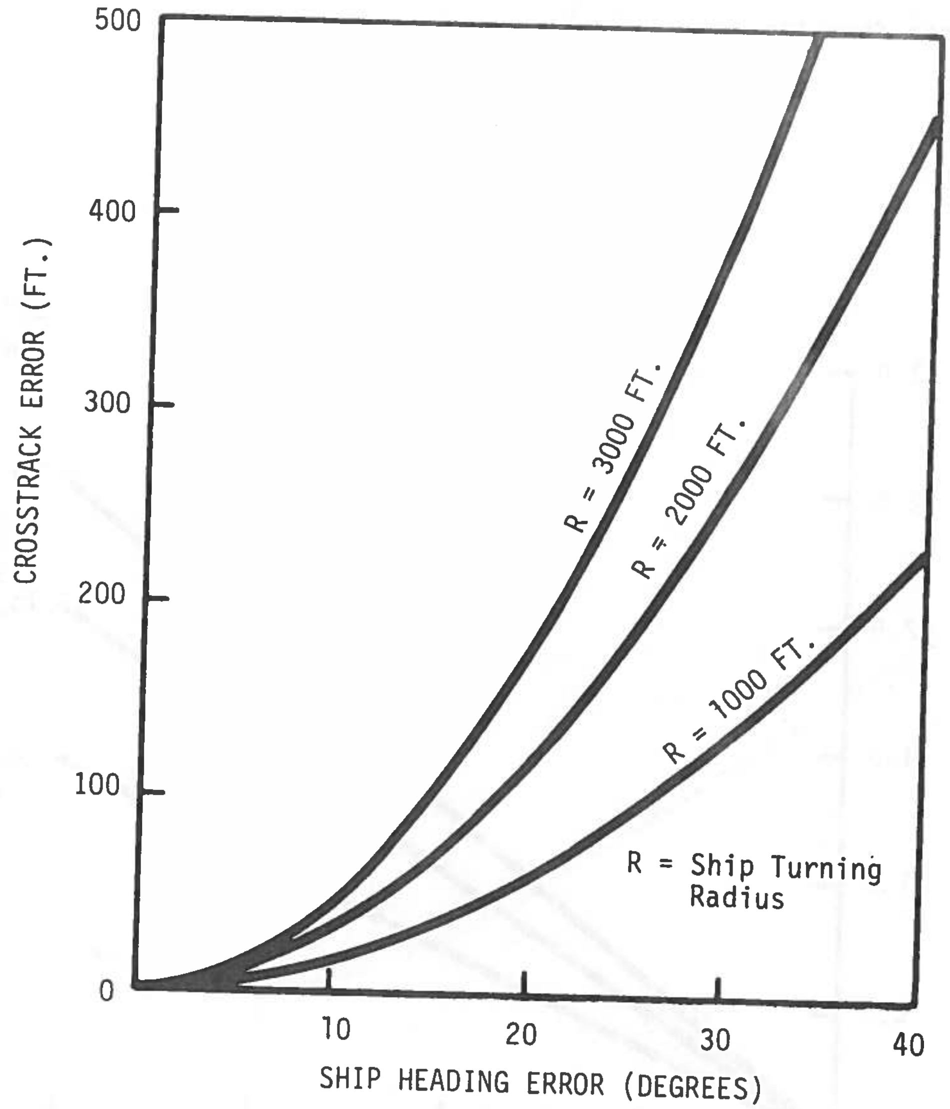


FIGURE 3-10. CROSSTRACK ERROR RESULTING FROM COURSE STABILITY

3. Course Trajectory Time (T)

The length of time that a ship dead reckons has an obvious influence on the amount of crosstrack error. This relationship is shown in Figure 3-11 for a range of ship speeds representative of those found in the Great Lakes area. The errors are determined from the previously stated error formula:

$$DR = (V^2 + dv^2)^{1/2} . \ T \ . \ \mathrm{Sin}\ \theta_t$$

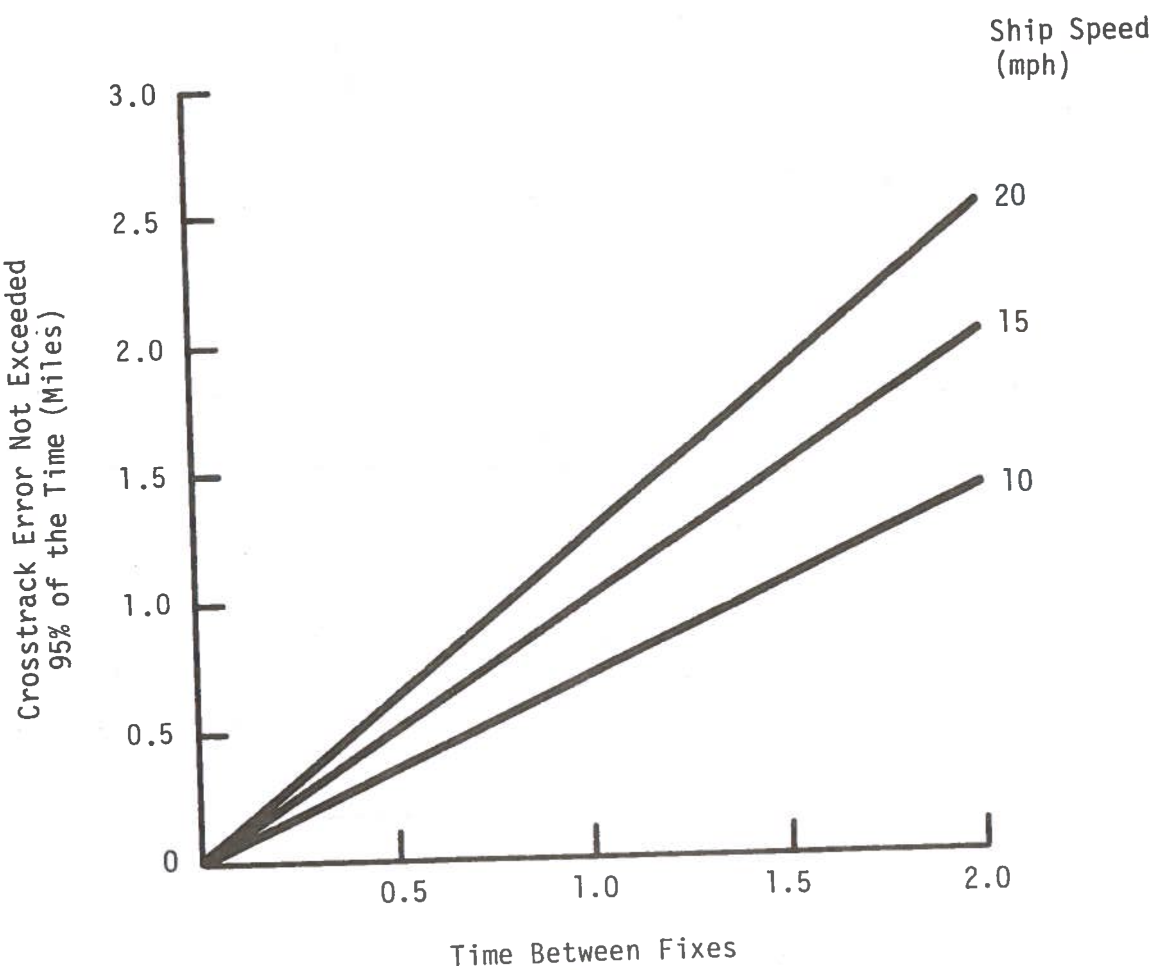


FIGURE 3-11. CROSSTRACK ERROR FOR TYPICAL SHIPS

Accuracy Requirement Computation

The desired position fixing accuracy requirements can now be calculated by using the equation fix = $[\text{track}^2 - CS^2 - TR^2]^{\frac{1}{2}}$ of Section 3.1.6.1. Figures 3-12, 3-13 (Ref. 16) and 3-14 present these resulting requirements for 10, 15 and 20 mph ships, respectively. As can be seen, the faster the ship, the more stringent the requirements are for the fixing aid accuracy. We will base our requirements on the needs of the 20 mph ship.

Referring to Figure 3-14, the position fixing requirement for a 20 mph ship, the criticality of limiting the dead reckoning time to a minimum can be seen, especially for the confluence lanes which have a track-keeping requirement of $\pm$ 0.3 miles (Ref. 16). Even if the ship had available a perfect fix aid (zero error), the ship could not dead reckon for more than 20 minutes between fixes without violating the 99 percent track containment criteria. For those ships that have an automatic position fixing system coupled into an autopilot course error computer (= zero dead reckoning time) or for a ship with a manual navigation system that dead reckons for no more than approximately 15 minutes, a position fixing accuracy of $\pm$ 0.25 miles 95 percent of the time would be sufficient.

For ships in the open waters of the Great Lakes area or in the five mile wide lane where the track-keeping requirements are $\pm$ 1.6 miles, the position fixing accuracy requirements are greatly relaxed. For the ship that continually follows the read out of the position fixing device (zero time), a fix accuracy of $\pm$ 1.6 miles 95 percent of the time will be sufficient. If the fix aid gave perfectly accurate fixes, the ship could go as long as one hour and 50 minutes between fixes. A reasonable compromise is to set the accuracy requirement for the fix aid at $\pm$ 1.2 miles. This will allow time between fixes up to an hour and a half in length.

The position fixing accuracy requirements associated with the boundaries of the existing prescribed courses are summarized in Figure 3-15. These fix accuracy demands are the 95 percent crosstrack requirements.

If we specify that the 2 d_{rms} repeatable accuracy of the hyperbolic fix aid should be at least equal to these requirements, then an additional degree of conservatism is introduced into the safety capabilities of the system because

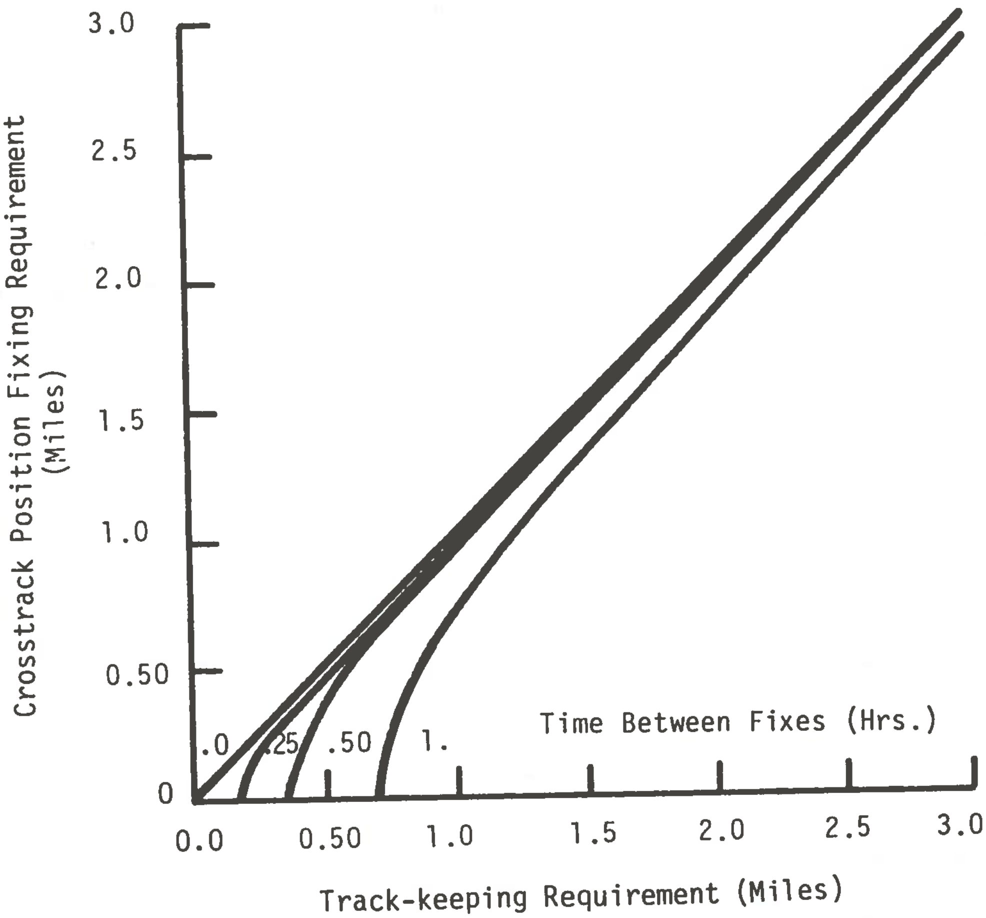


FIGURE 3-12. POSITION FIXING REQUIREMENTS FOR A 10-MPH VESSEL

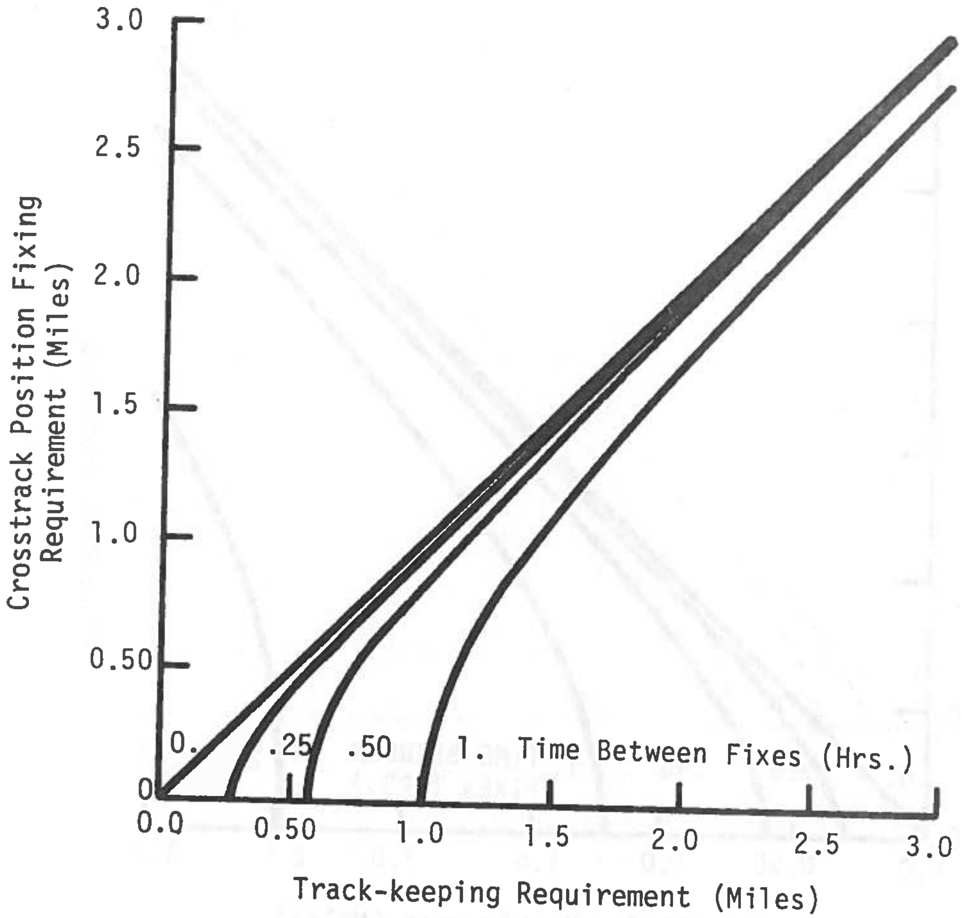


FIGURE 3-13. POSITION FIXING REQUIREMENTS FOR A 15-MPH VESSEL

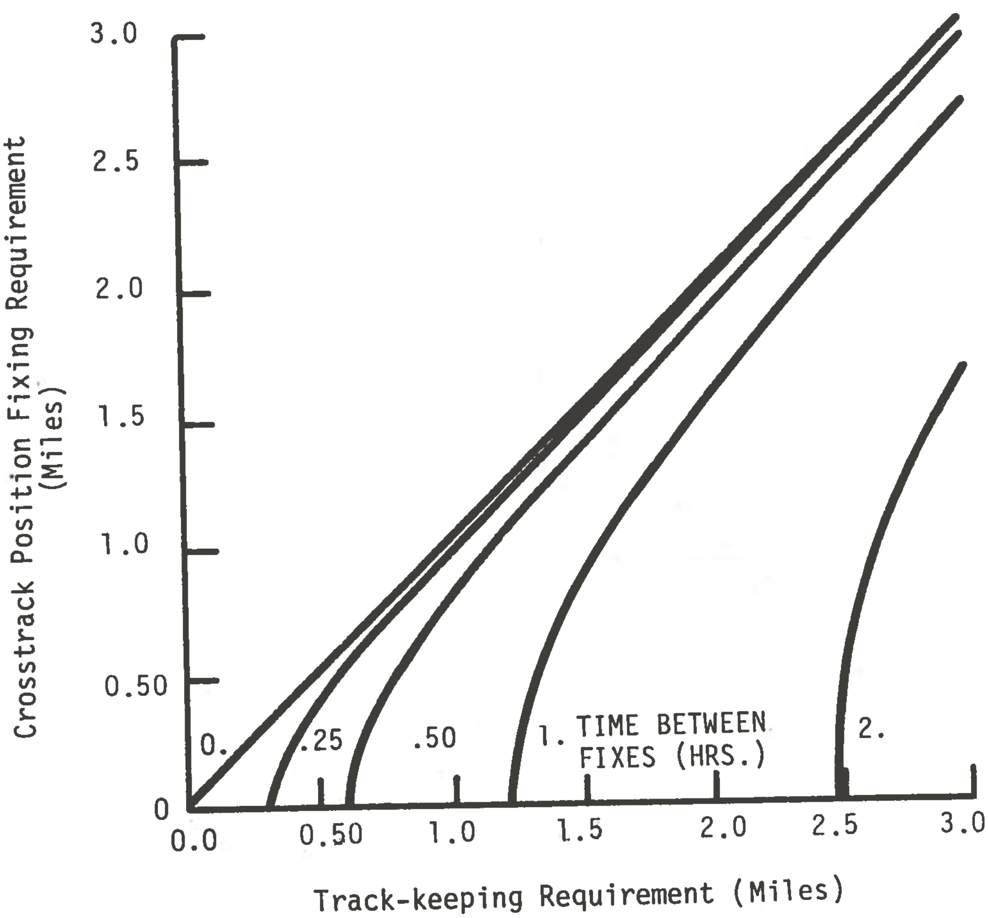


FIGURE 3-14. POSITION FIXING REQUIREMENTS FOR A 20-MPH VESSEL

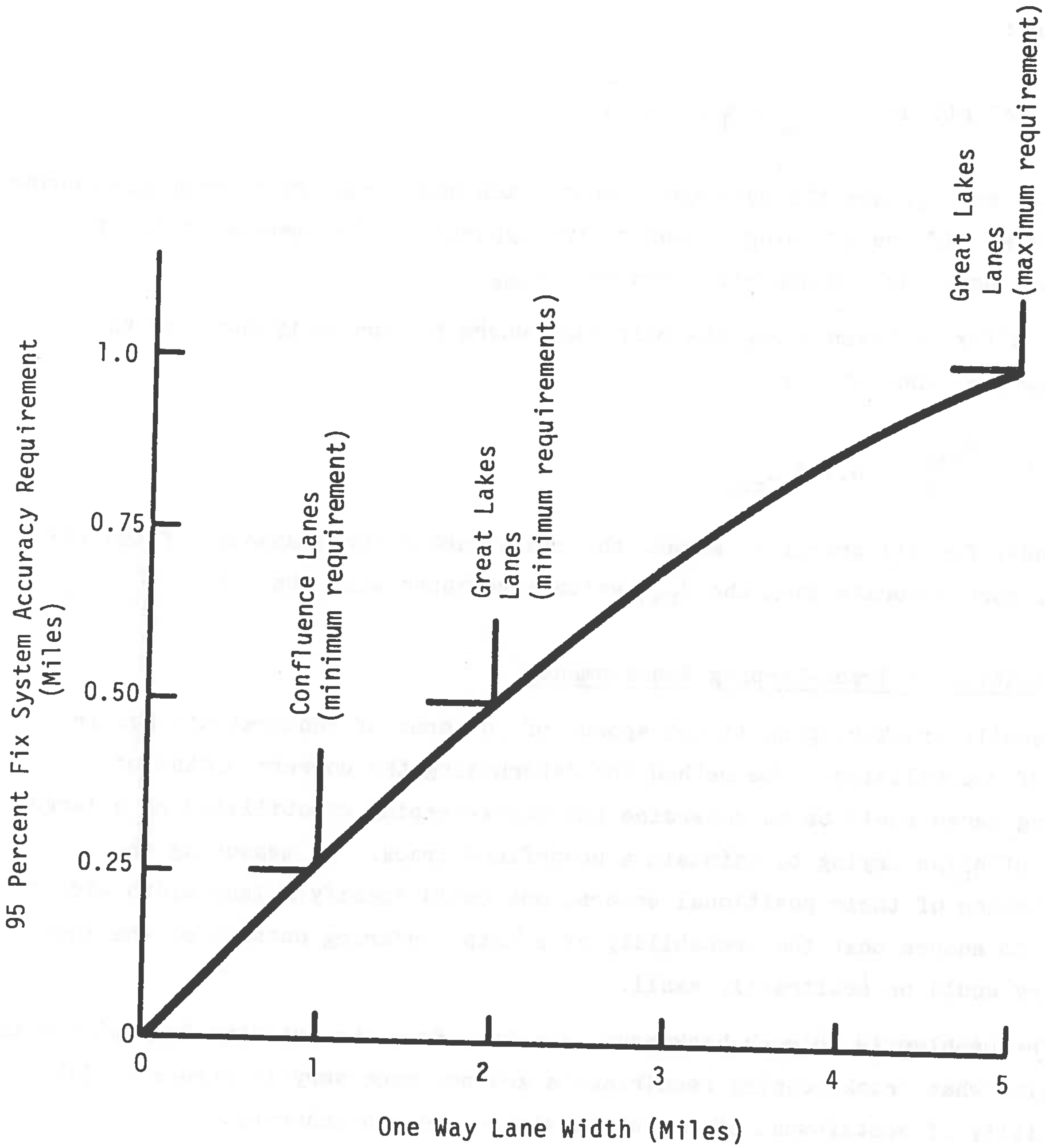


FIGURE 3-15. SUMMARY -- POSITION FIXING CROSSTRACK ACCURACY REQUIREMENTS

the crosstrack accuracy that a hyperbolic aid can supply for a given d_{rms} value is always more accurate than the d_{rms} value. This can be seen from the following:

by definition: $d_{rms} = \sqrt{xt^2 + at^2}$

where xt and at are the orthogonal crosstrack and along-track error components of the fix. If the crossing angles of the hyperbolic LOPs making up the fix were very bad, say = 0 degrees, then $xt = d_{rms}$.

If a fix is taken along the base line where the crossing angle of the LOPs = 90 degrees, then $xt = at_1$

and $= xt \quad \frac{d_{rms}}{1.414} = 0.707\ d_{rms}$

Thus, for all practical cases, the crosstrack error component of the fix will be more accurate than the d_{rms} value associated with the fix.

Determination of Track-Keeping Requirements

Usually track-keeping is not spoken of in terms of requirements but in terms of capabilities. One method for determining the correct widths of shipping lanes would be to determine the track-keeping capabilities of a large number of ships trying to maintain a predefined track. By measuring the distribution of their positional errors, one could specify a lane width wide enough to ensure that the probability of a ship wandering outside of the lane boundary would be arbitrarily small.

The problem is to work backwards, starting from the existing lane widths to determine what track-keeping requirements are now necessary to ensure a high probability of containment of the ships within these boundaries.

Since a high probability of containment is desired, one must analyze the "tails" of track-keeping error distributions for it is here that large errors can occur. Unfortunately, there is no information in existence on the shape of tails based on observational data, since a prohibitive amount of data would be needed to infer the detailed shapes of these rare occurrences.

To circumvent the problem, many separation studies done in the aviation field have fit Gaussian error distributions to the few track error measurements at hand to help infer the frequencies of occurrence of the rare errors in the tails of the distribution. As more observational data have been collected, however, it has become apparent that the frequency of occurrence of large navigational errors is much greater than one would predict using Gaussian distributions. Because of this some of the more recent analytic studies on traffic separation have assumed exponential error models for the behavior of systems. Exponential distributions are being used, not because they approximate the true shape of the distribution of rare occurrences (which is unknown), but because they predict the occurrence of rare events at a much higher frequency then Gaussian distributions. Thus, the exponential distribution yields more conservative safety predictions (approximately five times more conservative at the three-sigma point).

Track-keeping requirements necessary to support a given lane width are shown in Figure 3-16 with the probability curves based on the standard exponential error function. At this point, a judgement must be made as to what is an acceptable chance for going outside the traffic lane. Even if the calculations are carried one step further to the determination of the probability of occurrence of a collision with another ship or fixed object, a decision would still be necessary as to what is an acceptable chance of collision occurrence. Containment of a ship within its lane at least 99 percent of the time (1 in 100 chance of going outside its lane) has been established as a reasonable goal of the Coastal/Confluence Navigation System, and has been adopted here for the Great Lakes open water navigation requirements.

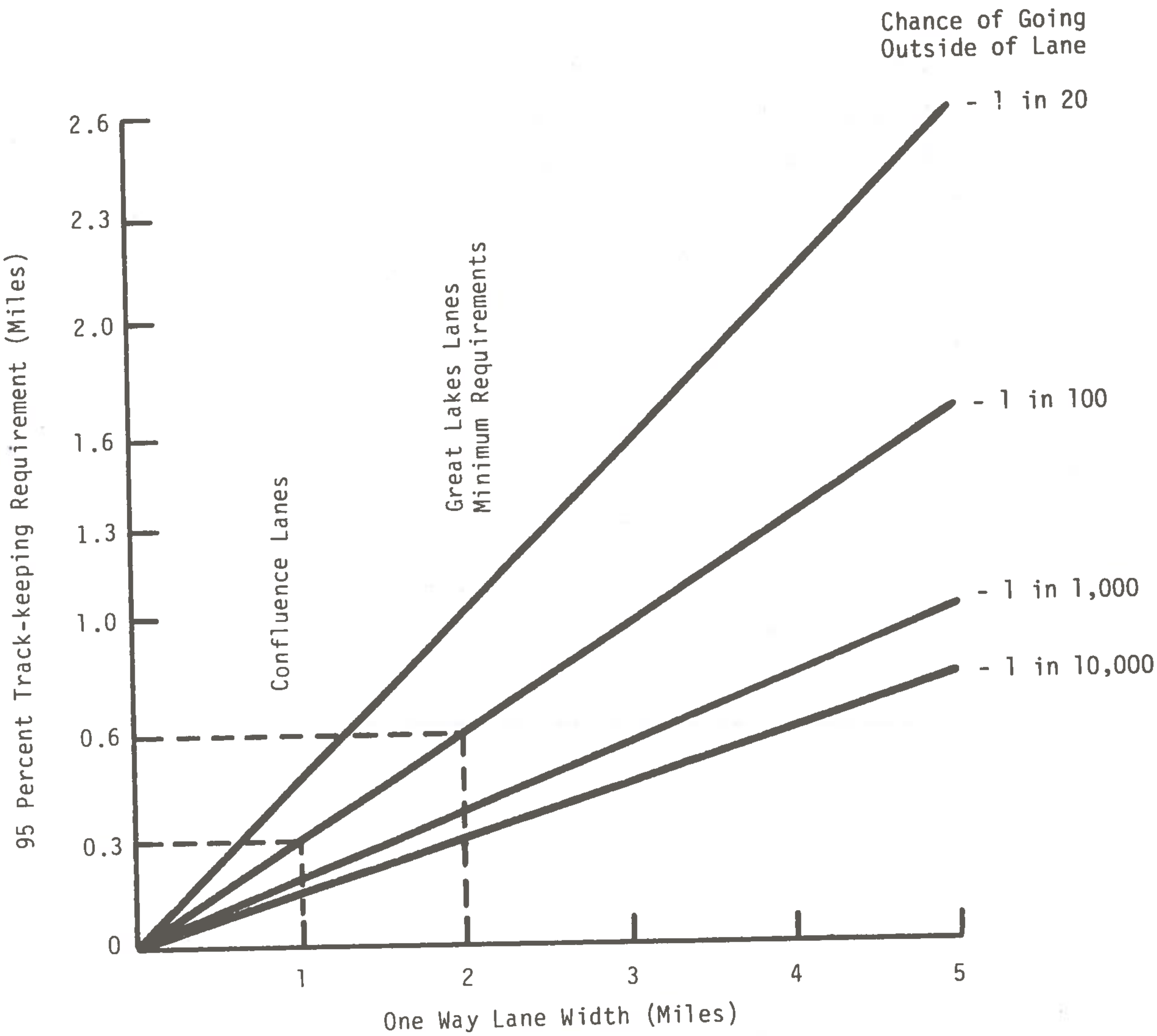


FIGURE 3-16. TRACK-KEEPING REQUIREMENTS TO STAY WITHIN A GIVEN LANE WIDTH

Using this criterion, the following track-keeping requirements for open water are obtained: When the lane width is 5280 feet, the accuracy requirement is ± 1584 feet; a lane width of 10,560 feet has an accuracy requirement of ± 3168 feet. Most open water lanes on the Great Lakes are five or six miles wide.

The deterioration in performance with channel width was not proportional to the increased space available, suggesting that wide channels are not a special piloting problem or, therefore, a special design problem.

3.1.6.2 Constricted Waterway Accuracy Requirements - Track-keeping is not spoken of in terms of requirements but in terms of capabilities. One method for determining accuracy requirements would be to determine the track-keeping capabilities of a large number of critical ships trying to maintain a predefined track. By measuring the distribution of their positional errors, one could specify a track width wide enough to ensure that the probability of a ship wandering outside of this lane boundary would be very small. Measurements of track-keeping, waypoint and tactical maneuvering track widths have not been made for constricted waterways.

Another technique used to determine capabilities is with a simulator. Although two of the more sophisticated simulators are at CAORF and Eclectech Associates Division of Ship Analytics, neither has been validated for restricted waterway conditions. Subsequent research has shown the two simulators are similiar, particularly for investigating relationships between aids to navigation and piloting performance. Nevertheless, there remains a requirement to compare the simulator with real-world conditions and thereby validate the data and the conclusions.

A third technique used to determine the track-keeping capabilities of ships transiting constricted waterways is through modeling. Modeling includes a range of techniques from captive modeling -- scale vessels -- to mathematical modeling. All modeling techniques require that data be validated by full scale trials.

At present there are no standard methodologies for quantifying accuracy requirements in restricted waterways. The consequence is that although individual aids to navigation can be described in terms of type and quality of navigational information provided in highly quantified terms, the ultimate question of whether they are good enough cannot be answered without a measurement program.

3.1.6.3 Piloting-Aid Requirements - A meaningful statement of the requirement for a piloting aid cannot be made without understanding the functional use of navigational aids by masters and pilots. Under conditions of good visibility existing visual system meets the requirements of masters and pilots. The interplay between several aids and their weighting as a function of the dynamic demands of the transit complicates the problem. For example, the navigational information provided by the navigation aids includes orientation, guidance accuracy, and rate information. The combination of aids and their attributes are in Table 3-6.

TABLE 3-6. NAVIGATION INFORMATION PROVIDED BY NAVIGATION AIDS

Visual Aid	Orientation	Guidance	Accuracy	Rate Info.
Buoys	Good	Excellent	30 to 50 feet	None
Ranges or Leading Marks	Excellent	Excellent	30 to 70 feet	Fair
Beacons	None	Good	1000 feet	None
RACONs	Excellent	Excellent	1000 feet	None
RACONs (Range)	Good	Excellent	50 to 100 feet	None
Reflectors (Radar)	Good	Good	50 feet	Fair

The dynamic information provided by vessel instrumentation includes heading and speed. The vessel's progress in altered by current and wind forces which are sensed by the pilot. Table 3-7 is derived from Section 3.1.6.1.

TABLE 3-7. SOURCE/ERROR INFORMATION

Source	Error
Compass	±2 degrees
Speed	±0.5 mph
Current	±0.29 mph
Wind	±6.0 mph

The information is derived continuously as the vessel transits the waterway.

An instrumental system that meets the piloting-aid requirements would give the pilot excellent orientation and guidance information within 30 to 50 feet of accuracy with fair rate information, and it would sense current and wind forces and present all this data in real time to the pilot on a display and in a form which can be readily assimilated. If the set of parameter values were presented in a quantified manner, the time period between values presented to the pilot, in combination with the errors associated with these values, is of critical importance. Along the St. Marys River, the typical transit time is eight to twelve hours from Whitefish Bay to DeTour Passage. This transit can be described as 25 to 28 straight line segments where each segment is the centerline of its respective channel. The average length of a channel is three miles and at a speed of 11.5 mph a waypoint maneuver is usually required every 18 minutes and in some reaches as often as every eleven minutes. A master on a superlaker will move a ship's length each minute traveling at 11.5 mph, or 16 feet per second. During a simulation experiment the number of rudder commands were recorded during a six segmented transit of six miles. The average number of rudder movements were 95 for the run. The rudder commands compensated for many factors such as waypoint maneuvers. The only factor which appears to have influenced the number of commands issued was the distance traversed. On the average the pilot gave a rudder command every 372 feet or once every 20 seconds. This suggests the pilot needs a ship position update every two seconds, which is feasible with today's 32-bit microprocessors.

3.1.6.4 Performance Measures - A variety of performance measures are used to evaluate scenario conditions. The principal measures are the ships center-of-gravity (the crosstrack position in a channel) and the closest point of approach to the other vessel in a meeting maneuver. The characterization of piloting-aids must include more than static bias estimates and sensor output standard deviation. Dynamic lag effects must be included. This means we must abandon such standard system performance measures as CEP or d_{rms} and be concerned with dynamic measurements of vessel bow and stern position relative to centerline, wind speed and direction at the vessel, rudder position and closest point of approach during the meeting maneuvers. With the measurements in hand a desired vessel trajectory can be developed and a closed loop error prediction model designed which explicitly accounts for vessel and sensor dynamics, as well as wind, current, and sensor noise disturbances. Results would be expressed in terms of mean-square error, or variances, as averaged for many operations of the vessel through track-keeping, waypoint or tactical maneuvers. These error distributions may be expressed in terms of probabilities of risk of collision or stranding. Such performance measurements can be used to develop the size and orientation of the vessel's footprint relative to the channel boundaries or to the meeting vessel.

3.1.7 Existing System

3.1.7.1 Navigation on the Great Lakes-St. Lawrence River System - Navigation on the system is primarily visual, i.e., pilots navigate by day and night using a system of fixed and floating aids or buoys. This system of visual aids provides for safe, efficient day/night navigation during periods of good visibility. At-sea experiments and theoretical studies have shown that track-keeping on the order of 15 to 30 feet is achievable with these visual systems under ideal conditions (little current or wind), however, reliance on visual aids limits system capacity. During periods of low visibility (fog, heavy rain, snow, etc.) significant delays of several hours can occur. Prudent pilots of these vessels will stop and seek safe anchorage when they cannot see the visual navigation aids, especially in narrow channels. In addition, there is a period of "aids-out" operation on the St. Lawrence Run (west of Montreal) in which only daytime navigation is permitted. For a period of 1 to 5 weeks at the beginning and at the end of each season, the floating aids in the system are not all available for use. Some aids must be removed at the end of each season and deployed at the beginning of the next season to avoid winter damage by ice.

In good visibility it is hazardous to assume that a floating aid is in the position it should be without checking the validity of that supposition by other means. When the pilot relies on such an aid to execute a waypoint maneuver on constricted waterways he is simply trusting to luck, which is a poor foundation for safe navigation. This is one of the most common faults in the practice of navigation, hence its prominent display on nautical charts and publications. This misguided practice is encouraged by the number of times there is apparent unqualified reliance by pilots on floating aids for course changes. In many of those cases the reliance is only apparent as the pilot has in fact used leading marks or ranges, or some other less obvious means of confirming the position of the buoy.

There are places where the position of floating aids cannot be readily checked by recourse to nearby fixed points. In such cases electronic systems like radar or LORAN-C are often available, and the elementary evidence of the echo sounder can be of great assistance. An equally fundamental and frequent practice is checking the ship's estimated position against that given by the floating aid. In many cases while there may not be nearby fixed points there may also be others further off that can be used to advantage. There may also be other floating aids within sight, and bearings and ranges of these may be used as further evidence in building up a navigational mosaic.

The guidance and accuracy provided by the visual navigation system should be sufficient during all but the most extreme environmental conditions (fog, heavy weather, etc.) during which the prudent navigator will not be underway or will have sought and found safe anchorage.

3.1.7.2 Piloting Scenarios - For purposes of analysis vessel pilotage will be separated into three modes: track-keeping, waypoint maneuvering, and tactical maneuvering. Track-keeping and waypoint maneuvering are the modes employed in the absence of vessel meeting, overtaking or avoidance situations. On straight segments extremely fine track-keeping may be maintained under visual conditions, if leading marks or ranges are available. Experiments at CAORF showed that when leading marks or ranges were used as references for any maneuver other than straight track-keeping navigation, performance degraded to poor or unsatisfactory. Just prior to waypoint arrival the experienced pilot judges from visual bearings when to order helm. Additional helm inputs are given as the turn continues. During this maneuver the goal is to simultaneously keep both the bow and stern of the vessel within a nominal track width. Performance is largely influenced by the pilot's familiarity with the dynamics of the vessel, the strength of current and wind disturbances, and the type of buoyage marking the turn.

In a tightly controlled traffic management system, most meeting vessel maneuvers can be anticipated well in advance, however, unexpected maneuvers may be required in emergency situations. At such times the pilot's judgement as to permissible course changes is vital.

3.1.7.3 Simulation Efforts - Simulation efforts have been carried out to study pilot and vessel response during various modes of pilotage. The influence of buoyage geometry and the effect of underkeel clearance on turning performance received attention during these simulation efforts. It was found, as clearances were decreased from 600 feet to one foot, that smaller clearances were helpful in reducing standard deviation on turns of under 35 degrees. The effect on larger turns was detrimental. This result was confirmed by measurements made in the St. Marys River. (Ref. 6)

3.1.7.4 At-Sea Piloting Performance - In the Fall of 1980 an effort was made to measure track-keeping and turning performance of ships passing through the Craighill Channel of the Chesapeake Bay. At this time a large number of vessels were continuously queued up waiting for coal loading in Baltimore, providing an excellent opportunity for in situation experimentation. The piloting conditions were similar to those reported in the simulation work. Channel width is approximately 600 feet on each leg, with a cutoff turn of 20 degrees. Buoyage is of the gated type with spacing of approximately 4/5 mile.

Data was taken on 21 ships, 14 of which were tracked by a properly calibrated Raydist high frequency position-fixing system. On 30 of the leg transits where were no incidents of traffic interference which could degrade track-keeping and turn performance. The ships were primarily coal carriers but other vessel types were included in the experiment. The aggregate track-keeping standard deviation for runs without vessel interference, including all weather and current conditions, was approximately 45 feet. This compares very favorably with the cited simulation results.

The data from the at-sea experiment were arranged into two wind speed groups below and above 12 mph. Prevailing from the northwest, the winds typically were on the port bow during leg 1 and on the bow in leg 2. On the more difficult leg 1 segment, track-keeping standard deviations were about the same for each wind classification indicating that, on a straight course with gated buoyage, pilots may easily adjust vessel helm to overcome wind disturbances. However, at the turn there was a very large difference between the two wind classification. In the under 12 mph group, standard deviation of 60 feet were obtained -- consistent with simulation results. In the over 12 mph group, standard deviations increased to 270 feet -- much larger than the simulated results. Among possible factors contributing to degraded pilotage may have been the variability of windage for different vessels, and the lack of vessel dynamics familiarity obtained on the brief passage from anchorage to the test range. The large difference between track-keeping and waypoint turning performance underscores the greater difficulty pilots have in estimating the vessel state and developing good control inputs on turns.

3.1.8 Navigation Needs

3.1.8.1 General - Efforts are now underway to develop near- and long-term improvements to the navigation, communications, and traffic information systems on the combined network of the Great Lakes-St. Lawrence River, known as the Fourth Seacost. In the near-term, the emphasis is on supporting a fixed-duration operating season with 24-hour service. In the longer term (greater than six years), new navigation, communications and traffic information systems must be developed to support safe operations under degraded weather conditions, and during periods when portions of the visual aids system are out of service. An important aspect of this upgrading effort will be the development of advanced electronic navigation and pilot-aiding devices capable of increasing the confidence of masters and pilots during normal visual operations, and which will permit safe operations during periods of poor visibility as well as during the early and late portions of the season when the visual aids system may experience planned or unplanned outages. The development and deployment of such a new capability will be challenging, both institutionally and technically.

While electronic navigational aids and systems have in large part supplanted and superseded more traditional and simpler means and techniques of navigation, these "old fashioned" methods, though of greatly diminished significance on the modern navigational scene, cannot be entirely ignored or dismissed. Many people perhaps feel that just as the sextant replaced the astrolabe and cross staff for the determination of latitude and longitude so radar, RACONs, LORAN-C, and satellite navigation have supplanted celestial navigation.

The radio direction finder, which in a way might be viewed as a precursor of today's electronic navigation systems, has understandably taken a back seat to its sophisticated cousins. It was never capable of any great degree of precision and its chief advantage of being available in all conditions of visibility is only one of the advantages offered by electronic systems. The U.S. Coast Guard is in the process of discontinuing high-powered, sequenced beacons and is returning to low-powered, non-sequence operations. Recreational boaters, the main users of radio beacons, will still have the continuous homing signal from the low powered beacons, although an increasing number of recreational boaters are also installing LORAN-C navigation.

To meet stringent channel navigation requirements, a combination of additional conventional aids (more ranges and fixed lights) and two or more additional systems such as radar, RACONs, electronic positioning systems, night vision enhancement devices and sonar positioning systems will be needed.

Radar will likely be one of the component systems, and an integrated display is highly desirable, if not required, for user acceptance.

As mentioned in Section 3.1.6.3, there are some unanswered questions regarding how good any navigation system must be to satisfy precision navigation requirements in restricted waterways. Navigation is only part of the problem a vessel encounters while negotiating restricted passages. Solutions may become evident after results of a measurement program are studied.

3.1.8.2 Aided Pilot Options - Viewed from an information flow standpoint, the role of an aided pilot system is to transform sensor-derived estimates of vessel dynamical state into cues most useful to the pilot. The pilot uses the display, together with local knowledge of wind and currents and vessel handling properties, to order helm commands. Since the display is but one component in the overall vessel control loop, the effectiveness of displays and the impact of sensor errors have been difficult to quantify.

A variety of pilot aiding display systems have been suggested for use in confined waterways, ranging from simple digital readouts to accurate renditions of the pilot view seen from the ship's bridge. Figures 3-17 through 3-20 show four options. These were computer generated and plotted on a medium resolution display, 700-by-700 picture elements. One quadrant of the display, 350-by-350 picture elements, is shown. Navigation features have been omitted.

The first of the displays, Figure 3-17, gives a vessel status block and a presentation of the present vessel location/orientation and course-made-good CMG vector. Such a display is commonly generated in the track-up format as own-vessel progresses up the display. The channel features are updated when the vessel approaches the edge of the display. Human factors simulations have shown the display to have merit over other non-predictive display formats. The vessel status block displays crosstrack error and turn rate with high numerical resolution. In the example shown the vessel is offset from centerline in the starboard direction by 60 feet, and has a turn rate to port of 5 degrees per minute. With modern sensors turn rate data can be displayed in real-time with great accuracy.

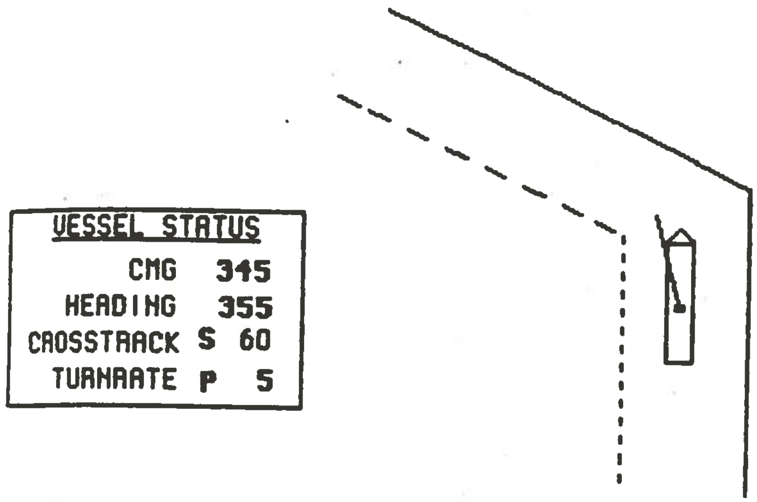


FIGURE 3-17. VESSEL SITUATION DISPLAY

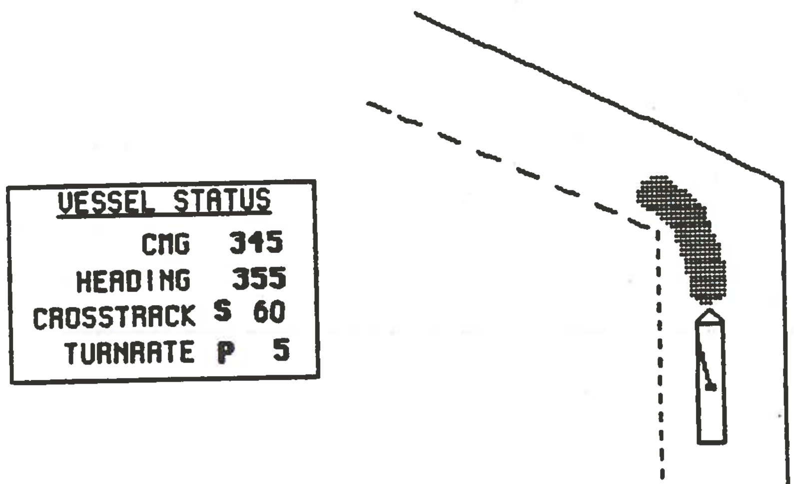


FIGURE 3-18. FOOTPRINT PREDICTION PRESENT HELM

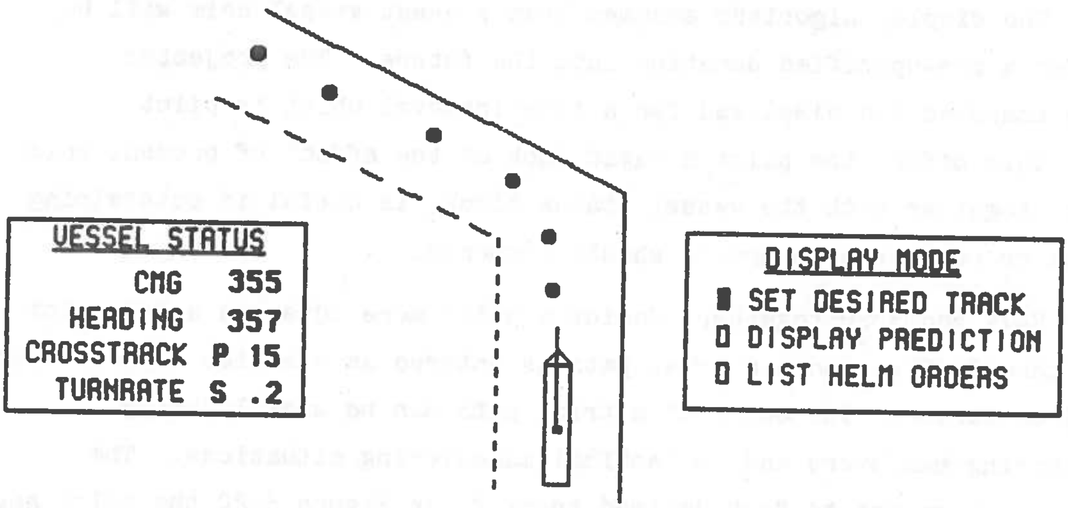


FIGURE 3-19. PILOT-ENTERED TRIAL PATH

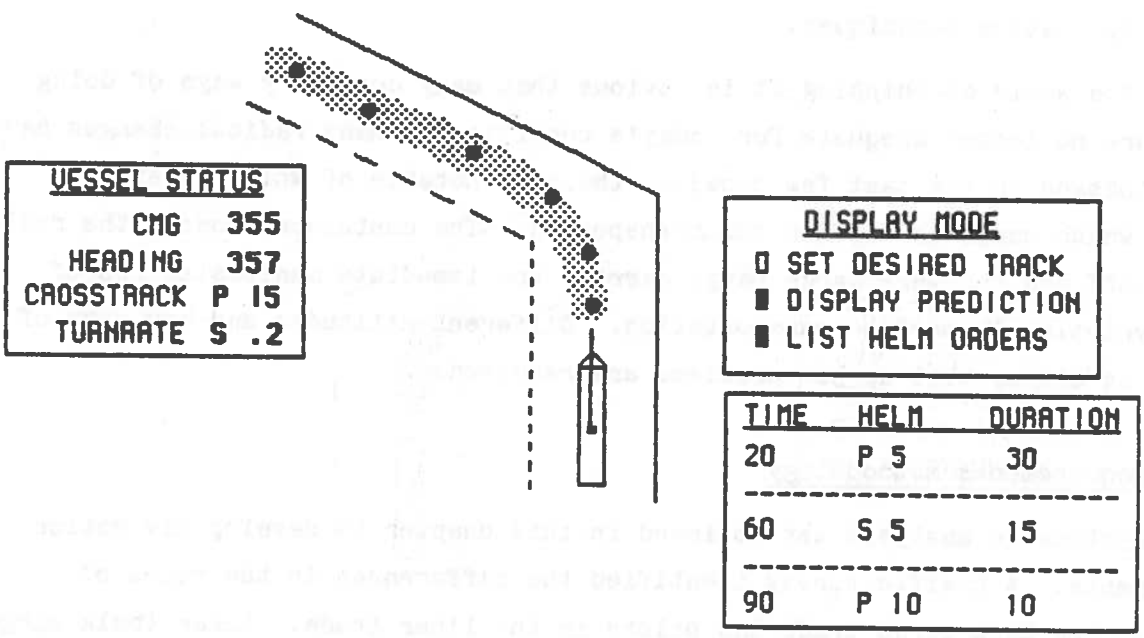


FIGURE 3-20. PREDICTED FOOTPRINT AND HELM ORDERS

Figure 3-18 introduces an additional pilot-aiding feature, footprint prediction. The display algorithm assumes that present vessel helm will be maintained for a pre-specified duration into the future. The projected footprint is computed and displayed for a time interval which is pilot adjustable. This offers the pilot a rapid look at the effect of present helm orders which, together with the vessel status block, is useful in determining when midships or reverse helm orders should commence.

Figures 3-19 and 3-20 together, depict a still more advanced aided-pilot mode. In Figure 3-19 is shown a trial path as entered as a series of dots using a track-ball or cursor. The entry of a trial path can be useful during preplanned turning maneuvers and in tactical maneuvering situations. The display mode has been set to "set desired track." In Figure 3-20 the pilot has switched mode, asking now for a rapid display of the predicted vessel footprint, based upon a sequence of computer-derived helm orders from a software control algorithm. The pilot also has the option of displaying the sequence of trial helm orders generated by the control algorithm. With 32-bit microprocessors this approach appears to be economically feasible. The potential performance benefit of such a concept can be found by a combination of analytical and human factors simulation techniques.

In the world of shipping it is obvious that many customary ways of doing things are no longer adequate for today's conditions. Many radical changes have been witnessed in the past few decades, the most notable of which relate to ways in which cargo is handled and transported. The container vessel, the roll-on/roll-off and the very large cargo carrier are immediate manifestations of that revolution in marine transportation. Different attitudes and new ways of looking at old as well as new problems are required.

3.1.9 Requirements Methodology

A systematic analysis was followed in this chapter to develop navigation requirements. A traffic survey identified the differences in the roles of pilots in the bulk cargo trade and pilots in the liner trade. Laker (bulk cargo vessel) masters as well as other officers are licensed pilots. By experience they have gained a strong feel for their vessel's maneuverability in all situations. Their routes are established and pilots have identified key navigation aids for critical maneuvering. In addition, masters communicate rudder commands with alacrity to the helmsman. Salty pilots, on the other hand, must quickly determine the maneuverability of their strange, recently boarded vessel, the operational characteristics of the radars, the lines-of-sight to navigation aids, and their ability to communicate swiftly with the helmsman and the master to whom English is usually a second language.

Commodity flow patterns were reviewed to identify traffic densities in confluence areas and constricted waterways. Critical vessel types were identified; if the navigational problems can be solved for a critical vessel, all other vessels can readily adopt the same solution. Critical vessels are the most difficult vessels to maneuver in the Great Lakes system. The most numerous vessel is the recreational boat; more are registered in the Ninth USCG District than anywhere else in the U.S. A recreational boat is not a critical vessel.

A nominal track width was determined for the critical vessel in three types of maneuvering: track-keeping, waypoint and tactical maneuvering. Several sources of data were examined, i.e., simulation and modeling. Traffic patterns for the critical vessels were traced through the waterway.

The waterways of the Great Lakes system were analyzed to catagorize the reaches by length, depth, width, bearing, wind, and current forces. The system was divided into three areas to make the analysis tractable: the Great Lakes, St. Lawrence River, and connecting waterways. Maps of the reaches are included in Appendix F. The next step in the analysis was to determine the complicating effects of environmental factors on navigation. Winds, currents, banks, and shallow water effects, visibility and the ice environment were all considered as contributing elements in the maneuverability study.

Casualty assessment had been studied in 1979 and this data was used to examine, through collisions and stranding occurrences, areas which demanded unusual navigation skills for safe and efficient passage. Many of these areas had been examined by riding teams, from the bridge of vessels. Other areas, such as harbor entrances, were examined from the deck of a tug as it towed a vessel to the dock or from a breakwater where in one case a vessel was turned around and backed into the river, assisted by tugs. Harbor entrance navigation, and river navigation such as the Calumet, Cuyahoga and Maumee were not included in the study. These areas with assistance from tugs and those with specific local anomalies are also excluded. A combination of the critical vessels' routes and the waterway survey identified the critical maneuvering scenario. Simulation study results were analyzed for application to the maneuvering scenario.

The requirements for navigating on the Lakes and in the constricted waterways were determined and compared with the existing system of navigation.

In Appendix B a plan is described which will provide the necessary data base for a model of ship track-keeping capabilities in the presence of perturbing forces.

3.1.9.1 Required Measurements - There is no measured data on the capability of the critical vessels to maneuver in the critical waterway. The measured data is needed not only for this program but to support all narrow channel navigation. It is also required to validate simulation data and modeling data. Technical instrumentation to measure vessel performance is available. Modeling techniques to use the data have been developed. (See Appendix B.) The product of the measurement program will be a software driven system which can be used to evaluate the ability of a combination of sensors to aid a pilot with navigation functions.

3.1.9.2 Sensor Performance Specification Methods - Sensor errors can be classified as noise errors, dynamical errors, and bias errors. To understand more clearly these error sources consider Figure 3-21, a unified model for the sensors in the overall vessel control system. Implicit in the model are integrated heading and radionavigation sensors.

Noise errors are those fluctuating errors observed at the sensor output in the absence of any sensor motion. For example, in radionavigation systems such as GPS or LORAN-C, a fundamental sensor function is the measurement of the received signal time delay between transmitters. Receiver specifications often list delay jitter standard deviation at the tracking loop output, for a specified level of receiver input signal-to-noise ratio. It is often assumed that these noise errors are completely random, or uncorrelated. Upon closer

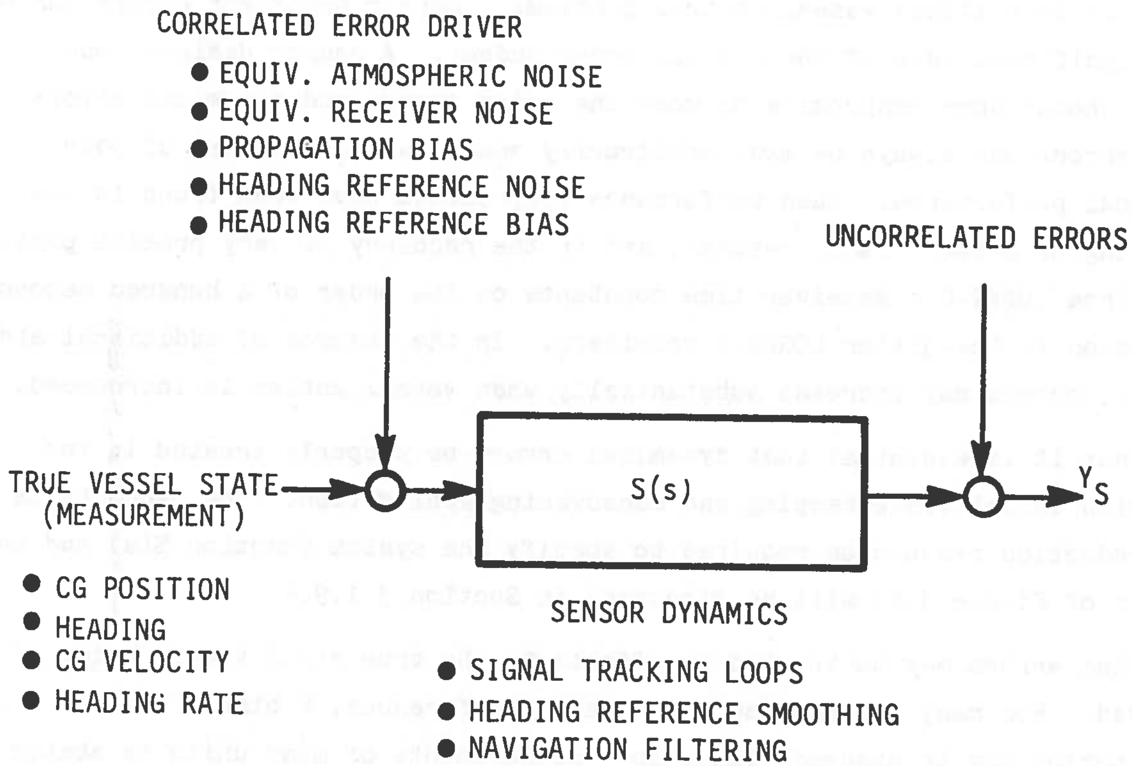


FIGURE 3-21. SENSOR SPECIFICATION MODEL

examination, such jitter errors are found to be correlated in time. The temporal correlation properties of the jitter sequence is determined by tracking loop filter properties. Noise errors are usefully modeled in terms of a tracking loop filter S(s) forced with a noise source, or driver. An additional noise source, at the sensor dynamics output, models sensors which may have wide-band analog output amplifiers, such as analog speed-logs, accelerometers and the like.

In the marine industry, sensor dynamical errors have received little attention in critical vessel control problems. Sensor transient errors can be a very significant part of the overall error budget. A sensor designer must always choose some compromise between the noise errors and dynamical errors. Noise errors can always be made arbitrarily small, at the expense of poor dynamical performance. Such performance compromises have been found in the smoothing of primary radar returns, and in the recovery of very precise position fixes from LORAN-C. Receiver time constants on the order of a hundred seconds are common in low-jitter LORAN-C receivers. In the absence of additional aiding sensors, errors may increase substantially when vessel motion is introduced.

Thus it is essential that dynamical errors be properly treated in the precision vessel track-keeping and maneuvering application. The bench tests and data reduction techniques required to specify the system function S(s) and noise sources of Figure 3-21 will be discussed in Section 3.1.9.4.

Bias errors may be treated as offsets to the true state vector being observed. For many sensors, such as heading references, a bias error distribution may be assumed, based upon measurements of many units in static conditions. Since such bias terms are slowly varying compared with the quantity being observed they will pass through the sensor function S(s), resulting in a readily computed offset of the vessel states being controlled.

Because of their slowly changing nature it is sometimes possible to track the bias errors themselves with a suitable calibration sensor and control loop. This approach is especially appropriate for differential GPS, wherein the calibration station is used to track purposely-introduced denial-of-accuracy time jitter terms.

3.1.9.3 GPS and LORAN-C Track-Keeping Examples - The usefulness of the above sensor model for predicting overall vessel control performance will now be illustrated with two well-known systems, differential GPS and differential LORAN-C. Starting with the LQG methodology discussed in Appendix B, software was developed for predicting aided-pilot performance. As a preliminary exercise of the software, a very simple track-keeping scenario is explored below. This lends important insight into the relationship between sensor model parameters and vessel dynamics and disturbance parameters. At the conclusion of the test program, this same software will be used to investigate more thoroughly various combinations of navigation-aid and heading sensors, as applied to control of a full vessel state model.

In this preliminary study only sway motion is considered. Neglected are yaw and turn-rate. The relationship between sway and rudder input, P(s), was approximated with a first order system function. The bandwidth was adjusted to a typical value for a large laker, .05 radians/second. Disturbances were then applied to model the effects of wind and current. Three random disturbance levels were applied to the vessel model, resulting in open-loop vessel cross-track standard deviations of 150, 45, and 15 feet.

Since the vessel control was restricted to one dimension, a single crosstrack sensor was employed for measuring crosstrack displacement. The sensor dynamical model of Figure 3-21 was employed, with sensor dynamics S(s) modeled as first order. The sensor error driver was adjusted in all cases to maintain a constant sensor output variance of 15 feet, typical of the values quoted for high performance LORAN-C equipments designed for precision vessel control purposes.

Using this model an optimum LQG controller was derived for a range of sensor/vessel bandwidths. The achieved crosstrack error performance was found to depend strongly upon the sensor/vessel bandwidth ratio. Poor control was obtained when the sensor bandwidth was narrower than the vessel bandwidth. To underscore this effect the resulting error data was reduced in terms of the sensor/vessel bandwidth ratio. The results are shown in Figure 3-22.

At very small sensor/vessel bandwidth ratios the controller is essentially operating without the benefit of a sensor, and the errors are the open-loop values of 150, 45 and 15 feet. For a unit value of bandwidth ratio the errors

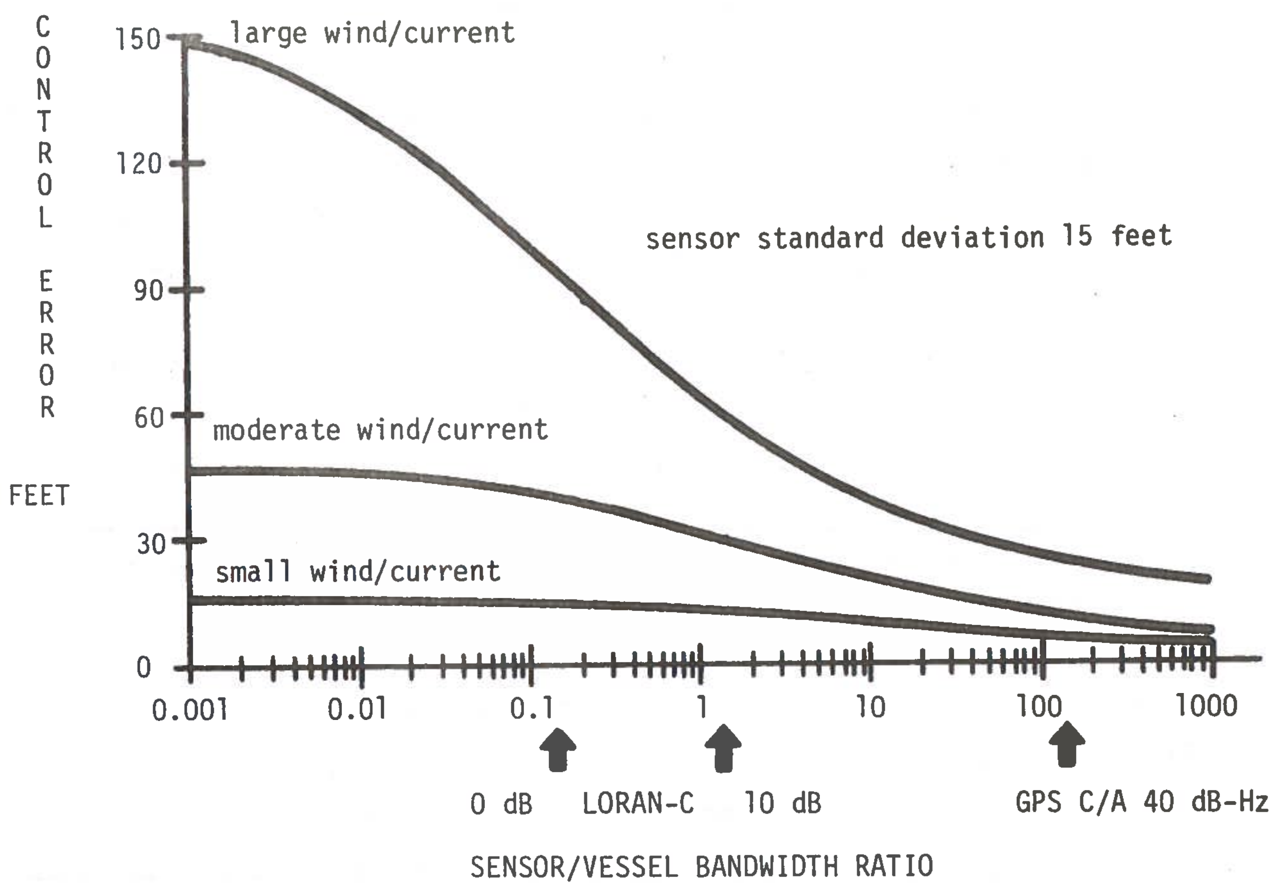


FIGURE 3-22. VESSEL CONTROL ERROR VERSUS SENSOR QUALITY

decrease to 63, 30 and 13 feet, respectively, with the biggest improvement occurring for the large wind/current disturbance scenario. The steepest reduction in error occurs in the three decades between .1 and 100.

Using the above results, the performance for ideal differential LORAN-C and GPS were investigated. Demodulator tracking loops were adjusted so that the 15-foot sensor performance could be obtained at the available signal strength. For a 20 KHz SNR of +0 dB, a typical LORAN-C receiver operates with a bandwidth of .007 radians/second. At +10 dB SNR the receiver loop bandwidth may be widened to .07 radians/second. For a coherent delay-loop GPS tracking loop operating at a carrier-to-noise ratio of 40 dB-Hz, the bandwidth is considerably broader, approximately 6 radians/second. As is seen in Figure 3-22, this wider bandwidth permits considerably better vessel control performance.

LORAN-C falls betwen 14 and 1.4 on the sensor/vessel bandwidth axis of Figure 3-22. GPS C/A reception at 40 dB-Hz SNR achieves a bandwidth ratio of 125. For the large wind/current example, the vessel control performances for the different sensors fall between 100 and 27 feet. Even though both LORAN-C and GPS receivers have been designed to have identical jitter (15 feet in the above example), the much wider bandwidth of GPS affords better control of the vessel. This conclusion holds true regardless of the type of display employed in the aided-pilot system. At the conclusion of the test program, the same analysis and modeling approach will be employed for the complete vessel and multi-sensor model.

3.1.9.4 A New Approach to Sensor Specification - The above analysis underscores the need for a new approach to sensor specification. Specification of accuracy based solely upon static error measures are misleading. It is proposed that a test procedure be documented for bench testing and evaluating radionavigation sensors. It appears that this procedure can be conveniently carried out using standard navigation test signal generators. Treating the sensor as a "black box", identification techniques similar to those successfully employed for estimating vessel dynamical parameters can be used to establish sensor noise and dynamics parameters.

3.2 COMMUNICATIONS REQUIREMENTS

3.2.1 General Requirements

The navigation, communications and traffic information management project requires a sophisticated, wide area communications network which can provide both data and voice capability over the entire Great Lakes and St. Lawrence River, and connecting waterways. The communications system should be able to provide the capacity to phase in various capabilities, as well as allow for future growth requirements. The communications network should also be transparent to the user. Therefore, computer controlled automation of most functions would be required.

3.2.2 Topological Requirements

The Great Lakes-St.Lawrence River has several communication needs that affect the topological design. Data related to navigation, vessel traffic management, weather, dynamic water depth, etc. need to be transmitted and received by ships moving anywhere on the waterway system. In order to provide this coverage, several transmitter/receiver sites would be required for each of the Great Lakes and for the St. Lawrence River. These transmitter/receiver sites will provide communications capabilities for the open waterways, while several additional transmitters will be needed to provide communications capabilities for connecting waterways such as rivers, canals, locks, and ports. The open waterway transmitter/receiver sites require both the capability to produce periodic updating of data (to and from the ships) and the capability for continuous updating. The switch between periodic and continuous updating would be determined automatically by the software logic. Connecting waterways and their approaches require continuous updating of both shore and ship information. In all updating situations, open water and connecting waterways, the need for accurate, timely, and complete data is critical for safe and efficient transits.

To meet these requirements, local control sites are needed. The control sites should be located at the connecting waterways and at large ports. Each control site would provide communications capabilities for the connecting waterway, as well as adjacent open waterways via several substations located along the shore. Each substation would be positioned to provide total coverage of the local waterway system.

At the present time the USCG operates 28 VHF-FM transmitter/receiver sites along the shores of the Great Lakes. This system, as shown in Table 3-8, can provide total communications coverage of the U.S. controlled waterway. Co-location of control and substation transmitter/receiver sites on U.S. government owned property provides the most efficient and effective implementation of the proposed communications system. If VHF-FM frequency is used for ship-to-shore and shore-to-ship communications, and if total Great Lakes coverage is necessary, then some transmitter/receiver sites would also be required on Canadian soil.

In multiple control site topology, handoff procedures between control sites is critical in order to enhance safety and efficiency. All communications handoffs between control sites needs to take place in open waterways while control of connecting waterways should always be provided by a single control site. Based on this requirement and the location of USCG VHF-FM sites (see Figure 3-23), the following control and substation sites are recommended. Site surveys will need to be conducted and proposed antenna configurations will need to be investigated to validate the best topology. It should also be noted that a memorandum of agreement between MARAD and the USCG is required before this configuration could be implemented.

If total coverage is necessary and sites are installed on Canadian soil, they will be added to the appropriate control site.

Each control site should be connected point-to-point with each of its substations. The control sites should be connected to each other via multi-drop circuits. This configuration will provide several capabilities. Using point-to-point circuits between the control site and its substations will reduce the impact on the system in case of a failure. In the event of an equipment failure at a substation or a circuit failure between the control site and a substation, only that part of the system will fail while the remaining substations will continue to function.

TABLE 3-8. USCG GREAT LAKES TRANSMITTER SITES

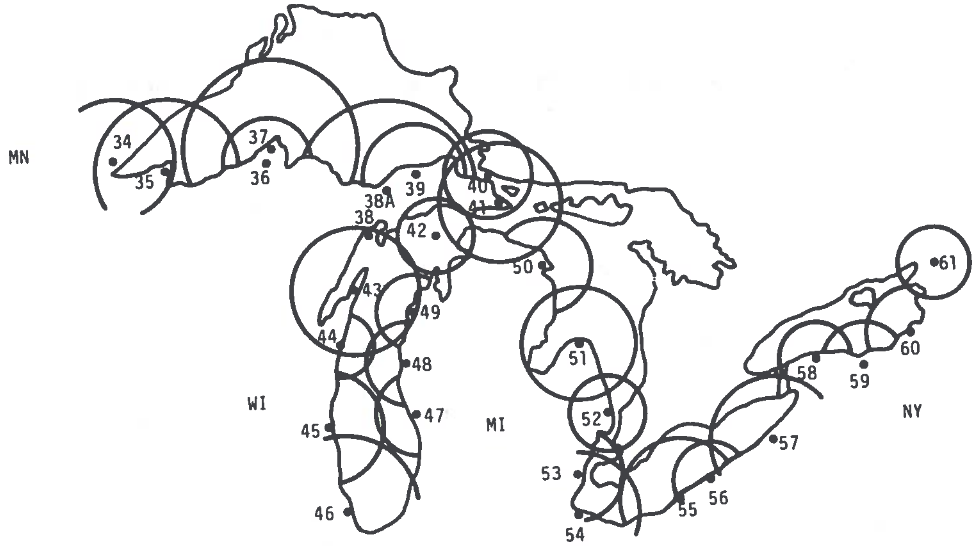
STATION TYPE	LOCATION	USCG NUMBER
1. Control	Alexandria Bay, NY	61
Sub	Oswego, NY	60
Sub	Rochester, NY	59
2. Control	30 Mile Point, NY	58
Sub	Forestville, NY	57
Sub	Ashtabula, OH	56
Sub	Cleveland, OH	55
3. Control	Detroit, MI	53
Sub	Toledo, OH	54
Sub	Port Huron, MI	52
Sub	Port Austin AFS, MI	51
4. Control	Sault Ste Marie, MI	40
Sub	Alpena, MI	50
Sub	Goetzville, MI	41
Sub	Beaver Island, MI	42
Sub	Grand Marian, MI	39
5. Control	Duluth, MN	34
Sub	Bayfield, MN	35
Sub	Mancoch, MN	36
Sub	Calumet AFS, MN	37
Sub	Munsing, MN	38A

TABLE 3-8. USCG GREAT LAKES TRANSMITTER SITES (CONTINUED)

STATION TYPE	LOCATION	USCG NUMBER
6. Control	Chicago, IL	46
Sub	Milwaukee, WI	45
Sub	West Olive, MI	47
Sub	Ludington, MI	48
Sub	Two Rivers, WI	44
Sub	Sturgeon Bay, WI	43
Sub	Frankfort, MI	49

All control sites should be connected by a multi-drop circuit so that data regarding the total waterway system can be shared. This will provide each control site with the capability to have access to the entire data bank related to adjacent control sectors; or any sector which may be of interest. A multi-drop circuit is specified for this capability because it is more economical and a failure in the circuit would not seriously affect safety and effectiveness considerations. In the event of a multi-drop circuit failure, the control sites would still be able to provide local communication services for their region of coverage. The control sites, however, would not be able to provide systemwide information until the problem with the multi-drop circuit was repaired.

An additional requirement of the multi-drop circuit is to provide a backup control capability. In the event of a control site failure, a total section of the waterway system would be without communications capability. In this instance, limited control capability needs to be automatically transfered to another control site. This limited control should be able to provide adequate data for safe transit of the restricted waterways which are affected by the failure.



	SITE	LAT/LONG	CONTROL POINT	ELEV
34	DULUTH, MN	46.46N 92.05W	GROUP DULUTH	806
35.	BAYFIELD, WI	46.49N 95.50W	GROUP DULUTH (Remote site) Alternate control Bayfield	710
36.	HANCOCK, MI	47.11N 88.35W	GROUP DULUTH (Remote site) Alternate control Portage Station	625
37.	CALUMET AFS, MI	47.22N 88.10W	GROUP DULUTH (Remote Site) Alternate control of Portage Station	1010
38.	ESCANABA, MI		Group Milwaukee (control) Alternate Station Sturgeon Bay	
38A.	MUNSING, MN	46.25N 86.59W	GROUP SAULT STE. MARIE (Remote site) Alternate control Marquette Station	
39.	GRAND MARIAS, MI	46.35N 86.59W	GROUP SAULT STE MARIE (Remote site)** Alternate control Grand Marias Station	750
40.	SAULT STE. MARIE, MI	46.30N 84.20W	GROUP SAULT STE. MARIE Alternate control COTP Sault Ste. Marie	305
41.	GOETZVILLE, MI	46.03N 84.05W	GROUP SAULT STE. MARIE (Remote site) Alternate control St. Ignace Station	1121
42.	BEAVER ISLAND, MI	45.34N 85.34W	CHARLEVOIX STATION (Remote site)	310
43.	STURGEON BAY, WI	44.54N 87.22W	GROUP MILWAUKEE (Remote site) Alternate control Sturgeon Bay	776
44.	TWO RIVERS, WI	44.08N 87.33W	GROUP MILWAUKEE (Remote site) Alternate control Two Rivers	95
45.	MILWAUKEE, WI	43.06N 87.53W	GROUP MILWAUKEE (Remote site)	550
46.	CHICAGO, IL	41.53N 87.37W	GROUP MILWAUKEE (Remote site) Alternate control Calumet Harbor Station	537
47.	WEST OLIVE, MI	42.54N 86.12W	GROUP MUSKEGON (Remote site) Alternate control Muskegon Station	393
48.	LUDINGTON, MI	44.01N 86.30W	GROUP MUSKEGON (Remote site) Alternate control Ludington Station	350
49.	FRANKFORT, MI	44.38N 86.14W	GROUP MUSKEGON (Remote Site) Alternate control Frankfort Station	290
50.	ALPENA, MI	44.51N 83.25W	GROUP DETROIT (Remote site) Alternate control Texas Station	521
51.	PORT AUSTIN AFS, MI	44.01N 83.00W	SAGINAW RIVER STATION Alternate control Port Huron Station	260
52.	PORT HURON, MI	43.00N 82.25W	GROUP DETROIT (Remote site)** Alternate control Port Huron	175
53.	DETROIT, MI	42.21N 83.00W	GROUP DETROIT (Remote site)** Alternate control Belle Isle Station	550
54.	TOLEDO, OH	41.40N 83.22W	MARBLEHEAD STATION Alternate control Toledo Station	570
55.	CLEVELAND, OH	41.30N 81.41W	CLEVELAND HARBOR STATION Alternative control COMMCEN Cleveland	600
56.	ASHTABULA, OH	41.54N 80.47W	ASHTABULA STATION	150
57.	FORESTVILLE, NY	42.28N 79.14W	GROUP BUFFALO (Remote site)	930
58.	30 MILE POINT, NY	43.23N 78.29W	GROUP BUFFALO	210
59.	ROCHESTER, NY	43.16N 77.38W	GROUP BUFFALO (Remote site) Alternate control Rochester Station	190
60.	OSWEGO, NY	43.27N 76.31W	GROUP BUFFALO (Remote site) Alternate control Oswego Station	543
61	ALEXANDRIA BAY, NY	44.19N 75.59W	ALEXANDRIA BAY STATION	225

FIGURE 3-23. USCG NATIONAL VHF-FM DISTRESS SYSTEM, 9TH DISTRICT

3.2.3 Ship-to-Shore Requirements

The ship-to-shore communications consist of four major categories:

1. Navigation data - periodic to continuous polling
2. General data - periodic polling
3. Official advisories - voice as required - random
4. Telephone service - voice or data as requested - random

The telephone service is not an official requirement of the communication system. Therefore, it will not be covered in any detail in this report. If telephone service capability can be provided without significant increase in cost, in a manner which will not degrade the official functioning of the system or impinge on the existing commercial system, then it should be considered for future implementation. Official communications consist of the following:

Navigation Data

* Vessel ID
* Position
* ETA at locks
* Vessel velocity
* Heading

General Data

* General status: draft, cargo, destination, pilot status, length, beam
* Operational traffic: agent/owner, pilots, requests for information

Official Advisories

* Voice channel as required, however, it should not interfere or degrade the data communications in any way.

Ship-to-shore message length requirements are:

Navigation Data

* Vessel ID	4 characters
* Position	8 characters (longitude)
	1 character (delimiter)
	8 characters (latitude)
* ETA to locks	7 characters (time)
	3 characters (lock ID)
* Vessel velocity	4 characters
* Heading	3 characters

In order to meet the navigation update requirements this data should be available every 20 seconds in open waterways and every 1 second in restricted waterways or in hazardous situations.

General Data

* Draft	4 characters
* Cargo	3 characters
* Destination	3 characters
* Pilot Status	3 characters
* Agent/Owner	3 characters
* Pilots	10 characters
* Vessel size	
Length	4 characters
Beam	3 characters

General data may be sent at low polling rates (e.g., every 15 minutes)

Offical Advisories

* Analog channel - random spacing, real time

3.2.4. Shore-to-Ship Requirements

The shore-to-ship communication consists of four major categories:

1. Navigation data - periodic to continuous
2. General data - periodic
3. Official Advisories - voice as required
4. Telephone Service - voice or data as requested

As with the ship-to-shore requirements, telephone service is not a priority.

The official communications consist of the following:

Navigation Data

* Information transmitted to a ship's navigation display system which provides visual display of the locations, directions, and maneuvers of all other ships in the area.

General Data

* Scheduling information
* Navigation system status
* Weather messages, NOAA service
* Agent/owner traffic (dock and port assignments), personnel traffic, company business

Official Advisories

* Voice channel as required, however, it should not interfere or degrade the data communications in any way.

Shore-to-ship message length requirements are:

* Position	17 characters per ship
* Heading	3 characters per ship
* Velocity	4 characters per ship
* Vessel ID	4 characters per ship

* Vessel Size

  Length 4 characters per ship

  beam 3 characters per ship

This data needs to be transmitted to all ships in close proximity to each other.

General Data

* Scheduling information, weather messages, dynamic water depth, wave height, agency/owner traffic
  - these may be several hundred characters long and need only be sent at very low update rates (e.g. every 15 minutes).

General Advisory

* Analog channel-random spacing, real time

3.2.5 Communications Systems Evaluation

In order to determine the capacity and configuration of any communications system, several factors should be considered. In general these factors include accuracy, completeness, and timeliness. In the case of the proposed Great Lakes-St. Lawrence River Navigation/Communication Program, this translates into developing a system which can provide complete navigation data, general information, and official advisories as accurately as possible within the required time to all ships transiting the waterway system.

In section 3.1.6.3 Piloting-Aid Requirements, the required time (vessel display update) was established as one second in restricted waterways and during hazardous situations on open waterways. If in a meeting maneuver the pilots need the same update rate for the approaching vessel as they have for their own position, then the communications polling and update rate needs to be one second. This would be true for all ships regardless of the number of ships involved. In fact the larger the number of ships involved, the more critical the timeliness of the update cycle. In order to design a communications system which can meet these requirements, several evaluation steps need to be completed.

The first step in configuring the communications system is to list all of the requirements. These requirements are:

Navigation Data

* Open waterways - Update data should be transmitted every 20 seconds (the average time between rudder movements)
* Restricted waterways - Update should be transmitted at 1 second intervals

General Data

* All waterways - Update can be transmitted every 15 minutes, however, the update should not interfere with nor slow down the navigation updating procedure.

Official Advisories

* Voice channel as required. However, it should not interfere or degrade the data communications in any way.

The second step is to determine the message length and timing requirements of a total update cycle for the most critical component of the system. In this case the most time critical component is the navigation requirement, which will be used for the analysis. Any system which is incapable of meeting the navigation requirements will be rejected from further analysis.

An update cycle consists of the following functions:

1. The control site polls a ship
2. The ship sends its navigation data
3. The control site stores and analyzes the data
4. The control site broadcasts the data to all ships in the area
5. The ships receive the data and update their navigation display devices

Each of these functions require time to execute. The amount of time required depends on the number of characters, speed of transmission, and processing time. Based on the message lengths listed before, a message length calculation can be derived. Using the vessel ID as the polling address (4 characters), ship-to-shore navigation data (38 characters), and shore-to-ship navigation data (35 characters) a total message length of 77 characters is derived. Assuming an ASCII standard of 10 bits/character, the total bit requirement for each navigation update per ship would be 770 bits. To estimate the maximum polling frequency, several additional assumptions need to be made:

1. The 220 ships which are estimated to be transiting the waterway system are evenly distributed across all six control regions (37 ships in each).
2. All ships within a control region will be polled sequentially.
3. The transmit and receive speed will be the same for both ship-to-shore and shore-to-ship communications.
4. All ship-to-shore transmissions will be on the same frequency.
5. All shore-to-ship transmissions will be on the same frequency but will be different from the ship-to-shore frequency.

Assuming a transmit/receive speed of 1200 BPS, it will take 23.74 seconds to complete the navigation update cycle. This system cannot meet the open waterway requirements of 20 seconds and is therefore rejected from further consideration.

Assuming a transmit/receive speed of 2400 BPS, it would take 11.87 seconds to complete the cycle. This will meet the navigation requirements for open waterways but does not fulfill the restricted waterway needs. If 4800 BPS is used, it will take 5.94 seconds which still does not meet the restricted waterways requirement of a 1 second update cycle. Even if 9600 BPS is used, it will take at least 2.97 seconds to complete the cycle. Given the present state-of-the-art, sequential polling of all the ships in a control region cannot meet the navigation requirements let alone the rest of the communication needs.

If the assumption is changed that all ships in a control region would be polled sequentially, then another possible solution is available for analysis. If the point-to-point (substation to control station) circuits are wired as individual inputs to the computer, then all substations could be polled concurrently. This would reduce the effective number of ships in each coverage area, and thus reduce the cycle time. Given the proposed 28 separate coverage areas and 220 ships transiting the waterway, the average number of ships in any single coverage area would be eight. These would be polled sequentially by each of the sub/control sites. The data from each of the sub/control sites would be entered into the computer concurrently. The information would then be stored and sent back to the appropriate sites for transmission out to the ships in their respective areas.

Using a 1200 BPS transmission speed it would require 5.13 seconds to complete an update cycle. If a 2400 BPS is utilized it would take 2.57 seconds which still does not meet the restricted waterway requirements. A 4800 BPS system would still not meet the requirements because it would take 1.28 seconds to update the navigation displays aboard the ships. The use of a 9600 BPS system will meet the navigation requirements because it only requires .64 seconds to complete the update cycle. However, this system does not provide enough time to offer the other data and information services required.

In addition, several other problems related to this system are evident. One major concern is related to the overlapping coverage areas between the shore sites. The problem is caused by the use of the same transmit (ship-to-shore) frequency for all ships and the use of the same transmit frequency (different from the ship-to-shore frequency) by all shore sites. Data from a ship located in an overlap area may be polled by two sites, the data entered into the computer twice, and transmitted back over two transmission locations. This could lead to redundant or confusing information presented on the onboard displays. Another problem could be that the signals in the overlapping areas may be out of phase and cancel each other. This would result in dead spots in the coverage and no communication would be possible in those locations during periods of phase shift.

Several other large scale communications systems were evaluated in terms of the requirements and rejected. They are stated below along with the reason for exclusion.

1. Cellular Radio - limited coverage area and cost - (does not meet completeness requirement)

2. HF - probable interference problems and reliability of signal range - (does not meet accuracy requirement)

3. Satellite - cost of user equipment (this is changing rapidly) and the delay in transmission/reception of the signals (2/5 of a second delay for each transmission for a total update delay of 1-1/5 seconds) (does not meet time requirement)

None of these large scale communications systems or the single frequency system described before can meet the Great Lakes-St. Lawrence River communications requirements. Therefore, the next evaluation will focus on multiple frequency communication systems. This violates assumptions 4 and 5.

One multiple frequency system has been implemented, the automated Waterway Communication System (WATERCOM). Designed to provide communication service for the Mississippi, Ohio, and Illinois Rivers, it links the Gulf of Mexico with the Great Lakes. The WATERCOM system utilizes the SELCALL message format which provides multiple sources of compatible U.S. and international equipment. The receiver/transmitter operates in the VHF frequency range (216 MHz to 220 MHz). These frequencies have been approved by the FCC for mobile maritime communications for the inland waterways. Approval to use these frequencies for the Great Lakes-St. Lawrence River would need to be gained through the FCC.

The frequency range (216 MHz to 220 MHz) is divided into 120 channels spaced 12.5 KHz apart. The communication channels operate in full duplex mode. The channel frequencies are divided into groups. Each group is assigned to a shore station. The assignment of frequency groups is configured such that there will be no overlap of like frequencies thus avoiding the problems of the single frequency system stated before.

The advantage of the WATERCOM system is its large communications (voice and data) capability. Given the 120 channel capability alone, it has twice the communications power of the present marine radio system. Add the capability of reusing the frequency groups along the total length of the Great Lakes-St. Lawrence River, and it has tremendous capacity for growth. Regardless of the present requirements, this system provides room for growth in terms of the number of ships, increases in information requirements, faster polling rates, and/or more precise navigational display requirements.

Example - Fully Developed System

The 120 channels are divided into four groups, each having 30 full duplex channels. Each of the 28 transmitter/receiver sites would be assigned a group of channels which do not touch or overlap any coverage area using the same channels. Each transmitter/receiver site would have 30 full duplex channels to communicate with the ships in its coverage area. Considering the estimate of 220 ships transiting the waterway at any given time spread evenly across the 28 transmitter/receiver sites, the average ship density in any coverage area would be 8. Assuming automated handoff and frequency allocation the following example of channel usage is derived (Table 3-9).

TABLE 3-9. CHANNEL USE FOR EACH SITE WITH EIGHT SHIPS AND FULL UTILIZATION OF SYSTEM CAPABILITIES

FUNCTION	MODE	STATUS	TOTAL CHANNELS USED
Log on and Initialization	Manual	Periodic-shared	1
Navigation Data	Automatic	Continuous-assigned	8
General Data	Automatic	Periodic-assigned	8
Official Advisories (voice)	Manual	Random-assigned	8
Telephone	Manual-charge	Random-shared	5
TOTAL			30

The example given above represents a fully developed and dynamic system. As the number of ships decrease in a specific area, more telephone channels would be available. If the number of ships increased beyond eight, the telephone channels would automatically switch to the navigation mode. If the number of ships increased beyond the five telephone channels, the general data channels would automatically change to one channel, sequentially polling the ships for their general data. The remaining seven channels would switch to the navigation data mode. These additional navigation channels would automatically provide continuous polling of the additional ship or ships.

To initially implement a fully developed system as described above would have a serious budgetary impact on anyone considering installing it. The major advantage of this approach is its capability to be phased in slowly and expand as the need develops. In general, this system provides a cost-effective communication network which can be implemented quickly, meets the stated requirements, and which uses proven and tested technology.

3.3 TRAFFIC INFORMATION MANAGEMENT SYSTEM REQUIREMENTS

3.3.1 General Requirements

An integrated traffic information management system is desirable if the Great Lakes-St. Lawrence River system capacity increases. This is particularly true of some lock areas, which are the normal constraints to capacity. Decreases in ship maneuvering time, increases in ship speed and the use of computer control centers for the locks would help reduce lock delays. The computer center would optimize lock use and determine ship speeds, lock arrival times and locking priorities. For each of the above improvements, it is estimated that the following reductions in lock time would be realized:

- Decrease in Ship Maneuvering Time - 0.4% decrease in lock time at the Welland Canal, 0-1% at the Soo, 0-2% at the St. Lawrence River.
- Increase Ship Speed Entering Lock - 0-5% at the Soo and St. Lawrence River, 0-10% at the Welland Canal.
- Traffic Control Improvements - 1-8% at the Soo and St. Lawrence River, 1-5% at the Welland Canal.

In order to reduce pilot and traffic controller workload an automated position reporting system is envisioned. Shore-based information centers would be located at the connecting channels (St. Marys River, St. Clair/Detroit Rivers, Welland Canal, St. Lawrence River, see Section 3.2.2) and should augment the existing rudimentary traffic control facilities.

The following are general system requirements:

- o All traffic information shall be available to the monitors on suitable displays.
- o The displays shall be capable of showing the same information as the shipboard displays, i.e., ship position, velocity, channel outline.
- o The displays should allow selection of one reach, two or more reaches, or an entire area.
- o The system must have a capacity for 220 vessels.
- o All traffic information shall be recorded on tape for later playback to allow reconstruction of events.
- o The system must provide direct communications between the information center and any pilot for the purpose of providing assistance in terms of traffic advisories.
- o The system shall incorporate sensors which can provide early warning of the onset of low visibility, water depths, wave heights, winds and currents.

A system capacity of 220 vessels at any given time was arrived at in the following manner:*

1. Welland Canal can manage approximately 30 vessels per day maximum.
2. St. Lawrence River (Eisenhower Lock) can manage approximately 40 vessels per day maximum.
3. Soo Locks can manage approximately 40 vessels per day maximum.
4. Daily traffic on each of the lock systems are independent of each other.

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*These estimates were based on COE traffic forecasts. Recent communication with the Lake Carriers Association indicated the numbers are high by 20 percent.

5. It is assumed that 45 lakers are on open water either entering and leaving confluence areas.

6. The assumption is made that 35 salt water vessels are sailing on the lakes, or are entering or leaving the confluence area.

7. Therefore, the number of vessels which must be tracked are 30 + (40 x 2) + 45 + 35 = 190. Adding a 15 percent margin of error yields approximately 220 vessels.

The following sections list the data items necessary for ship/shore communications.

3.3.2 Data from Ship

The vessel addresses its identification, position, ETA at locks, velocity and heading. In addition, the vessel reports its general status (draft, cargo, destination, pilot status) and operational traffic (agent/owner, pilots, requests for information). Note that under the Seaway Nightcast System ships can be identified that have room for additional cargo.

The information centers should contain information pertaining to the whole Great Lakes-St. Lawrence River system. It would need displays similar to shipboard displays and other equipment necessary to monitor and assist the whole network. Several scenarios for the system are possible, with cost probably being the controlling factor.

There presently exists a great deal of marine information which is broadcast via radio to system users. The idea is to integrate all information sources into one network where they can be used most efficiently.

3.3.3 Data from Shore

Data items from shore should contain information for ship navigation display (other vessels' positions, meeting maneuvers), scheduling information (lock passage and dock), navigation system status messages (capacity situation), agent/owner traffic (dock and port assignments), personal traffic, and company business (confidential).

In the case of water depth information, the data acquisition must be upgraded at a data rate sufficient to allow vessels to load to depth. Given existing short term water level fluctuations (see Table 3-1) hourly reports should be sufficient. To compensate for the journey time between port and lock a forecasting model would need development.

The weather service broadcasts should be integrated into the traffic information management system. The Lake Carriers' Association suggestions for an improved weather service (National Weather Service Great Lakes Forecasting Center which focuses on marine weather problems) should be adopted and integrated into the traffic information management system.

3.3.4 Message Length Requirements

Navigation system information should be separated from scheduling and weather information since the former must be sent at the highest rates while the latter is much less time critical. The number of time critical characters (navigation information) is small and can be easily handled by a multiple frequency communications system for the number of vessels in the water network system (see Section 3.2).

3.4 DISPLAY EQUIPMENT REQUIREMENTS

3.4.1 Carry-On Equipment Constraints

To insure quality control, all shipboard equipment will be "carry on" equipment which can be installed as each vessel enters the St. Lawrence River-Great Lakes System. An exception to this would be superlakers, which are landlocked and never leave the system and lake vessels that don't go into the Atlantic Ocean. For these ships, a permanent system could be installed. Under the general assumption of carry-on equipment, however, the following shipboard equipment requirements must be met:

- All carry-on equipment must be portable; no item should weigh more than 25 lbs.
- Use of multiprocessor computer system would enhance system reliability.
- Costs should be kept low enough to insure the equipment's acceptance by shipowners and operators.

3.4.2 Shipboard Display Requirements

The items listed below are required for a shipboard display. The requirements would be validated by field testing in the Great Lakes-St. Lawrence River system. Acceptance by pilots is critical. The items are listed below and a rationale for these items follows:

- Ship outline - own ship and other traffic
- Extended ship centerline - own ship and other traffic (collision avoidance feature)
- Crosstrack, along track position - reported to nearest foot
- Ship course and heading - reported to nearest degree
- Bearing - to nearest degree
- Waypoint display
- Bearing to waypoint - to nearest degree
- Estimated time to waypoint - minutes and seconds
- Ship speed - to 0.1 knots
- Rate of turn
- Update rate - 1 to 2 seconds
- Shoreline, aids to navigation, physical features displayed
- Color display

The display should be a moving map type, "track up" display, i.e., own ship to be always located at the bottom of the display screen.

The display system should be 1024 x 1024 picture elements and have separate horizontal and vertical scales ranging from 0.6 miles to 150 miles. This provides for high resolution in narrow reaches on one end of the scale and a snapshot of vessel traffic for entire connecting waterways (e.g., St. Marys River) on the other end.

Simulator studies have shown that a display system incorporating "track up" presentation, extended ships centerline, navigation features (channel boundaries, buoys, physical features and landmarks), and other vessels, is the best in terms of pilot performance. Color displays add a safety dimension and allow for features to be easily identified. Displays with data box with deleted information, as shown in Section 3.1.8.2, were demonstrated to increase confidence in the analog presentation.

4. SUMMARY AND CONCLUSIONS

A MARAD/TSC team studied navigation and communications problems on the Great Lakes and St. Lawrence River between June 1983 and May 1986. It identified shortcomings and defined technologies which would improve the efficiency and increase the capacity of marine transportation from and into the Fourth Seacoast ports through this inland waterway system.

4.1 SUMMARY

In the first phase of the program a detailed analysis was conducted of the existing maritime transportation systems on the Great Lakes and St. Lawrence River. Three major shortcomings in these systems were identified: dependence on visual aids as the sole means for navigation, congestion in the communications channels, and lack of key environmental measurements to maximize economic benefits. Improvements in the visual aids to navigation would reduce stress and anxiety for the pilots and masters but would neither improve efficiency nor increase capacity. A supplemental navigation aid system is required to permit vessels to move safely in reduced visibility situations and when lighted floating aids are removed from the waterway. Position location is only part of the solution. A pilot must know the location of meeting vessels as well as distance to a waypoint maneuver. Communications systems needed to pass information between vessels are already congested. Hence with additional communications capability, vessels can be given information on water depths, wave heights, weather forecasts, and existing traffic flow problems. In turn, vessels can give lock managers their estimated time of arrival, present position, velocity, and other data pertaining to cargo.

Requirements must be defined from an overall system point of view. Implementation of new systems will take place when and if the economic benefits to the user community can justify the cost of the system. The major considerations are a supplemental (to the visual aid) navigation system, an increased communications capacity, a traffic information management system, and displays that present information to pilots, masters and shore-based traffic advisors.

Primary sources of information for the requirements statement include reports from the vessel riding teams, user interviews, research into previous studies, examinations of technical documentation on the results of simulation experiments, modeling studies and measurement programs. Riding teams examined the navigation events from the bridges of salties and lakers. Pilots and masters identified critical maneuvers and demonstrated how they used visual cues to negotiate passage. The teams also listened to the communications channel and witnessed the congestion in areas with a large number of recreational boaters. Identified during the interviews were the needs of users for accurate and timely information on environmental conditions and estimated economic benefits through systems improvements.

A review of published literature revealed the need for a navigation performance measurement program in constricted waterways. The major portion of available documentation is made up of results from simulated experiments. These documents identify a critical need for validation of these results by empirical measurements. Modeling studies make up the second largest source of information but these studies also indicate the need for field validation. Measurement programs of vessel performance at sea and in confluence areas have been conducted and reported in these documents.

4.2 CONCLUSIONS

4.2.1 Navigation

The analysis performed resulted in the division of the study into a traffic survey, a waterway description, an environmental factor identification, and an assessment of critical areas and maneuvers. Based on this background, navigation requirements were developed and compared with the existing system in order to identify existing deficiences and needs. Subsequently, a procedure for filling these needs was recommended.

The traffic survey reviewed the differences in the bulk cargo trade and the liner trade, and focused the analytical process on laker and salty vessels. This geographical area also includes the largest registration of recreational boaters in the U.S. as well as other types of marine vessels.

Waterway traffic has two peaks when the grain harvest is being moved in the Fall, and when depleted raw material stockpiles are replenished in the Spring. There is a geographical influence to traffic density as vessels move from the open lakes to the confluence areas and into the constricted waterways. Traffic in the St. Marys and St. Lawrence Rivers can reach a density of one vessel per three miles and in the Welland Canal one vessel per five miles. Heading changes have a correlated direct impact on smooth flowing traffic. For instance, there are 34 heading changes in the 41.2 miles of the St. Clair River (0.83 heading changes per mile). In contrast, on a 14.2 mile stretch of Lake St. Clair there is just one heading change. These represent the maximum and minimum situations in the Great Lakes-St. Lawrence River network.

A critical vessel is one with unique characteristics. If the system is designed to accommodate a critical vessel all the needs of other non-critical vessels also can be accommodated. For the Great Lakes and St. Lawrence River there are two critical vessels, one for the bulk cargo trade and one for the liner trade. A critical bulk carrier is a superlaker (1000 feet long and 105 feet wide), and a critical liner is a large salty (730 feet long and 76 feet wide). Nominal or theoretical track widths for these critical vessels are the widths of the narrowest lock that can accommodate the vessels (the Poe Lock at 110 feet, and the Welland Locks at 80 feet). Nominal separation distances are 105 feet for two superlakers, 76 feet for two salties, and 92 feet for a salty meeting a superlaker. The projected traffic volume for the year 2000 indicates that the St. Marys River will be the busiest waterway in the system. (Ref. 7)

The 2342-mile waterway is graphically depicted in Appendix F. Specific details germane to navigation problems are in the text. The 2342-mile system includes 16 sets of locks that lift vessels a total of 602 feet. Reaches with the minimum widths (200 feet) are in the St. Marys River and the Welland Canal. The maximum heading change of 70 degrees is negotiated by vessels sailing on the St. Lawrence River. The St. Marys River has one heading change of 65 degrees while the remaining changes are less than 45 degrees.

Environmental factors include wind, currents, bank and shallow water effects, visibility and ice. Simulation data was used to determine the impact on navigation performance of environmental factors. It might be propitious to mention once again that the simulation results need to be validated with a field measurement program. In one simulation scenario a following wind of 35 mph that became a port wind when the vessel changed course had no impact on ship track-keeping performance. The vessel was kept on the centerline with a standard deviation of 31 feet. When heavy winds were simulated (52 to 75 mph) an 80K tanker tracked 100 feet from the centerline with a standard deviation of 90 feet. A smaller tanker (30K) tracked 148 feet from the centerline with a standard deviation of 110 to 120 feet. In general pilots would use 200 to 250 feet of the leeward side of an 800-foot wide channel if they encountered heavy winds.

In another scenario, the effect of a crosscurrent on a vessel's ability to track-keep was evaluated in a simulator experiment. Without a current the vessel was on the centerline (500-foot channel) with a standard deviation of 30 feet. A 0.3 mph crosscurrent shifted the track by 85 feet and increased the standard deviation about this track to 56 feet. Polly's Cut in the St. Lawrence River has a 3.2 mph current with a current direction of 85 degrees. It is understandably a difficult task to maneuver a vessel in this reach.

The waterway system is designed to maintain a 25.5 foot vessel draft. If the bottom is rock (the Canadian Shield section) pilots tend to stay closer to the centerline, increasing the risk potential for a collision with a meeting ship. Shallow water has a stabilizing effect on a ship's course. In this situation a ship tends to resist change, requiring more rudder to make a turn. Pilot performance improvement with knowledge of a ship's course stability characteristics in shallow water also was evaluated. When the pilot was familiar with ship characteristics, improvements ranged from 100 feet closer to the track-line in the confluence area to a 35-foot improvement in a 500-foot wide waterway.

The day versus night (or visibility) environmental impact on performance was measured with a simulator and independently verified by the riding teams. When large vessels meet smaller vessels they usually move to the right and let the smaller vessels determine the separation distance. The separation distance is greater at night between vessels of unequal sizes, however, the standard deviation is less.

Ice as an environmental factor has three effects. Because ice can move buoys from their moorings, buoys must be removed in the Fall and repositioned in the Spring. In addition, ice cover has an effect (on ship course stability) similar to shallow water. The pilot uses more rudder commands to maneuver a vessel in ice cover than in ice free conditions.

A casualty assessment identified the Detroit and St. Clair Rivers as the most dangerous areas. The St. Marys River ranked next in criticalness in the assessment. The pivotal operations in these rivers include lock entry and meeting maneuvers. For vessels of equal size or weight, daytime separation was 90.6 feet with a standard deviation of 15.3 feet. At night the separation was 143.4 feet with a standard deviation of 25.3 feet. For ships of unequal sizes the separation distance in the daytime was 97.4 feet with a larger standard deviation of 50.5 feet. At night the separation distance was 106.1 feet with a smaller standard deviation of 32 feet. It was felt that pilots could not define the edge of the bank at night so well as they could during the daytime; therefore they kept closer to the centerline. A ship meeting a vessel of equal size will aim for a position to the right of the centerline -- about one-sixth of the channel width (for an 800-foot channel this is 133 feet to the right of the centerline; for a 500-foot channel it is 83 feet to the right of centerline). Using these conclusions it can be calculated that two superlakers in an 800-foot wide channel would have a separation distance of 161 feet; two salties in a 500-foot wide channel would have a separation distance of 90 feet.

A pilot is much more active when using radar for assistance. The average track, using radar, is 30 feet to the right and a zero standard deviation is maintained when passing buoys. Without radar and using only visual aids the track is still slightly to the right, but it is much smoother.

On the Fourth Seacoast, the St. Marys River is the most difficult to navigate, has the second highest number of casualties as pointed out previously, and is used by both types of critical vessels. Regaining the centerline track after a waypoint is another difficult maneuver. During a simulated scenario to compare centerline track performance before and after a waypoint maneuver, it was discovered that a pilot could be given too much information that influences him to overcontrol a vessel. In this case the standard deviation gets large even if the mean displacement from the track-line is small. This has been verified with the radar assisted scenarios. With a straight reach the vessel maintained the centerline with a standard deviation of 40 feet. After a 35 degree heading change the vessel tracked 50 feet to the right and the standard deviation was increased to 80 feet. In the scenario to determine optimal spacing of the buoys (used as the reference for waypoint maneuvers and centerline recovery) two spacing configurations of gated buoys were evaluated. The closer spaced buoys gave a poorer performance which further substantiated that too much information can cause overcontrol of a vessel.

The three sets of navigation requirements which must be defined for the Great Lakes and St. Lawrence River network are those for: 1) the open water, 2) the confluence areas and, 3) the constricted waterways. The first two sets have been documented in previous studies of other areas and the results are adaptable to the Great Lakes (Ref. 16). For an open water lane of two miles the track-keeping requirement is ± 0.6 miles. (Most open water lanes are five or six miles wide.) In a confluence area with a tapering lane averaging one mile at its midpoint, the track-keeping requirement at the midpoint is ± 0.3 miles. Accuracy requirements have not been defined for constricted waterways. There are three distinct situations in constricted waterways: track-keeping, waypoint maneuvering, and tactical maneuvering, and each situation has unique characteristics. Although the results of simulation scenarios indicate expected levels of performance, the need still exists for validation by a field measurement program. Existing navigation systems provide information on orientation, guidance, accuracy and rate. Leading markers (or ranges) provide orientation and guidance, position fixing accuracy of 30 to 70 feet, and some rate information for ships that are track-keeping. In a tactical or waypoint maneuver, however, leading markers do not provide necessary cues.

A recent study determined that a pilot gives a rudder command every 20 seconds when negotiating a constricted waterway. (Ref. 11) This suggests that a pilot needs a position update every one or two seconds which is quite feasible with state-of-the-art microprocessors.

There are a variety of methods used to measure the contribution of a navigation aid to ship track-keeping performance. For this report, programs were referenced in which a ship's center-of-gravity (crosstrack position in a channel) and the separation distance between the widest beam of meeting vessels were measured and the standard deviations about these measurements were computed. This corresponds to measurements reported in simulation studies. Since it is important to include dynamic effects, one of the conclusions of this study is to employ a closed loop error prediction model (see Appendix B) in order to develop the size and orientation of a critical vessel's footprint relative to channel boundaries and to other vessels in a meeting situation. Error distributions then can be expressed in terms of collision risks or stranding probabilities.

Several studies (Ref. 3,5,9) confirmed results of extensive mathematical modeling and simulation. Course stability in shallow water and with an ice cover was verified by measurement in the St. Marys River as were the track-keeping and turning of vessels in the Chesapeake Bay area. Although simulation results were verified for wind speeds below 12 mph, they were not confirmed for higher wind speeds. A summary of this data is in Table 4-1. These differences between measured and simulated performances underscore the need to validate the simulated results by field measurements.

To demonstrate a recommended methodology of modeling vessel control and sensor characteristics, three types of vessel sensors were examined under three different conditions of winds and currents. The sensors had the same standard deviation of 15 feet but exhibited different dynamic characteristics. Two sensors were differential LORAN-C with different signal-to-noise ratios and the third sensor was GPS. For large cross wind and current forces (wind greater than 50 MPH), the vessel control performance was between 100 and 27 feet (crosstrack error) (see Figure 3-22), depending upon sensor dynamics.

4.2.2 Communications

A cost-effective communications system was suggested in Section 3.2.5 that can provide the rapid exchange of data (one or two seconds) between meeting vessels in a constricted waterway. A system of 28 transmitter sites (six are control stations) is recommended to provide total coverage. Most proposed additions would be located at existing USCG VHF-FM transmitter sites. For total Great Lakes coverage some of the additional sites would be needed on Canadian shores.

TABLE 4-1. SUMMARY OF AVAILABLE DATA

CONSTRICTED WATERWAY MODE	CENTERLINE OFFSET (FEET)	STANDARD DEVIATION (FEET)
<u>TRACK-KEEPING</u>		
FOLLOWING/LEADING FORCE[1]		
CROSS CURRENT	0	30
CROSS CURRENT 0.3 MPH	+85[2]	56
CROSS WIND 50 MPH	0	31
CROSS WIND _ 50 MPH	+100[2]	90
WAYPOINT MANEUVERING		
MANEUVER _ 35°	+50[3]	80
TACTICAL MANEUVER	SEPARATION (FEET)	STANDARD DEVIATION (FEET)
SAME SIZE VESSEL, DAY	90.6	15.3
SAME SIZE VESSEL, NIGHT	143.4	25.2
DIFFERENT SIZE VESSELS, DAY	97.4	50.5
DIFFERENT SIZE VESSELS, NIGHT	106.1	32.0

(1) CURRENT AND/OR WIND

(2) IN THE DIRECTION OF THE FORCE

(3) RIGHT OF THE CENTERLINE

NOTE: VESSEL (30K DWT AND 80K DWT TANKERS) PERFORMANCE MAY NOT REPRESENT THE CRITICAL VESSELS' PERFORMANCE

Four categories of ship-to-shore communications are navigational data, general data, official advisories and telephone service (not a specific requirement). The update requirement for navigational service is twenty seconds on the open water and one second in constricted waterways. The general data update rate is every fifteen minutes. Official advisories would be regularly scheduled as they are now with emergency interruptions when required.

A multiple frequency system in the VHF frequency range (216 MHz to 220 MHz) meets the requirements for update rate in constricted waterways. The total bit requirement per vessel based on an ASCII standard of 10 bits/character is 770 bits, which includes four characters for vessel identification, 38 characters for navigation data ship-to-shore, and 35 characters for navigation data shore-to-ship.

4.2.3 Traffic Information Management

Requirements of a Traffic Information Management System includes: vessel specific data (position, velocity, estimated time of arrival and identification); navigation data (relative positions of vessels, estimated meetings and maneuver locations); scheduling data; system status (capacity situation); environmental data (water depths, wave heights, velocities of winds and currents); and marine weather forecasts tailored for specific areas.

There are 190* vessels in the system on a typical day during its 275-day season -- 40 in the St. Lawrence River, 40 in the St. Marys River, 30 in the Welland Canal, 45 lakers on the open water or entering or leaving a confluence area, and 35 salties on the open water or entering or leaving a confluence area. During its peak traffic days in the Spring and Fall, the daily average increased 15 percent to 220 vessels.

4.2.4 Display

Display presentations have been evaluated by CAORF and demonstrated as feasible on the St. Lawrence River. (Ref. 17) In terms of pilot performance

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*These numbers are based on COE estimates. Recent correspondence with the Lake Carriers Association indicate a total of 153 vessels would be more appropriate.

and acceptance, the following features are needed: color for added information content, graphics, ship outline with extended centerline, navigation aids locations, shore boundaries and other vessels' position, a digital call-out of course, position location, time-to-waypoint, and velocity. Other attributes could be added if requested by pilots.

5. RECOMMENDATIONS

Based on the results of the Great Lakes and St. Lawrence River System Study and the requirements definitions statement, the MARAD/TSC team has five recommendations to make to the user community, program sponsors, and other government organizations. The recommendations address the geographical area of the study, a navigation accuracy measurement program, a methodology for specifying sensor performance, a state-of-the-art survey, and a benefit/cost study.

5.1 GEOGRAPHIC AREA

The original study effort was intended to include the entire 2342 miles from the Atlantic Ocean to Duluth-Superior Harbor. However, the region identified as the lower St. Lawrence River from Montreal east to the Gulf of St. Lawrence, has been given a cursory treatment. It is a different system from the rest of the network, although the same water passes through both, as it is serviced by a separate pilot organization and is a year round operation. The water depths are greater and the system can handle larger vessels. It is recommended that the lower St. Lawrence River not be included in any further study effort.

5.2 MEASUREMENT PROGRAM

In the requirements study, an extensive search was made of published documents treating accuracy requirements for vessels in constricted waterway systems. It was found that many simulation experiments have been conducted, some modeling methods have been developed, and measurement programs have been attempted. Nevertheless, it appears that simulation and modeling efforts that were reviewed require field measurement programs for validation. Consequently, it is recommended that an accuracy measurement program be conducted in the St. Marys River using superlakers and salties prior to the full deployment of any supplemental navigation system. A test program that has been proposed is described in Appendix B.

5.3 MEASUREMENT METHODOLOGY

The MARAD/TSC team proposes adopting a mathematical control model using dynamic sensor characteristics to evaluate adequacy of proposed technologies for navigating on constricted waterways. As illustrated by the example in Figure 3-22, sensors with the same static characteristics can have different dynamics. The utility of this control model would be enhanced by data from the aforementioned navigation accuracy measurement program. Use of this control model will provide adequate data for relative system performance measures.

5.4 STATE-OF-THE-ART SURVEY

The GPS system should be in place in the 1990s. Other high precision navigation systems are available now. Data collected in this requirements statement define ranges of accuracy. WATERCOM has developed a new system for communications on the inland waterways. There are communications satellites with additional marine functions in place. The Welland Canal now operates a new traffic information management system. Marine technology magazines are advertising integrated shipboard displays.

It is recommended that a state-of-the-art survey be conducted to compare available and proposed equipment with stated requirements.

5.5 BENEFIT/COST STUDY

The three driving forces behind the Great Lakes and St. Lawrence River navigation and communications program are: 1) economic goals (increase the efficiency and capacity of marine transportation through the ports on the Fourth Seacoast); 2) national defense goals (support armed forces by moving cargoes regardless of weather or other environmental constraints); and 3) national strategic goals (facilitate the movement buildup of strategic materials). Worldwide, the international marine transportation system is slowly recovering from a severe economic depression. The benefits that could be realized by implementing new navigation and communications capabilities on the waterway network need to be quantized. In addition, since most of the systems that would be proposed currently are available, the costs of such systems also can be quantized. It follows that a benefits to cost study should be conducted.

APPENDIX A

REVIEW OF THE NAVIGATION AND COMMUNICATIONS PROBLEM AREAS

A MARAD/TSC field team interviewed the Great Lakes-St. Lawrence River user community and recorded verbatim all the comments on navigation-aids and communications systems. In this appendix the comments are categorized into three groupings: navigation, communications, and traffic information management. The comments are paraphrased to preserve the intent of the message, yet reduce the word length. The comments are regrouped into generic classes and then analyzed with regard to the following criteria:

A. Source of the Comment

A.1 User community; pilots, masters, and mates.

A.2 Shipping community: shipowners, port authorities, etc.

A.3 Responsible agency: USCG, SLSDC, COE, FCC, etc.

B. Geographic Area

B.1 St. Lawrence River

B.2 Connecting waterways

B.3 Great Lakes

C. Impact on Maritime Industry

C.1 Reduces stress and anxiety

C.2 Increases traffic capacity

C.3 Assists United States strategic goals

D. Technical Complexity

D.1 Off-the-shelf hardware

D.2 Off-the-shelf hardware with modification

D.3 Development of new hardware needed.

E. Cost

E.1 Inexpensive (less than $10K)

E.2 Moderate cost (greater than $10K, less than $100K)

E.3 Expensive (greater than $100K)

F. Time to Implement

F.1 Near-term (less than 5 years)

F.2 Mid-term (5 to 10 years)

F.3 Long-term (longer than 10 years)

Note: The numbers used in the D, E, and F analyses are engineering estimates, which are suitable for this analysis, but need to be substantiated before they are used in a program plan.

A.1 NAVIGATION COMMENTS

The following are the paraphrased comments. The parenthesis indicate the number of times that the comment was recorded.

A.1.1 Visual-aid System

(13) Sailing ranges; need repair, eastbound and westbound, brighter illumination, and better spacing.

(14) Traffic movement depends on visual aids; system needs better designed fixed aids, and use less floating aids.

(8) The green paint and green lights on the fixed and floating aids are difficult to see. (Note: Research into the coloring of buoys and their lights is underway in Europe, some buoys having already been recoated with a higher contrasting shade of green.)

(4) Improve and maintain the present system.

(2) Ship bridges are designed differently. However, the visual-aid system is designed for lakers.

(2) The lights on the Thousand Islands Bridge were installed as an obstruction warning for migrating birds. During fog and haze the backscatter from the lights causes problems as pilots try to find the center-of-the channel. The pilots will contact the bridge authorities to have the lights turned off.

(2) Floating aids are subject to ice damage if they are left in the water all winter.

(1) Immediate goal is a firm eight and one-half month season with 24-hour service, albeit some reaches will be restricted to one-way passage.

(1) Accuracy of the location of a marker buoy is ± 22 feet.

(2) Fixed lighted-aids appear to be dimmer than floating lighted-aids.

(1) To tie up to a wall, a pilot has to be able to see the wall.

(3) Once the aids are removed for the winter, only daytime transits are allowed on the St. Lawrence River; the days are also getting shorter at this time.

(1) With new aids the pilots will develop new navigation skills.

(1) The winter markers are difficult to see at Irvine Point Range.

(2) Canada Island Range favors the port side (upbound); meeting maneuvers are difficult to execute, and Goose Neck Range has a dimly illuminated back range and cannot be used with confidence.

(1) Ships waiting in the channel for down bound lockage at Eisenhower need reference buoys.

(3) Strobe lights are very useful in fog situations.

(2) Steering lights are useful alternatives to sailing ranges. (Note: The USSR has reported that it is using a new laser based sectoral beacon to guide ships approaching the port of Yuzhny on the Black Sea.)

(1) A system approach to navigation-aid installation is needed; remove old aids when new types are being installed.

(6) Private docks maintain their own floating and fixed aids to assist the vessels when they approach the dock.

(1) There are several places where the lighted-aids blend into the background, for example Milwaukee and Green Bay.

(1) There are major delays (3 to 5 hours) caused by fog in the St. Marys River after the floating aids are removed.

A.1.2 Shipborne Radar and Radar Enhancements

(11) RACONs are good aids in fog. SLSDC and the Canadian Coast Guard are considering adding RACONs to the St. Lawrence River.

(12) Radar reflectors should be added to all fixed and floating aids on the seaway and Great Lakes to enhance the reflected signal.

(1) The "frequency able" RACONs are very useful navigation aids on the Great Lakes even though this capability was slightly overdue in that the technology is twenty years old.

(1) The COE is looking for a better way to monitor vessel positions in the St. Marys River, e.g., radar.

A.1.3 Electronic Positioning Systems

(1) There is a definite role for precision navigation systems on the Great Lakes, and efficiency could be improved during the months that the buoys are out.

(5) LORAN-C is not used east of the Welland Canal.

(1) Pilots do not use LORAN-C for navigation to any significant extent.

(2) LORAN-C inputs are used in the St. Marys River to measure speed over the ground.

(1) LORAN-C waypoints, for open lake sailing, are programmed into the navigator, and the read-out displays cross-track error. The vessel's automatic pilot is adjusted when the cross-track error approaches one mile.

(2) LORAN-C receivers have precipitation static problems, possible due to poor grounding of the receiver.

(2) Rouge Steel ship captains use LORAN-C to stay in the shipping lanes in the lakes and think it works well.

(3) The existing radiobeacon system on the Great Lakes is inconsistent with its coverage; it is mostly used by recreational boaters for homing references.

A.2 COMMUNICATIONS COMMENTS

(12) Channel 16 is saturated by recreational boating conversations. The merchant trade should have their own channel for bridge-to-bridge and security calls. (Security calls made by commercial vessels are valuable to recreational boaters, particularly when planning to leave or enter harbors. A problem could arise if those calls were to be made on a different channel which is not used by all types of vessels.) The ability to monitor channel 16 for emergency traffic has some serious coverage gaps, especially around Saginaw Bay.

(2) The information transferred in French between Canadian masters and marine traffic controllers cannot be used by pilots not fluent in the language.

(5) The cost of ship-to-shore service is increasing; alternative methods are being investigated.

(1) Rogers City Radio experiences some holes in their coverage of the four upper lakes, due to weather, time of year, etc. Improvements are expected with new equipment.

(1) Interference problems are occassionally experienced from WCO in New Orleans.

(1) U.S. Steel reports 99 percent satisfactory communications with its vessels when using HF-SSB from Rogers City.

(2) Coverage from the new INMARSAT system might be marginal in Duluth.

(1) The Upper Great Lakes Pilots, Inc. needs more communication channels available in their office.

(1) Agents need constant communications with vessels over the lakes to control schedules, docks, etc.

A.3 TRAFFIC INFORMATION MANAGEMENT

(10) Inadequate water-depth knowledge throughout the system restricts maritime commerce.

(5) The present weather forecasts do not provide the information needed by the decisionmakers in the shipping companies.

(4) The system goal is to have a firm, fixed-duration shipping season with twenty-four-hour service.

(2) Procedures for tying to the wall at the locks while waiting for passage should be investigated.

(1) Terminal delays and waiting for bridges are more significant cost factors than poor weather or waiting in queues.

(1) In many reaches a ship cannot stop until it reaches an anchorage area.

(1) There is a need for instrumentation which will indicate the range of atmospheric visibility.

(4) Ports that configure their docks for specific mixes of bulk cargo are severely hampered when expected vessels are diverted to other ports.

(2) Ports with direct access to their stock piles of bulk products are more like gas stations; they can fill all vessels with any mixture of their product.

(2) When the ice plug in the St. Clair River was released it was difficult to find a person who could authorize the movement of the vessels (there is a jurisdictional split in the authority between the U.S. and Canada).

(5) Dual responsibility of the COE and the USCG in the St. Marys River causes confusion and excessive bureaucratic delays and dual authority of the USCG and the Canadian Coast Guard prevents clear reaction to system-wide problems of navigation and hampers definitive action by either country.

(3) USCG officers and controllers at Sault Ste. Marie and port officers are not versed in local shipping and environmental history and often do not have the experience to deal with extraordinary situations, i.e., when a port should be closed.

(2) An organization such as the COE or the SLSDC is better equipped for traffic control (turnover in personnel is less and the institutional memory is retained).

(2) Foreign shipping companies view the St. Lawrence River as slow, dangerous, and expensive.

(2) J.W. Wescott II, the mail boat, provides traffic information service to vessels turning from the Rouge River into the Detroit River.

(1) The COE feels a need for an independent surveillance system for the St. Marys River.

A.4 PHYSICAL CONSTRAINTS

(11) The physical limitations of the present system dictate that the traffic flow must stop if the single lock system needs repair. Provide a duplicate 1000-foot lock at Sault Ste. Marie and provide 1000-foot locks on the St. Lawrence River.

(6) Water depth is the second most important profit controlling factor in most bulk ports; the number of vessels to be loaded is first.

(1) Icebreaking is done by commercial tugs and is expensive.

(3) Deepen Vidal Shoals (from Big Point down to the locks) by at least one foot. A 1000-foot laker downbound with ore can earn $1500 more in revenue for each inch of draft increase.

(1) Keep Livingston Channel (downbound Detroit River) at project depth; the channel is often constricted due to boulders rolling into the channel.

(1) Some turning basins are not large enough for the superlakers to maneuver without making sharp turns.

(1) Ships are outgrowing the Seaway but many of the third world countries have small harbors and there will always be a need for the size ship that uses the system today.

A.5 ANALYSIS

Problem areas are listed in Table A-1. The matrix shows that the source of most of data in this report was the ship operators: masters, pilots, mates. These users are concerned with the systems that they encounter each day as they engage in marine commerce. Their comments to the interview team emphasize the use of the visual-aids for navigation and the existing communications systems. In addition, open water sailing on the Great Lakes is not as stressful an operation when compared to transiting the St. Lawrence River and the connecting waterways. Infusing all twenty-one modifications into the present system would reduce stress and anxiety, and enhance strategic national goals. Four of the modifications, if implemented, would also increase the system capacity. Only two of the modifications are judged to be technically complex: range markers for meeting-maneuvers and removal of physical constraints such as depth restriction, present lock sizes, and lack of parallel locks. These two, and the installation of additional range markers for centerline guidance, are the three modifications which require the largest amount of time to implement. The installation of range markers for centerline guidance and meeting-maneuvers will reduce stress and anxiety, and will also support national considerations. To increase capacity, the masters, pilots, and mates need a system which is useable during poor visibility conditions (less than 0.2 miles range). In addition to the navigation system, a dedicated communications system is needed for marine commerce and a traffic information management system. This combination would increase capacity, improve the efficiency of operation, and as a byproduct, enhance safety. That is, all ship positions would be known at a central location.

TABLE A-1. ANALYSIS OF PROBLEM AREAS

CATEGORY \ CRITERIA	A. SOURCE			B. GEOGRAPHIC			C. IMPACT			D. COMPLEXITY			E. COST			F. TIME		
	A.1	A.2	A.3	B.1	B.2	B.3	C.1	C.2	C.3	D.1	D.2	D.3	E.1	E.2	E.3	F.1	F.2	F.3
PHYSICAL CONSTRAINTS																		
WATER DEPTHS	x	x	x	x	x	x	x	x	x		x		x		x		x	
LOCK CONSTRAINTS	x	x	x	x	x	x	x	x				x						x
TRAFFIC INFO. MGMT.																		
WEATHER FORECASTS	x	x			x	x	x	x	x		x			x			x	
TRAFFIC CONTROL[1]	x		x	x		x	x						x			x		
PROCEDURES[2]	x			x		x	x			x			x			x		
VISIBILITY EQUIP.	x		x	x	x		x	x	x	x	x			x			x	
NAVIGATION																		
VISUAL AID SYSTEM																		
RANGES (CENTER)	x		x	x	x		x				x				x			x
RANGES (MEETING)	x			x	x		x		x			x			x			x
FIXED AIDS[3]	x			x	x		x		x	x				x		x		
FLOATING AIDS[4]	x			x	x		x			x			x			x		
AIDS (MAINT.)	x			x	x		x		x	x			x			x		
AIDS (DESIGN)[5]	x			x	x		x			x			x			x		
STROBE LIGHT	x			x	x		x		x		x			x			x	
STEERING LIGHT	x			x	x		x		x		x			x			x	
RADAR ENHANCEMENTS																		
RACON	x		x	x		x	x		x	x				x			x	
REFLECTORS	x			x		x	x		x	x			x				x	
ELEC. POSITION SYS.																		
LORAN-C	x			x		x	x		x	x			x				x	
RADIOBEACON			x			x	x		x	x			x				x	
COMMUNICATIONS																		
CHANNEL 16[6]	x	x	x		x		x			x			x				x	
PRIMARY LANGUAGE[7]	x			x			x			x			x			x		
SHIP-TO-SHORE		x				x	x			x				x		x		

1All meeting maneuvers should take place in authorized areas
2All vessels should tie to the wall while awaiting lockage
3Replace floating aids with fixed aids
4Green color paint and lights are difficult to see
5Navigation aids were designed for lakers
6Channel congestion
7French is used occasionally by Canadian traffic controllers

The removal of physical constraints to traffic flow also will increase capacity. Table A-2. summarizes Great Lakes-St. Lawrence River navigational data: channel depths, lock sizes and lift heights. All locks, except the Poe at Sault Ste. Marie, limit the length of transmitting vessels to 730 feet. The COE, Buffalo District, is conducting a study to determine physical characteristics which are constraints to traffic in the Saint Lawrence River. Preliminary indications favor increasing the length of the American owned locks on the St. Lawrence River to accommodate superlakers. This increase would have a life span of 50 years before projected traffic demands would exceed the system's capacity. (Assuming the Canadians followed in a similar manner.)

In summary, the daily users of the system want immediate problems with the visual-aids system solved and the communications channel congestion relieved. Long range planners want to remove physical constraints to projected traffic densities of the 1990s. Between these two positions is the requirement for an integrated navigation, communications, and traffic information management system which could support a firm, fixed-duration, operating season with 24-hour service.

<u>Appendix A Reference</u>:

MacKenzie F., "Maritime Navigation/Communications Program, Vol. I: Navigation and Communications Systems Study," Final Report DOT-TSC-RSPA-84-9 (October, 1984).

TABLE A-2. SUMMARY OF GREAT LAKES-SAINT LAWRENCE RIVER NAVIGATION DATA

	Channel Depth (feet)	Lock Sizes (feet)	Normal Lift at Locks or Lock Groups (feet)	Number of Locks
<u>ST. MARYS RIVER</u>				
New Poe Lock &	-	1200 x 110 x 31	21.7	1
MacArthur Lock	-	800 x 80 x 31	21.7	1
Connecting Channels:				
Upbound Channels	27	None	-	-
Two-way Channels	27	None	-	-
<u>WELLAND CANAL</u>	27	800 x 80 x 30	327	8
<u>ST. LAWRENCE RIVER</u>				
Thousand Island Section	27	None	-	-
International Rapids Section	27	800 x 80 x 30	84	3
Canadian Section:				
Lake St. Francis Reach	27	None	-	-
Soulanges Reach	27	800 x 80 x 30	80	2
Lachine Reach	27	800 x 80 x 30	53	2
Below Montreal	-	None	-	-

APPENDIX B

NAV-AID PERFORMANCE REQUIREMENTS; FIELD TEST AND DATA ANALYSIS PLAN

B.1 PRECISION PILOTAGE WITH ELECTRONIC NAV-AIDS

A variety of pilot-aiding displays and systems have been suggested for use in confined waterways, ranging from simple digital readouts to accurate renditions of the pilot view seen from the ship's bridge. Display formats have included own-ship position and crosstrack error and velocity data, as well as predicted-track data. With today's powerful 32-bit microprocessors it is feasible to provide the pilot with rapid predictions of own-ship state, and to generate suggested helm command sequences. Such systems will be referred to as aided-pilot systems. The potential performance of such concepts can be evaluated with a combination of analytical and human factors simulation techniques. As understanding of nav-aid dynamical errors and ship handling dynamics is central to these evaluations.

An analytical approach for predicting overall vessel track-keeping errors is to model the pilot/display portion of the aided-pilot system with a control law. This methodology is particularly well suited to advanced aided-pilot concepts. While in an implemented system such controllers might only be utilized to display predictions of vessel footprint, a pilot operating with such an aid should achieve a performance level similar to the closed loop controller. The methodology to be discussed provides a consistent means for predicting vessel track-keeping and maneuvering errors, and allows the establishment of error budgets for the electronic nav-aid(s).

Recently there has been great interest in the analysis, simulation and at-sea testing of vessel controllers. For the most part this work has been aimed at control of vessels in difficult open seaways, the objective being improvement of fuel efficiency through reductions in vessel yaw and rudder activity. Studies have also been carried out for precision platform and vessel station-keeping control. A key aspect of these systems is the vessel dynamical model, which in the cited examples generally consists of at least four degrees of freedom in the ship-fixed coordinate system: roll, yaw, surge and sway. For the smooth sea conditions of interest in this report the model can be simplified to yaw and sway states. A complete model, in the geodetic frame, will typically include six state variables. The vessel dynamical equations are non-linear in nature, but may be linearized about the nominal vessel trajectory.

B.2 CLOSED LOOP PERFORMANCE PREDICTION METHOD

The general model for the system is shown in Figure B-1. Implicit are multiple nav-aids as well as specified reference trajectories. The sensor system might include single or multiple differential GPS receivers, heading references, etc. Both the vessel and sensors are subject to disturbances. The three major system elements are the vessel dynamics, P(s), sensor dynamics, S(s), and controller, C(s). The objective of the control is to have the vessel state vector Z follow "closely" the desired trajectory Yr. The function of the controller is to compute a "good" rudder control sequence from the sensor data Ys.

The reference signal vector Yr is used to define track-keeping and turn trajectories and typically includes such variables as desired vessel cg track as well as vessel yaw angle and rotation rate parameters. Given linearized vessel and sensor models' the best control law, in terms of mean-square deviation from the track, is the linear-quadratic-Gaussian (LQG) controller. The modern LQG controller approach has been successfully applied to many open-sea ship control problems and marine platform positioning problems. In the present context of confined waterway pilotage, the controller will be used primarily as a means for developing sensor requirements for advanced aided-pilot concepts. In this study a general method for deriving the vessel controller was implemented. Generation of predicted vessel error performance, averaged over many vessel transits, is an integral part of the method. Once the controller has been derived, ship trajectories are readily computed for any specific scenarios of interest. For carrying out the necessary vessel controller performance computations a software package has been developed and implemented on the CDC Cyber computer. In Section B.4 these techniques are explored in an illustration comparing GPS AND LORAN-C sensors for vessel track keeping.

B.3 VESSEL CONTROL PERFORMANCE VERSUS NAV-AID QUALITY

The vessel closed loop error predictions computed with the LQG approach explicitly accounts for vessel and sensor dynamics, as well as for wind, current

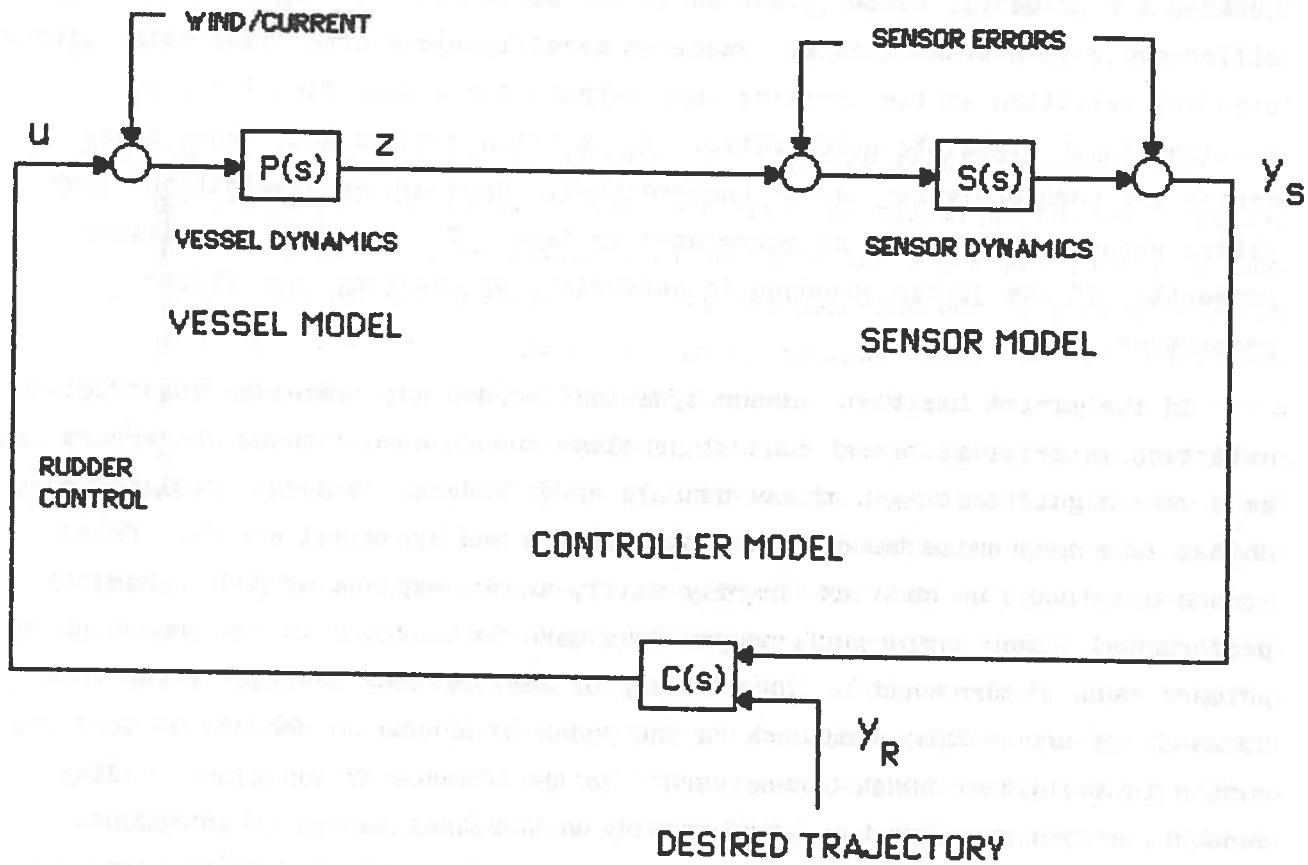

FIGURE B-1. VESSEL CONTROL MODEL

and sensor noise disturbances. The sensitivity of the vessel tracking error to these parameters is readily determined. Results are normally expressed in terms of mean-square error, or variance, as averaged for many operations of the vessel through a track-keeping or turning maneuver. These error distributions may be expressed in terms of stranding and collision probabilities. Such measures can account for the size and orientation of the vessel footprint relative to the channel boundaries.

Sensor errors are commonly divided into three classifications, noise errors, dynamical errors and bias errors. Noise errors are commonly understood to be those fluctuating errors observed at the sensor output in the absence of any sensor motion. For example, in radionavigation systems such as GPS or LORAN-C a fundamental sensor function is the measurement of signal time delay difference beteen transmitters. Receiver specifications often list delay jitter standard deviation at the tracking loop output, for a specified level of receiver input signal-to-noise ratio. It is often assumed that these noise errors are completely random, or uncorrelated. Upon closer examination, such jitter errors are found to be correlated in time. The temporal correlation properties of the jitter sequence is determined by tracking loop filter properties.

In the marine industry, sensor dynamical errors have received insufficient attention in critical vessel control problems though sensor transient errors can be a very significant part of the overall error budget. A sensor designer must choose some compromise between the noise errors and dynamical errors. Noise errors can always be made arbitrarily small, at the expense of poor dynamical performance. Such performance compromises have to be found in the smoothing of primary radar returns and in the recovery of very precise position fixes from LORAN-C. Receiver time constants on the order of a hundred seconds or more are common in low-jitter LORAN-C receivers. In the absence of additional aiding sensors, errors may increase substantially when vessel motion is introduced. Thus it is essential that dynamical errors be properly treated in the precision vessel control.

Bias errors may be treated as offsets to the true state vector being observed. For many sensors, such as heading references, a bias error distribution may be assume, based upon measurements of many units in static conditions. Since such bias terms are slowly varying compared with the quantity being observed they will pass through the sensor function S(s), resulting in a readily computed offset of the vessel states being controlled.

Because of their slowly changing nature it may be possible to track the bias errors themselves with a suitable calibration sensor and control loop. However, in practice it is neither economically feasible, or even theoretically possible, to completely removed all bias errors from the system. The residual calibration errors can then be introduced into the sensor model as a correlated noise process. This approach is especially appropriate for differential GPS, wherein the calibration station is used to track purposely introduced selective availability errors.

B.4 GPS AND LORAN-C TRACK-KEEPING EXAMPLES

The usefulness of the above sensor model for predicting overall vessel control performance will now be illustrated with two well-known systems, GPS and LORAN-C. It will be shown that simple error variance specifications are inadequate to predict the vessel control performance. In particular, under suitable conditions vessel control error may be significantly larger than the error performance quoted for the nav-aid. As an exercise of the preliminary LQG software, a very simple track-keeping scenario was explored. This lends important insight into the relationship between nav-aid accuracy and vessel control accuracy. At the conclusion of the recommended test program this software would be used to investigate such nav-aid options as dual-antenna differential GPS and microwave ranging sensors, as applied to control of the full vessel state model.

In this illustration of the methodology, only sway motion is considered. Neglected are yaw and turn-rate. The system relationship between sway and rudder input, P(s), was approximated with a first order system function. The bandwidth was adjusted to a value typical of a large lake vessel, .05 radians/second. Disturbances were then applied to model the effects of random wind and current. Three disturbance levels were applied to the vessel model, resulting in open-loop vessel crosstrack standard deviations of 150, 50 and 15 feet.

Since the vessel control was restricted to one dimension, a single sensor was employed for measuring crosstrack displacement. Sensor dynamics, S(s), were also modeled as first order. Typical of the values claimed for high performance LORAN-C equipments designed for precision vessel control purposes, the nav-aid error standard deviation was adjusted in all cases to 15 feet. Performance was then computed as a function of nav-aid bandwidth, a wider bandwidth representing a more capable nav-aid. As will be seen, depending upon the nav-aid tracking loop bandwidth, the resulting vessel crosstrack error may be much larger than 15 feet. The LQG controller was readjusted to give the best possible control performance for each value of sensor/vessel bandwidth.

The achieved crosstrack error performance was found to depend strongly upon the sensor/vessel bandwidth ratio. Very poor control was obtained when the sensor bandwidth was narrower than the vessel bandwidth. The results are shown in Figure B-2.

At very small bandwidth ratios the controller is essentially operating without the benefit of a nav-aid, and the errors are the open-loop values of 150, 50 and 15 feet, as determined by vessel disturbances. For a bandwidth ratio of one, the errors decrease to 69, 30 and 15 feet, respectively, with the most dramatic improvement occurring for the large wind-current disturbance scenario. The steepest reduction in error occurs in the three decades between .1 and 100.

Every point on the bandwidth ratio axis represents a system operating with specified received signal power, and with a sufficiently narrow demodulator tracking loop bandwidth to meet the nav-aid variance of 15 feet. For a 20 KHz SNR of +0 dB, a typical LORAN-C receiver operates with a bandwidth of .007 radians/second. At +10 dB SNR the receiver loop bandwith may be widened to .07 radians/second. For a coherent delay-lock GPS tracking loop operating at a carrier-to-noise ratio of 40 dB-Hz, C/A code, the bandwidth is considerably broader, approximately 6 radians/second.

For the given vessel dynamics, LORAN-C falls between .14 and 1.4 on the sensor/vessel bandwidth axis. GPS C/A reception at 40 dB-Hz CNR operates at a bandwidth ratio of 125. For the large wind/current example, the vessel control performances for the different sensors fall between 100 and 27 feet. Even though both LORAN-C and GPS receivers have been designed to have an identical

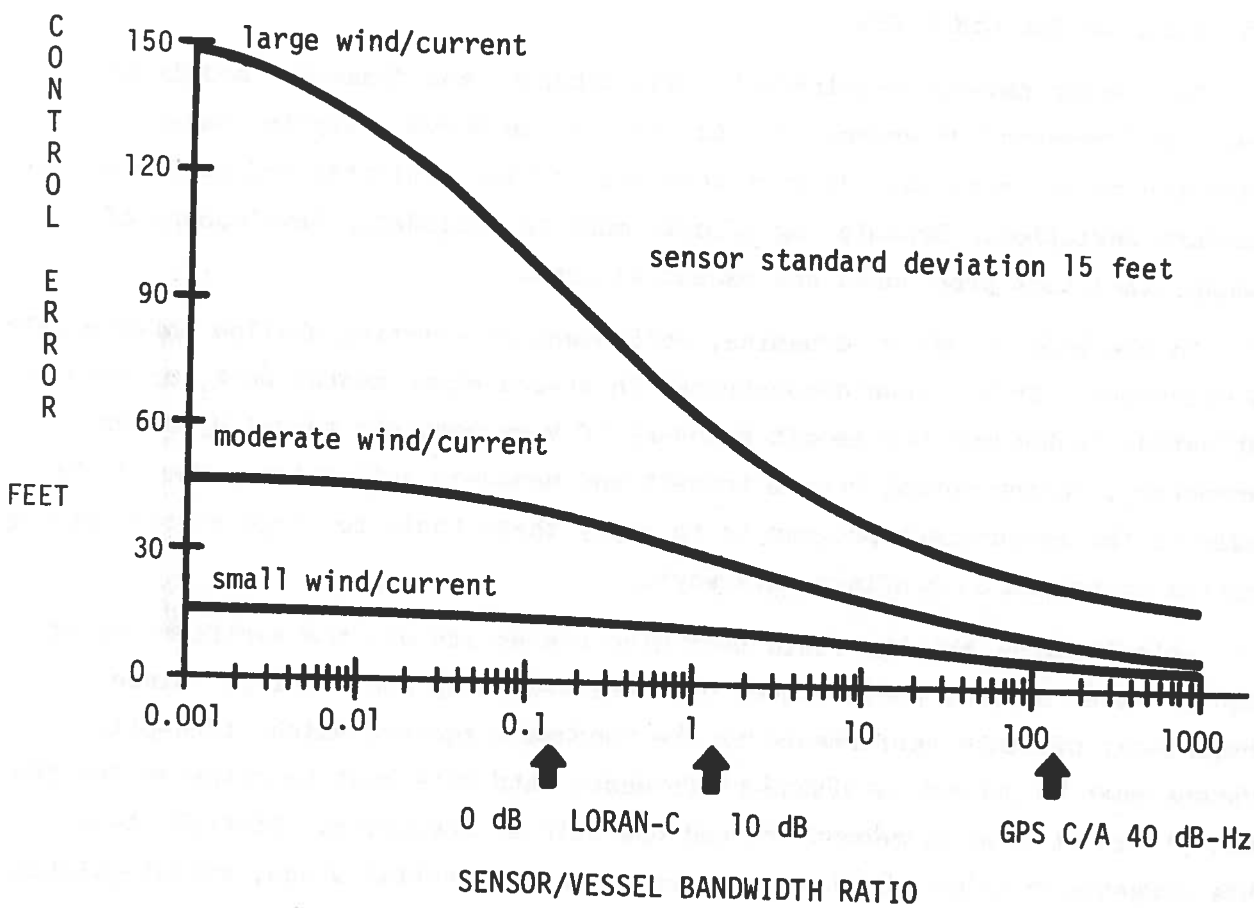

FIGURE B-2. VESSEL CONTROL ERROR VERSUS SENSOR QUALITY jitter, 15 feet in the above example, the much wider bandwidth of GPS affords far better control of the vessel. This conclusion holds true regardless of the type of display employed in the aided-pilot system.

At the present time the error analysis above is being extended to the full vessel state model, including yaw, sway and yaw rate. At the conclusion of the field test the analysis and modeling approach would be employed for the complete vessel and multi-sensor model.

B.5 GOALS OF THE FIELD TEST

To develop nav-aid requirements, disturbances and dynamical models of vessel and sensors are essential. As seen in the above analysis, nav-aid characterization must include more than static bias estimates and sensor output standard deviation. Dynamic lag effects must be included. Development of standardized test procedures are essential here.

In the area of vessel dynamics, refinement of existing shallow water models is necessary. As has been demonstrated in at-sea experimental work, modern estimation techniques now permit recovery of very complete vessel dynamics parameters, during normal vessel transit and maneuver activities. One of the goals of the measurement program is to apply these tools to large vessels during routine operation on confined waterways.

At the same time, the field test also has as its aim the verification of visual vessel control performance, both track-keeping and turning. Since present-day pilotage performance is the benchmark against which aided-pilot systems must be judged, a visual-performance data base must be gathered for the most difficult channel geometries and operational scenarios. Limited at-sea data suggests that in turning maneuvers, with substantial winds, visual pilotage performance may greatly degrade. To establish the potential benefit of aided-pilot systems, it is therefore essential that the most difficult scenarios involving winds and turning maneuvers be addressed.

B.6 TEST SITE DESCRIPTION

The proposed test site is the St. Marys River, which forms the outlet of Lake Superior, connecting it with Lake Huron. From Whitefish Bay, at Point

Iroquois and Gros Cap, the river flows in a general southeast direction to Lake Huron at Point De Tour, a distance of 63 to 75 miles, according to the route traversed. On this waterway are found the largest vessels traversing the Great Lakes, the superlaker bulk carriers. These ships are accommodated by the Poe lock, which measures 1200 by 110 feet. On certain one-way segments of the St. Marys passage these ships must maneuver through channels as narrow as 300 feet, a very demanding pilotage task even under good visual and weather conditions.

The 25 largest bulk carriers account for 45 percent of the carrying capacity of the Lake Carrier Association fleet. It is this vessel type which must bear the burden as attempts are made to improve system capacity. At the same time, these vessels represent the most demanding control problem for aided-pilot systems. Measurement of visual pilotage performance aboard these vessels, and measurement of their dynamics in a variety of channel conditions, would be given the highest priority during the tests. At the same time a variety of smaller ocean vessels will be included. Pilot vessel familiarity would be treated as an important experimental condition.

Test sites were evaluated in terms of channel widths, water depths, turning configurations, and estimates of required personnel and equipment resources were generated. In order to capture the vessel dynamics and pilotage performance on a substantial number of turns. A major segment of the St. Marys passage was tentatively selected, and an operation plan developed allowing equipment and test personnel to be rapidly recycled between vessels.

The test region extends from Nine-Mile point southward to Lime Island. On the southward passage the vessel must make six major course changes, traversing a distance of approximately 35 miles. In this way each vessel passage is used to its maximum. A preliminary examination of elevations, topography and existing tower shore-sites suggests that a five station network of UHF Trisponders would provide the desired ranging geometry and signal reliability.

A typical south-passage data taking sequence is shown in Figure B-3. With the arrival of a pre-selected south-bound vessel at Gros Cap Reef light at 0900 hours, the boarding team sequence begins. The vessel is boarded at the locks at

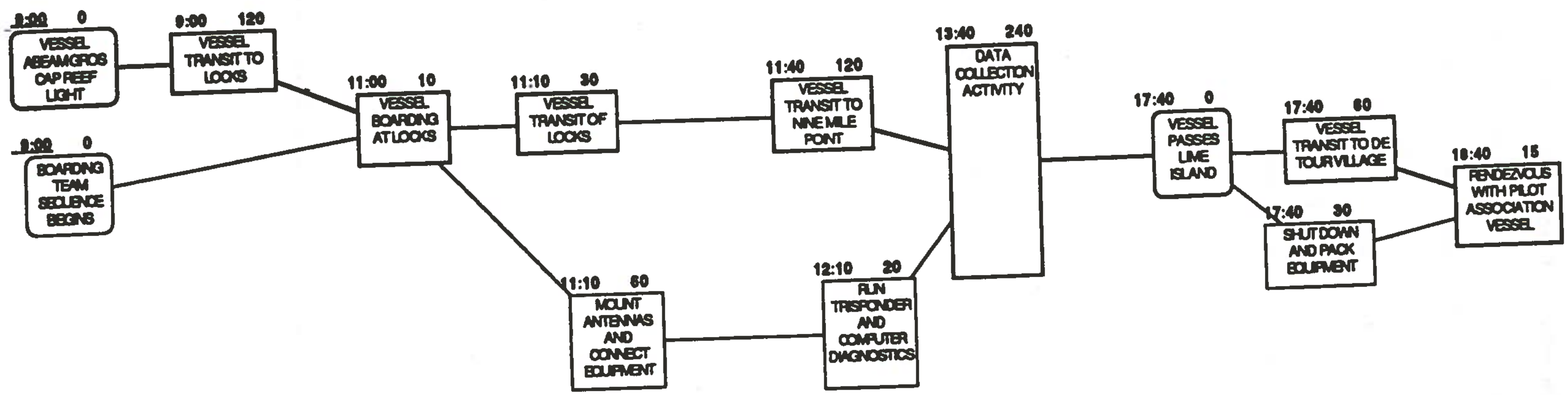

FIGURE B-3. TYPICAL BOARDING AND DATA COLLECTION TIMING

1100, the boarding team consisting of two or three individuals. Taken aboard are three equipment containers, each of 35 pounds or less. These are described below. Between 1100 and 1340 two small UHF whip antennas and a wind instrument are installed, and the transponder equipment and data gathering computer are checked out. From 1340 to 1740 range and wind data are automatically recorded in the computer. Helm data is manually keyed into the computer. Depending upon weather conditions the team rendezvous with a pilot vessel at De Tour village or remains with the ship until Detroit.

Table B-1 is an estimate of the data which would be gathered over a 45-day period. Also listed is the 1981 Chesapeake Bay experiment, and two USCG simulations performed shore-side with experienced pilots. The proposed experiment in the St. Marys will collect data on a far larger number of maneuvers, and greater number of turns per vessel, than in previous at-sea experiments; six turns/vessel over a passage of 30 miles, for a total of 162 turns and 810 miles. This compares with the single turn/vessel and 112 total miles recorded in the Chesapeake Bay. The 6-to-1 improvement in efficiency per vessel is achievable using a large test range, wide-area coverage UHF transponder system, and quick turnaround field measurement approach.

B.7 CONFIGURATION OF FIELD INSTRUMENTATION

The ship and environmental variables to be estimated dynamically include the following:

1) vessel bow and stern position

2) windspeed/direction at the vessel

3) rudder position

To achieve the desired experimental efficiency the operational characteristics set down for the field hardware are as follows:

1) lightweight portable package aboard vessel

2) one-hour vessel setup

3) all-weather 24 hour operation

4) minimal shoreside support

5) system static and dynamical errors well below pilotage errors, over the complete test range.

TABLE B-1. FIELD TEST DATA SAMPLE SIZE

STUDY	TURNS/RUN	TOTAL RUNS	TOTAL TURNS	TOTAL MILES
St. Marys '87 (Proposed)	6	27	162	810
Chesapeake Bay December '81	1	14	14	112
RA-2 Simulation USCG July '81	1	64	64	448
Lights Simulation USCG February '83	1	80	80	560

Notes on Proposed Field Test:

1. Two independent field test teams will be available.
2. Average of three vessels boarded each week.
3. Boarding at Soo locks with team recovery as follows:
   a) In good weather recovery will be by pilot boat at De Tour village
   b) In poor weather the team transits to Detroit and returns via air
   c) Poor weather recovery 40% of trips, with 36 hour return time.

Among the position-fixing options examined were differential GPS, post-processed high resolution primary radar, laser ranging, UHF multilateration, and microwave multilateration. The only system to meet requirements, in the time frame of interest, was the UHF multilateration system. Each of the other systems had specific advantages with respect to one, or several, of the criteria but were seriously deficient in other respects. For example, the primary radar system could operate with little shoreside support, but was found to be subject to severe clutter problems in the geographical area of interest. The GPS system is not yet available on a 24-hour basis, and may be hampered by shielding problems in portions of the test range. Readily available laser ranging systems have inadequate coverage and are weather dependent.

Figure B-4 depicts the data collection system to be used for the tests. On-board equipment consists of four functional groups: 1) dual RF antenna system, 2) windspeed-direction remote unit, 3) the master interrogator and 4) data collection microcomputer and battery system. The UHF Transponder system and antenna switcher will be mounted in one case and the computer and battery components in another. Weight per unit is estimated at under 35 pounds. A design goal is to have case dimensions conform to under-seat air carrier luggage standards. On laker vessels, the antenna system and windspeed/direction remote would remain mounted aloft for the duration of the test program.

It should be noted that the master interrogator unit aboard the vessel would operate in a dual-antenna configuration. Antennas would typically be located across the vessel beam, on top of the wheelhouse. Transmissions would alternate between each UHF whip antenna. This approach has two benefits. First, the diversity reception will reduce the effects of multipath and shielding. Second, and more importantly, since all system biases are common to each antenna, a very accurate translocation fix will be obtained, permitting an accurate and convenient determination of vessel footprint and eliminating the need for a separate heading reference.

A preliminary error analysis was carried out for the UHF multilateration system. A general purpose program was developed for computing crosstrack and along-track error components for vessels traveling between defined waypoints.

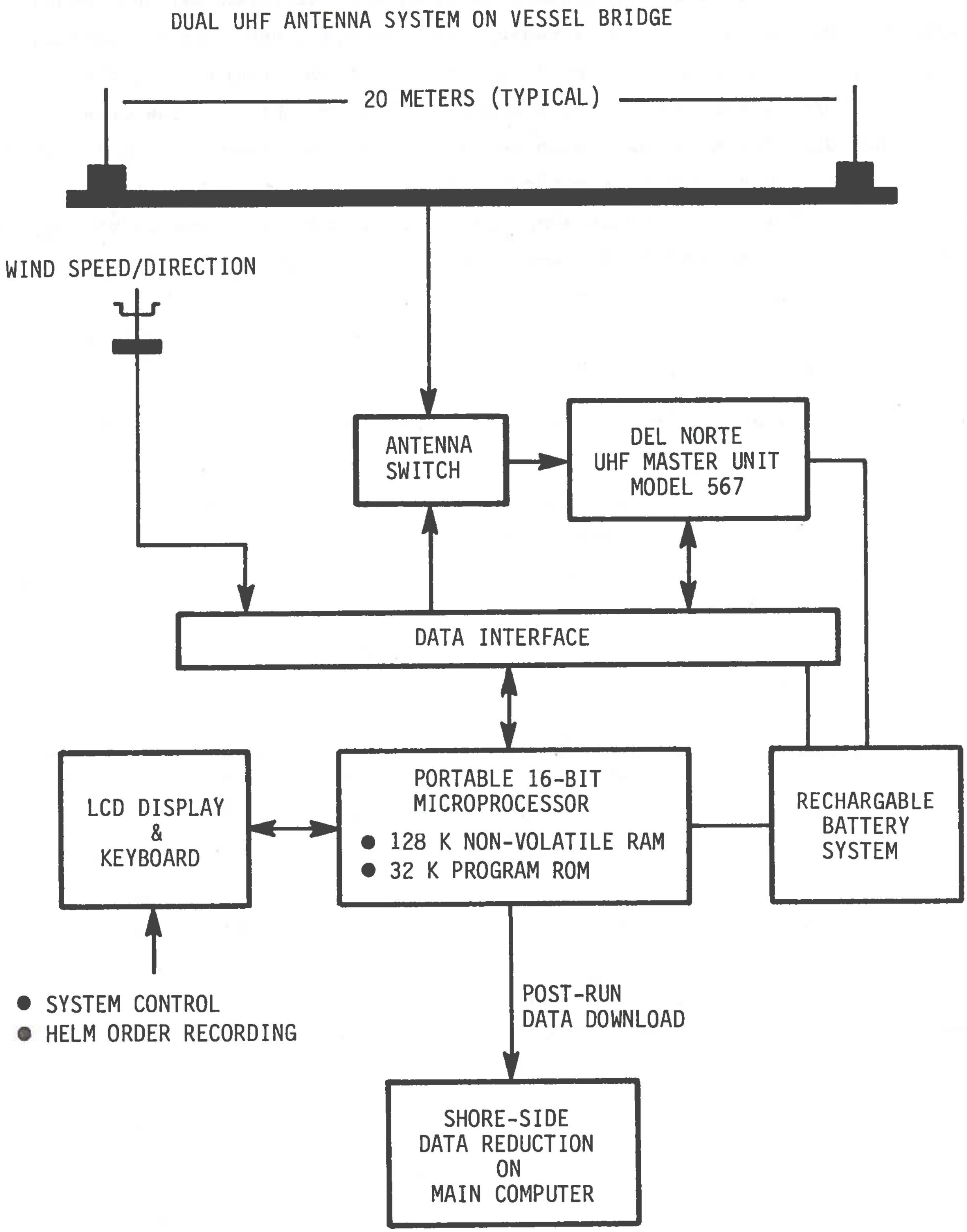

FIGURE B-4. DATA COLLECTION SYSTEM

The error analysis treats the over-determined case, assuming an optimum least-square fit to all available transponder ranging data. The program can also handle data from multiple interrogators on the vessel. This feature is useful for estimating the performance of dual-antenna systems. This program will be used in the final selection of transponder shore sites.

In consultation with experienced transponder survey personnel and factory representatives, the test range was studied using the most recent topographic and tower location information. Based upon the terrain, available towers in the area and ranging geometry, a set of five transponders should provide unsmoothed position errors of 7-10 feet. Accuracy could be further enhanced using Kalman filtering techniques. Transponder sites must be further evaluated for suitability by field inspections and additional error analyses.

B.8 TEST PHASE SCHEDULE

Figure B-5 shows the sequence and interrelation of tasks involved in the field test portion of the effort. In the figure two numbers appear above each task. The number to the left indicates the starting day for the task, relative to day one. The number to the right indicates the estimated number of working days required for task completion. For example, the "Review Test Plan" task is defined to begin on day one. Completion of the review process is estimated to take thirty working days, or six work weeks. Following this task is the milestone, "Test Plan Approval." This chart is computerized so that the impact of delays can immediately be determined.

The task network is aimed at obtaining maximum field data, at minimum leased-equipment and personnel cost. Field data would be collected over a period of nine weeks, with an average of three vessels tracked each week. Two independent vessel test teams would be supported. To maintain optimum test site activity during this period a detailed operations schedule would be developed and coordinated with the participating shipping companies and other organizations, including USCG, COE, and Pilots Associations.

Among the more time-critical items found in the task network are those involving hardware and software for the portable carry-on test package. It is recommended that design work for these items be carried forward in parallel with the test plan review process. Initial inspection of candidate transponder sites

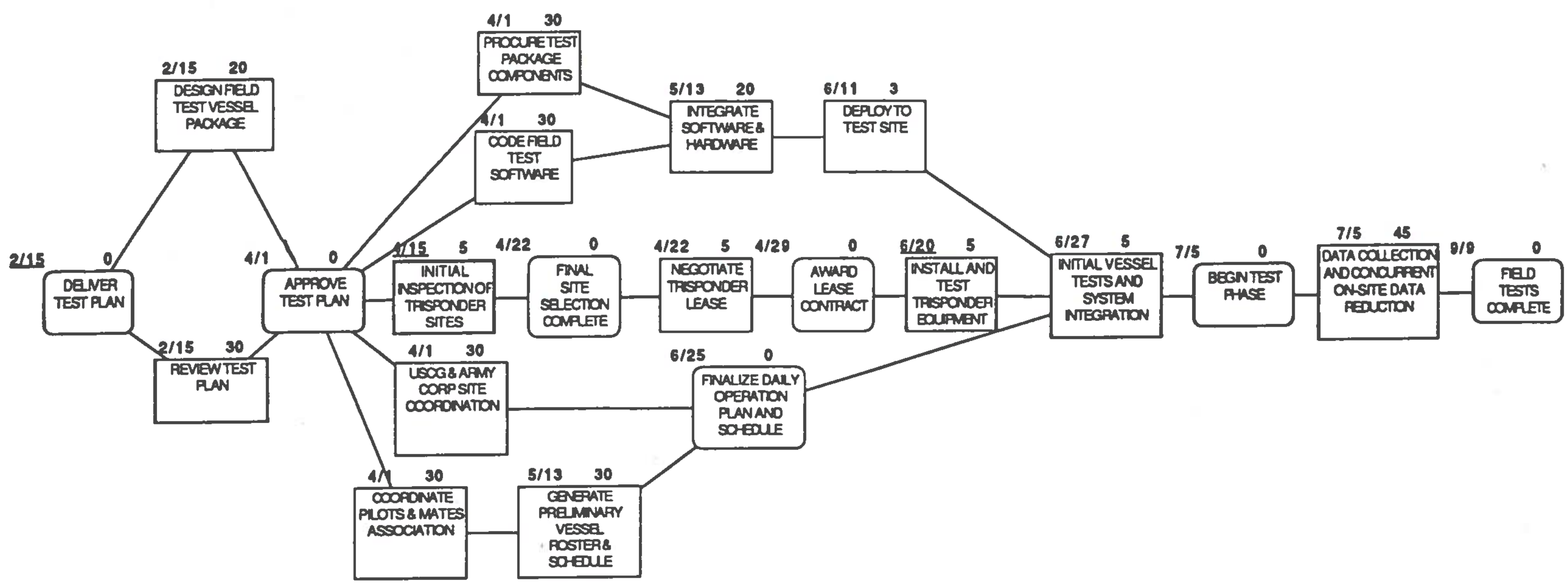

FIGURE B-5. FIELD TEST

by an experienced ranging system consultant is another task critical to the effort. This activity should be performed as early as weather conditions in the test area will permit.

B.9 DATA REDUCTION PLAN

The data reduction activities to be carried out during and following the field tests are shown in Figure B-6. Four stages are envisioned. During system integration tests, calibration of the precision ranging system will be carried out. Bias parameters will be estimated for each of the five transponder sites, and static performance measures computed using residuals from the calibration process. To ensure quality control, on-site data reduction will be carried out continuously once vessel measurements commence. A preliminary version of the Kalman filter software for accomplishing this has been developed. Written in the language "C", an efficient and machine-portable language, the program outputs include smoothed estimates of the six vessel-trajectory state variables listed in Table B-2. Preliminary plots of vessel tracks will be prepared at this time. In the second phase of the data reduction the on-site software will be expanded to a larger state vector, six vessel states together with 13 vessel model parameter states. In addition to the ranging data, the wind and current observations will be introduced. Computations will be carried out on DEC-VAX and CDC-CYBER computers.

The final stage of the data reduction and analysis process consists of two parallel activities. Using analytical and human-factors simulation methods, the vessel dynamical parameters and measured pilotage results will be employed to assess the performance of candidate display and sensor options.

In the analytical evaluation, the performance prediction method developed in Section B.2 will be used to develop candidate sensor performance requirements and the predicted performances will be compared against the trajectories observed for visual pilotage. Human-factor simulations of several aided-pilot control and display options will be carried out at CAORF or other existing simulation facilities.

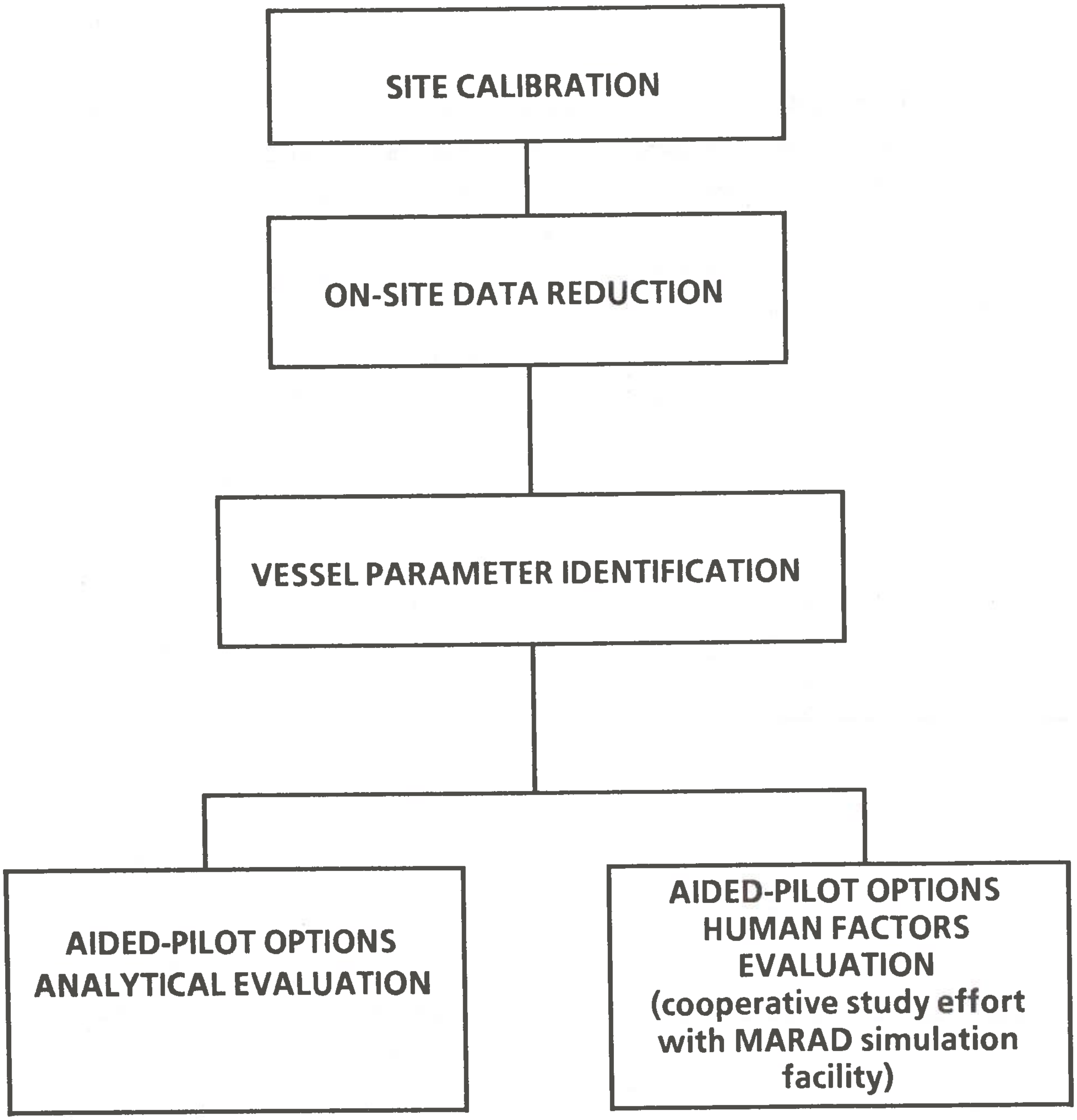

FIGURE B-6. DATA REDUCTION ACTIVITIES

TABLE B-2. VESSEL DYNAMICAL MODEL

State Variables

- Sway Velocity (vessel frame)
- Angular Velocity (vessel frame)
- Longitudinal Velocity (vessel frame)
- East/West Position
- North/South Position
- Heading

Model Parameters

- Hydrodynamic Derivities
- Wind Force Coupling Constants

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APPENDIX C

PRESENT NAVIGATION SYSTEM

The federal role in navigation and pollution evolves from the intrinsically international character of commercial shipping. The federal government is traditionally concerned to promote consistent practices with regard to the waterways: rules of the road, safety and navigational aids, and to pollution prevention. The USCG, SLSDC, and COE implement the federal role on the Great Lakes-St. Lawrence River.

Navigation on the Great Lakes-St. Lawrence River is primarily visual, i.e., pilots navigate by day and night using a system of fixed and floating aids on buoys. These include beacons, daybeacons, daymarks, directional lights, flash tubes, ice buoys, leading lights, passing lights, special purpose buoys, and winter markers. The federal navigation system is supplemented by privately owned and maintained aids usually installed in ports to assist with docking functions. Special devices are used to indicate the status of a lock to a waiting vessel and to define the limits of approach to a lock.

Radar enhancements, reflectors and RACONs, help the pilot locate the visual aids at night and during low or poor visibility conditions. Radar reflectors have been installed on many lighted buoys and some fixed aids. Pilots use their radar at night to locate channel and harbor entrance buoys, when approaching constricted waterways from the open water. Limiting factors are the quality of the on-board radar and the skill of the radar operator. There is a systematic program of RACON installation on the Great Lakes sponsored by the USCG and directed by a group of experienced mariners. RACONs are used predominantly to identify waterway entrances and obstructions for vessels sailing on open waters.

Two electronics positioning systems used on the Great Lakes system are LORAN-C and radio beacons. Both are predominantly used on open water. LORAN-C is used by the bulk carriers and the radio beacons are used primarily by the recreational boaters as homing devices.

C.1 GLOSSARY OF AIDS TO NAVIGATION TERMS

BEACON: A lighted or unlighted aid to navigation. (Lights and daybeacons are both considered beacons.)

DAYBEACON: An unlighted fixed structure which is equipped with a daymark for day time identifications.

DAYMARK: The daytime identifier of an aid to navigation presenting one of several standard shapes (square, triangle, rectangle) and colors.

DIRECTIONAL LIGHT: A light illuminating a sector on a very narrow angle and intended to mark a direction to be followed.

FLASH TUBE: A discharge lamp, operated with electronic equipment, giving a high light output for a brief period, capable of repetition.

FLOATING AID: A buoy, secured in its assigned position by a mooring.

ICE BUOYS: A lighted buoy of sturdy construction that replaces a buoy more easily damaged during the ice season.

LEADING LIGHTS: A light located so that vessels may steer directly for it until close aboard, when a new course is taken.

PASSING LIGHTS: A term applied to a lower candlepower light mounted on a light structure. Used where a mariner passes out of the main light beam (such as a range light) but still needs to keep the structure in sight during transit.

RACON (RADAR RESPONDER BEACON): A radio navigation system that transmits a coded signal which is displayed on the user's radar display allowing one to identify the aid and determine the aid's range and bearing.

RADAR REFLECTOR: A special fixture fitted or incorporated into the design of certain aids to enhance their ability to reflect radar energy.

RADIO BEACON: Electronic apparatus which transmits a radio signal for use in providing a mariner with a line-of-position.

SPECIAL PURPOSE BUOYS: A buoy having no lateral significance used to indicate a special meaning to a mariner which must be determined from appropriate nautical documents.

WINTER MARKERS: An unlighted buoy without a sound signal, which is established as a replacement during winter months when other aids are closed or withdrawn.

C.2 LATERAL SYSTEM OF BUOYAGE

The Great Lakes-St. Lawrence River aid to the navigation system is a buoyage system consisting of aids which are floating or fixed, lighted or unlighted, that have been established to mark the waterway. It is a lateral system of buoyage employing a single arrangement of colors, shapes, numbers, and light characteristics to show the side on which a buoy should be passed when proceding in a given direction. The characteristics of buoys and other aids are as if a vessel were "returning from seaward" when proceeding in a northerly and westerly direction on the Great Lakes (except southerly on Lake Michigan).

On April 15, 1982 the U.S. agreed to make modifications to incorporate the International Association of Lighthouse Authorities Maritime Buoyage System: red buoys and daymarks to starboard, green buoys and daymarks to port (when proceeding from seaward).

C.3 BUOYS

COLORS When proceeding from seaward:

(a) Green buoys mark the port side of channels, or the location of obstruction which must be passed by keeping the buoy on the left.

(b) Red buoys mark the starboard side of channels, as the location of obstructions which must be passed by keeping the buoys on the right.

(c) Red and green horizontally banded are preferred channel buoys marking forks or obstructions which can be passed on either side. The topmost band color indicate the preferred channel.

(d) Red and white vertically striped buoys mark the mid-channels.

SHAPES — In order to provide ready identification certain unlighted buoys are differentiated by shape.

(a) Red buoys, or red and green horizontally banded buoys with the topmost band red are conical and called "nun" buoys.

(b) Green buoys, or green and red horizontally banded buoys with the topmost band green are cylindrical and called "can" buoys.

(c) Red and white vertically striped buoys are spherical.

NUMBERS — (a) Solid color buoys are numbered, the red buoys bearing even numbers and the green buoys bearing odd numbers.

(b) No other color buoys are numbered; however, any color buoy may be lettered for the purpose of identification.

LIGHT COLORS: Red lights on buoys are used only on red buoys or red and green horizontally banded buoys with red as the topmost band. Green lights on buoys are used only on green buoys or red and green horizontally banded buoys with green as the topmost band. White lights may be used only on "safe water" aids which show a House Code characteristic.

REFLECTIVE MATERIAL: is placed on buoys to assist in detection at night by use of a searchlight. The color of the reflective material agrees with the buoy color.

C.4 LIGHTS ON FIXED STRUCTURE

Fixed structures are aids to navigation placed on shore or on marine sites to assist a mariner to determine a position or safe course, to mark channels, and to warn of danger or obstructions. They are identified by their light color and flashing characteristics at night, and by their shape and color of their daymark during daytime. All bearings referring to lights are given as true, in degrees from 000 degrees through 359 degress as observed from a vessel sailing toward the light.

C.5 DAYBEACONS

Daybeacons are unlighted fixed aids to navigation placed on shore or on marine site. They are identified by their color and the shape of the daymark. Reflective borders are placed on the daybeacons to assist the navigator, using a searchlight, to more readily locate them at night.

SHAPE

SQUARE	used to mark portside of channel when proceeding from seaward.
TRIANGLE	used to mark starboard side of channels when proceeding from seaward.
OCTAGON	used to mark the middle of the channel.
RECTANGULAR	when both the front and rear range daymarks are aligned on the same bearings the observer is on the axis of the range. Visually used to mark the center of the channel.
DIAMOND	used for special purpose, warnings, distance, or location markers.

C.6 FOG SIGNALS

The function of a fog signal in the system of aids to navigation is to warn of danger, and to provide the mariner with a practical means of determining his position with relation to the fog signal at such times as the station or any visual signal which it displays is obscured from view by fog, snow, rain, smoke, or thick weather.

C.7 RADAR REFLECTORS

Certain aids to navigation may be fitted with or have incorporated in their design special fixtures (radar reflectors) designed to enhance their ability to reflect radar energy. In general, these fixtures will materially improve the aids for use by vessels equipped with radar. Many lighted buoys are equipped with radar reflectors.

C.8 RADAR BEACONS

A radar beacon, which when triggered by a ship's radar signal, transmits a reply which provides the range and bearing to the beacon on the ship's PPI display. The reply may be coded for identification purposes, in which case, it will consist of a series of dots and dashes (i.e., short and/or long intensifications of radar beams beginning at and extending beyond the RACON on a radial line drawn from the radar through the target) on the PPI. The range is the measurement on the PPI to the first dot or dash nearest its center. If the reply is not coded, the RACON signal will appear as a radial line extending from just beyond the reflected echo of the RACON installation or from just beyond the point where the echo would be painted if detected.

NOTE: The coded response of RACONs installed in the U.S. may not be received if the radar set is adjusted by the operator to remove interference or sea return from the PPI scope. Mariners are advised to turn off radar interference controls when reception of a RACON signal is desired.

C.9 RADIO BEACONS

The Coast Guard operates about 200 radio beacons located at lighthouses, lightships, large buoys and along the coasts, all positions being charted.

In order to use this system, the mariner needs a radio direction finder, which is a specially designed radio receiver with a directional antenna. This antenna is used to determine the direction of the signal being emitted by the shore station, relative to the vessel. (See Figure C-1.)

A radiobeacon is basically a short range navigational aid, with ranges from 10 to 175 nautical miles. Although bearings can be obtained at greater ranges, they will be of doubtful accuracy and should be used with caution. When the distance to a radiobeacon is greater than 50 miles, a correction is usually applied to the bearing before plotting on a mercator chart.

All radiobeacons operated and maintained by the USCG are classified as either Sequenced or Continuous as shown in Table C-1.

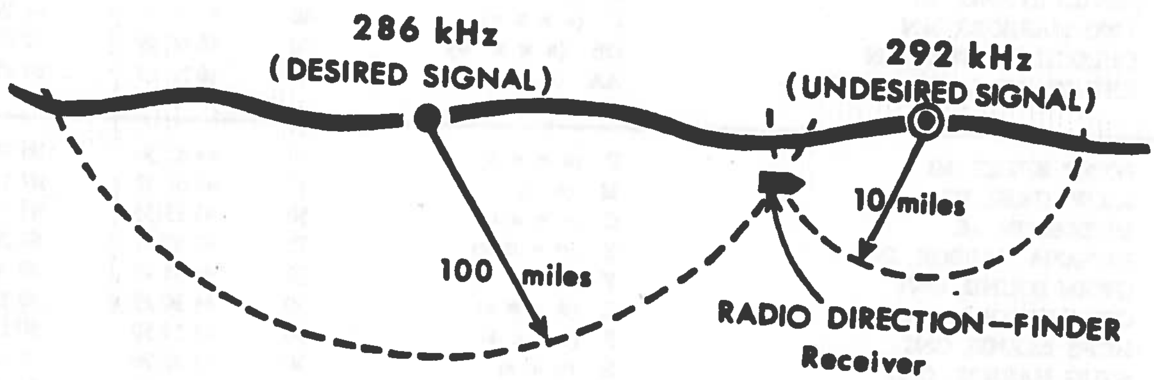


FIGURE C-1. DIRECTION FINDER DIAGRAM

TABLE C-1. RADIOBEACON SYSTEM, GREAT LAKES BY FREQUENCIES

SEQUENCED

Freq kHz		Station	Characteristic	Range (n. m.)	Lat. (N) ° ′ ″	Long. (W) ° ′ ″
292	I	WHITEFISH POINT, MI	OE (■ ■ ■ ●)	100	46 46 18	84 57 28
	II	CARIBOU ISLAND, ONT	A (● ■)	40	47 20 23	85 49 32
	III	MARQUETTE, MI	W (● ■ ■)	100	46 32 47	87 22 30
	IV	SLATE ISLAND, ONT	B (■ ● ● ●)	30	48 37 11	86 59 46
	V	MICHIPICOTEN ISLAND, ONT	Q (■ ■ ● ■)	30	47 45 15	85 35 45
	VI	MICHIPICOTEN HARBOR, ONT	R (● ■ ●)	30	47 56 33	84 54 27
294	I	CLEVELAND, OH	C (■ ● ■ ●)	50	41 30 32	81 43 04
	II	LONG POINT, ONT	L (● ■ ● ●)	40	42 33 00	80 03 20
	III	PORT COLBORNE, ONT	Z (■ ■ ● ●)	35	42 52 07	79 15 10
	IV	ERIE HARBOR, PA	Y (■ ● ■ ■)	20	42 09 21	80 04 17
	V	LONG POINT, ONT	L (● ■ ● ●)	40	42 33 00	80 03 20
	VI	PORT COLBORNE, ONT	Z (■ ■ ● ●)	35	42 52 07	79 15 10
296	II	DEVILS ISLAND, WI	O (■ ■ ■)	70	47 04 46	90 43 44
	III	TWO HARBORS, MN	P (● ■ ■ ●)	40	47 00 51	91 39 48
	V	DULUTH HARBOR, MN	OE (■ ■ ■ ●)	70	46 46 49	92 05 16
	VI	KEWEENAW LOWER ENT	AA (● ■ ● ■)	40	46 58 12	88 25 54
298	II	POINT BETSIE, MI	P (● ■ ■ ●)	50	44 41 30	86 15 18
	III	MILWAUKEE, WI	M (■ ■)	50	43 01 37	87 52 55
	IV	MUSKEGON, MI	C (■ ● ■ ●)	50	43 13 36	86 20 23
	VI	INDIANA HARBOR, IN	Y (■ ● ■ ■)	70	41 40 51	87 26 28
	I	OWEN SOUND, ONT	X (■ ● ● ■)	30	44 34 43	80 56 19
	II	COLLINGWOOD, ONT	C (■ ● ■ ●)	50	44 30 29	80 12 33
	III	HOPE ISLAND, ONT	F (● ● ■ ●)	50	44 54 50	80 10 00
	IV	SNUG HARBOR, ONT	R (● ■ ●)	50	45 22 26	80 18 38
	V	GEREAUX ISLAND, ONT	J (● ■ ■ ■)	30	45 44 39	80 39 35
	VI	KILLARNEY, ONT	K (■ ● ■)	30	45 58 05	81 29 22
302	I	DETOUR REEF, MI	OT (■ ■ ■ ■)	40	45 56 58	83 54 12
	II	POE REEF, MI	W (● ■ ■)	40	45 41 41	84 21 43
	IV	DETOUR REEF, MI	OT (■ ■ ■ ■)	40	45 56 58	83 54 12
	V	LANSING SHOAL, MI	Z (■ ■ ● ●)	50	45 54 12	85 33 42
	VI	GRAYS REEF, MI	X (■ ● ● ■)	40	45 45 57	85 09 13
	I	PORT WELLER, ONT	V (● ● ● ■)	30	43 14 39	79 13 06
	II	BURLINGTON BAY, ONT	R (● ■ ●)	25	43 18 04	79 47 26
	III	OAK ORCHARD, NY	OQ (■ ■ ■ ■ ■ ● ■)	30	43 22 24	78 11 24
	IV	PORT WELLER, ONT	V (● ● ● ■)	30	43 14 39	79 13 06
	V	BURLINGTON BAY, ONT	R (● ■ ●)	25	43 18 04	79 47 26
	VI	OAK ORCHARD, NY	OQ (■ ■ ■ ■ ■ ● ■)	30	43 22 24	78 11 24

TABLE C-1. RADIOBEACON SYSTEM, GREAT LAKES, BY FREQUENCIES (CONTINUED)

SEQUENCED

Freq kHz		Station	Characteristic	Range (n. m.)	Lat. (N) ° ′ ″	Long. (W) ° ′ ″
306	II	MAIN DUCK ISLAND, ONT	Y (■●■■)	30	43 55 53	76 38 20
	III	POINT PETRE, ONT	P (●■■●)	30	43 50 20	77 09 19
	IV	OSWEGO, NY	W (●■■)	60	43 28 24	76 31 01
	V	ROCHESTER, NY	M (■■)	60	43 15 25	77 36 11
	II	SANDUSKY,OH	X (■●●■)	40	41 29 17	82 41 39
	III	SOUTHEAST SHOAL, ONT	H (●●●●)	40	41 49 40	82 27 40
	IV	ASHTABULA, OH	G (■■●)	40	41 55 06	80 47 46
308	I	STURGEON BAY CANAL, WI	OE (■■■ ●)	20	44 47 42	87 18 48
	III	KEWAUNEE, WI	G (■■●)	20	44 27 27	87 29 35
	IV	MINNEAPOLIS SHOAL, MI	Y (■●■■)	20	45 34 54	86 59 56
	V	LUDINGTON, MI	OT (■■■ ■)	50	43 57 11	86 27 36
	VI	RAWLEY POINT, WI	L (●■●●)	50	44 12 40	87 30 30
	II	ST. MARTINS, MI	SM (●●● ■■)	60	45 30 16	86 45 28
312	I	KEWEENAW, MI	C (■●■●)	50	47 13 40	88 37 27
	II	ANGUS ISLAND, ONT	F (●●■●)	30	48 14 09	89 00 25
	III	ROCK OF AGES, MI	Z (■■●●)	40	47 52 00	89 18 50
	IV	MANITOU, MI	M (■■)	100	47 25 12	87 35 18
	V	PASSAGE ISLAND, MI	X (■●●■)	80	48 13 24	88 21 54
	VI	EAGLE HARBOR, MI	J (●■■■)	100	47 27 40	88 09 32
	I	COVE ISLAND, ONT	D (■●●)	40	45 19 40	81 44 09
	II	HARBOR BEACH, MI	U (●●■)	70	43 50 46	82 37 53
	III	THUNDER BAY ISLAND, MI	K (■●■)	70	45 02 13	83 11 40
	IV	COVE ISLAND, ONT	D (■●●)	40	45 19 40	81 44 09
	V	GREAT DUCK ISLAND, ONT	B (■●●●)	40	45 38 30	82 57 48
	VI	PORT GRATIOT, MI	P (●■■●)	70	43 00 17	82 25 22

CONTINUOUS

285	CHICAGO, IL	RT (●■● ■)	20	41 53 21	87 35 26
285	GRAND MARAIS, MN	GD (■■● ■●●)	10	47 44.7	90 20.30
286	BUFFALO HARBOR, NY	BL (■●●● ●■●●)	10	42 52 14	78 54 09
286	GODERICH, ONT	GD (■■● ■●●)	30	43 44 48	81 43 55
286	GROS CAP REEF, ONT	A (●■)	20	46 30 45	84 36 54
286	SHERWOOD POINT, WI	SP (●●● ●■■●)	10	44 53 34	87 26 00
288	FRANKFORT, MI	FR (●●■● ●■●)	10	44 37 50	86 14 42
288	LA POINTE, WI	V (●●●■)	20	46 43 44	90 47 05
289	MANITOWOC BREAK-WATER, WI	MO (■■ ■■■)	10	44 05 34	87 38 37
289	MICHIGAN CITY, IN	MI (■■ ●●)	10	41 43 42	86 54 42
290	GRAVELLY SHOAL, MI	GV (■■● ●●●■)	10	44 01.2	83 32.30
290	DETROIT RIVER, MI	M (■■)	20	42 00 03	83 08 28
290	GIBRALTER POINT, ONT	TZ (■ ■■●●)	25	43 36 50	79 25 10

TABLE C-1. RADIOBEACON SYSTEM GREAT LAKES, BY FREQUENCIES (CONTINUED)

Freq kHz	Station	Characteristic	Range (n. m.)	Lat. (N) ° ′ ″	Long. (W) ° ′ ″
293	TIBBETS POINT, NY	Q (■ ■ ● ■)	20	44 06 03	76 22 14
304	SILVER BAY, MN	SB (● ● ● ■ ● ● ●)	10	47 16 53	91 15 51
304	WAUKEGAN, IL	W (● ■ ■)	20	42 21 38	87 48 48
314	SODUS OUTER LIGHT, NY	SZ (● ● ● ■ ■ ● ●)	10	43 16 39	76 58 27
314	MANISTEE, MI	ST (● ● ● ■)	10	44 15 06	86 20 48
316	GRAND HAVEN, MI	GO (■ ■ ● ■ ■ ■)	10	43 03 27	86 15 22
316	PORT INLAND, MI	PI (● ■ ■ ● ● ●)	10	45 58 09	85 52 38
316	SUPERIOR ENTRY SOUTH BREAKWATER, WI	SN (● ● ● ■ ●)	10	46 42 37	92 00 22
317	GREEN BAY, WI	K (■ ● ■)	20	44 39 12	87 54 04
318	FAIRPORT HARBOR, OH	FP (● ● ■ ● ● ■ ■ ●)	10	41 46 04	81 16 52
320	ALPENA, MI	AL (● ■ ● ■ ● ●)	20	45 03 36	83 25 22
320	CALUMET HARBOR, IL	KX (■ ● ■ ■ ● ● ■)	10	41 43 34	87 29 36
320	NORTH MANITOU ISLAND MI	NU (■ ● ● ● ■)	20	45 01 16	85 57 27
320	TACONITE HARBOR, MN	TH (■ ● ● ● ●)	10	47 31 18	90 55 24
320	TOLEDO HARBOR, OH	TJ (■ ● ■ ■ ■)	15	41 45 43	83 19 44
322	PRESQUE ISLE HARBOR, MI	PX (● ■ ■ ● ■ ● ● ■)	10	46 34 28	87 22 28
322	ROUND ISLAND PASSAGE, MI	RD (● ■ ● ■ ● ●)	10	45 50 34	84 36 55
322	SOUTH BUFFALO, NY	B (■ ● ● ●)	60	42 50 01	78 52 04
323	HURON HARBOR, OH	HR (● ● ● ● ● ■ ●)	20	41 24 18	82 32 36
324	PLUM ISLAND, WI	UM (● ● ■ ■ ■)	60	45 18 42	86 57 28
324	SHEBOYGAN, WI	SY (● ● ● ■ ● ■ ■)	10	43 44 58	87 42 15
325	THUNDER BAY, ONT	P (● ■ ■ ●)	25	48 25 57	89 11 46

MARKER

Freq kHz	Station	Lat. (N)	Long. (W)
286	BATTLE ISLAND, ONT.	48 45 06	87 33 24
288	COGOURG, ONT.	43 57 12	78 09 53
290	GRAVELLY SHOAL, MI.	44 01 12	83 32 18
299	PORT STANLEY, ONT.	42 39 18	81 12 49
306	McNAB POINT, ONT.	44 28 23	81 23 36
314	OSHAWA, ONT.	43 15 52	78 49 19
316	PORT DOVER, ONT.	42 46 51	80 12 06

The characteristic identifiers assigned to marine radiobeacons in this country have been limited to a brief and simple combination of dots and dashes much like the lights along the coast, except that radiobeacons have a 10-second dash at the end of each operating minute to allow a mariner to refine bearings. Also, the identifying signal of all marine radio beacons is superimposed on a continuous carrier to facilitate their use by navigators having automatic direction finders.

C.10 RADIOBEACON ACCURACY

Accuracy of radio direction finders depends upon the skill of the operator, the equipment used, and radio wave interference. Skill in operations of a manual radio direction finder can be acquired only through practice and by following the operating instructions provided with the equipment. An understanding of adverse conditions and direction finding limitations will be an asset to the prudent navigator.

Erroneous radio direction finders bearings may result from the following conditions:

(a) Currents induced in the direction finder antenna by re-radiation from the structural features of the vessel's superstructure and distortion of the radio wave front due to the physical dimensions and contour of the vessel's hull.

(b) Night effect caused by the combination of two radio wave fronts arriving at the receiver simultaneously. One wave travels directly from the transmitter to the direction finder and is called the ground wave. The other is a downcoming radio wave reflected off the ionosphere and is called the skywave. This effect is more predominant around the time of morning and evening twilight, but it remains throughout the night on the low frequency band. On higher frequencies a similar effect exists during the day as well as at night. Beyond the normal ground wave range, only the skywave is received.

Bearings taken around the periods of morning and evening twilight and at night should be treated or accepted with doubt as to their accuracy.

Since the skywave itself is complex in nature it should not be used with a conventional direction finder.

(c) Lateral deviation of the radio wave can occur when the great circle route between the transmitter and the receiver is roughly parallel to a coastline or passes over a coastline. Bearings that are within 10 to 15 degrees of a coastline should not be trusted. Likewise, bearings taken when a land mass is between the transmitter and the vessel should be used with caution.

(d) Most direction finders have a vertical sensing antenna to eliminate any possibility of a 180 degree error in reading. Such an ambiguity is possible in all direction finders if the sensing circuits should become inoperative.

The marine radiobeacon system is based on direction finder selectivity specifications as shown in Table C-2.

TABLE C-2. DIRECTION FINDER SELECTIVITY SPECIFICATIONS

Frequency deviation from resonant frequency (KHz)*	DB below resonance response	Appromixate signal ratios for rejection of undesired signal
+ - 2	3	1.4
+ - 3	12	4.0
+ - 4	25	17.5
+ - 6	50	300.0
+ - 9	70	3,000.0
+ - 12	80	10,000.0

*Resonant frequency to which the receiver is tuned.

Errors in bearing may result in a radio direction finder if its selectivity is poor. For example, a bearing is desired on radiobeacon transmitting on 286 KHz and having a field intensity of 50 microvolts per meter at 100 miles. Assume that a ten mile continuous radiobeacon is operating on 292 KHz as shown in the Direction Finder Diagram. The direction finder is located near the extreme service range of both transmitters.

Using the desired selectivity tables shown previously, a direction finder with these characteristics can distinguish between the two frequencies. The desired 286 KHz radiobeacon signal affect the direction finder 300 times more than the undesired marker radiobeacon signal. If the selectivity were half as good, the desired 286 KHz signal would affect the direction finder only four times more than the undesired 292 KHz signal. The resultant bearing obtained would probably be some value between two radiobeacons.

C.11 LORAN-C

LORAN-C (an acronym for LOng RAnge Navigation) is a radionavigation system which operates on the principle that the difference in the time of arrival from two precisely synchronized transmitting stations described a hyperbolic line-of-position (LOP). This time difference is measured with a LORAN receiver, and converted into geographic LOPs by the use of nautical charts over-printed with LORAN lines, or LORAN tables. Since at least two LOPs must be determined to establish a position fix, the user must be within the range of two pairs of transmitting stations, or as is normally the case, a LORAN chain whereby a centrally-located station serves as a common station with the other stations in the chain. This station is called the master station (designated M) and the other stations, secondaries, are designated by the letters W, X, Y, or Z. C-chain operates on a different group repetition interval (GRI). This allows the operator to make at least two time difference measurements without changing channels on the receiver. The low frequency of LORAN-C permits usable ground-wave signals over several hundred miles.

LORAN-C signals are transmitted in groups of pulses at a specified group repetition interval (GRI). The secondary stations transmit groups of eight pulses, while the master station transmits an extra ninth pulse which is used for identification purposes. This pulse is also used for acquisition by automatic LORAN-C receivers. Each LORAN-C pulse contains a 100 KHz carrier wave which is time synchromized. The LORAN-C GRI rate structure is such that a GRI of between 40,000 and 99,900 microseconds is chosen for each chain. The chain designations are 4-digit numbers which indicate the GRI in tens of microseconds. For example, the Northeast U.S. LORAN-C chain is designated 9960 and has a GRI of 99,600 microseconds. (See Table C-3 and Figure C-2.)

TABLE C-3. LORAN-C CHAIN DATA

Station	Latitude	Longitude
CANADIAN EAST COAST CHAIN - 5930		
Caribou, ME - Master	46° 48' 27.2" N	67° 55' 37.7" W
Nantucket, MA - Xray	41° 15' 11.9" N	69° 58' 39.1" W
Cape Race, Newfoundland - Yankee	46° 46' 32.2" N	53° 10' 28.2" W
NORTHEAST U.S. CHAIN - 9960		
Seneca, NY - Master	42° 42' 50.6" N	76° 49' 33.9" W
Caribou, ME - Whisky	46° 48' 27.2" N	67° 55' 37.7" W
Nantucket, MA - Xray	41° 15' 11.9" N	69° 58' 39.1" W
Carolina Beach, NC - Yankee	34° 03' 46.1" N	77° 54' 46.7" W
Dana, IN - Zulu	39° 51' 07.5" N	87° 29' 12.1" W
GREAT LAKES CHAIN - 8970		
Dana, IN - Master	39° 51' 07.5" N	87° 29' 12.1" W
Malone, FL - Whisky	30° 59' 38.7" N	85° 10' 09.3" W
Seneca, NY - Xray	42° 42' 50.6" N	76° 49' 33.9" W
Baudette, MN - Yankee	48° 36' 49.8" N	94° 33' 18.5" W

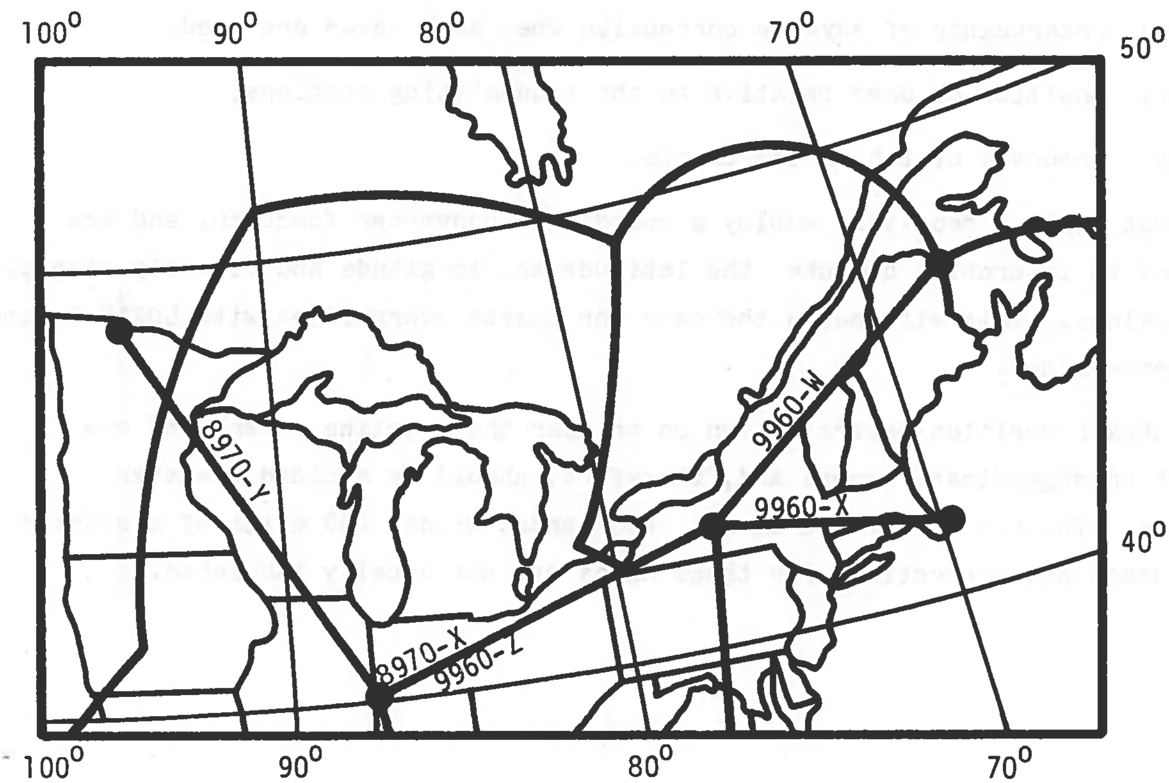


FIGURE C-2. GREAT LAKES LORAN-C COVERAGE DIAGRAM

The accuracy of a LORAN-C fix is determined by the accuracy of the individual LOPs used to establish the fix, as well as by crossing angle of intersection. The accuracy of the individual LOP depends upon the following factors:

(a) synchronization of the transmitting stations,

(b) skill of the operator,

(c) type of receiver and its condition,

(d) skill in plotting the LOP,

(e) uncertainty of skywave correction when such waves are used,

(f) position of user relative to the transmitting stations,

(g) accuracy of tables and charts,

Most LORAN-C receivers employ a coordinate converter function, and are designed to internally compute the latitude and longitude and directly display these values. This eliminates the need for charts overprinted with LORAN-C time difference lines.

LORAN-C position determination on or near the baseline extensions are subject to significant errors and, therefore, should be avoided whenever possible. The use of skywave is not recommended within 250 miles of a station being used, and corrections for these areas are not usually tabulated.

The following lists updated U.S. RACON installations in the Great Lakes-St. Lawrence River, the first such update since December, 1981.[1]

Location	Position Lat N	Lat W	Code	Comments
Manitou Island Light, MI	47 25.2	87 35.2	M	
Passage Island Light, MI	48 13.4	88 22.0	G	
Port Huron, MI	43 05.4	82 24.6	T	Seasonal*
Detroit River Light MI	42 00.1	83 08.5	X	
Peche Island Front Range Light, MI	42.21.6	82 54.4	G	
Lake St. Clair Light, MI	42.27.9	82 45.3	N	
Round Isl. Pass Light, MI	45 50.6	84 36.9	X	
Straits of Mackinac, MI	45 48.8	84 43.7	M	Seasonal*
White Shoal Light, MI	45 50.5	85 08.2	K	
Detour Reef Light, MI	45 57.0	83 54.2	D	
Sweets Point Light, MI	46 02.3	83 56.2	O	Seasonal*
Calumet NE Shoal, LBB2	41 45.6	87 28.0	C	
Brush Point, MI	46 28.2	84 27.4	G	Seasonal*
Detroit Riv. E. Outer LB1	41 54.8	83 06.4	O	Seasonal*
Grays Reef Light, MI	45 46.0	85 09.2	G	
Whitefish Point Light, MI	46 46.3	84 57.4	O	
Poe Reef Light, MI	45 41.7	84 21.7	Z	
Maumee Bay LBB2	41 49.7	83 11.8	M	Seasonal*
Rawley Point Light, WI	44 12.7	87 30.5	K	

*Seasonal - December 15 to April 15

+Lighted buoy

Source (1) Seaway Review, Vol. 14, No. 1 (Dec., 1984) pg. 122-123.

<u>Appendix C References</u>

1. DOT CG Light List, Vol. IV, CG159 1984 Great Lakes - United States and Canada.

2. O'Brien, Arthur E., "History and Status of U.S. Marine Radio Beacon System," Final Report DOT-TSC-CG-82-7, Transportation Systems Center, Cambridge, MA (February, 1983).

APPENDIX D

PRESENT COMMUNICATIONS SYSTEM

D.1 SCOPE

Communications systems which are currently in use on the Great Lakes and St. Lawrence River were investigated:

1. VHF-FM (Very High Frequency-Frequency Modulated)
2. Maritime Satellite Communications
3. MF/HF-SSB (Medium Frequency/High Frequency-Single Sideband)

D.1.1 Methodology

Each of the above communications systems was considered in terms of technical parameters and state-of-the-art technologies, as well as their communication capabilities in the Great Lakes and St. Lawrence River.

D.1.2 Federal Requirement

The Federal Communications Commission (FCC) is the government agency charged with assigning broadcast frequencies to different users and certifying their radio equipment. The FCC requires that every boat for hire carrying more than six passengers and all commercial vessels carry radio equipment.

D.2 VHF-FM SYSTEM

The very high frequency band (VHF) extends from 30 to 300 MHz. The VHF-FM marine band extends from 156 to 162 MHz. VHF communications are essentially line-of-sight, and therefore their range is limited. The average ship-to-ship range is about 10 to 15 miles, while the average ship-to-shore range varies from 20 to 30 miles. Specific range depends upon transmitter power, antenna height and terrain.

D.2.1 VHF-FM Radio Equipment

D.2.1.1 Transmitter - The FCC requires that the transmitter power of VHF-FM be limited to 25 Watts for vessels. It also requires that the transmitter have the capability to reduce its power to no more than one watt for short-range communications.

D.2.1.2 Receiver - The performance of a VHF-FM receiver is crucial in marine communications. Its quality is specified by: sensitivity, and adjacent channel rejection.

Sensitivity is given as the number of microvolts required to produce 20 decibels (dB) of quieting. The smaller the number of microvolts required for the same quieting, the better the sensitivity of the receiver. For example, a sensitivity of 0.5 microvolts is better than one of 2.0 microvolts.

Adjacent channel rejection is one of several specifications that indicate the receiver's ability to reject noisy, unwanted signals and to accept the desired signals. Rejection is usually described with a negative number of dB. The larger the negative value of dB, the better the adjacent channel rejection of the receiver. For example, a receiver with an adjacent channel rejection of -70 dB should perform better than one with -50 dB.

D.2.2 VHF-FM Marine Channel Allocation

The VHF-FM marine band extends from 150 to 162 MHz. In the United States, the marine band is comprised of 48 channels including three weather channels. The number of channels installed in a single radiotelephone set will depend on how the set is to be used; as few as 12 channels may be adequate for some vessels, however, better communication capabilities are provided with more channels.

The FCC has designated each channel in the VHF marine band for use in various marine operations. Channel 16 (156.8 MHz) is the distress, safety and calling channel. It is the primary emergency channel in the VHF-FM band.

Vessels are required to maintain a listening watch on this channel at all times. Channel 6 (156.30 MHz) is an Intership Safety Channel, and vessels equipped with VHF equipment must have this channel installed in their unit. It must not be used for any non-safety communications. Other channels have been classified according to the subject matter of the communications. They are: Public Correspondence, Commercial, Non-Commercial, Port Operations, Coast Guard, and Weather.

D.2.3 Applications of VHF to the Great Lakes and St. Lawrence River

All commercial vessels, including the superlakers sailing on the Great Lakes and all commercial vessels sailing on the St. Lawrence River, are required by law to carry radiotelephone equipment.

The most widely used type of communication is VHF. Most of the vessels are equipped with at least one multi-channel VHF radiotelephone set. The radiotelephone system is used to: (1) monitor distress, safety and calling frequencies, (2) provide frequencies for communication between vessel and Federal and local agencies, (3) provide separate frequencies for communication between vessel and shore telephones, and (4) provide special frequencies for information regarding navigation, traffic management, commerce and recreation.

As a ship sails on the Great Lakes and St. Lawrence River, it must use the appropriate channel for the kind of communication it desires. For example, if a ship is in distress, it must use the appropriate distress channel to call for help. Ships sailing on the Great Lakes and St. Lawrence River must maintain a listening watch on channel 16 at all times. The only exception is in the Detroit and St. Clair River area where all ships are required to monitor a Sarnia Ontario Station Channel. The area is divided into two sectors. Channel 11 is allocated to the St. Clair River sector and Channel 12 to the Detroit River sector. When they move out of this area, they have to monitor channel 16 as before. This is done to relieve the congestion of channel 16 in that area.

Different marine operations are assigned different channels. A detailed description of the number of channels, the transmit and receive frequencies, and the use of each channel on the Great Lakes and St. Lawrence River is provided in Table D-1.

The procedures involved in making ship-to-ship and ship-to-coast calls are basically similar. In a ship-to-ship call, the radiotelephone is tuned to channel 16. If it is not in use, the transmitter is activated by depressing the push-to-talk button. The caller attempts to contact the other ship by calling out its name. The call initiator then identifies his ship by its name as well as its call sign. As soon as contact is established on channel 16, the caller must switch to an appropriate working channel to continue with the communication. At the end of the communication, both ships sign off by giving their call signs.

When making a ship-to-coast call, the procedure is the same except that the initial call is normally made on the working frequency assigned to the particular coast station involved.

D.2.4 Seaway Stations

The section of the water network from Montreal to the middle of Lake Erie has been divided into seven traffic control sectors. Located in each sector is a seaway station which is assigned a particular frequency for communication with vessels. See Figure D-1.

Any vessel intending to transit in this section of the Great Lakes and St. Lawrence River is required to keep a listening watch and to report in at a designated seaway station when sailing opposite a calling-in point (CIP) or a check point. When reporting in, the vessels must provide certain information. A table indicating check points, stations to call and message content is provided in Table D-2.

A downbound vessel passing through the St. Lambert Lock is required to switch to channel 10 (156.5 MHz) to obtain a traffic report from the Montreal Vessel Traffic Management Centre. After obtaining the report, it has to return

TABLE D-1. FREQUENCIES

Channel Number	Frequencies (MHz) Ship Transmit	Ship Receive	Intended Use of Channel
6	156.300	156.300	Intership safety - required on all VHF-FM equipped vessels for intership safety and for search and rescue (SAR) communications with ships and aircraft of the U.S. Coast Guard (USCG). It must not be used for non-safety purposes.
7A	156.350	156.350	Commercial (intership and ship-to-coast). Working channel for commercial vessels to conduct their daily business.
8	156.400	156.400	Commercial (intership). Same as channel 7A but limited to intership communications.
9	156.450	156.450	Commercial and non-commercial (intership and ship-to-coast). Used for communications with commercial marines and public docks to obtain supplies, schedule repairs and to contact other vessels about matters of mutual concern.
10	156.500	156.500	Commercial (intership and ship-to-coast). Similar to channel 7A.
11	156.550	156.550	Commercial (intership and ship-to-coast). Same functions as channel 7A but is used exclusively by USCG in certain ports for vessel traffic management.
12	156.600	156.600	Port Operations (intership and ship-to-coast). Is available to all vessels as a traffic advisory channel for use by agencies directing the movement of vessels in or near ports, locks, and waterways. In some ports, it is used exclusively by the USCG vessel traffic service.
13	156.650	156.650	Navigational (Ship's) Bridge to (Ship's) Bridge. Available but is not used on the Great Lakes.
14	156.700	156.700	Port Operations (Intership and Ship-to-Coast). Similar to Channel 12.

TABLE D-1. FREQUENCIES (Con't)

Channel Number	Frequencies (MHz) Ship Transmit	Ship Receive	Intended Use of Channel
15		156.750	Environmental (Receive Only). A receive only channel used to broadcast information relating to the weather, sea conditions, time signals for navigation, notices to mariners, etc.
16	156.800	156.800	Distress, Safety and Calling (Intership and Ship-to-Coast). It must be monitored at all times. The station is in operation except when actually communicating on another channel. This channel is also monitored by the Coast Guard, public coast stations and many limited stations. Calls to other vessels are normally initiated on this channel after which a switch should be made to a working channel.
17	156.850	156.850	State Control. A low power channel (1 watt) that is available to all vessels to communicate with ships and coast stations operated by state or local government. Messages are restricted to regulation, control and rendering assistance.
18A	156.900	156.900	Commercial (Intership and Ship-to-Coast). Similar to channel 7A.
19A	156.950	156.950	Commercial (Intership and Ship-to-Coast). Similar to channel 7A.
20	157.000	161.600	Port Operations (Intership and Ship-to-Coast). Same as channel 12 but is not used by the Coast Guard.
22A	157.100	157.100	Coast Guard Liaison. This channel is used for communications with USCG ships, coast and aircraft stations after initiating contact on channel 16. Navigation warnings and weather forecasts are also made on this channel. It is strongly recommended that every VHF radiotelephone include this channel.

TABLE D-1. FREQUENCIES (Con't)

Channel Number	Frequencies (MHz) Ship Transmit	Ship Receive	Intended Use of Channel
22	157.200	161.800	Public Correspondence (Ship-to-Coast). Is available to all vessels for communications with public coast stations. Channels 26 and 28 are the primary public correspondence channels and therefore become the first choice for the cruising vessel having limited channel capacity.
25	157.250	161.850	Public Correspondence (Ship-to-Coast). Similar to channel 24.
26	157.300	161.900	Public Correspondence (Ship-to-Coast). Similar to channel 24.
27	157.350	161.950	Public Correspondence (Ship-to-Coast). Similar to channel 24.
28	157.400	162.00	Public Correspondence (Ship-to-Coast). Similar to channel 24.
65A	156.275	156.275	Port Operations (Intership and Ship-to-Coast). Similar to channel 12.
66A	156.325	156.325	Port Operations (Intership and Ship-to-Coast). Similar to channel 12.
68	156.425	156.425	Non-Commercial (Intership and Ship-to-Coast). A working channel for non-commercial vessels. It is used to obtain supplies, and schedule repairs from yacht clubs or marines and for intership operational communications such as piloting or arranging for rendezvous with other vessels.
69	156.475	156.475	Non-Commercial (Intership and Ship-to-Coast). Similar to channel 68.
70	156.525	156.525	Non-Commercial (Intership). Similar to channel 68 but is limited to intership communications.

TABLE D-1. FREQUENCIES (Con't)

Channel Number	Frequencies (MHz) Ship Transmit	Ship Receive	Intended Use of Channel
71	156.575	156.575	Non-Commercial (Intership). Similar to channel 68.
73	156.675	156.675	Port Operations (Intership and Ship-to-Coast). Similar to channel 12.
74	156.725	156.725	Port Operations (Intership and Ship-to-Coast). Similar to channel 12.
77	156.875	156.875	Port Operations (Intership) Is limited to intership communications to and from pilots concerning the docking of ships.
78A	156.925	156.925	Non-Commercial (Intership and Ship-to-Coast). Similar to channel 68.
79A	156.975	156.975	Commercial (Intership and Ship-to-Coast). Similar to channel 7A.
80A	157.025	157.025	Commercial (Intership and Ship-to-Coast). Similar to channel 24.
84	157.225	157.225	Public (Intership and Ship-to-Coast). Similar to channel 24.
85	157.275	161.875	Public (Intership and Ship-to-Coast). Similar to channel 24.
87	157.025	157.025	Public (Intership and Ship-to-Coast). Similar to channel 24.
WX1	-	162.550	Weather (Receive Only). Used to receive weather broadcasts of the Department of Commerce, National Oceanic and Atmospheric Administration.
WX2	-	162.400	Weather (Receive Only). Similar to WX1.
WX3	-	162.475	Weather (Receive Only). Similar to WX1.

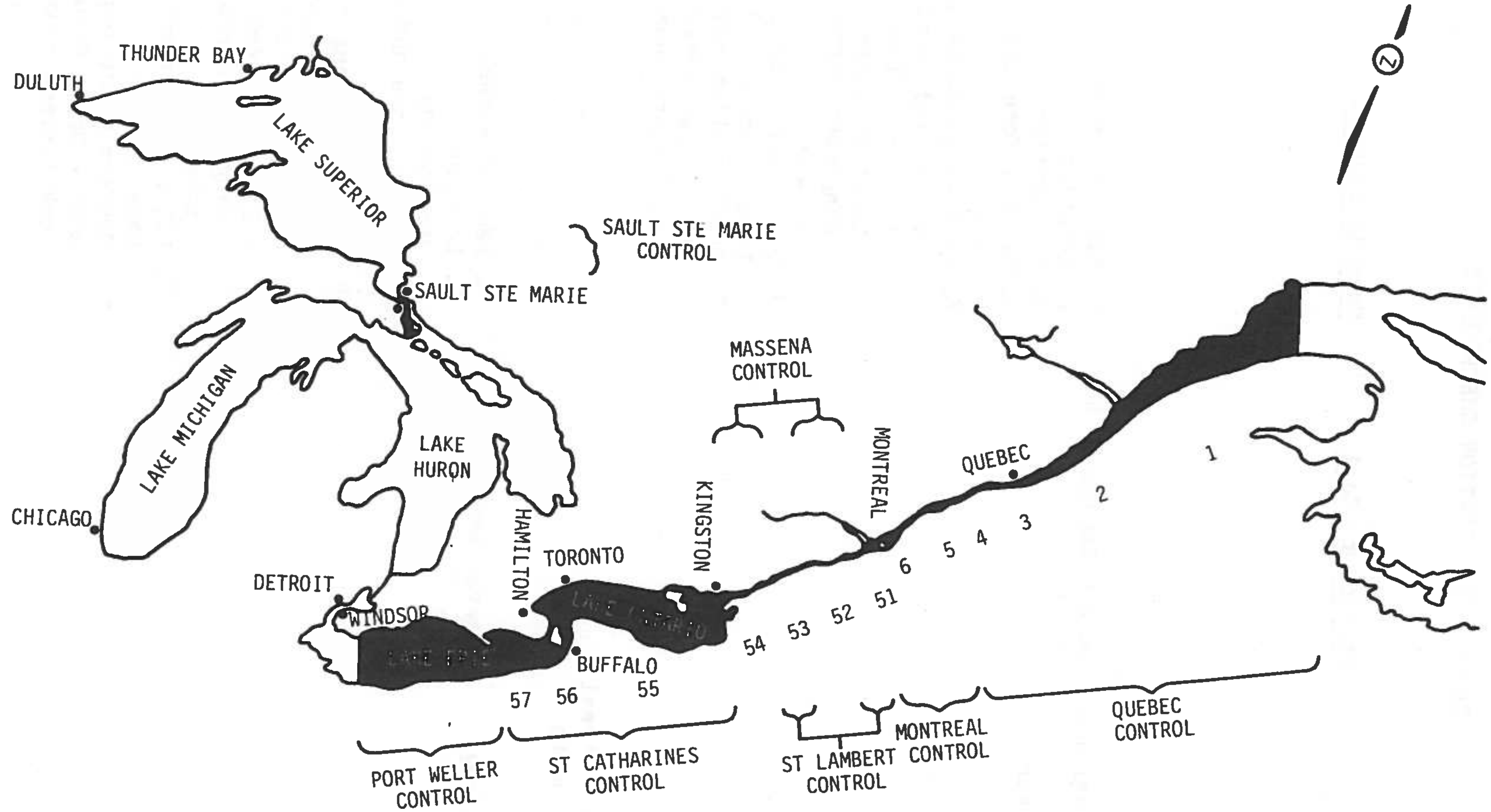


FIGURE D-1. GREAT LAKES-ST. LAWRENCE TRAFFIC CONTROL SECTORS

TABLE D-2. STATION CHECKPOINTS

CIP and Check Point	Station to Call	Message Content
Upbound Vessels		
1. CIP - Entering Sector 1 (order of passing through established)		
(a) Vessels transiting from the Lower St. Lawrence River	Seaway Beauharnois Ch. 14	1. Name of vessel 2. Location 3. Destination 4. Drafts, fore and aft 5. Cargo 6. Manifested dangerous cargo - Nature and quantity - IMO classification - Location where dangerous cargo is stowed 7. Pilot requirement - Lake Ontario 8. Confirm pilot requirement - Upper Beauharnois Lock (inland vessels only)
(b) Vessels in Montreal Harbour, dock, berth or anchorage		
(i) Before getting under way	Seaway Beauharnois Ch. 14	1. Name of vessel 2. Location 3. Destination 4. Drafts, fore and aft 5. Cargo 6. Manifested dangerous cargo - Nature and quantity - IMO classification - Location where dangerous cargo is stowed 7. Pilot requirement - Lake Ontario 8. Confirm pilot requirement - Upper Beauharnois Lock (inland vessels only)

TABLE D-2. STATION CHECKPOINTS (Con't)

CIP and Check Point	Station to Call	Message Content
(ii) CIP 2 - Enginering Sector 1 (order of passing through established)	Seaway Beauharnois Ch. 14	1. Name of vessel 2. Location
2. CIP 3 - (order of passing through established)	Seaway Beauharnois Ch. 14	1. Name of vessel 2. Location
3. Exiting Upper Beauharnois Lock	Seaway Beauharnois Ch. 14	1. Name of vessel 2. Location 3. ETA CIP 7 4. Confirm pilot requirement - Snell Lock (inland vessels only)
4. CIP 7 - Leaving Sector 1	Seaway Beauharnois Ch. 14	1. Name of vessel 2. Location
5. CIP 7 - Entering Sector 2	Seaway Eisenhower Ch. 12	1. Name of vessel 2. Location 3. Destination 4. Drafts, fore and aft 5. Cargo 6. ETA Snell Lock
6. CIP 8 - (ordering of passing through established)	Seaway Eisenhower Ch. 12	1. Name of vessel 2. Location
7. CIP 8A	Seaway Eisenhower Ch. 12	1. Name of vessel 2. Location
8. Exiting Eisenhower Lock	Seaway Eisenhower Ch. 12	1. Name of vessel 2. Location 3. ETA CIP II 4. Confirm pilot requirement - Lake Ontario 5. First U.S. port of call 6. ETA first U.S. port of call
9. CIP 11 - Leaving Sector 2	Seaway Eisenhower Ch. 12	1. Name of vessel 2. Location
10. CIP 11 - Entering Sector 3	Seaway Iroquois Ch. 11	1. Name of vessel 2. Location
11. CIP 12 - (order of passing through established)	Seaway Iroquois Ch. 11	1. Name of vessel 2. Location

TABLE D-2. STATION CHECKPOINTS (Con't)

CIP and Check Point	Station to Call	Message Content
12. Exiting Iroquois Lock	Seaway Iroquois Ch. 11	1. Name of vessel 2. Location 3. ETA Crossover Island
13. Crossover Island - Leaving Sector 3	Seaway Iroquois Ch. 11	1. Name of vessel 2. Location
14. Crossover Island - Entering Sector 4	Seaway Clayton Ch. 13	1. Name of vessel 2. Location 3. ETA Cape Vincent or River Port 4. Confirm pilot requirement - Lake Ontario
15. Wolfe Is. Cut (Beauvais Point) - Vessels leaving main channel	Seaway Clayton Ch. 13	1. Name of vessel 2. Location 3. ETA Kingston
16. Cape Vincent	Seaway Clayton Ch. 13	1. Name of vessel 2. Location 3. ETA Sodus Point 4. ETA Port Weller (CIP 15) or Lake Ontario Port 5. Pilot requirement - Port Weller
17. Sodus Pt.	Seaway Sodus Ch. 13	1. Name of vessel 2. Location 3. ETA mid-Lake Ontario 4. ETA Newcastle
18. Mid-Lake Ontario - Leaving Sector 4	Seaway Sodus Ch. 13	1. Name of vessel 2. Location
19. Mid-Lake Ontario - Engineering Sector 5	Seaway Newcastle Ch. 11	1. Name of vessel 2. Location 3. Manifested dangerous cargo - Nature and quantity - IMO classification - Location where dangerous cargo is stowed
20. Newcastle	Seaway Newcastle Ch. 11	1. Name of vessel 2. Location 3. Updated ETA Port Weller (CIP 15) or Lake Ontario Port 4. Confirm pilot requirement - Port Weller

TABLE D-2. STATION CHECKPOINTS (Con't)

CIP and Check Point	Station to Call	Message Content
21. CIP 15 - (order of passing through established)	Seaway Welland Ch. 14	1. Name of vessel 2. Location 3. Destination 4. Drafts, fore and aft 5. Cargo 6. Pilot requirement - Lake Erie
22. Port Colborne Piers	Seaway Welland Ch. 14	1. Name of vessel 2. Location 3. ETA Long Point
23. CIP 16	Seaway Long Point Ch. 11	1. Name of vessel 2. Location
24. Long Point - Leaving Sector 7	Seaway Long Point Ch. 11	1. Name of vessel 2. Location
25. (Revoked)		
26. (Revoked)		
Downbound Vessels		
27. (Revoked)		
28. (Revoked)		
29. Long Point - Entering Sector 7	Seaway Long Point Ch. 11	1. Name of vessel 2. Location 3. ETA CIP 16 4. Manifested dangerous cargo - Nature and quantity - IMO classification - Location where dangerous cargo is stowed
30. CIP 16 - (order of passing through established)	Seaway Welland Ch. 14	1. Name of vessel 2. Location 3. Destination 4. Drafts, fore and aft 5. Cargo 6. Pilot requirement - Lake Ontario
31. Exiting Lock No. 1 - Welland Canal	Seaway Welland Ch. 14	1. Name of vessel 2. Location 3. ETA Newcastle 4. ETA Cape Vincent or Lake Ontario Port 5. Pilot requirement - Cape Vincent

TABLE D-2. STATION CHECKPOINTS (Con't)

CIP and Check Point	Station to Call	Message Content
32. CIP -	Seaway Newcastle Ch. 11	1. Name of vessel 2. Location
33. Newcastle	Seaway Newcastle Ch. 11	1. Name of vessel 2. Location 3. ETA Mid-Lake Ontario 4. ETA Sodus Point
34. Mid-Lake Ontario Leaving Sector 5	Seaway Newcastle Ch. 11	1. Name of vessel 2. Location
35. Mid-Lake Ontario Entering Sector 4	Seaway Sodus Ch. 13	1. Name of vessel 2. Location 3. Manifested dangerous cargo - Nature and quantity - IMO classification - Location where dangerous cargo is stowed
36. Sodus Point	Seaway Sodus Ch. 13	1. Name of vessel 2. Location 3. Destination 4. Drafts, fore and aft 5. Cargo 6. Updated ETA Cape Vincent or Lake Ontario Port 7. Confirm river pilot requirement - Cape Vincent 8. Pilot requirement - Snell Lock and/or Upper Beauharnois Lock (inland vessels only)
37. Cape Vincent	Seaway Clayton Ch. 13	1. Name of vessel 2. Location 3. ETA Crossover Island or river port
38. Wolfe Is. Cut (Quebec Head) - Vessels Entering Main Channel	Seaway Clayton Ch. 13	1. Name of vessel 2. Location 3. ETA Crossover Island or river port
39. Crossover Island - Leaving Sector 4	Seaway Clayton Ch. 13	1. Name of vessel 2. Location

TABLE D-2. STATION CHECKPOINTS (Con't)

CIP and Check Point	Station to Call	Message Content
40. Crossover Island - Entering Sector 3	Seaway Iroquois Ch. 11	1. Name of vessel 2. Location 3. Destination 4. Drafts, fore and aft 5. Cargo
41. CIP 14	Seaway Iroquois Ch. 11	1. Name of vessel 2. Location
42. CIP 13 (order of passing through established)	Seaway Iroquois Ch. 11	1. Name of vessel 2. Location
43. Exiting Iroquois Lock	Seaway Iroquois Ch. 11	1. Name of vessel 2. Location 3. ETA CIP 10 4. Harbor or river pilot requirement - St. Lambert 5. Confirm pilot requirement - Snell Lock (inland vessels only)
44. CIP 10 - Leaving Sector 3	Seaway Iroquois Ch. 11	1. Name of vessel 2. Location
45. CIP 10 - Leaving Sector 2	Seaway Eisenhower Ch. 12	1. Name of vessel 2. Location
46. CIP 9 - (order of passing through established)	Seaway Eisenhower Ch. 12	1. Name of vessel 2. Location 3. ETA Snell Lock
47. Exiting Snell Lock	Seaway Eisenhower Ch. 12	1. Name of vessel 2. Location 3. ETA CIP 6
48. Buoy D47 - Lake St. Francis	Seaway Eisenhower Ch. 12	1. Name of vessel 2. Location 3. Confirm pilot requirement - Upper Beauharnois Lock (Island vessels only)
49. CIP 6 - Leaving Sector 2	Seaway Eisenhower Ch. 12	1. Name of vessel 2. Location
50. CIP 6 - Enginering Sector 1	Seaway Beauharnois Ch. 14	1. Name of vessel 2. Location

to guarding channel 14 (156.7 MHz) and remain on that channel until it has cleared the St. Lambert Lock chamber. When a vessel has cleared the St. Lambert chamber, its captain must call Seaway Beauharnois to request permission to switch to channel 10 (156.5 MHz). When Seaway Beauharnois grants permission, it also advises the downbound vessel of any upbound traffic that is about to enter CIP 2.

D.2.5 Lock Communications

A vessel traveling from Montreal to Duluth must transit sixteen locks on the Great Lakes and St. Lawrence River complex: seven in the St. Lawrence Seaway, eight in the Welland Canal, and one in the St. Marys River.

Within the lock area, instructions between vessels and lock operations are carried out via a loudspeaker system. The exception is in the Flight Locks (Locks 4, 5 and 6 of the Welland Canal) and the Soo lock where portable radiotelephones are used.

Radio communications procedures in effect in the Flight Locks are:

1. Acknowledge the initial call from the lockmaster.
2. Answer all subsequent calls from the lockmaster whenever possible.
3. Upbound Vessels: The lockmaster, at Lock 3, is required to place a portable radio set onboard all ocean and inland vessels in excess of 190 meters in length and ensure that the channel selector is set at position "1", which is referred to as the "west" channel. This channel is to be used by upbound vessels only and should not be altered once the set is placed onboard. The radio is removed from the vessel at Lock 7.
4. Downbound Vessels: At Lock 7, the lockmaster places a portable radiotelephone set onboard all ocean and inland vessels in excess of 190 meters in length and makes sure that the channel selector is set at position "2", also known as the "east" channel. This channel is restricted to downbound vessels only and should not be changed once the radio set is onboard. The radio set is removed at Lock 3.

D.2.6 VHF Public Coast Stations and Lorain Radio

The VHF-FM public coast stations are also known as Public Class III-B Coast Stations. Channels 24, 25, 26, 28, 84, 85, 86 and 87 in the VHF marine band have been assigned to public coast stations for public correspondence purposes. It is through these stations that ships may make and receive telephone calls to and from any telephone with access to the nationwide network, including overseas telephones and telephones on other ships and aircraft. Various companies, own and operate public coast stations around the Great Lakes and St. Lawrence River, but Lorain Electronics Corporation owns and operates the most.

Lorain Electronics Corporation of Ohio owns and operates Lorain Radio. They presently own 15 operational VHF public coast stations, and they propose to build 6 additional new stations around the Great Lakes. The start of the 1986 shipping season in the Great Lakes saw most U.S. bulk fleets terminating their contracts with Lorain Electronics. Four U.S. companies remained with the network others are investigating alternatives. See Figure D-2.

The procedures for making and receiving radiotelephone calls through a public coast station are listed below.

D.2.6.1 Placing a Ship-to-Ship Call -

1. Select the channel assigned to the desired coast station.
2. If the channel is busy, wait for it to clear or switch to an alternate channel if available.
3. If the channel is not busy, press the push-to-talk button, call out the name of the coast station, and identify the ship by its call sign.
4. When the coast station replies, give the name of the ship, its call sign and its telephone number, as well as, the city and telephone number to be called.

D.2.6.2 Receiving a Shore-to-Ship Call - VHF coast stations call on channel 16 unless a ship has ringer service in which case the coast station will dial the number on a working channel.

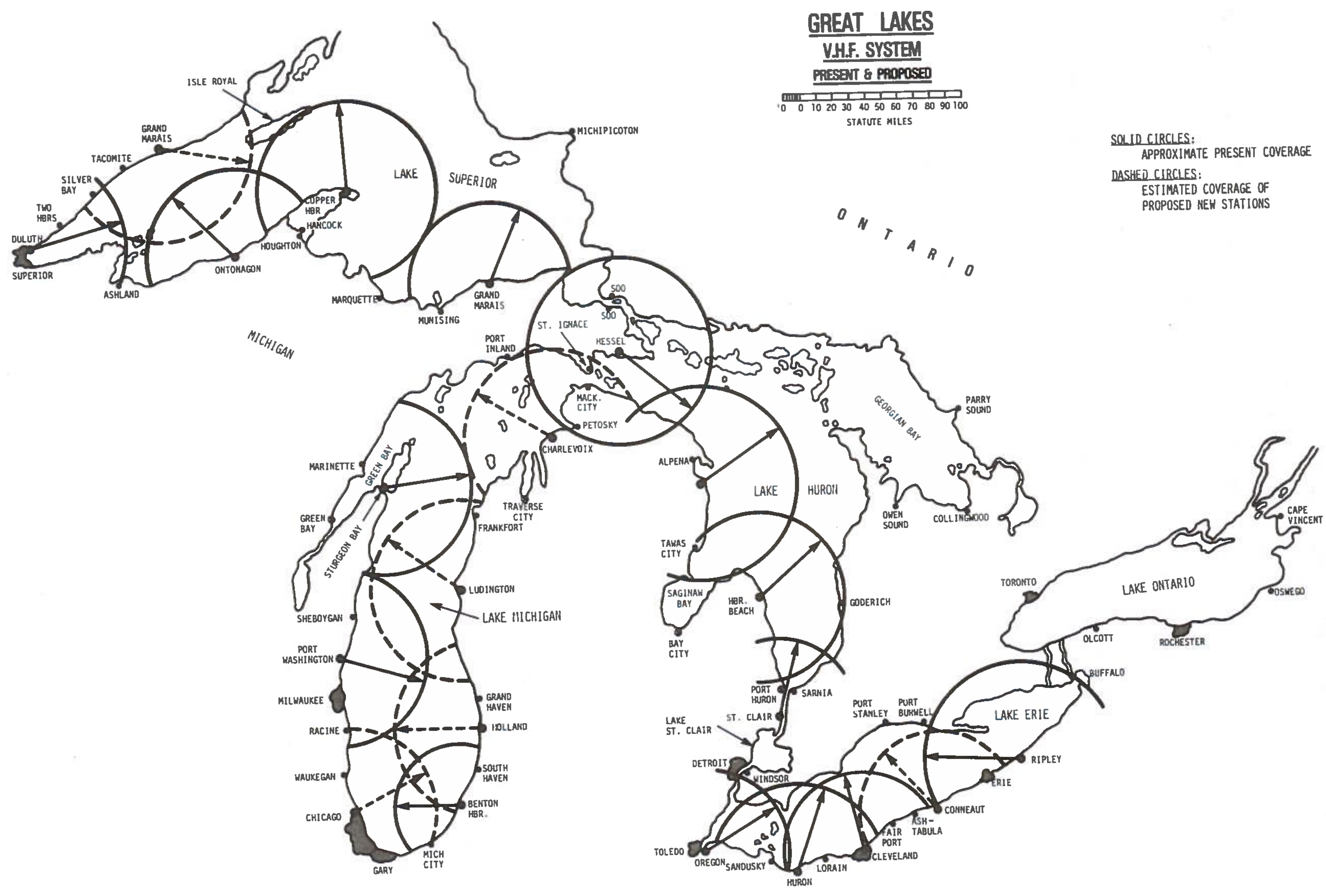


FIGURE D-2. GREAT LAKES VHF SYSTEM PRESENT AND PROPOSED

D.2.6.3 Placing a Shore-to-Ship Call - Shore-based calls are placed through a common carrier network to the coastal station network. If the working channel of the appropriate coastal station is not in use, the call is completed as described above. If the working channel is busy, the caller receives a busy signal or is informed by the station operator that the channel is busy. In either case, the call initiator terminates the connection. This procedure continues until the call is completed or until the caller decides to stop trying. Because a shore-based caller cannot monitor the working channel to determine when the channel is available, it is probable that multiple attempts to call a ship will have to be made before the shore-to-ship connection is made. This tends to increase frustration in those needing to contact ships on the waterway network. This is especially true in areas of high traffic where the working channels are heavily used.

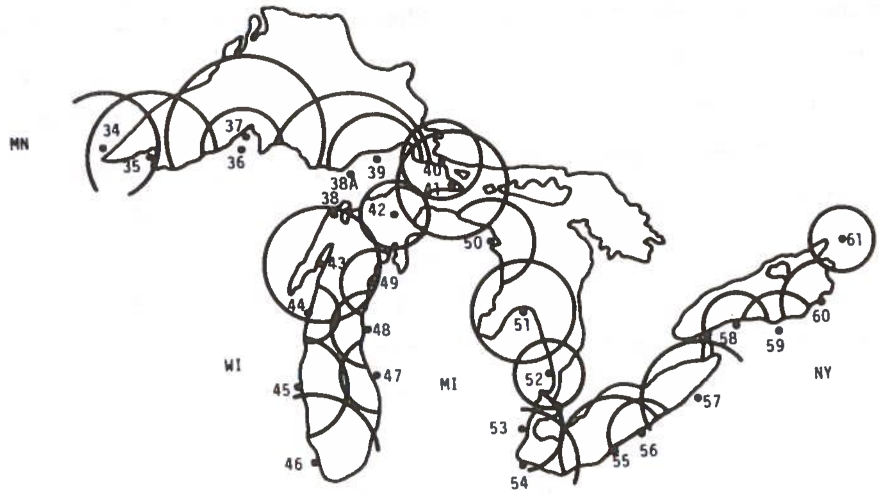
D.2.7 Coast Guard

The Coast Guard owns and operates 29 VHF-FM shore stations around the Great Lakes as part of its National VHF-FM Distress System. See Figure D-3. Each station provides complete communications coverage to about 20 miles offshore.

A number of channels in the VHF marine band have been assigned to provide communications with the Coast Guard. The Coast Guard is always monitoring channel 16, and any vessel in distress or needing assistance can communicate with the Coast Guard on this channel. If the vessel is not in any immediate danger, it is shifted to channel 22A for further communications in order to keep channel 16 open for emergency calls.

D.3 SATELLITE COMMUNICATIONS

In general, the use of satellites in telecommunications is widespread, and new applications are being implemented almost on a daily basis. Satellites have allowed the transfer of business data to and from offices from one continent to another in a matter of a few seconds. Making international calls is now as easy as placing a long distance call. Satellite communications have two major segments: the space segment and the ground segment.



	SITE	LAT/LONG	CONTROL POINT	ELEV
34	DULUTH, MN	46.46N 92.05W	GROUP DULUTH	806
35.	BAYFIELD, WI	46.49N 95.50W	GROUP DULUTH (Remote site) Alternate control Bayfield	710
36.	HANCOCK, MI	47.11N 88.35W	GROUP DULUTH (Remote site) Alternate control Portage Station	625
37.	CALUMET AFS, MI	47.22N 88.10W	GROUP DULUTH (Remote Site) Alternate control of Portage Station	1010
38.	ESCANABA, MI		Group Milwaukee (control) Alternate Station Sturgeon Bay	
38A.	MUNSING, MN	46.25N 86.59W	GROUP SAULT STE. MARIE (Remote site) Alternate control Marquette Station	
39.	GRAND MARIAS, MI	46.35N 86.59W	GROUP SAULT STE MARIE (Remote site)** Alternate control Grand Marias Station	750
40.	SAULT STE. MARIE, MI	46.30N 84.20W	GROUP SAULT STE. MARIE Alternate control COTP Sault Ste. Marie	305
41.	GOETZVILLE, MI	46.03N 84.05W	GROUP SAULT STE. MARIE (Remote site) Alternate control St. Ignace Station	1121
42.	BEAVER ISLAND, MI	45.34N 85.34W	CHARLEVOIX STATION (Remote site)	310
43.	STURGEON BAY, WI	44.54N 87.22W	GROUP MILWAUKEE (Remote site) Alternate control Sturgeon Bay	776
44.	TWO RIVERS, WI	44.08N 87.33W	GROUP MILWAUKEE (Remote site) Alternate control Two Rivers	95
45.	MILWAUKEE, WI	43.06N 87.53W	GROUP MILWAUKEE (Remote site)	550
46.	CHICAGO, IL	41.53N 87.37W	GROUP MILWAUKEE (Remote site) Alternate control Calumet Harbor Station	537
47.	WEST OLIVE, MI	42.54N 86.12W	GROUP MUSKEGON (Remote site) Alternate control Muskegon Station	393
48.	LUDINGTON, MI	44.01N 86.30W	GROUP MUSKEGON (Remote site) Alternate control Ludington Station	350
49.	FRANKFORT, MI	44.38N 86.14W	GROUP MUSKEGON (Remote Site) Alternate control Frankfort Station	290
50.	ALPENA, MI	44.51N 83.25W	GROUP DETROIT (Remote site) Alternate control Texas Station	521
51.	PORT AUSTIN AFS, MI	44.01N 83.00W	SAGINAW RIVER STATION Alternate control Port Huron Station	260
52.	PORT HURON, MI	43.00N 82.25W	GROUP DETROIT (Remote site)** Alternate control Port Huron	175
53.	DETROIT, MI	42.21N 83.00W	GROUP DETROIT (Remote site)** Alternate control Belle Isle Station	550
54.	TOLEDO, OH	41.40N 83.22W	MARBLEHEAD STATION Alternate control Toledo Station	570
55.	CLEVELAND, OH	41.30N 81.41W	CLEVELAND HARBOR STATION Alternative control COMMCEN Cleveland	600
56.	ASHTABULA, OH	41.54N 80.47W	ASHTABULA STATION	150
57.	FORESTVILLE, NY	42.28N 79.14W	GROUP BUFFALO (Remote site)	930
58.	30 MILE POINT, NY	43.23N 78.29W	GROUP BUFFALO	210
59.	ROCHESTER, NY	43.16N 77.38W	GROUP BUFFALO (Remote site) Alternate control Rochester Station	190
60.	OSWEGO, NY	43.27N 76.31W	GROUP BUFFALO (Remote site) Alternate control Oswego Station	543
61	ALEXANDRIA BAY, NY	44.19N 75.59W	ALEXANDRIA BAY STATION	225

FIGURE D-3. U.S. COAST GUARD NATIONAL VHF-FM DISTRESS SYSTEM, 9TH DISTRICT

The space segment consists of one or more satellites placed into geostationary orbits approximately 22,000 miles above the equator or in elliptical orbits around the north or south hemispheres. Most of the commercial satellites owned by the United States are in geostationary orbit. They use ground stations that are fixed in position and aimed at the satellites. The ground stations are able to track any slight shift in the satellites' positions. There are presently 20 American and 6 Canadian commercial geostationary satellites.

Satellite communication is achieved through microwave radiation. During the transmit phase of messages, the ground station converts the incoming signals from the user to a gigahertz (GHz) frequency and then transmits them to the satellite. The satellite receives the signals and converts them into a lower GHz frequency. The signals are then amplified and retransmitted back to earth. During the receive mode, the ground station picks up the signals, processes them and sends them to the appropriate user.

D.3.1 The INMARSAT Satellite System

The International Maritime Satellite Organization (INMARSAT) is a consortium of 40 maritime nations. It provides global maritime satellite comunications. The system is growing rapidly and INMARSAT predicts that by the year 1990 its satellites will be handling some 12 million minutes of telephone and 20 million minutes of telex traffic.

INMARSAT has three satellites placed in geostationary orbit, and there are eight operational coastal earth stations (CES) located in different parts of the world: two in the United States, two in Japan, one in Norway, one in the United Kingdom, one in Singapore, and one in Kuwait. There are at least 6 CESs under construction, and it is projected that there will be as many as 22 by the end of 1987. Calls to and from vessels on the Great Lakes and St. Lawrence River are normally routed through the U.S. station at Southbury, CT.

Presently, INMARSAT provides the following services:

1. Telephone: automatic calling from ship-to-shore and in some cases semi-automatic calling from shore-to-ship.

2. Telex: automatic interconnection from ship-to-shore or shore-to-ship within the worldwide telex network.

3. Priority access to the satellites in the event of an SOS alert and instantaneous connection with the appropriate rescue coordination center.

4. High speed data transmissions from ship-to-shore (56,000 BPS)

5. High quality facsimile transmission via a telephone channel.

6. Group broadcasting: The same information can be sent to a number of users in a given ocean area at the same time.

The INMARSAT system comprises three major segments: satellites, coastal earth stations (CES), and ship earth stations (SES).

The CESs are owned and operated by the participating nations. They establish and control all communications on the system. Each CES has three major components: a parabolic antenna system; radio frequency equipment; and access, control and signaling equipment (ACSE).

The parabolic antenna is between 33 and 43 feet in diameter. It transmits signals to the satellites in the 6 GHz band and receives in the 4 GHz band.

The radio frequency component consists of an upconverter which receives the signals in the intermediate range frequencies and converts them into the GHz range. The signals are then amplified to a specified level and sent to the antenna for transmission to the satellite.

The ACSE is a complex computer-controlled switching, testing and auditing system which provides connections to the international network.

The SES consists of two main components: above deck equipment (ADE) and below deck equipment (BDE). The ADE consists of a stabilized parabolic antenna aimed at the satellites, a duplexer to separate the transmitted signals from the received signals, a high power transmitting amplifier, a low noise receiving amplifier and a power supply. The ADE is housed in a fiberglass radome for protection from the weather and other corrosive elements.

The BDE is usually rack mounted or set in a desktop console. It typically consists of a telephone, telegraph and facsimile equipment as well as a microcomputer.

D.3.2 Applications Of INMARSAT To The Great Lakes And St. Lawrence River

The INMARSAT system was designed specifically to provide maritime communications. The system is already in place and is operational. The satellite which covers the Atlantic Ocean area also covers the Great Lakes and St. Lawrence River. With the exception of marginal coverage in the Port of Duluth area, all other parts of the Great Lakes and St. Lawrence River are adequately covered by INMARSAT.

At present, there are six U.S. registered commercial lakers operating on the Great Lakes that is equipped with satellite communications equipment. They belong to American Steamship Company or Oglebay Norton Company. In August 1982, the American Steamship Company fitted the MV/Indiana Harbor with a satellite communication terminal. It consists of a telephone, a telex machine and a computer. The telephone is used on a daily basis to make ship-to-ship and ship-to-shore calls and to receive calls from the shore.

To initiate a call from the ship, the captain has to transmit a call request. This is achieved by transmitting a code which consists of a short burst of signals. The code contains the identity of a particular CES through which the ship wishes to communicate, the nature of the information being transmitted and the identity of the ship making the call. The code is transmitted at a data rate of 4800 bits/second on one of two dedicated request channels. The two channels are provided to ensure that access is still possible even if one of them is not usable. The importance of the code is to provide security during communications. All calls to and from the MV/Indiana Harbor are routed through the United States CES at Southbury, CT.

The American Steamship Company is currently experimenting with a variety of innovative applications of the INMARSAT capabilities. These include digital transmission of semi-daily reporting functions, facsimile transmission of bills of lading as well as other pertinent forms, and computer-to-computer transfer of administrative data files such as payroll and logistic data. The company reports that use of the digital communication capabilities of INMARSAT has: (1) reduced the overall costs of communication, (2) made the communication activities more effective, and (3) provided more information in a timely fashion for those that need it. At the present time, American Steamship Company is conducting feasibility studies regarding the installation of INMARSAT ship earth stations in the rest of its fleet.

D.4 MF/HF-SSB SYSTEM

The medium frequency band (MF) extends from 0.3 to 3 MHz, and the high frequency band (HF) extends from about 3.1 to 30 MHz. In each band, the signals are propagated by both groundwaves and skywaves. The skywaves are refracted and reflected by the ionosphere and are returned to earth a great distance away from their point of origin. In this way, they can be used for very long range radio communications. The MF band has a range of 50 to 150 miles and the HF band has a range up to hundreds and even thousands of miles.

The radiotelephones used in both the MF and HF bands work in the single-sideband (SSB) mode. The single-sideband technique in communications is when only one of the sidebands of a modulated signal is used. The upper sideband is normally used. The major advantage derived from using single-sideband equipment is to reduce the bandwidth of the transmitted signals by about 60 percent and thereby increase the number of transmission channels.

There are several MF and HF frequencies available for ship-to-shore as well as ship-to-ship communications. The frequencies are assigned to different marine operations and must only be used for those operations to which they are assigned.

All ship radiotelephone stations operating in the MF marine band must be capable of operating on 2182 KHz, which is the international distress and calling frequency. Table D-3 lists the most commonly used frequencies and their intended use on the Great Lakes and St. Lawrence River.

TABLE D-3. COMMONLY USED FREQUENCIES

Frequency (KHz)	Intended Use
2003	Intership and business communication
2082.5	Intership and business communication
2638	Intership and business communication
2670	Ship-to-coast (communication with the USCG stations only). Also used to receive Coast Guard weather and traffic management broadcasts.

D.4.1 Application Of The MF/HF-SSB System To The Great Lakes And St. Lawrence River

MF and HF bands are used for marine communications on the Great Lakes and St. Lawrence River to a certain extent. They operate in the SSB mode and are used for long range communications. Their use must be confined to those areas that are beyond normal VHF coverage, and they must not be used in ports and harbors. The FFC requires that a vessel be equipped with a VHF radiotelephone before installing a SSB radiotelephone intended for use in the HF and MF marine bands.

The output power of most SSB radiotelephones is between 50 and 150 watts. The choice of power will depend on the required range. SSB radiotelephones requires a good grounding system and therefore care should be taken during the installation.

The procedures involved in making and receiving intership and ship-to-shore calls are basically the same as for VHF radiotelephones with the exception that the emergency and calling frequency is 2182 KHz.

D.4.2 MF/HF Public Coast Stations

There are three MF/HF public coast stations on the Great Lakes that provide public correspondence services. They are Rogers City radio station (WLC) in Michigan, Buffalo radio station (WBL) in New York and Lorain Radio (WMI) of Ohio. Similar to the VHF public coast stations, ships may make and receive telephone calls to and from telephones with access to the nationwide telephone network, including overseas telephones and telephones on other ships and aircraft.

Rogers City radio station is owned and operated by the United States Steel Company. It is equipped with HF-SSB equipment most of which is of the old tube type, but plans are underway to acquire modern equipment that will provide greater coverage and confidentiality in communications. The station also provides some VHF-FM services. There are three VHF remote sites situated at Transverse City, Charlevoix and Sault St. Marie, Michigan.

The HF-SSB broadcasts are full duplex and operate on the following frequencies shown in Table D-4.

TABLE D-4. H-F-SSB BROADCAST FREQUENCIES

Transmit (KHz)	Receive (KHz)
2514.0	2118.0
4369.8	4075.4
8796.4	8272.5

The information routed through the station includes traffic movement, search and rescue (SAR) operations with the Coast Guard, ship-to-shore calls, and business operations. The station also provides weather broadcasts.

D.5 WATERCOM

WATERCOM is a developing communication system on the Mississippi, Illinois, and Ohio Rivers. It is included in this report because some of the vessels transiting the Illinois River also transit the Great Lakes.

The WATERCOM system is designed to provide telephone services to all member vessels on the Mississippi, Illinois, and Ohio Rivers. It also will provide two special data communication services: emergency broadcasts, and automatic data readouts.

The system utilizes VHF-FM technology operating in the 216-220 MHz frequency range. The frequency range is divided into 120 channels spaced at 125 KHz, with 1.5 MHz separations between the shore transmit/ship receive and ship transmit/shore receive frequencies. The channel frequencies are divided into three groups: A, B, and C. Each group has 40 channel frequencies. Each shore station along the inland waterway will be assigned a frequency group (A, B, or C) which is different from the two adjacent shore stations. This allows frequency reuse and reduces channel interference. The ship's transceiver must be able to switch between groups A, B, and C depending on the operating group of the shore station to which it is closest. The SELCALL system at each shore station will automatically poll each ship in its area of coverage. Calls to and from a vessel will use the set up frequency to establish a connection and to automatically switch the transceiver to an open frequency.

At the present time, the WATERCOM frequencies with the range of 216-220 MHz are not used on the Great Lakes and the St. Lawrence River. If the WATERCOM VHF-FM transceivers are not capable of operating in the marine bands discussed before this, a marine radio must be installed.

If the WATERCOM system frequencies were made available for use on the Great Lakes and St. Lawrence River, several communications problems could be solved. Ship-to-shore and shore-to-ship congestion would be greatly reduced. Also, the WATERCOM system provides data transmission capability which could greatly reduce the time required for vessels to make their periodic reports to the company. Vessel traffic management information, weather data, and dynamic water depth information could be communicated without totally congesting the system.

D.6 SUMMARY

The first three communications systems, VHF-FM, MF/HF-SSB, and INMARSAT described in this report are all in place and are operational. They provide ship-to-ship, ship-to-shore and shore-to-ship communications. The information contained in the communications includes emergency calls, vessel traffic management, weather broadcasts and other marine business operations. The fourth system, WATERCOM, is a developing communications system which is presently not used on the Great Lakes and St. Lawrence River.

The VHF-FM system is the primary communications system on the Great Lakes and St. Lawrence River. It is an FCC requirement for all commercial vessels to be equipped with a multi-channel VHF radio. The system is fully developed, is reliable and readily available. Its biggest drawback is channel congestion especially in the western part of Lake Erie and the Detroit and St. Clair Rivers.

The MF/HF-SSB system is intended for use in long-range communications and as a backup for VHF-FM. It is only used in those areas that lack VHF-FM coverage. The system is well developed and is readily available.

The INMARSAT system is already in place, readily available and very reliable but is presently used by only one United States registered laker operating in the Great Lakes. In August 1982, the American Steamship Company pioneered the use of satellite communication on the Great Lakes by fitting a satellite terminal on one of their ships the MV/Indiana Harbour.

Various shipping companies are presently exploring the feasibility of equipping their own fleet with satellite communications.

The overall communications on the Great Lakes and St. Lawrence River seems adequate at this time. However, the expected growth in annual trade will mean an increase in the number of commercial ships. Therefore, it is essential at this time to study ways of overcoming any limitations on communications to meet the future needs of the maritime industry. A number of studies in the past two decades have addressed the expected growth in annual trade with rather peak accuracy. A modular system which can be expanded as traffic increases will lessen the dependence on accurate forecasts.

Appendix D References:

1. Powell, Jerry and Charles K. Nsibirwa, Maritime Radio Communications Study, Great Lakes-St. Lawrence River, DTRS-57-84-C-00001, B & M Technological Services, Inc. (April, 1985).

2. Maritime Telecommunication Study, Great Lakes-St. Lawrence River, DTRS-57-84-P-81179, B&M Technological Services, Inc. (August, 1984).

APPENDIX E
PRESENT SHIP INFORMATION SYSTEMS

E.1 ST. LAWRENCE RIVER AND WELLAND CANAL

Traffic on the St. Lawrence River is regulated mainly in the vicinity of the locks. In the east, a traffic control center is located at the lock at St. Lambert near Montreal; in the west the center is at St. Catherines near the northern end of the Welland Canal. In the Montreal-Lake Ontario section, locks are instrumented with some combination of ultrasonic, microwave or sonar sensors that automatically report and record vessel progress through the locks. In both the St. Lawrence River and Welland Canal sections, closed circuit television provides positive vessel control within critical lock areas. This visual capability provides rudimentary traffic control over Montreal-Lake Ontario and Welland Canal operations.

The U.S. role in traffic control on the St. Lawrence River is centered about operations of the Snell and Eisenhower Locks and the Thousand Islands section of the river. The U.S. uses manual control through its sectors of responsibility along with closed circuit television within the vicinity of the locks. The control center is located at the Eisenhower Lock at Massena, NY.

There are eight control sectors in the Great Lakes-St. Lawrence River System. The Montreal, Quebec and Port Weller Control sectors are operated by the Canadian Ministry of Transport. St. Catherines Control is operated by the St. Lawrence Seaway Authority. The Montreal to Lake Ontario section is operated jointly by the U.S. and Canada. The St. Lambert sector is the responsibility of the St. Lawrence Seaway Authority. The Massena sector is controlled by the St. Lawrence Seaway Development Corporation. A vessel must call in to the appropriate traffic control center and report its current position, speed, and estimated time of arrival at the next point.

The locks in the Great Lakes-St. Lawrence River System currently operate on a first come, first served basis. In the Welland Canal, a central control area with closed circuit televison, display boards, and a communication network is used to aid in controlling the movement of traffic. The Canadian operated locks in the St. Lawrence River are operated in the same manner. These locks each have approach walls with up to three limit-of-approach signs on each wall to indicate mooring locations for vessels waiting to enter the lock. They receive proceed or wait instructions by means of signal lights mounted on the limit of approach signs. Also, there is a panel of signal lights at each lock which depicts lock status and the time left before it will be available to the next ship.

The U.S. operated locks both have approach walls with two limit-of-approach signs on each to indicate waiting positions for vessels preparing to enter the lock. There are eight berthing stations along the approach wall at which waiting ships can moor.

Traffic at each U.S. lock is controlled by a single panel of signal lights for each direction. The lights indicate either the lock is not ready, the lock is being prepared, or the lock is ready and the ship can proceed into the lock. Mooring lines at the tie-up walls are handled by lock personnel at all of the St. Lawrence River locks.

E.2 GREAT LAKES

On the lakes, ship information consists mainly of weather and marine information broadcasts. Safety and distress signals can also be broadcast. Channel 16 (VHF, 156.8 MHz) may be used to transmit and receive distress, urgent, and safety information. Channel 22A (157.1 MHz) is the Coast Guard working and broadcast frequency. After establishing communications with the Coast Guard on Channel 16, a shift to this channel is made. All Coast Guard Marine Information Broadcasts are made on 157.1 MHz.

Channel 12 (156.6 MHz) is a port operations frequency. The use of this frequency is restricted to communications involving vessel movements and/or information which affects the safety of vessels or persons.

The Coast Guard has three types of broadcasts:

1) Scheduled Broadcasts - These include important notices to mariners, oceanographic information, storm warnings, advisories. They are broadcast every three hours.

2) Safety Broadcasts - These include information so important to the safety of navigation such that a delay in its dissemination would definitely create a hazard to boating/shipping.

3) Urgent Broadcasts - These include information concerning the safety of a ship, aircraft or other vehicle, or the safety of a person.

Besides the USCG, there are marine forecasts broadcast by NOAA and private stations. The NOAA forecasts can be found on frequencies 162.40 and 162.55 MHz. They are broadcast 24 hours daily. Private stations include those operated by Lorain Electronics (156.850 MHz, Channel 17, broadcast twice daily) and Central Radio (161.9 MHz, Channel 26; 2514 KHz, Channel 57, both broadcast twice daily).

Detailed information on marine information broadcasts may be found in Appendix D.

The source of weather forecasts on the Great Lakes originate from one of four National Weather Service Marine Weather Forecasting Centers. Weather forecasts for Lake Ontario and Lake Erie are prepared in Buffalo, New York and Cleveland, Ohio. Meteorologists in Ann Arbor, Michigan and Rosement, Illinois track and project the weather for Lakes Superior, Michigan and Huron.

Position reporting on the Great Lakes has been discussed in the previous section. In addition to those areas mentioned, there are call-in points at either end of the St. Marys River and a number of call-in points while transmitting the river.

E.3 ST. CLAIR/DETROIT RIVERS

The St. Clair and Detroit River System, including Lake St. Clair, is serviced by a voluntary Vessel Traffic Management system in Canadian waters from Long Pont in Lake Erie through the Detroit and St. Clair Rivers to False Detour Channel in Lake Huron. The system is designed to enhance the safe and expedious movement of marine traffic by encouraging the monitoring of a common radio frequency by vessels within each sector of the system. The system provides users with information on traffic situations pertaining to no meeting zones, as well as information to pilots, the St. Lawrence Seaway Authority, the public, vessel owners, and shipping agents.

The system is divided into 3 sectors:

1. Sector 1 - VHF Channel 12 (156.60 MHz), Lake Erie entrance and the Detroit River.

2. Sector 2 - VHF Channel 11 (156.55 MHz), Lake St. Clair and St. Clair River.

3. Sector 3 - VHF Channel 11 (156.55 MHz), Lake Huron entrance.

The Vessel Traffic Management (VTM) system is administered by a VTM Center at Sarnia, Ontario at the head of the St. Clair River.

Depth of water in this and other channels varies because of daily and seasonal weather conditions plus silting caused by channel flow. The COE has gauge stations that continuously record water levels. The Detroit District of the Corps publishes these records on the 5th and 20th of each month in a document called the "Great Lakes and Connecting Channels Water Levels and Depths", NCE Form 11. This flyer shows the average water levels for that date, the existing levels, and the expected levels for the next reporting date. These water levels are shown for each of the Great Lakes, the St. Lawrence River, the Detroit River, the St. Clair River, and the St. Marys River.

E.4 ST. MARYS RIVER

The St. Marys River sector is controlled by the ninth District Coast Guard. The Soo Locks are controlled by the COE with the exception of the smaller Canadian lock, which is controlled by the Sault Ste. Marie Canal authorities.

The Soo Locks consist of five parallel locks: Poe, MacArthur, Sabin, Davis, and Canadian. Each lock has its own pier which can accommodate several ships in a queue. Signal lights, operated by the lockmaster, control the flow of traffic at the Soo Locks. As vessels approach, they are directed by means of the signal lights and radio communication. VHF channels 14 and 16 are used.

Appendix E References:

1. "Enhancing Weather Forecasting on the Great Lakes," Seaway Review (September, 1984).

2. United States Coast Pilot, 6, Great Lakes (April, 1983).

APPENDIX F

DESCRIPTIONS OF WATERWAYS AND REACHES

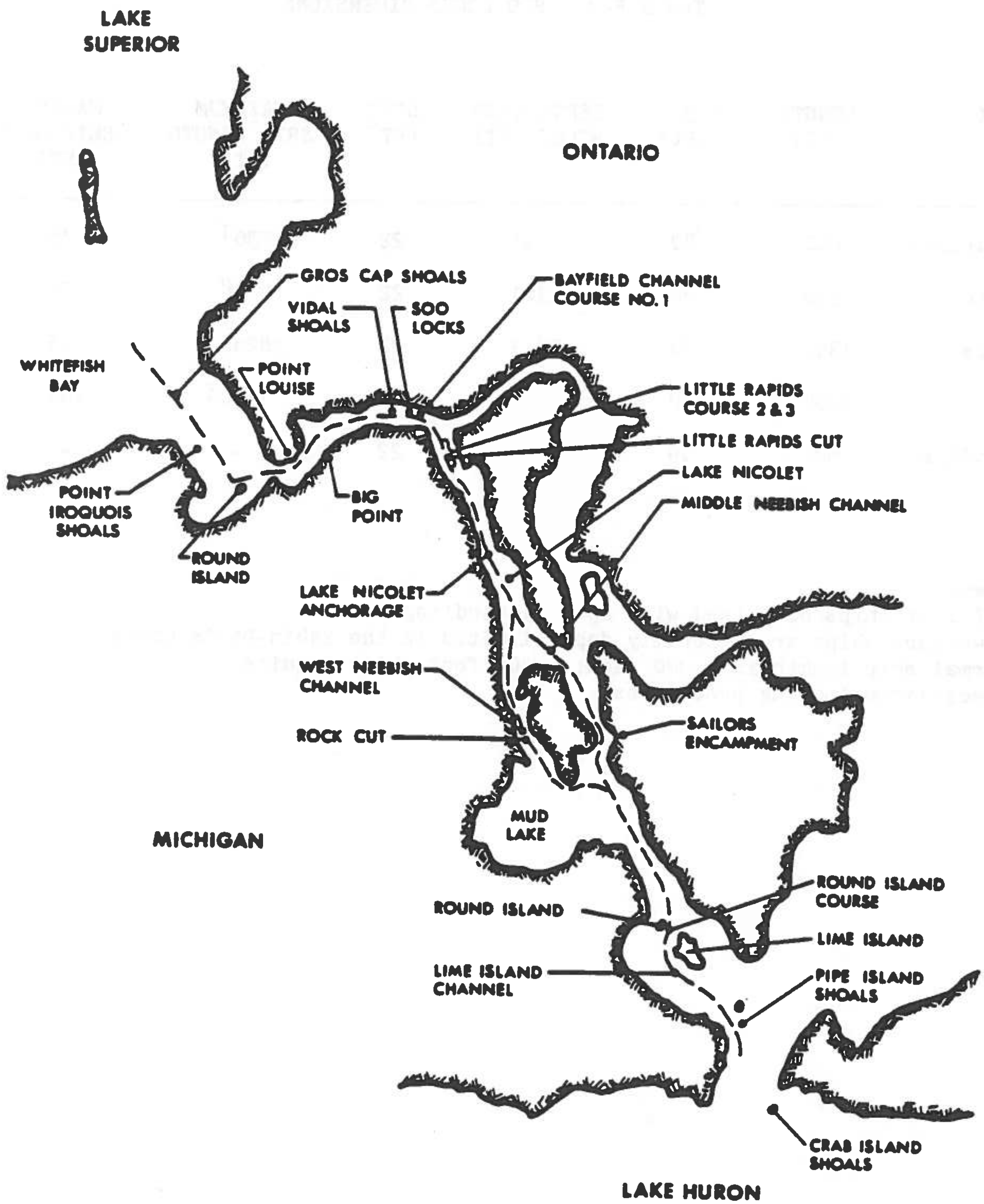


FIGURE F-1. ST. MARYS RIVER CHANNEL

TABLE F-1. SOO LOCKS DIMENSIONS

LOCK	LENGTH (FT)	WIDTH (Ft)	DEPTH OVER SILLS (FT)	LIFT (FT)	MAXIMUM SHIP LENGTH (FT)	MAXIMUM SHIP BEAM (FT)
MacArthur	800	80	31	22	730[1]	75
Sabin	1350	80	23.1	22	826[2]	75
Davis	1350	80	23.1	22	826	75
Poe	1200	110	32	22	1100[3]	105
Canadian	900	59	16.8	22	-	-

Notes:
[1] 767 foot ships permitted with special handling.
[2] Downbound ships are generally depth-limited in the Sabin-Davis Locks.
[3] Normal ship length is 1,000 feet; 1,100 foot ships require specialized locking procedures.

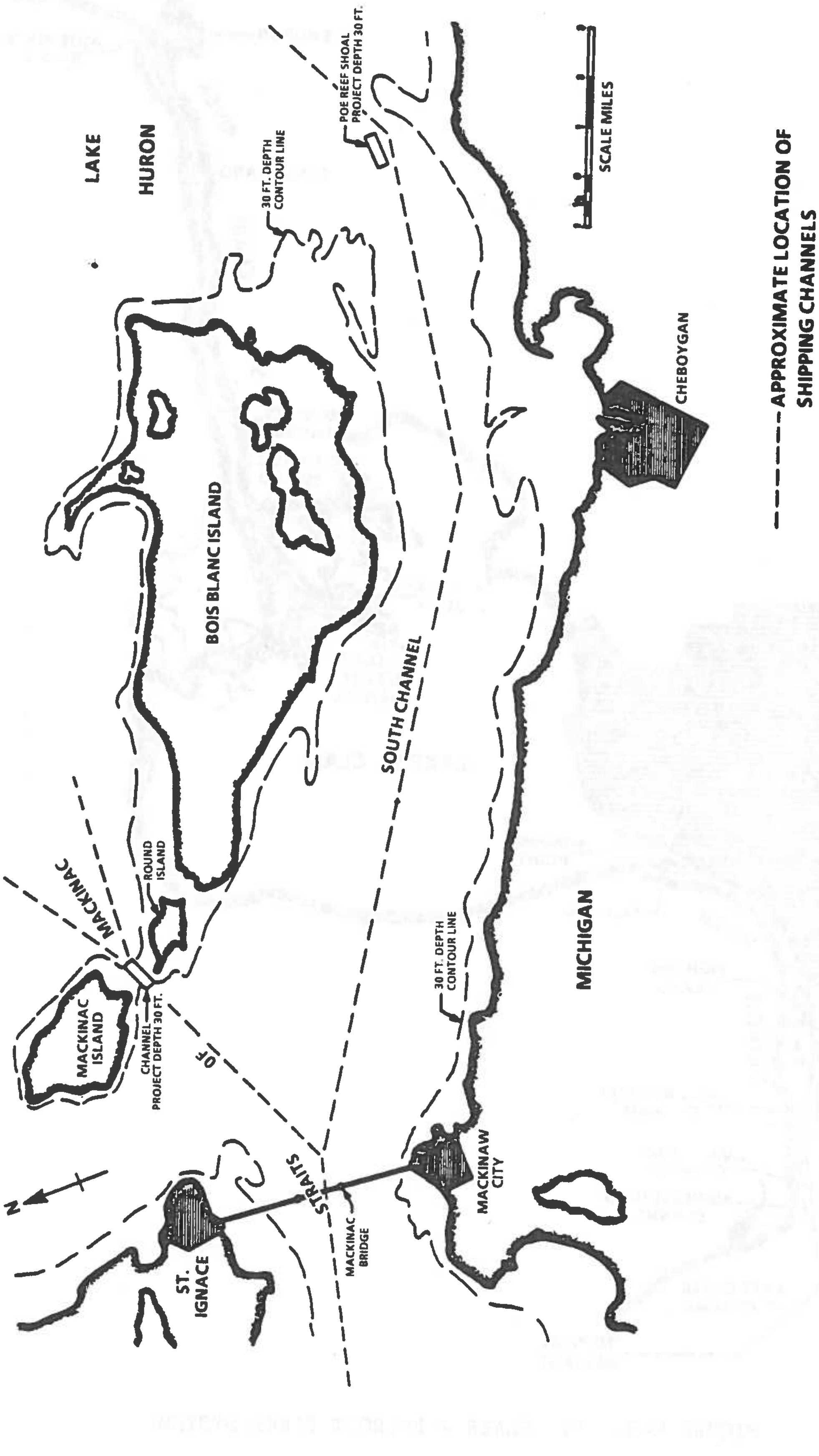


FIGURE F-2. STRAITS OF MACKINAC

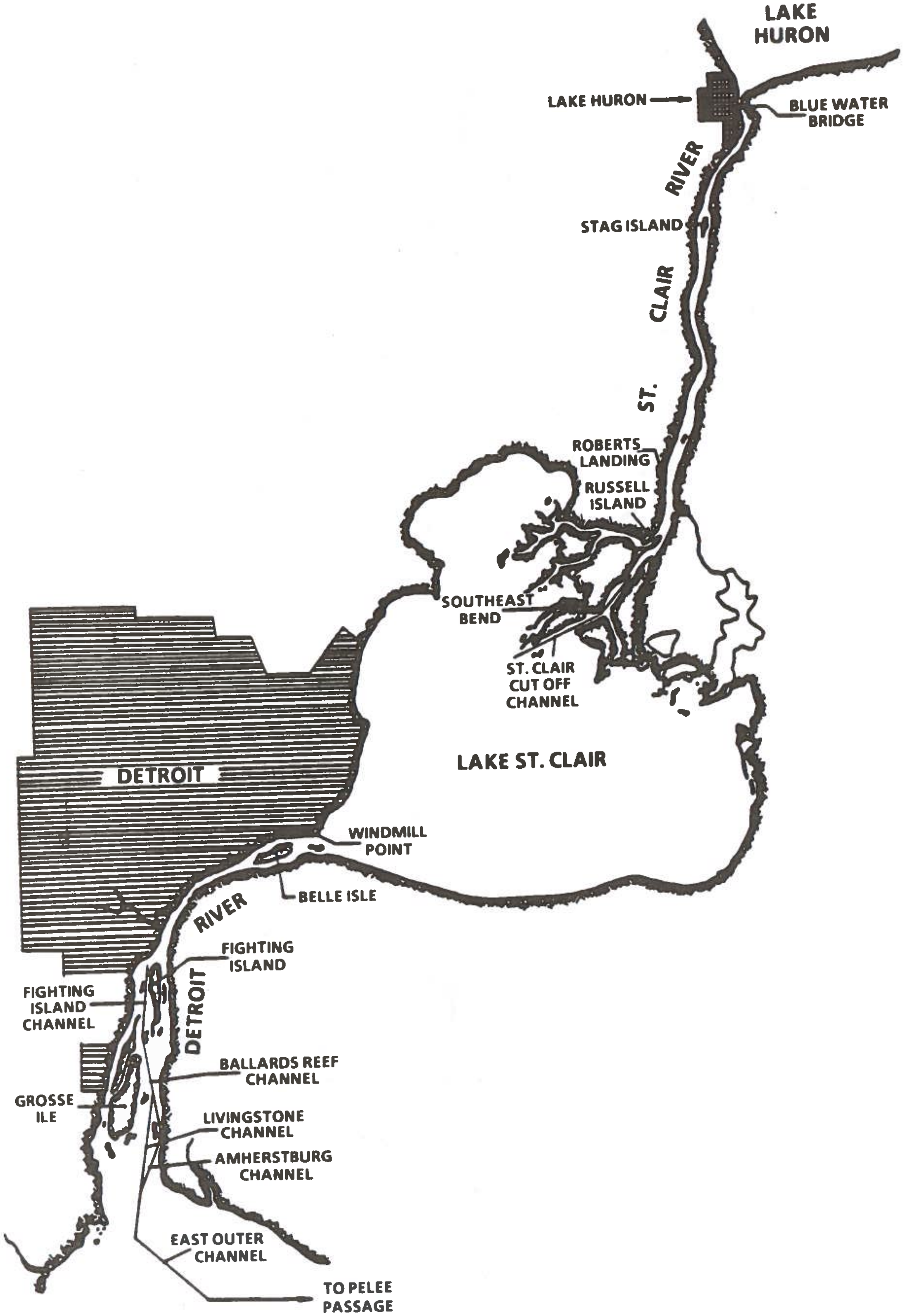


FIGURE F-3. ST. CLAIR - DETROIT RIVER SYSTEM

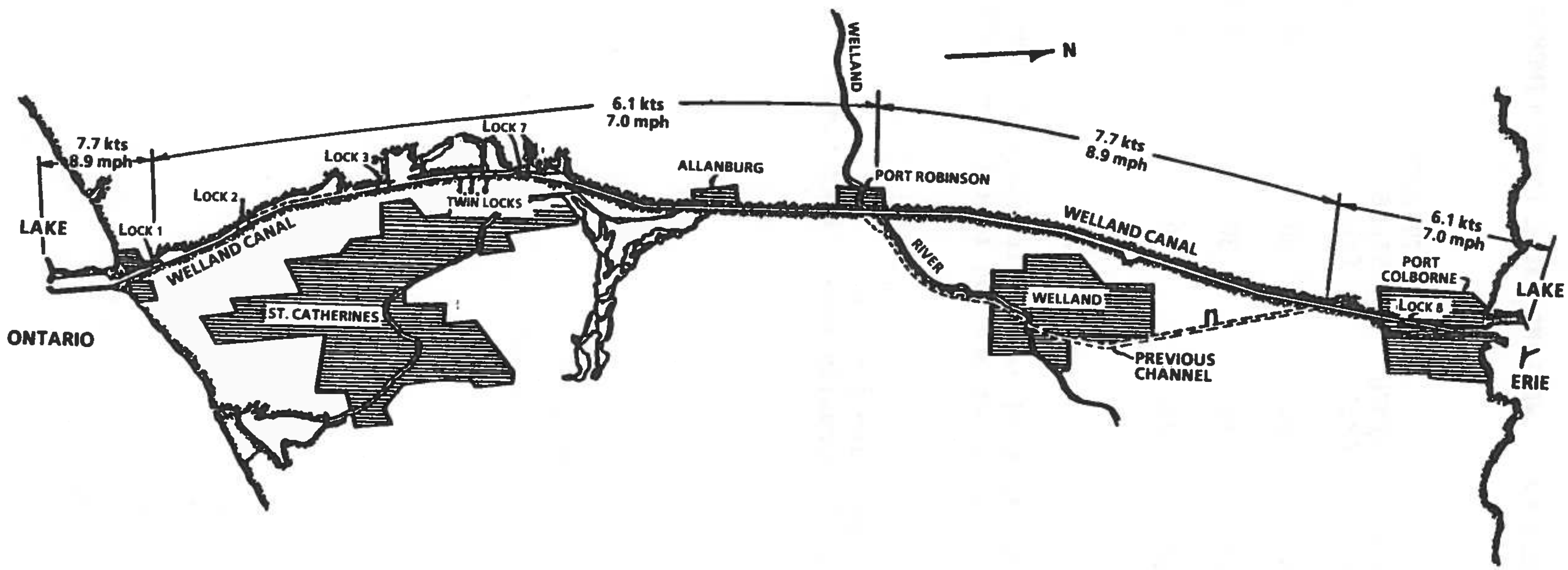


FIGURE F-4. THE WELLAND CANAL AND LOCKS

TABLE F-2. WELLAND CANAL LOCKS DIMENSIONS

LOCK	LENGTH (ft)	WIDTH (ft)	DEPTH OVER SILLS (ft)	LIFT (ft)
Lock 1	865[1]	80	30	46.5 (±)
Lock 2-7	859[1]	80	30	46.5 (±)
Guard Lock 8	1380[1]	80	30	3.0 (±)

Ships may not exceed 730 feet in overall length or 76 feet in maximum beam or 26 feet draft. All locks are 766 feet breast wall to gate fender.

Notes:
[1]Center to center of inner gate pintles.
[2]Variable lift for Lock 8, normally less than 3 feet.

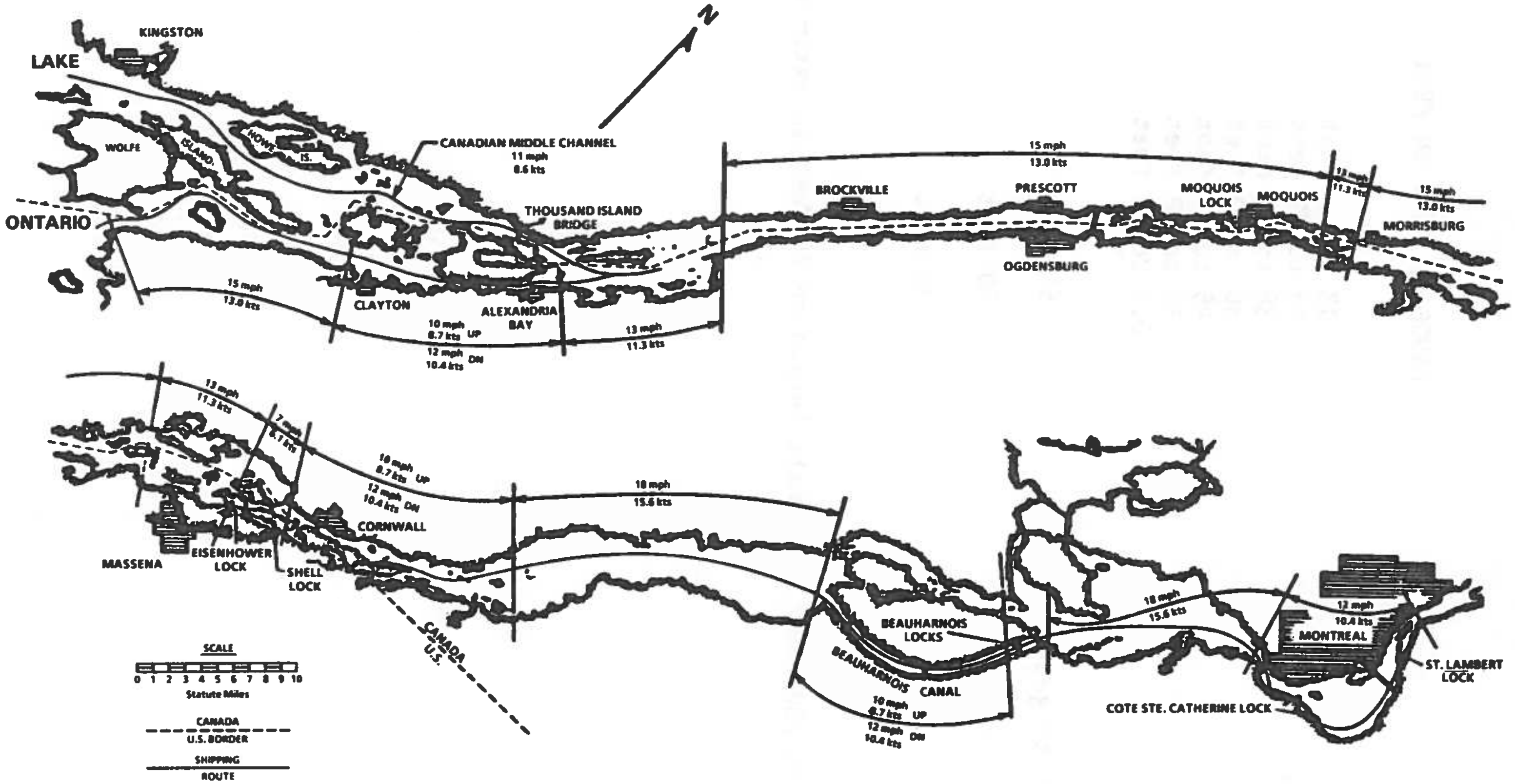


FIGURE F-5. THE ST. LAWRENCE RIVER CHANNEL AND LOCKS

TABLE F-3. ST. LAWRENCE RIVER LOCK DIMENSIONS

LOCKS	RANGE OF LIFT IN FEET
St. Lambert	13 to 22 feet
Cote Ste. Catherine	28 to 37 feet
Lower Beauharnois	38 to 42 feet
Upper Beauharnois	36 to 40 feet
Snell	45 to 49 feet
Eisenhower	38 to 42 feet
Iroquois	0.5 to 6 feet
Length, breast wall to gate fender	766 feet
Width	80 feet
Depth over sills	30 feet

Ships may not exceed 730 feet in overall length or 76 feet in maximum beam or 26 feet draft.

TABLE F-4. PHYSICAL CHARACTERISTICS OF CONNECTING WATERWAYS ON THE GREAT LAKES-ST. LAWRENCE RIVER

Waterway	Reach No.	Length, (mi)	No. of Turns	Minimum Width (ft)	Average Depth (ft)	Maximum Change in Heading (deg)	No. of Turns (mi)
St. Marys River		74.8	25	200		65.0	0.33
	SMR1	11.5	6	1200	33.0	44.3	0.52
	SMR2	9.5	4	600	27.0	44.0	0.42
	SMR3	18.0	5	500	27.5	65.0	0.28
	SMR4	17.0	4	300	27.0	40.0	0.24
	SMR5	9.0	4	200	28.0	39.0	0.44
	SMR6	9.8	2	800	29.0	39.0	0.20
St. Clair River		41.2	34	600		51.0	0.83
	SCR1	11.6	11	600	27.0	51.0	0.95
	SCR2	13.9	12	900	31.0	25.0	0.86
	SCR3	15.7	11	700	26.5	23.3	0.70
Lake St. Clair	LSC1	14.2	1	700	27.0	7.0	0.07
Detroit River		47.5	24	300		40.0	0.51
	DR1	15.5	10	900	32.0	28.0	0.65
	DR2	9.1	9	300	25.0	40.0	0.99
	DR3	7.2	1	600	28.0	21.5	0.14
	DR4	7.8	1	400	27.0	23.5	0.13
	DR5	7.9	3	600	27.5	21.0	0.38
Straits of Mackinac	SM1	8.2	2	3000	71.0	29.0	0.24
St. Lawrence River		191.1	107	528		70.0	0.56
	SLR1	35.3	28	528	27.5	43.0	0.79
	SLR2	28.6	15	528	40.4	34.0	0.52
	SLR3	25.1	19	528	32.0	35.0	0.76
	SLR4	25.5	10	528	55.0	34.0	0.59
	SLR5	24.5	14	528	92.2	21.0	0.41
	SLR6	25.5	14	528	92.2	28.0	0.55
	SLR7	26.6	6	528	87.3	70.0	0.23
Welland Canal	WC1	26.9	21	200	27.0	18.0	0.78

Appendix F Reference:

1. "General Description of Great Lakes-St. Lawrence Seaway Physical System, Task 6 - Report of Great Lakes-St. Lawrence Seaway Regional Transportation Studies," Artec, Inc., Report No. 719C-1 (September, 1981).

APPENDIX G

PROJECT IMPLEMENTATION PLAN FOR THE MARITIME NAVIGATION COMMUNICATIONS PROGRAM

G.1 INTRODUCTION

The Maritime Navigation and Communications Program for the Great Lakes and St. Lawrence River is a study undertaken by the Department of Transportation, Center for Navigation, Transportation Systems Center (TSC) for the Maritime Administration (MARAD), Office of Advanced Ship Development and Technology. The intent of the program is to identify problems and recommend solutions to facilitate maritime shipping from the Fourth Coast seaports to deep water. Objectives of the program include the determination of the navigation and communications requirements for the inland waterway composed of the Great Lakes-St. Lawrence Seaway and connecting rivers, canals, locks and lakes, and the identification of candidate systems which might satisfy these requirements.

G.1.1 Purpose of Project Implementation Plan

The purpose of the Project Implementation Plan (PIP) is to outline TSC's perception of the efforts necessary for successful performance of tasks identified in TSC's Project Plan Agreement (PPA) with the MARAD. The PIP essentially elaborates on the PPA by discussing in detail how specific tasks will be accomplished. It also defines products and deliverables planned for each task, establishes schedules and identifies problem areas.

The PIP is a working document which can be modified as knowledge and understanding of a job is accrued and the need for a task change or a shift in emphasis is required. Constructive comments and suggestions are requested, especially from program sponsors, in order to keep the PIP current and in line with program goals.

G.1.2 Problem Definition

In winter months, the ability to navigate on the Great Lakes-St. Lawrence River is impeded by the removal of some navigation aids from channels. It would be possible to maintain a greater traffic throughput if vessels were able to navigate and communicate at all times and in all types of weather, independent of the presence or absence of navigation aids. The impact of restricted navigation and communications is a matter of great concern to the MARAD. However, cost effective electronic navigation and communications systems that would permit safe, 24-hour, all-weather transits of the Fourth Coast waterway network have not been identified or demonstrated to date.

G.1.3 Objective

The program objective is to determine the navigation and communications requirements of a system which would facilitate maritime shipping from Fourth Coast seaports to deep water - from Duluth, Minn. to the Atlantic Ocean. Using the system requirements as a standard, TSC will identify candidate systems which could provide integrated navigation and communications services.

G.2 STATEMENT OF WORK

Task 1 Navigation and Communications Study Project Implementation Plan

A PIP outlines the scope, technical approach, schedules and deliverables for a program. The PIP was written after planning meetings were held with MARAD to assure that sponsor concerns and objectives were properly addressed.

Task 2 Navigation and Communications Systems Study

A study was made to evaluate and catalog navigation and communications systems used on the Great Lakes and St. Lawrence River. The study commenced with a compilation and synopsis of all previous studies on this subject. Interviews and on-site investigations were conducted at specified areas of interest along the Great Lakes-St. Lawrence River network. Interviews with the user community were designed to identify existing situations and problem areas where navigation and communications systems failed to provide the user with satisfactory service. As a result of the interviews and observations, an assessment was made of the relationship of existing navigation and communications systems to the productivity of the waterway systems and the maritime fleet.

Task 3 Requirements Definition

Navigation and communications system requirements, presented in this report, were developed to satisfy technological and regulatory demands for vessel movement in adverse weather and during periods when floating aids are not deployed. Operational procedures also will be developed for navigation and communications during times of reduced visibility.

Task 4 State-of-the-Art Assessment

A study will be conducted to determine the availability of state-of-the-art (SOA) navigation and communications systems which could satisfy the system and procedural requirements of Task 3. Systems will be analyzed for the technical and operational risks involved with their deployment. Candidate systems will be ranked and recommendations will be prepared for systems that should be evaluated at TSC.

Task 5 Operational Analyses*

An analytical evaluation will be made of system alternatives recommended in Task 4. A statistical analysis will be performed to determine systems which should be tested at the Computer Aided Operational Research Facility (CAORF) of MARAD. TSC will assist CAORF by developing evaluation models for the selected systems. System performance characteristics will be developed and recommendations for a system concept will be prepared based on the results of CAORF tests.

Task 6 System Evaluation*

A system evaluation test plan will be prepared, necessary equipment procured, and field tests conducted in conjunction with MARAD, USCG, FCC, COE and Great Lakes ship operators to evaluate system performance. Operational system specifications will be prepared after the evaluation.

*Not presently included in MARAD's program plan.

Task 7 Implementation Plan*

A promotional and implementation plan will be prepared that includes recommended regulatory revisions (if needed) and estimates of productivity improvement potential.

G.3 PLAN OF ACTION

The selected approach was to send two people from TSC and a MARAD representative to visit the Fourth Coast area to collect operational data necessary for the navigation and communications requirements definition task. The purpose of the initial visit was to hold discussions with representatives of the user community: Maritime Administration Regional Office, Great Lakes Region; Saint Lawrence Seaway Development Corporation, Resident Manager; USCG District Office, District 9; Federal Communications Commission; U.S. Army Corps of Engineers; and the director of the U.S. Lake Carriers Association. From these initial contacts, TSC compiled a list of interested groups to be visited for detail discussions on navigation and communications needs. In all cases where specific geographic problem areas were identfied, TSC endeavored to conduct an on-site inspection. These inspections ensured the operational authenticity required in the system requirements analysis effort. The SOA in position location systems, communications systems, and other technologies such as portable displays, will be reviewed in preparation for defining a candidate navigation and communications system. A plan to test and demonstrate the selected system configurations will be prepared. A test program will evaluate the validity of selected systems configurations and provide data necessary for specification of an operational system. These activities will include the utilization of previous project studies and activities completed by MARAD, SLSDC, COE, USCG and TSC, to prevent duplication of effort and to build upon acquired experience.

*Not presently included in MARAD's program plan.

G.3.1 Primary Research Method

A TSC team visited the Fourth Coast during the last quarter of 1983 to acquire data necessary for defining MARAD navigation and communications system requirements. Initial visits to Cleveland, Ohio and Massena, New York were made by MARAD representatives. The offices of the Great Lakes Region, the USCG Ninth District and the U.S. Lake Carriers Association are located in Cleveland. The SLSDC Resident Manager's Office is in Massena. From their initial visits, a comprehensive list was created of appropriate user groups, and specific key individuals were indentified within these groups. Technical contacts were established with individuals from the following U.S. agencies and their Canadian counterparts, through liason with MARAD:

- o St. Lawrence Seaway Development Corporation
- o U.S. Coast Guard
- o U.S. Army Corps of Engineers
- o National Oceanographic and Atmospheric Administration
- o Federal Communications Commission

The study project was directed at the user community. The initial point of contact was the U.S. Lake Carriers Association. Additional interviews were conducted at Pilotage Offices, Port Authorities and with ship operators.

The MARAD/TSC team gathered the following types of information from the various parties involved in the project:

Navigation data

- o types of navigation aids or visual cues used by masters and pilots transiting from Duluth to the Gulf of St. Lawrence.
- o locations where the navigation functions are most difficult.
- o times when the existing system is inadequate for efficient transiting.
- o penalties accrued from an inadequate navigation aid system.
- o manner is which responsibility for vessel improvement is shared between certified pilots and deck officers.

- minimum impact of a navigation system on traffic flow for it to be economically viable.
- required ship position information accuracy: along-track, cross-track.
- other required information such as ship heading, velocity, rate-of-turn, rudder position.
- required navigation cues such as distance to next turn.
- navigation display information requirements: channel outline, ship position, velocity, heading, and landmarks.
- special requirements for navigation under reduced visibility conditions, such as identification and present location of other vessel traffic and collision avoidance information.
- advantages of color displays; any indications that color cues will assist system acceptance.
- method of getting additional equipment on board ship, regulatory or voluntary.
- system reliability considerations and available options in case of a navigation guidance system failure.

Communications data

- types of equipment and functions of communications system used in the present operation.
- locations where communications are difficult to maintain or acquire.
- times when the existing system is inadequate for efficient transiting.
- penalties accrued from an inadequate communications system.
- minimum impact of a communications system on traffic flow for it to be economically viable.
- required communications, frequencies, channels, voice, data, teletype, ship-to-ship, ship-to-shore, bridge-to-ship, aircraft-to-ship (search and rescue).

- number of traffic management centers, ports, pilotage offices, and radio offices in the Great Lakes and St. Lawrence River linked together by a communications network.
- description of the VHF radio network which links vessels and control stations: range, number of channels, usage.
- description of the FM radio network for ship-to-ship communications.
- supportive relationship between navigation and communications.

G.3.2 Secondary Research Method

Secondary research was conducted to accumulate information from previous navigation and communications studies. The two main sources of this type of data were TSC's Technical Reference Center and the National Maritime Research Center's (NMRC) Study Center at Kings Point, New York. References were solicited through the Technical Reference Center, from the National Technical Information Service, the Transportation Research Information System, Conference Papers Index, Oceanic Abstracts, Science Citation Index and the Smithsonian Science Information Exchange.

The NMRC Study Center had a distinctive collection of maritime technical literature, including back issues of the major maritime trade journals and periodicals for the past decade.

The working outline for the secondary research is the following:

1. INTRODUCTION

2. NAVIGATION AND COMMUNICATIONS STUDIES

   2.1 General Navigation and Communications Studies
   2.2 Great Lakes and St. Lawrence Seaway Studies
   2.3 Other Lake, River, Canal or Lock Studies

3. GREAT LAKES AND ST. LAWRENCE SEAWAY AS A SYSTEM

   3.1 Physical Characteristics - Waterways
      3.1.1 Lakes and River
      3.1.2 Canals and Locks

3.2 Physical Characteristics - Port
- 3.2.1 Principal Shipping Ports
- 3.2.2 Drydock Facilities

3.3 Great Lakes and Seaway Fleet
- 3.3.1 Lake Vessels
- 3.3.2 Ocean Vessels

3.4 Pilotage

3.5 Traffic Management

4. SYSTEM TRANSIT TIME AND DELAYS

4.1 System Capacity
- 4.1.1 Vessel Throughput
- 4.1.2 Tonnage Throughput

4.2 System Transit Time

4.3 Transit Delays
- 4.3.1 Weather Related Delays
- 4.3.2 Pilotage Related Delays
- 4.3.3 Other Delays
- 4.3.4 Cost of Transit Delays

4.4 Traffic Delays
- 4.4.1 Causes of Delays
- 4.4.2 Cost of Traffic Delays

5. SYSTEM SAFETY

5.1 Accident Record
5.2 Accident Frequency
5.3 Accident Costs

6. SYSTEM REQUIREMENTS DEFINITION

6.1 Navigation Accuracy Requirements
- 6.1.1 Ship Position Location Accuracy
- 6.1.2 Navigation References
- 6.1.3 Dynamic Accuracy Requirements
- 6.1.4 Vessel Traffic Information
- 6.1.5 Navigation Cues

6.2 Communications Requirements
- 6.2.1 Ship-to-Shore
- 6.2.2 Ship-to-Ship
- 6.2.3 Voice, Data and Teletype Transmissions
- 6.2.4 Safety Related Communications

6.3 Display Requirements
    6.3.1 Update Rate
    6.3.2 Display Format and Content

7. STATE-OF-THE-ART ASSESSMENT

7.1 Systems and Techniques Used on Other Seaways

7.2 Navigation Systems
    7.2.1 Satellite Based
    7.2.2 OMEGA Global System
    7.2.3 LORAN-C System
    7.2.4 Microwave Ranging System
    7.2.5 Radar Systems
    7.2.6 Other Candidates

7.3 Communications Systems
    7.3.1 Multichannel
    7.3.2 Discrete Address
    7.3.3 Other Candidate Techniques

8. OPERATIONAL ANALYSIS*

8.1 Integrated Navigation and Communications Systems
8.2 Selection Criteria
8.3 Evaluation Criteria
8.4 Cost and Reliability Estimates

9. SYSTEM EVALUATION*

9.1 Test Plan
9.2 Resource Requirements
9.3 Schedule and Staging Plan

10. IMPLEMENTATION PLAN*

10.1 Promotional and Implementation Plan
10.2 Regulatory Revisions
10.3 System Justification

*Not presently included in MARAD's program plan.

A working bibliography was constructed and all sources were identified and evaluated. The bibliography and abstracts of articles identified by the research were recorded in a TSC word processor. During report preparation this data was accessed and used to support the primary analysis.

A draft of the results was sent to MARAD for circulation and comment. After the draft had been reviewed and approved by MARAD, a final draft was issued in the Final Report.

G.3.3 Requirements Definition

The information gathered by the MARAD/TSC team on the waterway network from Lake Superior to the Gulf of St. Lawrence was consolidated with TSC's prior program experience in seaway, harbor and canal projects, and with the data bank from the secondary research and used in this report on Fourth Coast Navigation and Communications Requirements. This report addresses each of the major system areas.

Navigation/Guidance Requirements

- ship location accuracy and navigation references
- ship heading, velocity and rate-of-turn
- other ship traffic, location and identification
- navigation cues such as distance to next turn, landmarks, range markers, buoys
- digital and graphic display content, format and features
- visibility information

Communications Requirements

- ship-to-shore
- ship-to-ship
- ship-to-aircraft
- bridge-to-ship
- general communications
- discrete address communications
- mariner advisories
- weather forecasts and visibility warnings

Traffic Management System Requirements

- extent of management zones
- traffic magnitudes
- type of vessel management (active or passive)
- vessel information requirements (position and velocity)
- communication requirements
- weather information, present weather, weather warnings
- traffic management display requirements, information control, area segmentation, traffic management information

Equipment Requirements

- o carry-on equipment constraints: size, weight, power.
- o shore-based equipment constraints: size, power.

A draft of the Systems Requirement Statement will be sent to MARAD for circulation and comment. After a consensus is reached the final draft of the statement will be issued as a volume in the Final Report.

G.3.4 State-of-the-Art Assessment

The definition of an economically viable navigation and communications system concept which can be complemented with SOA equipment requires a review of performance capabilities and availability. This review will evaluate existing navigation and communications aids and new developments which are capable of meeting some or all of the established requirements. This activity will include a review of several elements of a system: management techniques used on other waterways and canals, navigation systems, position location systems, display technology, communications technology, and computer systems. Specifically the following will be reviewed:

Traffic Management Systems

- o Panama Canal
- o Suez Canal
- o Vessel Traffic Management

Navigation Systems

- o Satellite-based GPS, TRANSIT
- o OMEGA Global Radionavigation
- o LORAN-C Radionavigation

Position Location Systems

- o Precision Ranging
- o Radar
- o Trilateration

Display Technology

- o Large panel displays
- o Liquid crystal displays (LCD)
- o Vacuum florescence displays
- o Light weight cathode ray tubes (CRT)
- o Light weight package configurations
- o Built in intelligence (microprocessors)

Communications Technology

- o Communications Satellite, INMARSAT
- o Conventional communications
- o High baud rate data communications
- o Shared voice and data communications
- o Teletype communications

Computer Systems

- o Multiprocessors
- o Multi-user network

System alternatives will be ranked and recommendations will be prepared for those systems that should be included in a performance statistical analysis. The results of this analysis will be reviewed to determine candidate systems for evaluation at the CAORF, Kings Point, New York. As a result of the state-of-the-art assessment, a project memorandum draft will be submitted to MARAD for review and approval.

G.3.5 Operational Analyses*

TSC will develop integrated navigation and communications systems alternatives and evaluate each alternative on the basis of its greatest overall utility throughout the Great Lakes and St. Lawrence Seaway. The process for selection and evaluation will be included in the resulting document. Costs and estimated reliability factors for each candidate will be compiled and compared.

Major emphasis will be placed on a modular system configuration, that can be expanded or reconfigured to provide increased capabilities without requiring major hardware retrofits or modifications. The future expansion of a system installed in areas of constricted traffic flow would be accomplished through use of software modules. In addition, maximum utilization will be made of existing navigation and communications facilities and equipment to reduce projected implementation costs.

*Not presently included in MARAD's program plan.

The definition of a candidate system will include recommendations for evaluation of the system concepts at CAORF. The following major elements of the system will be defined:

- The selected management strategy, i.e., a shore-based centralized management center where go/no-go decisions are made and surrounding traffic is coordinated; or decentralized management where each vessel pilot or master makes decisions; or a third option which shares management responsiblities between the vessel and the management center. Given the length of the network - 2342 nautical miles - and the rapidity of weather changes, a single center that covers the entire route does not appear to be feasible.
- The navigation system or composite system used to determine ship location, heading and velocity, the number of ships which might be in the system simultaneously, the required navigation shore installation support, including numbers, locations and characterisitics.
- The configuration of onboard equipment defining display requirements, display content, onboard processing, data, and data rate.
- The communications system used to keep information flowing from ship-to-shore and ship-to-ship, including teletype and voice communications systems, and required shore communications network.
- The configuration of traffic management centers, functions, processor(s), display(s), and display content.
- A scenario which describes the operation of the system from the moment a ship enters the network, its passage through the Seaway and Great Lakes and its return.
- An estimate of the cost of the operational navigation/communications system, including acquisition, installation, operation and maintenance.

A draft project memorandum defining the system concept will be prepared and delivered to the sponsor for review and comment. Following approval by MARAD of the project memorandum, the report will be reissued in the Final Report.

G.3.6 System Evaluation*

A Test and Demonstration Program Plan will outline the limited deployment of a system that demonstrates the ability of a selected navigation and communications system configuration to meet stated system requirements.

The operational analysis will include four activities:

1. Define Sea Trials

   - o Summarize the results from previous studies and experiments, Section G.3.2, Secondary Research Analysis.
   - o Define the test conditions: vessel types, test area, test environment and test participants.
   - o State the hypotheses that are to be proven.

2. Draft a Preliminary Test Plan

   - o Estimate the experimental error.
   - o Define the sample size. The group of vessels and people to be studied are American vessels, masters and pilots traveling between two ports, at least one of which is on the Fourth Coast. The sample must be representative of the entire group. The variables to be studied are: the navigation problems experienced during a transit, the communications problems experienced during a transit, the frequency of occurrence of the problems, the duration of the problems, the distance traveled by the vessels and the types of vessels experiencing the problem.
   - o Estimate the cost of the sea trials in comparison to the cost of a wrong decison made without information developed from trial results.
   - o Recommend the type of vessels to be used during sea trials. The vessels will have to be of sufficient size to allow evaluation of critical performance parameters, such as location of the ship's bow and stern with respect to a desired centerline. Depending on the equipment configuration, it also may be feasible to display targets of opportunity to pilots or masters for a more realistic evaluation of system capabilities. This has the added advantage of promoting user acceptance.

*Not presently included in MARAD's program plan.

- o Prepare an acquisition plan for navigation and communications equipment and its installation in the test area.
- o Design a development and fabrication plan for two or more onboard configurations.
- o Define an independent standard which will be used to evaluate the performance of the navigation system. Because of the complexity of the measurements, this may be a difficult problem requiring a statistical approach to determine system accuracy.
- o Describe the data to be recorded during the sea trials, the data acquisition system, data reduction, analysis methods and expected products.
- o In order to evaluate the adequacy of onboard equipment, design a plan to measure its impact on the operations and functions of masters and pilots.
- o Determine how to implement hardware and software changes necessitated by shortcomings revealed during the sea trial phase.

3. Review the Test Plan with the Sponsor

- o Develop a list of decisions which depend on each outcome of the sea trials.
- o Jointly attempt to anticipate factors which might affect the results.
- o Establish technical contacts to coordinate activities in every participating group.
- o Discuss experimental techniques in sufficient detail to discover any procedures that may lead to bias in the results.

4. Prepare the Final Test and Demonstration Plan

- o Test procedures will be presented in clear terms so all participants understand their assignments.
- o The analysis method agreed to with the sponsor will be included in this plan.

A project memorandum defining the Test and Demonstration Program Plan will be sent to the sponsor.

Also under this task, the sea trials will be carried out, the data analyzed and a test report prepared. During the sea trials, communications will be maintained between all participants so that questions arising from unforeseen conditions or results may be answered in keeping with the approved test plan.

Analysis and Interpretation of the Data

- Follow the analysis method in the test plan.
- Present the data and results in tables and graphs.
- Compare the results with the stated objectives.
- If the results suggest that additional sea trials are required, outline the course of action that the additional experiments would follow.

Based on the results of the sea trials, TSC will make system recommendations and show justification for recommended compromises to accommodate vessels in the Great Lakes and St. Lawrence Seaway. This will be documented in the Final Report.

G.3.7 Implementation Plan*

Prepare a promotional and implementation plan for the navigation and communications system. Make recommendations for regulatory revision if needed for implementation. Estimate benefits versus costs to implement. Prepare the Final Report and an executive summary.

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