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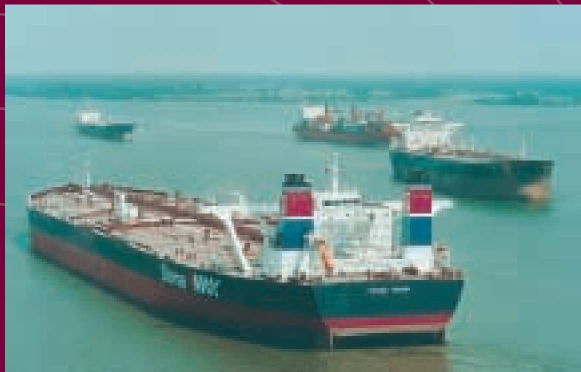

SHIPBOARD AUTOMATIC IDENTIFICATION SYSTEM DISPLAYS

Meeting the Needs of Mariners

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

SPECIAL
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SHIPBOARD AUTOMATIC IDENTIFICATION SYSTEM DISPLAYS

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Committee for Evaluating Shipboard Display of Automatic Identification Systems

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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This report has been reviewed by a group other than the authors according to the procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

In recent years the marine transportation system has come under increasing attention. Among the concerns are its safety and efficiency, prevention of and response to ship-caused pollution, and the use of vessels for inimical purposes, ranging from simple lawbreaking (such as smuggling) to serving as a vehicle or target for terrorist acts. Over the past two decades, automatic identification systems (AIS) have been developed in response to these concerns, and much work has been done to define AIS technical and communication requirements. These efforts have resulted in worldwide mandatory carriage requirements for AIS aboard vessels that must comply with the International Convention for the Safety of Life at Sea (SOLAS) and in discussions about non-SOLAS vessel carriage requirements in the United States. However, despite these efforts, little has been said about shipboard display of AIS information, a topic addressed in this report.

Because of the lack of standards and requirements for shipboard display of AIS information, the United States Coast Guard (USCG) requested that the National Research Council's (NRC's) Transportation Research Board (TRB)/Marine Board examine the technical and human factors aspects of shipboard display of AIS information. This effort was to include an assessment of the state of the art in AIS display technologies, an evaluation of current system designs and their capabilities, and a review of the relevant human factors aspects associated with operating these systems. In the course of the study, the committee was to consider

- The impacts of changing technology, security, economics, operational considerations, and human factors design principles on display of shipboard AIS systems;
- How a range of tasks to be supported by AIS will drive display requirements;
- The impacts of different operational environments and qualification and skill requirements on shipboard display of AIS information;
- How changes in existing and evolving technology, equipment/technical integration, international standards harmonization requirements, manufacturers' and standards bodies' requirements, and economics affect shipboard display of AIS information; and

- Lessons learned and best practices from relevant domestic and international AIS programs.

The mariner's need for better and real-time information about waterway conditions has increased with a number of factors, including the size of ships, traffic density in key areas, and the like. Transmission of such information by voice radio has been repeatedly cited by mariners as burdensome, and during the past decade other mediums have been actively sought. Understanding mariners' information needs and how they vary, therefore, is an important first step in developing requirements or standards for shipboard display of AIS information.

AIS information can be used by mariners in different ways—for vessel identification, navigation, maneuvering and collision avoidance, and tasks required by the practice of good seamanship. AIS information can be presented to mariners in many different ways—visually, aurally, haptically (i.e., through touch), and redundantly, for instance. Processes for understanding what AIS information should be presented to the mariner, and how it should be presented, are the focus of this report. Decades of human factors, systems engineering, and information systems research have focused on how to present task-relevant information to decision makers in various operational settings. That research is summarized in this report, and guidelines to consider in developing requirements for shipboard display of AIS information are suggested. A process that USCG should follow in developing standards and requirements for shipboard display of AIS information is recommended. The process includes research, requirements development, analysis, design, and implementation elements. It is intended to assist regulators with domestic and international carriage requirement responsibilities and members of the international community faced with global mandates for shipboard display of AIS information.

ACKNOWLEDGMENTS

The work of this committee has been greatly helped by the thoughtful advice and background information provided by the project sponsor, USCG. The committee gratefully acknowledges the contributions of time and information provided by the sponsor liaisons and the many individuals within and outside government who are interested or involved in shipboard display of

AIS information and who supported this assessment. The committee particularly thanks the USCG liaison representatives Mike Sollosi and Ed LaRue, as well as Joe Hersey, Jorge Arroyo, and Jeff High also of USCG, who responded promptly and with a generous spirit to the committee's many requests for information. The committee is also grateful to Diane Jordan of the Port of Tacoma for hosting and handling the logistics for the committee's August 2002 meeting and to Mike Gehrke, Director of Intermodal Services at the Port of Tacoma, for providing a tour of the port.

The committee is especially indebted to the active mariners, pilots, industry representatives, manufacturers, researchers, and scientists who provided input to the committee. In particular, the committee thanks Steve Hung of the St. Lawrence Seaway Development Corporation, who provided AIS background and status information on the St. Lawrence Seaway and Panama Canal AIS projects; and Chris Andreasen, Scientific Advisor for Hydrography at the National Imagery and Mapping Agency, who provided information on the background and status of electronic charting systems as they relate to the use and functions of AIS at the committee's first meeting.

Special thanks are also extended to Lee Alexander, University of New Hampshire; George Burkley, Maritime Institute of Technology and Graduate Studies; Captain Benny Pettersson, Swedish Maritime Administration; Holger Ericsson, Saab Transponder Tech AB; Tom Hill, SeaRiver Maritime; Edwin Hutchins, University of California, San Diego; Jeff McCarthy, San Francisco Marine Exchange; William Nugent, Space and Naval Warfare Systems Command; Allison Ross, Association of Maryland Pilots; Mark Stevens, Ingram Barge; Kim Vicente, University of Toronto; Jorge Viso, Tampa Bay Pilots; and all of the other participants in the committee's workshop in New Orleans. (See Appendix A for a summary of the workshop.) In addition, the committee is indebted to the AIS manufacturers who displayed their systems at the workshop and willingly answered any questions posed to them: Butch Comeaux, Michael Martinez, Allen Mitchener, Doug Sprunt, and Morne Stamrood, Tideland Signal Corporation; Larry DeGraff, Transas Marine USA, Inc.; Haruki Miyashita, JRC, Japan Radio; Mark Pfeiffer, Avitech Aviation Management Technologies GmbH; and Rudy Peschel, Speschel Interest Group/Saab. The committee is grateful to Captain Norrby Soeren of the *MV Mountain Blossom,* whose vessel the committee rode in a transit of the lower Mississippi River on April 4, 2002; and to Tony Weeks, general manager of Southport Agencies, Inc., who transported the committee members by launch to and from the *MV Mountain Blossom.*

We are very grateful to Ingram Barge Co., who arranged for John Lee's transit on the *Robert E. Lee* in order to conduct the observational task analysis. The committee also wishes to thank the members of the European community who provided advice and insight to the committee during a visit to AIS programs and installations in summer 2002, particularly Jan-Hendrik Oltmann, deputy head of division, and Hendrik Eusterbarkey, engineer, at the Waterways and Shipping Directorate for Baltic and North Sea coastal areas and ports and river entrances; Christoph Felsenstein of the Wismar University of Technology in Warnemunde at the ship training simulator center; Ralf-Dieter Preuss and staff of the German Federal Hydrographic and Maritime Agency; and Mr. Heesch of the vessel traffic center for managing traffic in the Kiel Canal in Brunsbuttel. (See Appendix B for a summary of information gathered during this trip.)

The committee was composed of talented individuals who worked tirelessly and thoughtfully together to produce this report. Working with this committee was a distinct pleasure. Bob Moore kept us on track and generously shared his deep knowledge of things maritime. Douglas Grubbs and Carl Bowler helped in providing active mariner and piloting insight to the committee, as well as their store of technical knowledge. Douglas was also our host throughout the committee's workshop in New Orleans and on the committee's vessel ride on the lower Mississippi River; we are most grateful to Douglas for his gracious hospitality. Beth Gedney and Roy Murphy provided important passenger vessel and "brown water" insights to the committee. Don Kim helped the committee considerably with its understanding of how commercial maritime systems and practices differ from aerospace and other large systems. John Lee and Nadine Sarter were key contributors to this report. They provided human factors knowledge and background from other domains that were critical to the committee. The committee particularly thanks John for his tutelage in understanding heuristics.

This project came together well because we were blessed with exceptional staff support. TRB staff members Beverly Huey and Pete Johnson provided help in drafting, assembling, packaging, and editing the report; in supporting the committee members; and in the committee's meeting, workshop, and report preparation processes. The study was performed under the overall supervision of Stephen R. Godwin, TRB's Director of Studies and Information Services. The committee gratefully acknowledges the work and support of Norman Solomon, who edited the report; Suzanne Schneider, Associate Executive Director of TRB, who managed the review process; and Nancy A. Ackerman, Director of Publications, under whose supervision the report was edited and prepared for publication.

The report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

The committee thanks the following individuals for their review of this report: Lee Alexander, University of New Hampshire; William Gray, Gray Maritime, Darien, Connecticut; I. Bernard Jacobson, IBJ Associates, Shelter Island Heights, New York; Raja Parasuraman, Catholic University of America, Washington, D.C.; David Patraiko, The Nautical Institute, London, United Kingdom; and Mark Stevens, Ingram Barge Company, Nashville, Tennessee. Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the findings and conclusions, nor did they see the final draft before its release.

The review of this report was overseen by Lester A. Hoel, University of Virginia, Charlottesville. Appointed by NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

It has been a great privilege to serve with the members of the committee. Many thanks to the members and staff. May we meet again in similarly interesting and engaging tasks.

Martha Grabowski, *Chair*
Committee for Evaluating Shipboard
Display of Automatic Identification Systems

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Executive Summary

Over the next several years, commercial vessels worldwide, operating on the high seas and in coastal and inland waterways, will begin to carry new technology, known as automatic identification systems (AIS), that promises to enhance the safety of navigation and allow traffic managers to do their jobs more safely and effectively. AIS is essentially a communications medium that automatically provides vessel position and other data to other vessels and shore stations and facilitates the communication of vessel traffic management and navigational safety data from designated shore stations to vessels. The onboard "AIS unit" (which consists of a VHF-FM transceiver, an assembly unit, and a communications transceiver) continuously and automatically broadcasts identification, location, and other vessel voyage data, and receives messages from other ships and shore stations.

Three functions have been identified by the International Maritime Organization (IMO) for AIS: (*a*) to serve as a collision-avoidance tool while the system is operating in the vessel-to-vessel mode, (*b*) to provide information about a vessel and its cargo to local authorities who oversee waterborne trade, and (*c*) to assist those authorities engaged in vessel traffic management. As AIS technology and its applications evolve, additional useful and beneficial functions of AIS will most likely also evolve.

Over the past few years, IMO, working through the International Telecommunication Union and other organizations, has published technical and operational standards for AIS; however, these standards do not address shipboard displays, except for a minimum alphanumeric presentation. For international shipping, AIS equipment requirements, including an implementation schedule, have been established through an amendment to the International Convention for the Safety of Life at Sea (SOLAS). In the United States, where AIS technology is in the early stages of implementation and just beginning to become available within certain port and waterway regions, the U.S. Coast Guard (USCG) has the responsibility for establishing carriage requirements for AIS equipment aboard vessels in U.S. waters and aboard U.S.-flag vessels. USCG is in the process of developing rulemaking to ensure compliance of

SOLAS vessels in U.S. waters and concurrently developing carriage requirements for non-SOLAS vessels operating in U.S. waters. The initial SOLAS carriage requirements for oceangoing vessels do not specify any shipboard display for use by the mariner except for minimal basic numerical data.

Because USCG has the responsibility in the United States for determining whether and what requirements should be established for shipboard AIS displays, it asked the Transportation Research Board (TRB)/Marine Board to undertake an investigation and analysis of the key issues affecting the design, development, and implementation of shipboard AIS displays. TRB convened a committee to address USCG's request for guidance. Specifically, USCG asked the committee to assess the state of the art in AIS display technologies, evaluate current system designs and their capabilities, and review the relevant human factors aspects associated with operating these systems.

The challenges associated with shipboard display of AIS information are addressed in this report. However, this does not cover the full spectrum of AIS challenges. For example, AIS complements traditional navigational aids; it does not replace them, nor does it substitute for good judgment or replace the need to use all available means appropriate to the prevailing circumstances and conditions to establish vessel position. Therefore, government and industry need to address the challenge of integrating existing navigation aids and, in the process, encourage the appropriate use of technology.

The introduction of onboard displays of AIS information represents an opportunity for significant improvements in available knowledge and awareness of waterway and vessel traffic situations for all mariners. It is intended to result in safety and efficiency benefits. If AIS displays are thoughtfully introduced aboard ships so that mariners' needs are met and they are not overburdened with unnecessary information, the benefits may be considerable. However, there are dangers and limitations associated with this technology that could overshadow such benefits. The committee is both encouraged at the prospects for major improvements for vessel operations with the proper display of AIS information and cautious about problems that could result from poor display of AIS information.

ESTABLISHING A SYSTEMATIC IMPLEMENTATION PLAN

It is important to have a plan and schedule for any process as complex and multifaceted as that for implementing AIS and their displays aboard vessels—

especially when there is some urgency to put needed improvements into effect. In the past, USCG has sponsored and conducted pilot tests of AIS in selected regions and has supported the introduction of AIS technology to enhance vessel traffic management and safety. However, USCG does not have a systematic plan for implementation of AIS shipboard displays in U.S. waterways or aboard U.S. vessels.

A systematic implementation plan is needed, for example, because assumptions are being made about particular types of equipment that are on board and with which the AIS will need to be integrated. While this is somewhat true for SOLAS vessels, it is not true for inland and coastal vessels. In turn, requirements for integrating AIS information with information from other onboard electronic navigation systems have not been developed. This is critical because AIS and other navigation aids may provide the same type of information (e.g., another vessel's location) but the information may conflict (e.g., the other vessel's location identified by the AIS is different from the location for that vessel identified by radar). Thus, when AIS displays are integrated with other bridge displays, the information must be presented to the mariner in such a way that it is clear, unambiguous, and accurate. Additional work is required to determine how to best integrate existing and new systems, and this will affect the entire process of introducing AIS displays aboard vessels.

Finally, USCG needs an AIS display implementation plan, schedule, and process to ensure that the underlying research will be accomplished to demonstrate the viability of the AIS display requirements and that the resulting system will meet the needs of the mariners who use it.

> ***Recommendation 1:*** USCG should establish an implementation plan and schedule for AIS shipboard display standards in consultation with stakeholders. Key elements of the plan should include
>
> - Research in technical and human factors,
> - Requirements determination and analysis, and
> - Development of international and domestic standards.

ESTABLISHING REQUIREMENTS FOR SHIPBOARD DISPLAYS

An important challenge for achieving a functional AIS is the timing and applicability of carriage requirements. Not all vessels will carry AIS, and AIS carriage requirements will be phased in over time. Thus, especially in the short term, most, if not all, vessels in a typical waterway may not be visible to (i.e., locatable) or identifiable by AIS technology. AIS requires a functioning and reliable transmitter on every vessel that is part of the system and thus requires each carrier of AIS to participate and cooperate with the protocol.

While displays are the means by which AIS data are converted into useful information for the operator, little has been done to define the information needs and priorities that would establish display parameters. And ultimately, the information needed by the vessel should determine what data are transmitted, which, in turn, should drive display requirements. During the introduction of AIS in both domestic and international settings, the initial emphasis has been on the shipboard transponder and the system to ensure accurate identification and location transmissions; only recently has much attention been given to shipboard display issues. Consequently, much development work remains to be done in the form and display of both ship- and shore-originated AIS messages.

Different types of information require different display strategies. The design of an AIS display interface needs to consider appropriate strategies for delivering information to the mariner in a readily cognizable form. For example, there are many different operating environments in which AIS information will be displayed: rivers and inland waterways, high-density ports with mixed traffic, coastal waterways, urban harbors with scheduled ferry and passenger vessel operations, and major commercial ports accommodating large deep-sea vessels. The mixed nature of carriage requirements for AIS, therefore, can create challenges in developing final recommendations for shipboard display of AIS information.

Because of the variety of operating environments, one AIS display may not fit all situations, particularly in domestic operations, and implementation plans need to reflect that reality. For example, the operating environment will greatly affect the configuration of displays that are appropriate as well as the operator training that is adopted. And, unlike large oceangoing vessels, many smaller domestic vessels may not carry all of the equipment (such as gyrocompass or heading indicator) with which an AIS needs to interface for proper operation. These interface issues will also affect shipboard display requirements.

The AIS international carriage requirements for oceangoing vessels that came into force during 2002 refer to equipment that is designated as

"Class A." The international bodies have defined two other classes that would be designated for other uses: (*a*) "Class A derivatives," which are portable units similar to the carry-aboard equipment now generally used by pilots in several U.S. ports and waterways; and (*b*) "Class B" units, which have less stringent requirements and are intended for use by domestic, inland, and coastal vessels (e.g., towboats, passenger ferries).

The Class A derivative units have received the most attention in the United States because of their similarity to those that pilots have used as carry-aboard units. The definition, role, and display requirements for Class B and Class A derivative units are incompletely specified at the present time, and this will affect display requirements for such units. More analysis of Class A derivatives and Class B AIS units will be necessary before specific display requirements for these units can be established.

Display standards are intended to ensure that designs meet user needs, that key requirements are understood, and that a proper certification process can be instituted for all operational units. Standardization of AIS displays is critical to the safety of navigation and the facilitation of commerce because shipping is an international business and it is essential that mariners find similar information displayed wherever they sail.

The process of setting standards for AIS equipment in general is under way within international bodies for Class A units, and a similar process has begun for display systems, including the issuance of IMO interim guidelines. However, the display standards process lags the carriage requirements schedule, and much remains to be done. For example, much of the effort on shipboard displays has focused on target data in ship-to-ship use for collision avoidance, with little attention to shore-to-ship data relating to traffic management.

Upon examination of existing standards and guidelines for AIS displays published by the international bodies associated with AIS and other related organizations, many gaps were found. Thus, supplementation or revision of these standards and guidelines will be needed to ensure adequate display designs. New requirements should be based on a more comprehensive and rigorous analysis as a basis for identifying operator needs and ascertaining the adequacy of displays and controls to meet those needs.

The international carriage requirements for Class A AIS units for SOLAS vessels do not specify any shipboard display except for a minimal numerical system known as MKD (minimum keyboard and display). MKD is inadequate to address minimal information needs of different mariners in different operational settings such as those prevailing in U.S. waters. However, because MKD is the only approved equipment, it poses the danger of becoming, by default, the accepted display until something better is approved. The committee concludes that using MKD as a shipboard display not only does not provide adequate information for the mariner but also, in some cases, could be detrimental to safe vessel navigation. It is important, therefore, to establish new minimal display standards before MKD becomes the default standard for U.S. operations.

Because AIS shipboard displays will be introduced over time and for many different operating situations as well as vessel classes, USCG needs a process for establishing requirements for shipboard displays that will accommodate these variables and provide effective leadership for the maritime community. The committee has concluded that this can be accomplished by clearly establishing minimum requirements for U.S. waters and for U.S. vessels first, followed by work with appropriate international bodies to ensure compatibility with international requirements where necessary. The committee also concluded that USCG should institute a process that recognizes the evolving nature of AIS display technology and the need to accommodate future improvements and growth.

Recommendation 2: USCG should establish requirements for shipboard display of AIS information in U.S. navigable waters by

- Defining mariner information needs,
- Defining key functions for AIS displays aboard different types of vessels and in different operating environments,
- Developing appropriate requirements for each major vessel class that take into consideration the wide differences in operating environments,
- Involving the key stakeholders in the entire process, and
- Developing a new requirement for minimum information display of AIS.

USCG should take a leadership role in establishing display requirements for AIS information and work with appropriate international organizations in this process to ensure compatibility with international requirements.

> ***Recommendation 3:*** USCG should recognize the evolving nature of AIS display technology in its requirements process and allow for technological change, growth, and improvements in the future.

HUMAN FACTORS IN THE DISPLAY DESIGN PROCESS

For AIS to meet its stated objective of promoting safe vessel navigation, an effective onboard interface with the vessel's operator is essential. To provide an effective interface, the focus of the design process must be on the best means to exchange information between the person and the AIS. Although the term "display" is usually used in this report in referring to this interface, it should be noted that, from the perspective of the human operator, the "interface" includes both display and control mechanisms that allow the exchange of information between the operator and the rest of the system. The interface includes not only the display of information through such means as a cathode ray tube, graphics, and auditory warnings, but also data entry and control elements such as keyboards or switches. Development of an effective human interface for the AIS requires a systematic process that considers the capabilities of users and the demands of the operating environment.

Three core elements make up a typical design process with human factors as a focus: understanding, design, and evaluation. The process begins with development of an understanding for the operational demands and the needs of the mariner. This provides the basis for the initial design, which is then evaluated. The process is iterated as new factors and inevitable changes are recognized.

Within the element of understanding is the notion that advanced technology can increase errors and risk even when appearing to be beneficial. This reinforces the need for attention to the human interface. It is also clear that AIS data need to be translated into decision-relevant information for the mariner. Thus it is important to understand how each task of the mariner is performed and how AIS data can support that task and, in turn, overall performance. There are substantial operating differences among the range of vessels that may be equipped with AIS, and it is clear that interface design needs to reflect that variation if it is to adequately support operator needs.

The second element, design, follows from the first and begins with incorporation of the large body of knowledge about human factors interface guidelines that already exists. The committee identified 13 human factors principles that are particularly relevant to AIS interface design, including ensuring that system behavior is completely visible to the operator, avoiding interface management tasks during high-tempo situations, and realizing that the representation of AIS data (e.g., graphic versus numeric) can greatly affect interpretations.

Finally, the evaluation element represents the step that tests a design and its performance and leads to either initial adoption or redesign to correct a problem. Heuristic evaluation with multiple evaluators is a very useful approach in identifying design problems. In addition, usability testing and operational evaluation are complementary approaches in identifying problems. Operational evaluations are a critical aspect of this process because important display issues cannot be anticipated and are often only detected when the system is evaluated in the operating environment.

Selection of an effective design process will have a large impact on how well a shipboard display and control system provides the promised benefits and avoids unexpected consequences. A combination of design, process, and performance standards is needed to ensure effective designs. Maritime technology and AIS applications will always be difficult to predict. Thus, designers must have the freedom to adapt to changes as they occur or are identified. USCG needs to allow for this in its standards-setting process.

> ***Recommendation 4:*** In its standards, USCG should specify that design, process, and performance standards be used in combination to promote adequate shipboard AIS display design.

SYSTEM LIMITATIONS

For a shipboard display to function adequately and provide necessary information to the mariner, the overall AIS and supporting infrastructure must also function reliably and accurately. However, current systems are not fail-safe. In addition, the integrity of the data supplied by the carrying vessel is not always assured for a variety of reasons. For example, there can be erroneous input from ship sensors, or the data that are manually entered by an operator can be changed or contain errors.

Several infrastructure issues also affect the display of AIS information: transponder coverage and the spacing of shore-based repeater stations, the adequacy and accuracy of digital charting in a given waterway, the availability of existing vessel instrumentation, and the need for standardized interfaces between existing equipment. In many U.S. waterways, surveys need to be updated to prepare accurate charts, and real-time environmental and hydrological data are inadequate for providing accurate waterway forecasts. International standards development efforts have inadequately considered such infrastructure issues and have not considered the impact of infrastructure issues on shipboard display of AIS information.

In addition to infrastructure, it is important to consider shipboard operating environments that will shape shipboard display of AIS information. For example, display designs will depend on such factors as the range of data that will be received by ships from shore stations; the areas and routes used by vessels with AIS; the work environment, tasks, and workload of the shipboard bridge watchstanders; and the skill levels and training of individuals using the AIS displays.

These and other operating parameters affect AIS performance in general, and especially the design and implementation of shipboard displays. For example, a potential problem with the use of AIS displays aboard vessels is that the human interfaces can, in some cases, mislead operators into believing that a complex system is well represented by a simple display. Some of this risk can be addressed by good display design. However, the general problem suggests that operator training may be needed in communication systems, AIS capabilities and limitations, and AIS operations. These and other factors suggest that the identification of skill requirements and concomitant AIS training needs will be an important consideration.

Recommendation 5: USCG should identify critical AIS limitations and infrastructure requirements and coordinate them with display requirements. USCG should establish a mechanism to inform all users about system limitations if they cannot be readily corrected.

Recommendation 6: USCG should work with stakeholders to develop appropriate training and certification guidelines for AIS users that will lead to effective use and an understanding of system functions and limitations.

NEED FOR ONGOING RESEARCH ON HUMAN INTERFACES

The development of AIS display and control requires a full consideration of human interface attributes that affect what information to display, how to present it to the operator, how to integrate other displays or other bridge information systems, and how to give the operator what is most needed to perform critical tasks. The term “AIS display” connotes a visual presentation of data; however, there are other methods of providing effective human interfaces that may be appropriate for shipboard use. Continuing evolution in the form and function of technology also suggests a range of presentation options for AIS information that may be appropriate in different shipboard settings.

AIS interface design should be subject to further analysis and critical investigation. For example, the system image and its physical representation may determine its use. A key consideration is whether AIS data will be presented to the operator separately or will be integrated with other existing equipment and information flows. This is a key research area and has received little attention to date. On board certain vessels, AIS units need to fit within existing bridge configurations to remain within the mariner's peripheral vision while not interfering with his or her view of the outside or other equipment. This condition might suggest that different types of AIS interfaces could be adopted, such as wearable computing devices, enhanced binoculars, or a mix of tactile and auditory devices. In addition, AIS interfaces could consider multimodal approaches in order to adequately address competing attention demands. Aboard smaller vessels, AIS visual displays will need to balance the need to be large enough to convey the necessary AIS information and small enough to fit unobtrusively among other equipment. Another consideration aboard small inland vessels is the ambient noise level in the wheelhouse that might interfere with audio signals. This effect of ambient noise on the hearing of auditory signals is not, however, limited to inland vessels.

Another area of necessary research relates to whether and how mariners need to input data into the AIS during the normal conduct of vessel operations and how this might interfere with other duties. Some mariners may have limited opportunities to input data into the system, given competing demands for operational task performance and decision making, particularly on board smaller vessels with one-person wheelhouses. Different types of information may require different data input strategies.

Symbology for visual displays is a fertile area for research and development. While some display symbology requirements have been articulated by international bodies, they have not been harmonized across different shipboard electronic navigational displays, nor across different operating environments (e.g., from inland waterways to coastal waterways to open ocean).

There are several human factors interface research topics that are particular to the operation of smaller inland and coastal vessels, including the evaluation of competing operator attention demands on board vessels with one operator, high noise levels, multiple communications links, and needs for multiple operational tasks. Furthermore, there is little commonality in bridge layouts, even for vessels of the same class, and this lack of bridge layout standardization affects potential shipboard displays of AIS information. This leads to the need to consider specific display requirements for specific operating environments rather than universal display requirements for all vessels.

The process of determining the proper shipboard display of AIS information will be dynamic and reflect the needs and requirements of different operating areas. Integration requirements for shipboard display of AIS information raise questions about appropriate task and function allocation between technology and people. For example, designers must strike the right balance between human integration and information processing and automation support for each key task.

A research program could address these questions about AIS display and control design and support. The research should be part of the iterative design process that would allow for improvements and inevitable future change without detracting from the urgent tasks of implementing initial requirements for use of AIS in U.S. waters.

> ***Recommendation 7:*** USCG should establish an ongoing research program to investigate information displays and controls that might be appropriate for AIS. The research program should consider AIS use with other navigational and communication technologies. The research program should include
>
> - Human factors aspects of interface design and the subsequent process of determining requirements, setting standards, and evaluating performance;

- Evaluation of multimodal interfaces (tactile, auditory) that could effectively support mariners' needs for attention management;
- Allowance for technological change and leverage of lessons learned from other fields (such as aviation) and related applications of similar technology; and
- Investigation of trade-offs between information requirements and the associated cost for shipboard display of AIS.

CONTINUED OPERATIONAL TESTING OF AIS DISPLAYS

USCG and other authorities have conducted a number of operational tests of AIS and transponder-based technology in the United States and abroad. Anecdotal reports from most of these tests have identified benefits and limitations of the equipment and shown the operators how it might be used within their operational environments. However, none of the tests with displays has resulted in evaluations of performance measured against specific standards. Also, few of the tests on displays have been performed on AIS equipment that was built to IMO standards.

International standardization has occurred late in the AIS development process, and this has caused difficulties in producing functional and reliable systems that provide information the mariner can use with ease. It has also hindered operational tests of AIS displays because no consistent performance standards have been developed against which to measure results.

The committee reviewed several operational tests of shipboard AIS displays. Most of these tests have not resulted in evaluation reports that clearly and critically document the functioning and usefulness of displays. Anecdotal reports from certain operations using AIS displays suggest that operators have gained confidence in the systems and used them successfully as navigational aids. From this experience, it appears that the whole community would benefit from more rigorous operational testing with clear functional requirements against which to measure performance, followed by critical evaluations.

Recommendation 8: USCG should sponsor continuing operational tests, evaluation, and certification of new display and control technology in consultation with stakeholders and prepare test and evaluation reports. To conduct tests and evaluations, USCG should develop standards for human performance with display and control technology. It should use heuristic evaluation, where multiple designers assess how well a design conforms to human factors rules of thumb or heuristics. It should also incorporate usability tests and operational evaluations as complementary approaches to assess how well AIS displays and controls support mariner performance.

SUMMARY

The introduction of AIS technology with effective displays aboard vessels can enhance the safety of vessel operations and the prudent management of waterway traffic. The benefits to the maritime community and the nation as a whole will depend on how well the industry, government authorities, and mariners work together to design effective systems, establish comprehensive standards and guidelines, and implement technologies that provide useful tools for the vessel operator. USCG should take specific actions to ensure an implementation process that meets safety improvement goals. These actions include preparing an implementation plan, establishing requirements for displays and their functions, including human factors in the display design process, addressing system limitations and shortfalls, developing training guidelines, establishing human performance standards, establishing a focused research program, and conducting operational tests and evaluations of display systems.

USCG cannot ensure that this new technology will bring the promised benefits to all without the involvement and cooperation of all the stakeholders, and without formal evaluation of such systems. Manufacturers, mariners, and the maritime industry as a whole need to be a part of the process to develop effective systems and to successfully implement this technology. While the focus of this report is on shipboard display of AIS information, the process of implementation and the use of human factors principles have wider application to many systems used aboard vessels operating in U.S. waters.

1 Introduction

Automatic identification systems (AIS) technology has been under development for well over a decade and has had at least two major driving forces behind it. First, mariners are interested in effective, reliable, and automatic vessel identification for a number of practical reasons:

- To eliminate the need to blindly call a vessel on VHF with a message seeking to identify another vessel (e.g., "northbound ship on my port bow"),
- To eliminate or reduce the hazard of making collision avoidance arrangements with the wrong vessel, and
- To identify a rogue ship holding on in contravention of the rules of the road.

Second, governmental agencies of coastal states that are responsible for the prevention of and response to marine pollution incidents, conservation of natural resources, vessel traffic management, maritime security, and law enforcement are interested in vessel identification as well as in monitoring certain vessel activities and movements. Until AIS and similar technologies came into use, such monitoring required physical sighting and identification of the vessels of concern, voluntary reporting by such vessels, or, in the proximity of a coast, use of radar or other active surveillance. All of these methods have significant drawbacks, not the least of which is cost.[1]

In addition to these two principal driving forces, commercial interests have motivated AIS development. Commercial interests include port authorities, vessel operators, and pilots, all of whom seek to improve safety and facilitate commerce through improvements in the availability and timeliness of the information available to mariners. AIS can contribute to such improvements unobtrusively without reliance on voice communications. Of these

[1] There is a wealth of literature detailing the application and development of such monitoring. For example, a useful snapshot of practices in the early 1990s is provided by HMSO (1994). Related issues were also addressed by Marine Board committees of the National Academies (NRC 1994; NRC 1996; NRC 1999).

forces, however, governments for the most part have led in shaping the technology and its applications.

The mariners' requirement for vessel identification could have been met by shipboard installation of transponders similar to those in common use in aircraft. When triggered by the receipt of radar impulses, such transponders respond in a manner that "paints" the name and call sign of the carrying ship next to the target as shown on the querying radar. However, there are limits to the amount of information that can be provided by such transponders—positional information provided by such transponders is relative to that of the querying ship, and its accuracy is determined by the radar used. Therefore, early marine transponder developments (i.e., before 1990) led to a second type of transponder system termed automatic dependent surveillance (ADS), which consists of a radionavigation receiver utilizing systems such as the Global Positioning System (GPS), Differential GPS (DGPS), or Loran-C coupled to a communications device capable of transmitting position and other predetermined information to a suitably equipped receiver. The advantages of this approach over a radar-based system, which is used in aircraft, include greater positional accuracy, longer ranges (depending on the communications medium used), and an ability to transmit a greater volume of data.[2]

Over the last 10 years transponder-based systems have been used in a variety of applications. For example, one system is used to identify fishing vessels as a tool in fisheries management (Zamora 1999). In the United States, other applications include a vessel traffic management system developed for the Tampa Bay waterways (see Chapter 3), ferry systems that use it to monitor ferry movements, and rescue tugs that are coordinated for marine emergency response in Puget Sound using AIS.

Standardization of these AIS developments is critical because shipping is an international business and it is essential that mariners find the same information environment wherever they sail. Over the past few years, the International Maritime Organization (IMO), working through the International Telecommunication Union (ITU) and other organizations, has published technical and operational standards that must be met for equipment to

[2] For a summary of early ADS capabilities and cost, see Volpe National Transportation Systems Center (1990).

be called “AIS.” All other applications are usually designated merely as “transponder-based systems.” However, international efforts to develop standards for AIS took place after many systems were already in use throughout the world, which has led to difficulties for those who have developed such systems as well as for those who have already purchased them.

The “universal” AIS as defined by IMO standards is based on the so-called “ship-ship, ship-shore” transponder developed by a Swedish–Finnish team (IALA 2001), a broadcast system operating in the VHF maritime mobile band. The shipboard component is capable of sending information such as a vessel’s identification, position, course, and speed to other ships and shore stations. Shore stations can also transmit a variety of “safety-related” messages, the scope of which is discussed elsewhere in this report.

OVERVIEW OF AIS CAPABILITIES AND APPLICATIONS

The IMO Performance Standards for AIS [IMO Resolution MSC.74(69)] (IMO 2002b) require that the systems be capable of functioning

- In the ship-to-ship mode, to assist in collision avoidance;
- In the ship-to-shore mode, as a means for littoral states to obtain information about a ship and its cargo; and
- In the ship-to-shore mode, as a vessel traffic service (VTS) tool.[3]

While the introduction of AIS for commercial ships and many other types of vessels has been under way for several years, the primary focus of most initiatives has been to provide improved ship-to-shore identification mainly for enhanced traffic management. VTS in many major ports and waterways has relied on radar surveillance, when available, for identifying and locating vessels, but AIS technology holds the promise of providing more accuracy and reliability while reducing the need for radio communications among ships and shore stations.

[3] Although MSC.74(69) (IMO 2002b) uses the language “Vessel Traffic Service tool,” this application is being interpreted more broadly by IMO in Resolution A.917(22) and by IALA (2001) as a general vessel traffic management tool useful even in areas where there is no VTS.

> AIS is intended to enhance: safety of life at sea; the safety and efficiency of navigation; and the protection of the marine environment. SOLAS[4] regulation V/19 requires that AIS exchange data ship-to-ship and with shore-based facilities. Therefore, the purpose of AIS is to help identify vessels; assist in target tracking; simplify information exchange (e.g., reduce verbal mandatory ship reporting); and provide additional information to assist situation awareness. In general, data received via AIS will improve the quality of the information available to the OOW [Officer of the Watch], whether at a shore surveillance station or on board a ship. AIS should become a useful source of supplementary information to that derived from navigational systems (including radar) and therefore an important "tool" in enhancing situation awareness of traffic confronting users. (IMO 2001a)

The three identified functions set the boundaries for AIS functionality. In general, AIS provides a means of exchanging a precisely defined range of data between ships, and between ships and shore facilities under the oversight of "competent authorities."[5] It is not, for example, a precision navigation device itself but a tool for exchanging navigation and other data. Nor is it a general correspondence messaging system. AIS not only suffers from limitations imposed by current standards, but it is also subject to the shortfalls common to all transponder-based tracking technology:

- The systems are not fail-safe. If the equipment is not operating, the carrying vessel simply disappears from the surveillance picture without notice.
- The systems require the cooperation of the vessels being tracked. A decision not to carry the required equipment, or to disable or otherwise turn it off, removes the vessel from those tracked.
- The integrity of the static data is not assured. Static data, including data showing the identity of the carrying vessel, are manually entered by an operator. The entries can therefore be changed at will or can have errors.
- Within VTS areas of responsibility, transponder-based tracking must be supported by an active surveillance capability and a "sorting" process, which can correlate vessels identified by transponder with those detected by other means.

[4] International Convention for the Safety of Life at Sea.
[5] "Competent authority" is a term used in much of IMO's documentation and is generally construed to mean the national-level agency responsible for maritime safety.

- Not all vessels will be equipped with AIS.
- AIS information may be subject to misinterpretation.

There is concern in the maritime community that anyone with an appropriate receiver could obtain transponder-transmitted data, which might allow competitors to gain business-related advantages from the information available or criminals to use such information in their crimes. In addition, some are concerned that businesses such as marine exchanges could be adversely affected by the general availability of vessel movement information or that the increasing visibility of ship operations and movement will lead to more regulatory action.

Since the focus of this report is AIS shipboard displays, a full description of the underlying AIS technology is beyond its scope. Many sources provide such a description, and they may be consulted to obtain a detailed understanding. However, a basic sense of the AIS communications scheme is essential to an appreciation of the factors affecting displays. Such a description is provided below.

Each AIS-equipped station (either a ship or shore facility) broadcasts and receives AIS messages to and from all stations within VHF radio range. To prevent transmissions from AIS-equipped ships and stations from interfering with each other, AIS uses a self-organizing time-division multiple access (SOTDMA) protocol to synchronize multiple data transmissions from many users on a single narrowband channel. The SOTDMA protocol divides each minute of time into 2,250 time slots. An AIS report fits into one or several of the 2,250 time slots, which are selected automatically on the basis of current and projected data traffic on the network. Time slots and time-out periods[6] are selected randomly. When a station changes its slot assignment, it announces its new location and time-out for that location to all other stations within range. This allows each station to continually update its internal "slot map" to reflect changes in occupied slots and time-outs. Provisions are made for automatic conflict resolution in the event that two stations occupy the same time slot. The key to SOTDMA is the availability of a highly

[6] "Time-out" is defined as an event that occurs when one network device expects to, but does not, hear from another device within a specified period of time. The resulting time-out usually results in a retransmission of information or the outright dissolving of the communication link between the two devices.

accurate standard time reference, which is supplied by the precise timing signal used by the radionavigation system. The radionavigation system thus not only performs the position component of shipboard messaging but also provides the universal time reference.

The area within which its AIS messages can be received is called the station's "cell," the size of which varies. For example, in areas of high traffic density a small cell might be preferable. If the number of AIS messages begins to overload the network, the system can automatically shrink its cell size by ignoring weaker stations further away in favor of those nearby. The size of AIS cells can be varied to reflect the volume of vessel traffic and the types and extent of "safety-related" messages transmitted by shore stations. Also, in areas of high traffic density and high volume of messaging, consideration of cell size may affect the configuration of the shore-based AIS infrastructure—the number and locations of shore-based AIS sites serve to determine cell size. The more stations and the less distance between them, the greater the volume of traffic that can be accommodated.

In general, the range of AIS coverage is similar to other VHF applications: it depends on the height of the antenna. AIS propagation is slightly better than radar because of its longer wavelength, so it is possible to see around bends and behind islands if the land masses are not too high. This is a major advantage in some waterways. At sea, a typical range for coverage is expected to be about 20 nautical miles. With the use of shore-based repeater stations, the coverage range can be increased (USCG 2001a).

AIS data transmissions use a robust 9.6-kbps FM/GMSK (Gaussian minimum shift keying) modulation technique.[7] ITU has designated two dedicated frequencies for AIS: 161.975 MHz (marine band Channel 87B) and 162.025 MHz (Channel 88B). In the United States those frequencies are not available, and alternative frequencies have been designated. Each ship station is equipped with two independent VHF receivers, which are normally tuned to the two AIS frequencies. The ship station is also equipped with a single VHF transmitter, which alternates its transmissions back and forth between the two frequencies. The shipboard system can also be retuned

[7] See ITU Recommendation M.1371-1 (ITU 2001).

to other frequencies when, for example, it operates within the area of responsibility of a VTS. The retuning can be accomplished either manually or remotely by an AIS shore station.

The shipboard component of AIS consists of three elements: a communications medium, an assembly "black box" that takes the various inputs and organizes them into AIS message format, and a display that presents incoming data to the shipboard user. The elements are shown graphically in Figure 1-1.

Within the current IMO standards for AIS, the only display that is specified is known as the "minimum keyboard and display" (MKD) (IMO 2001b). Although it is not shown in Figure 1-1, the MKD is used for monitoring the performance of the AIS unit and inputting required data elements. The limitations of the MKD are discussed in Chapter 4.

IMO and other bodies have also established a series of AIS international standards governing system performance, technical characteristics of the system, frequency allocation for the VHF communications medium, and

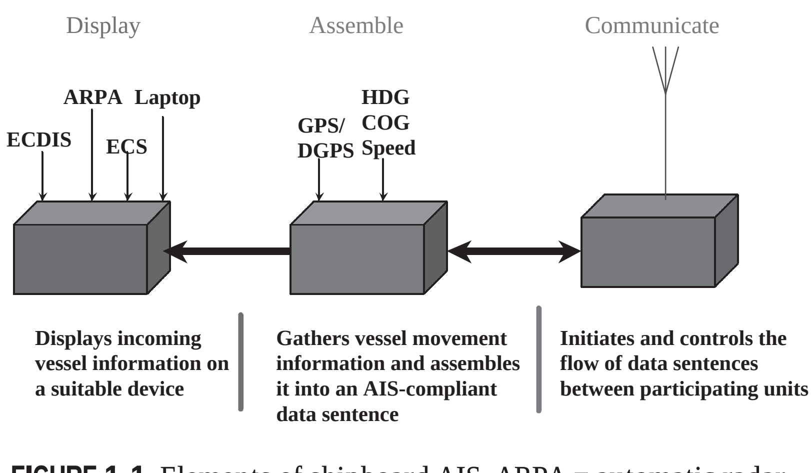

FIGURE 1-1 Elements of shipboard AIS. ARPA = automatic radar plotting aid; COG = course over ground; GPS = Global Positioning System; DGPS = Differential GPS; ECDIS = electronic charting and display information systems; ECS = electronic charting systems; HDG = heading. (Source: USCG 2001b.)

TABLE 1-1 Applicable International AIS Standards

Standard	Organization That Issued the Standard	Issue Date
Functionality	International Maritime Organization, MSC 74(69)	May 1996
Technical	International Telecommunication Union, ITU-R M.1371	November 1998
Certification	International Electrotechnical Commission, IEC 61933-2	February 2002
Applicability	International Maritime Organization, SOLAS Chapter V	December 2000
Compliance[a]	International Maritime Organization, SOLAS Chapter V	July 2002 to July 2006
Communications	Channel 87B / 88B—World Radio Conference, ITU-A S18	May 1997

[a] "Compliance" may be interpreted as the "requirement to carry and use."
Sources: USCG 2001a; IMO 2001a; IMO 2001b.

equipment test standards. They are summarized in Table 1-1. The three key standards are identified below:

- *IMO Resolution MSC.74(69), Annex 3, Recommendation on Performance Standards for a Universal Shipborne Automatic Identification System (AIS)* (IMO 2002b): This standard defines the basic performance requirements for AIS equipment and was used by ITU and the International Electrotechnical Commission (IEC)[8] in developing technical and test standards.
- *ITU-R Recommendation M.1371-1, Technical Characteristics for a Universal Shipborne Automatic Identification System Using Time Division Multiple Access in the Maritime Mobile Band* (ITU 2001): This standard defines in detail how the AIS works and is the primary AIS standard. The ITU Sector for Radiocommunications formally adopted this standard in August 2001 and gave to the International Association of Aids to Navigation and Lighthouse Authorities (IALA) the responsibility of maintaining technical guidelines for AIS design.
- *IEC 61993-2 Ed.1, Maritime Navigation and Radiocommunication Requirements—Automatic Identification Systems (AIS)—Part 2: Class A Shipborne Equipment of the Universal Automatic Identification System (AIS)—*

[8] IEC is the global organization that prepares and publishes international standards for all electrical, electronic, and related technologies; it also promotes international agreements on electrotechnical standardization.

Operational and Performance Requirements, Methods of Test and Required Test Results (IEC 2001): This standard defines the certification test requirements for Class A shipborne AIS equipment. IEC formally adopted this standard in November 2001.

In addition to the international performance and technical requirements shown in Table 1-1, the United States has established certain specific standards of its own. They are shown in Table 1-2. These standards are still evolving and, to date, do not cover any shipboard display issues.

Ship-Originated AIS Messages

AIS messages need to be updated and retransmitted every few seconds because the usefulness of some data, particularly data applying to the position and movement of vessels, decays rapidly as a function of time. For vessel position and movement data to be useful, the update rate must be sufficient to develop a cohesive representation of the transmitting vessel's position and track. In the case of vessels operating at higher speeds or maneuvering, the data must be refreshed more often. In consideration of this, the standards provide for updates that vary with the transmitting vessel's movements. Typical vessel movement conditions and the corresponding reporting intervals are shown in Table 1-3.

TABLE 1-2 Applicable U.S. AIS Standards

Standard	Organization That Issued the Standard	Issue Date
Certification	U.S. Coast Guard, 46 CFR 159	December 2001
Applicability	U.S. Coast Guard, 33 CFR 164.43	July 2001
Compliance	U.S. Coast Guard, 33 CFR 161	July 2001
Communications	Channel 228—Federal Communications Commission, 47 CFR 80.371(3)	July 1996
	Channel 87—U.S. Coast Guard, Memorandum of Understanding	March 2001
	Channel 288—National Telecommunications Information Agency	July 2001

Source: USCG 2001a.

TABLE 1-3 Vessel-Transmitted AIS Update Rates

Ship's Maneuvering Condition	Nominal Reporting Interval
At anchor or moored and not moving at more than 3 knots	3 minutes
At anchor or moored and moving at more than 3 knots	10 seconds
Under way, moving at 0–14 knots	10 seconds
Under way, moving at 0–14 knots and changing course	3.3 seconds
Under way, moving at 14–23 knots	6 seconds
Under way, moving at 14–23 knots and changing course	2 seconds
Under way, moving at more than 23 knots	2 seconds
Under way, moving at more than 23 knots and changing course	2 seconds

Sources: IMO 2001a; IALA 2001, Table 2-1.

Table 1-4 identifies vessel-originated AIS data and their source under three general headings: static, dynamic, and voyage-related. For oceangoing vessels, static data are pertinent to the particular vessel and typically would not change from voyage to voyage. However, static data for inland tows would change frequently. Voyage-related data change each time the vessel prepares to depart for another port. Dynamic data change from second to second as the vessel makes its way to its destination. In addition to these required data, discretionary data may be transmitted as desired by the vessel master, and optional data may be transmitted if appropriate sensor equipment is installed and properly connected to the AIS unit for compilation into the AIS message format and timely transmission.

From the perspective of the mariner, the data conveyed by ship-to-ship AIS can provide a heightened level of awareness of other vessels and their movements in a waterway. While there is an ongoing debate about the propriety of relying on AIS for collision avoidance, it holds the promise of serving this purpose when it is fully developed. Rule 7 of the International Regulations for the Prevention of Collisions at Sea states: "Every vessel shall use all available means appropriate to the prevailing circumstances and conditions to determine if risk of collision exists. If there is any doubt such risk shall be deemed to exist." Thus, it seems logical that AIS will, with the impo-

TABLE 1-4 Vessel-Originated AIS Data (Required, Discretionary, and Optional)

Data	Data Source
Static information: Every 6 minutes and on request of competent authority	
Vessel name	Set on installation
Call sign/mobile maritime service identity (for VHF DSC–equipped vessels only)	Set on installation
Length and beam	Set on installation
Type of ship	Set on installation from preinstalled list
IMO number	Set on installation
GPS antenna location	Set on installation
Height over keel	Set on installation
Dynamic information: Dependent on speed (see IALA 2001, Table 1-1)	
Ship position with accuracy indication and integrity	Automatic update from position course sensor Accuracy indication better or worse than 10 meters
Position time stamp	Automatically updated from main position sensor
Course over ground	Automatically updated from main position sensor
Speed over ground	Automatically updated from main position sensor
Heading	Automatically updated from main position sensor
Navigational status	Manually entered by the officer of the watch Under way by engine At anchor Not under command Restricted in ability to maneuver Moored Constrained by draft Aground Engaged in fishing Under way by sail
Rate of turn (ROT)	Automatically updated from ship's ROT sensor or derived from gyrocompass

Note: Provisions are made for input from external sensors of additional information where available (angle of heel, pitch, roll, etc.).

(continued on next page)

TABLE 1-4 *(continued)* Vessel-Originated AIS Data (Required, Discretionary, and Optional)

Data	Data Source
Voyage-related information: Every 6 seconds, when data amended or on request	
Ship's draft	Entered at start of voyage, updated as required
Hazardous cargo (type)	Entered at start of voyage
Destination and estimated time of arrival	Entered at start of voyage, updated as required
Route plan	Entered at start of voyage, updated as required
Number of persons on board	Includes crew; entered at start of voyage
Short safety-related messages: As required	
Free format short text messages manually entered as required	

Note: DSC = digital selective calling.
Sources: IMO 2001a; IALA 2001, Table 3-1.

sition of carriage requirements, be one of the "available means." In fact, AIS overcomes two important limitations of radar when that sensor is used for collision avoidance: (*a*) the raw radar echo targets do not normally represent the real dimensions of a target, and (*b*) significant delays occur in providing a true representation of a turning target.[9] The data must be properly displayed if AIS is to adequately support navigation.

When AIS is called on to serve a function such as collision avoidance, shipboard display becomes critical. The display of ship-to-ship data, specifically the dynamic data that deal with vessel movement, has developed faster than the display of other types of data. For example, IMO Resolution MSC.74(69), Annex 3 (AIS) (IMO 2002b), Paragraph 6 specifies that the minimum information to be displayed will consist of

- Position,
- Course over ground,

[9] For a detailed discussion of these radar limitations, see Chapter 4 of the *IALA Guidelines* (IALA 2001).

- Speed over ground,
- Heading, and
- Rate of turn or direction of turn as available.

IMO (2001b) has published recommended standards for the display of ship-to-ship data, including the symbology that should be used to display vessel targets.[10] The display of shipboard AIS information is the subject of this report.

Shore-Originated AIS Messages

Shore-originated AIS messages can encompass a broad range of subjects:

- Information about aids to navigation, including such details as whether they are working properly and environmental conditions at an aid's station;
- Meteorological or hydrological data;
- Information about pseudoaids to navigation, providing the location and identification of specific geographic reference points;
- The identity, position, and dimensions of offshore structures;
- VTS waypoints or route plans used by a VTS to advise ships of the waypoints or route to be used. Such plans may consist of up to 12 waypoints or a route specified by a textual description. If waypoints are transmitted, a recommended turning radius can be included for each one; and
- Shore-based radar target information from a vessel traffic center. The radar images would be converted and retransmitted to AIS-equipped vessels, where they could be displayed as pseudo-AIS targets.

In addition to the above, IALA (2001, Section 7.4) has suggested that AIS use in pilot waters can ultimately be broadened to "provide a bird's eye view of a docking operation with tugboats connected or pushing including information such as bollard pull, direction of pull and even issuing the commands to tugboats."

The sheer volume of the information messaging possible suggests that displays may be used for a wide variety of purposes. Displays, for example, may be considered as the means by which AIS data are converted into informa-

[10] See Chapter 4, *IALA Guidelines* (IALA 2001).

tion that the mariner can readily assimilate and use in decision making. For example, if the VTS waypoints/route plan are conveyed from VTS to the mariner as a series of latitude–longitude coordinates, the data must be plotted on a chart in order to be useful. If, however, the route is displayed graphically on an electronic charting system that also displays own ship and other vessel positions, it is immediately available without adding to bridge management workload. The requirements for a display are thus also dependent on what data are provided from shore. The volume of data that will be transmitted from shore affects the extent of the shore-based infrastructure. Close coordination is therefore needed between the carriage requirements for displays and the development of shore infrastructure. Standardization of what data are transmitted from shore is also critical to ensure a common operating environment between ports and regions.

IALA (2001) is considering a three-tiered structure that would provide

- International applications controlled by IMO;
- Regional applications controlled by organizations such as the European Union; and
- Local applications controlled ether by national competent authorities or local groups—ports, pilot organizations, and so forth.

Such an approach, however, could significantly complicate display requirements.

CURRENT DISPLAY DESIGNS AND THEIR CAPABILITIES

Shipboard AIS displays can take many forms. Several design concepts are available and have been used in a number of applications. Portable units in the form of laptop computers employing AIS or similar transponder-based technology are now in common use by ship pilots in the St. Lawrence Seaway and in several U.S. ports such as New Orleans, Tampa, and Delaware Bay. For existing vessels, AIS displays could be either portable or fixed units and could be either separate or integrated with other displays such as electronic charts. For new vessels, the opportunity exists to design and install any number of stand-alone or integrated systems that may be part of a modern integrated bridge navigation complex.

Shipboard AIS display technologies span a significant range of sophistication, complexity, functionality, and cost. While the technologies and their application and marketing are constantly evolving, it is still worthwhile to consider the basic types of AIS display devices available and being put into service aboard ships. These devices range from the simple minimum three-line alphanumeric displays to robust integration of AIS information into electronic chart displays and radar systems. Depending on a particular vessel's need or ability to accommodate varying levels of AIS display sophistication, the most appropriate installation can be implemented. Because the display is the primary interface between the AIS and the human operator (i.e., master, pilot, etc.), it is important to maximize the effectiveness of this information exchange. The following four general types of AIS displays are currently available:

1. MKD. This is the most elementary AIS display concept, incorporating a three-line alphanumeric display screen, typically a backlit monochrome liquid crystal display (LCD) device. Alphanumeric text conveying the basic AIS information scrolls across the display, allowing the operator to read the information. A simple keyboard or keypad is provided to allow limited operator input and control of the display device. Because it is limited to three scrolling lines of alphanumerics, this device does not lend itself to conveying the graphical images that are so often considered to possess much greater information density.
2. Iconic display. This is a relatively simple AIS display concept incorporating a display screen on which simple icons representing AIS targets are plotted. Along with the graphical representation of the vessel traffic environment, AIS information such as bearing, target angle, speed, and so forth are displayed for each icon. Although this type of display provides more information quickly to the operator than does a minimum three-line display, iconic displays are still typically monochrome, low-resolution devices. The information displayed is also a very simplified and limited representation of the actual traffic situation. Iconic displays are only capable of displaying dedicated AIS information and thereby serve only a single bridge function.
3. Computer display. A more sophisticated AIS display concept uses a full-color, high-resolution computer display screen. These screens provide the benefits of bright vibrant color, excellent resolution, large size,

and good contrast and can be traditional cathode ray tubes, plasma screens, or LCD flat panels. They can even be projection devices, in theory. Desktop personal computers, laptops, or notebook computers typically included in carry-aboard AIS pilot packs use these display devices and include full keyboards for data entry. A possible variation on this concept includes use of handheld computing devices with built-in display screens. Computer devices are typically adjustable for color, brightness, contrast, and other attributes and can easily be adapted to service in various ambient conditions, from bright sunlight to fluorescent work light to night darkness.

4. Electronic charting systems (ECS)/electronic charting and display information systems/radar/automatic radar plotting aid integration. Arguably the most sophisticated AIS display technology today involves the integration of AIS information with other bridge navigation and information systems, such as ECS and radar. Through the use of dedicated display devices intended for ECS, radar, or other established purposes, AIS information can be provided to the operator in the form of complex iconic plots representing each AIS target and associated details of the target, such as bearing, heading, and speed. Successful integration with an accurate electronic chart could allow for increases in the value of AIS information for navigation and safety purposes. However, many technical, logistical, political, and psychological issues related to such integration of bridge equipment remain to be resolved.

STATUS OF U.S. AND INTERNATIONAL IMPLEMENTATION OF AIS

Carriage Requirements

The 2000 Amendment to Chapter 5 of SOLAS, as amended at IMO's Diplomatic Conference of December 2002, requires that AIS be fitted aboard all ships subject to the convention and of 300 gross tons (GT) and upwards engaged on international voyages, cargo ships of 500 GT and upwards not engaged on international voyages, and passenger ships irrespective of size built on or after July 1, 2002. Cargo ships of 500 GT and upwards not engaged on international voyages must fit AIS not later than July 1, 2008. The implementation schedule is as follows:

- Passenger ships: not later than July 1, 2003;
- Tankers: not later than the first survey for safety equipment on or after July 1, 2003; and
- Ships, other than passenger ships and tankers, of 300 GT and upwards but less than 50,000 GT: not later than the first safety equipment survey after July 1, 2004, or by December 31, 2004.

U.S. rulemaking to implement the SOLAS requirements and perhaps extend carriage requirements to other vessels not affected by SOLAS is under development. The specific form and implementation schedule may reflect requirements of the Department of Homeland Security, particularly the provisions of the Maritime Security Act of 2002. In general, however, it appears that certain vessels not covered by SOLAS will be among those required to carry some form of AIS in the future and will be those subject to the Bridge-to-Bridge Radiotelephone Act.

In December 2002, the U.S. St. Lawrence Seaway Development Corporation and the Canadian St. Lawrence Seaway Management Corporation, in cooperation with the U.S. Coast Guard (USCG) and the Canadian Coast Guard, issued a mandatory AIS carriage requirement for all oceangoing and lake vessels transiting the seaway beginning March 25, 2003. The seaway authorities are arranging for vendors to rent or lease AIS units to vessels without permanent AIS equipment that transit the seaway after March 25, 2003.

Long-Range AIS

In January 2002 the United States proposed to IMO that the implementation of AIS be accelerated and that means be developed to extend its range to 200 miles (IMO 2002a). In February 2002 the Maritime Safety Committee (MSC) Intersessional Working Group on Maritime Security agreed to recommend acceptance of the proposed revision to the May 2002 meeting of the committee (MSC 75) (IMO 2002a). The final decision was made by a Diplomatic Conference on Maritime Security in December 2002.[11] It is by no means certain that technical and schedule changes will be adopted, and the changes necessary to extend AIS range may take significantly more time than now envisioned. International acceptance of such an application, while by

[11] IMO undated newsletter.

no means assured, is supported by many coastal states with related interests.[12] In its submission to IMO, the United States suggested that other long-range communication systems such as International Maritime Satellite might be better used for this purpose than AIS (IMO 2002a).

There is no IMO requirement that addresses communications systems for long-range applications for AIS Class A mobile systems (IALA 2001, Chapter 20). In principle, any long-range communications system can be used if it is suitable for data transmission. Using existing onboard high-frequency and satellite-based communications systems may prove difficult because of the problems associated with connecting the AIS unit to alternate communication systems. The physical connection, testing, and fail-safe changeover from the AIS's VHF connection to another (or parallel) system on entering the United States exclusive economic zone (EEZ)[13] may not prove reliable. As newer systems are deployed (e.g., low-earth-orbit satellite transceivers), planning may enable AIS-compatible preinstalled connectors and appropriate software applications to manage the interface and transmission of AIS data over long-range systems. Except as it may affect the overall AIS implementation schedule, the long-range application of AIS for security purposes should not affect shipboard display issues.

Long-range AIS communications are based on an interrogation–response system that effectively limits the ship-related data transmitted to one or more of three "long-range data formats" shown in Table 1-5. It should be noted that the long-range queries and responses are designed for automatic handling involving no additional workload for shipboard personnel.

Development of AIS for Non-SOLAS Vessels

Several nations, including the United States, are planning to extend AIS implementation to vessels not covered by the current SOLAS requirements discussed above. Vessels affected would range from those used in a harbor

[12] For expression of representative surveillance needs, see HMSO (1994).

[13] The United Nations Convention on the Law of the Sea (United Nations 1982) delineated three areas within which coastal states can exercise one or more forms of jurisdiction. The following are simplified definitions: *territorial seas,* immediately adjacent to the coast, are subject to the sovereignty of coastal states; *contiguous zones,* extending not more than 24 miles offshore, are areas wherein national jurisdiction can be exercised to enforce customs, immigration, or sanitary laws; and *exclusive economic zones,* extending not more than 200 miles offshore, are areas where the sovereignty of the coastal states is limited to the jurisdiction necessary for the preservation and protection of the marine environment. Limited sovereignty is also granted over some matters related to natural resources.

TABLE 1-5 Long-Range Data Formats

Data	IEC 61162-1 Sentences
MMSI of responder MMSI of requestor Ship's name Ship's call sign IMO number	LR1—long-range response, Line 1
MMSI of responder Date and time of message composition Position Course over ground Speed over ground	LR2—long-range response, Line 2
MMSI of responder Destination and ETA Draft Ship/cargo Ship's length, breadth, and type Number of persons on board	LR3—long-range response, Line 3

Note: MMSI = merchant marine station identifier; ETA = estimated time of arrival.
Source: IALA 2001, Table 20-2.

environment (tugs, pilot vessels, service vessels, etc.) to those used on the high seas, such as small commercial vessels, fishing vessels, and pleasure craft. All inland navigation vessels are also potential users of AIS. Within ITU, two classes of AIS have received the most attention and discussion: Class A systems designated for vessels under the SOLAS regulations, and Class B systems to be designated for non-SOLAS vessels.[14] These two classes are described by ITU (2001) as follows:

> Class A Shipborne Mobile Equipment will comply with relevant IMO AIS carriage requirements.
>
> Class B Shipborne Mobile Equipment will provide facilities not necessarily in full accordance with IMO AIS carriage requirements.

[14] Although they are not now within official ITU discussions, other AIS classes have received attention and may be designated in the future. These include systems for use by search and rescue aircraft, systems to be installed on aids to navigation, and systems to be installed at AIS base stations.

In general, the Class B AIS designated for non-SOLAS vessels differs from the Class A system in the following ways:

- It has a reporting rate less than a Class A (e.g., every 30 seconds at speeds under 14 knots, as opposed to every 10 seconds for Class A).
- It does not transmit the vessel's IMO number or call sign.
- It does not transmit estimated time of arrival or destination.
- It does not transmit navigational status.
- It is only required to receive, not transmit, text safety messages.
- It is only required to receive, not transmit, application identifiers (binary messages).
- It does not transmit rate-of-turn information.
- It does not transmit maximum present static draft.

In addition to the above, a third class of units, referred to as "Class A derivatives," is not presently dealt with in detail by any of the AIS-related documentation (IMO, ITU, IEC, IALA) but is discussed in a general way in the *IALA Guidelines* (IALA 2001). Class A derivatives are intended to serve particular groups of users (IALA 2001, Section 12.6). The examples described are systems of inland and coastal navigation, personal pilot units[15] (PPUs), and the use of AIS in harbors for service vessels such as tugs and pilot boats. Class A derivatives are intended to have the same functionality and reporting rate as Class A stations on the VHF data link message level, but all of the mandatory components of Class A stations will not be required.

The *IALA Guidelines* (IALA 2001, Section 1.6) identify European plans for a Class A derivative for use on inland waterways, with particular focus on areas where there is a mix of seagoing and inland vessels. This equipment would be based on and behave like the Class A shipborne mobile equipment but fall outside the purview of SOLAS. A digital selective calling component would not be included, and there may be other as yet unspecified differences.

[15] The personal pilot unit is also known as a personal pilot pack, portable pilot pack, portable pilot unit, and so forth.

The use of a Class A derivative as a PPU has been discussed with two variations. In one, the unit is essentially self-contained, with its own portable AIS combined with a laptop computer as a pilot workstation. In the other, the unit is a portable laptop workstation, which connects to the pilot port connector of an onboard AIS.

In general, PPUs are self-contained and are used primarily to provide pilots with their own capability in boarding vessels not fitted with AIS. According to the *IALA Guidelines* (IALA 2001), it is essential that such units be fitted with a heading sensor if the pilot pack is to be used in waters requiring frequent course alterations. IALA (2001) has concluded that without a heading sensor the PPU will not provide sufficient information to other vessels in the vicinity.

The standard shipboard AIS will be fitted with a pilot/auxiliary input/output port, which will allow the pilot to plug in his or her own workstation and receive more frequent "own ship" navigational information. In this way the pilot will also receive all other AIS information at the standard AIS rate and be able to forward information to other vessels in the vicinity or to a VTS.

A PPU may also be equipped with a display capability different from that installed on the ship. This would facilitate providing pilots with waterway-specific information beyond that which might be manageable with a typical shipboard display. Such use appears to be recognized by the *IALA Guidelines* (IALA 2001, Section 12.6.2).

Security Issues

Security issues associated with shipboard display of AIS information were considered by the committee. One question was how security concerns might affect display requirements; another was how additional display parameters for security purposes might add to the mariners' workload. Other security issues and the overall need to improve security in the nation's ports and waterways are not covered in this report.

The use of AIS to provide information about vessels within national waters is an extension of AIS's basic function to provide information to coastal states. No additional shipboard requirements will be imposed providing the data transmitted are limited to those already incorporated in the IMO requirements.

A number of past efforts have defined the need to prevent waterborne terrorism under the term maritime domain awareness (MDA). In simple terms, MDA is defined as having "effective knowledge of all activities and elements in the maritime domain that could represent threats to the safety, security or environment of the United States or its citizens" (Loy and Ross 2002). The term was used in USCG's 1999 Strategic Plan (USCG 1999).[16] The area encompassed by the "maritime domain" is considerable, consisting of the United States EEZ and, judging by recent actions [e.g., Brosnan (2002)], the nation's inland waterways. The maritime domain thus consists of the 3.4 million square miles of the nation's EEZ and an estimated 25,000 miles of inland waterways. There is no exact definition of MDA's appropriate level of "effective knowledge," but some tools include "real-time cargo, people, vessel tracking systems" (Loy 2001). The vessel-tracking requirements might encompass many types of vessels within a variety of waterway situations—most likely those regions where AIS will be used in the future. Conceptually, MDA can include surveillance, reporting of voyage/cargo/passenger/crew–related data, enforcement, data collection, and decision support.

AIS clearly supports the surveillance component, and the United States has made clear its intention to use AIS in that capacity. It is attractive for this purpose because it can piggyback on a carriage requirement that will be imposed for other reasons and because it provides a solution to U.S. inability to unilaterally require reporting of position and movement by all foreign-flag vessels operating within one of the areas of major interest, the EEZ outside U.S. territorial waters. As a surveillance tool, the basic automatic messaging will probably provide the necessary data without the requirement for additional input and without affecting the shipboard display of AIS information. The second component, reporting of voyage/cargo/passenger/crew–related data, may fit technically within the capability of ships to transmit short safety-related messages via AIS, depending on the data requirements imposed. Until those requirements have been established with respect to both data content and frequency, the effect on mariner workload and shipboard display requirements remains a matter of

[16] The relevant portion states, "The Coast Guard will achieve the ability to acquire, track, and identify in real time vessels and aircraft entering America's maritime domain."

conjecture. The remaining MDA components do not appear to affect shipboard operations or displays.

In November 2002, the Maritime Transportation Security Act of 2002 was signed into law, with the following provisions dealing with AIS:

§ 70114. Automatic identification systems

(a) SYSTEM REQUIREMENTS.—

(1) Subject to paragraph (2), the following vessels, while operating on the navigable waters of the United States, shall be equipped with and operate an automatic identification system under regulations prescribed by the Secretary:[17]

(A) A self-propelled commercial vessel of at least 65 feet overall in length.

(B) A vessel carrying more than a number of passengers for hire determined by the Secretary.

(C) A towing vessel of more than 26 feet overall in length and 600 horsepower.

(D) Any other vessel for which the Secretary decides that an automatic identification system is necessary for the safe navigation of the vessel.

(2) The Secretary may—

(A) exempt a vessel from paragraph (1) if the Secretary finds that an automatic identification system is not necessary for the safe navigation of the vessel on the waters on which the vessel operates; and

(B) waive the application of paragraph (1) with respect to operation of vessels on navigable waters of the United States specified by the Secretary if the Secretary finds that automatic identification systems are not needed for safe navigation on those waters.

(b) REGULATIONS.—The Secretary shall prescribe regulations implementing subsection (a), including requirements for the

[17] The "Secretary" is the Secretary of the Department within which USCG operates, which in 2002 was the Department of Transportation. In March 2003, USCG was transferred to the Department of Homeland Security, and in times of "national emergency" it moves to the Department of the Navy.

operation and maintenance of the automatic identification systems required under subsection (a).

§ 70115. Long-range vessel tracking system

The Secretary may develop and implement a long-range automated vessel tracking system for all vessels in United States waters that are equipped with the Global Maritime Distress and Safety System or equivalent satellite technology. The system shall be designed to provide the Secretary the capability of receiving information on vessel positions at interval positions appropriate to deter transportation security incidents. The Secretary may use existing maritime organizations to collect and monitor tracking information under the system.

(e) PHASE-IN OF AUTOMATIC IDENTIFICATION SYSTEM.—

(1) SCHEDULE.—Section 70114 of title 46, United States Code, as enacted by this Act, shall apply as follows:

(A) On and after January 1, 2003, to any vessel built after that date.

(B) On and after July 1, 2003, to any vessel built before the date referred to in subparagraph (A) that is—

(i) a passenger vessel required to carry a certificate under the International Convention for the Safety of Life at Sea, 1974 (SOLAS);

(ii) a tanker; or

(iii) a towing vessel engaged in moving a tank vessel.

(C) On and after December 31, 2004, to all other vessels built before the date referred to in subparagraph (A).

The committee briefly considered the potential for use of AIS "safety-related" messaging to provide emergency notification of security-related events or instructions. Such use might require incorporating the capacity for alerting mariners to the receipt or transmission of urgent messages into shipboard AIS displays. Such an alerting capability may have wider application than just security.

APPROACH

This report provides a critical examination of the technical and human factors aspects of shipboard display of AIS information. This examination has resulted in recommendations that USCG can use in the development of domestic requirements and in its participation in international rulemaking and standards development.

In conducting its examination, the committee considered the following factors and prepared analyses or evaluations of each:

- Evolving technology, security, economics, operational considerations, and human factors design principles will all affect the display of shipboard AIS. The technologies that have been used in early stages of AIS development aboard vessels as well as related systems in use in other fields, such as aviation, were reviewed; and data about vessel operational situations were obtained from numerous presentations, field visits, and vessel transits. This information is presented in Chapter 2 on operational environments and in Chapter 5, where the application of human factors principles to display design is described.

- The impact of differing operational environments is presented in Chapter 2, and skill requirements of operators who will use the AIS shipboard displays are described in Chapter 5. These factors should be taken into consideration early in the requirements process in order to meet operating and operator needs. Chapter 2 presents an assessment of the types of vessels that will use AIS and their operating parameters (including a description of integration with other bridge information systems), and alternative methods that might be considered when data must be collected, transmitted, and transformed are suggested.

- How the range of tasks to be supported by AIS will drive display requirements is reviewed in Chapter 4. AIS functions and shipboard tasks should be matched to the requirements that may be established for displays, and preliminary task analyses on board vessels that might carry AIS displays were conducted to illustrate a systematic approach for setting display requirements. The requirements analysis process that should be used to develop AIS display requirements is described fully in Chapter 4.

- How changes in existing and evolving technology, equipment/technical integration, international standards harmonization requirements, manufacturers' and standards bodies' requirements, and economics may affect shipboard display of AIS information is also described in Chapters 2 and 5. These factors were taken into consideration by reviewing relevant U.S. and international literature; convening an AIS display workshop where designers and other technical experts, manufacturers, operators, and human factors experts were invited to make presentations and engage in discussions of key issues; visiting officials and operational sites in key foreign countries where important AIS development work has been under way; examining recent experiences from relevant domestic and international AIS programs; and reviewing reports of test and evaluation programs. A summary of the workshop can be found in Appendix A, and a summary of the site visits can be found in Appendix B.
- Human factors considerations for AIS display systems, including the mariners themselves and their capabilities and training, are discussed in Chapter 5. The operating environments within which these systems will be used and the matching of technology with human factors requirements are included in the discussion.

As a result of its reviews, examinations, and analyses, the committee prepared findings and recommendations that address the types and organization of information important for shipboard display of AIS information. The recommendations also address the application of human factors design principles to the development of shipboard AIS displays and consider the impact of such displays on future systems and programs.

This report addresses the challenges associated with shipboard display of AIS information but does not cover the full spectrum of AIS challenges. For example, AIS is a complement to traditional navigational aids; it does not replace them, nor does it substitute for good judgment or replace the need to use all available means appropriate to the prevailing circumstances and conditions to establish vessel position. This principle is a basic tenet of this report.

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Abbreviations

HMSO	Her Majesty's Stationery Office
IALA	International Association of Aids to Navigation and Lighthouse Authorities
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ITU	International Telecommunication Union
NRC	National Research Council
USCG	U.S. Coast Guard

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2 Variability in Operations

The purpose of a shipborne automatic identification system (AIS) display, stated briefly, is to present AIS-transmitted data in a form that is useful to mariners in decision making. Present-day display technology, combined with advances in computer capabilities, provides the capacity to satisfy that purpose by presenting AIS-transmitted data in many different forms. The types of operating environments in which AIS will be deployed and the display impacts of those environments are described in this chapter.

TYPES OF VESSELS AND OPERATING PARAMETERS

Since the onboard AIS display must function with the other components from which a mariner draws information, an understanding of the environment into which such displays must fit is critically important. The committee considered four types of vessels and their shipboard display impacts: SOLAS vessels—large oceangoing vessels engaged in international trade that are governed by the Safety of Life at Sea (SOLAS) convention; non-SOLAS vessels—those vessels engaged in the U.S. domestic trade that are not governed by the SOLAS convention; offshore industry vessels; and public vessels. Each of these vessel types is considered in turn.

SOLAS Vessels

Large oceangoing ships—containerships, tankers, and bulk carriers—are one type of operating environment where AIS will be deployed. Oceangoing vessels are built and operated under the SOLAS treaty, which mandates the carriage of not only AIS but also gyrocompass, radar, automatic radar plotting aid (ARPA), and other equipment that may be required to interface with AIS. At sea, typically one officer and a helmsman are on watch in the wheelhouse, monitoring the transit and keeping lookout. When approaching pilotage waters, the officer of the watch (OOW) is normally joined by the master, then by the pilot and possibly another mate. Thus, aboard large oceangoing vessels there may be more than one person on the bridge of the ship in pilotage waters. A schedule for phasing in AIS carriage requirements for SOLAS vessels was described in Chapter 1.

The United States is one of the largest trading nations in the world, and large ships of every variety carry import and export cargoes to and from its major ports and waterways on all of its coasts. The four major categories of oceangoing ships are petroleum tankers, container carriers, bulk cargo ships, and passenger ships. While the ships that carry domestic cargo (from one U.S. port to another) are all registered under the U.S. flag, most of the ships in international trade are registered under a foreign flag, and these are by far the largest segment of the oceangoing fleet operating in U.S. waters. These foreign-flag ships are governed by the SOLAS convention, which means that most of the SOLAS vessels operating in U.S. waters will be required to carry AIS. The U.S. regulations will apply to vessels in U.S. waters regardless of flag, and since vessels in international trade will generally be required by SOLAS to carry AIS, U.S. domestic regulations must be compatible to avoid the need to change equipment for entry into U.S. waters. This underscores the necessity that the United States work with other nations and international bodies to ensure harmonization of standards for the technology and for training and certification of operating personnel.

The SOLAS ships that will carry AIS will operate in all major U.S. ports. The largest and most sophisticated of these vessels represent significant capital investments, and it can be expected that operators will readily incorporate systems that promise safety improvements. In addition, because the United States is such a large trading nation, almost all owners of major ships in the international trade will consider using their vessels in U.S. trade at some point in their lifetime. Thus the world fleet of more than 25,000 major merchant ships, registered in dozens of countries, will begin carrying AIS over the next several years and will be candidates for AIS displays as well.

Non-SOLAS Vessels

Non-SOLAS vessels are those vessels engaged in U.S. domestic trade that are not governed by the SOLAS convention. The vast majority of these vessels operating in the United States domestically that are likely to carry AIS units are shallow-draft tugboats, towing vessels, and passenger vessels of various sizes. This holds true even in the busiest ports. Specifically, four types of vessels in the United States will probably be required to carry AIS by a domestic carriage requirement: commercial vessels exceeding 20 meters, vessels carrying more than 50 passengers, commercial towing vessels exceeding 8 meters, and dredges and floating plants. A recent analysis by the U.S. Coast Guard (USCG) indicates that on the order of 8,000 non-SOLAS vessels falling within those four categories will be required to carry AIS (USCG 2003). Included in this figure are 2,697 passenger vessels and 4,191 tow/tug boats. The exact number of non-SOLAS vessels affected will not be finalized until completion of the rulemaking process now in progress. Most of these vessels are one-person wheelhouses, with that one person acting as helmsman, mate on watch, pilot, and master. Thus, in the wheelhouses of non-SOLAS vessels in the domestic trade, there is usually only one person on watch. Clearly, then, a domestic carriage requirement for AIS must meet the needs of the large fleet of smaller non-SOLAS vessels.

After fishing vessels, towing vessels make up the largest segment of the U.S. commercial vessel industry. About two-thirds of towing vessels are involved in the transportation of hazardous materials and petroleum products (NTSB 1998). Towing vessels, or tugboats, and coastal integrated tug/barges operate in coastal waters and along the U.S. intracoastal waterways, rivers, harbors, bays, sounds, and the Great Lakes on a system encompassing some 25,000 miles of inland waterways. These vessels operate in all weather conditions, 24 hours per day, 365 days per year. Towboats push flotillas of barges called tows. Tows vary in their number of barges and tow configuration. The area of operation and the size and power of the towing vessel determine the number of barges and how they are arranged to form the tow. A tow may consist of a towboat and 1 or 2 barges or a towboat with 50 barges. The larger tows with their accompanying larger and more powerful towing vessels are found in an area of the U.S. inland waterways known as the Mississippi River System but historically designated as the "Western Rivers."

Passenger vessels represent a huge variety of vessels, equipment, routes, and applications. Within the passenger vessel fleet there is a segment of large ferries, overnight cruise vessels, and high-speed vessels that tend to have a sophisticated array of electronic equipment. However, most passenger vessels are small and travel on very short routes with only the most basic equipment appropriate for their operation and operating area. The latter group includes charter fishing vessels, whale watchers, dinner boats, and excursion boats. For many of these small passenger vessels, there is little variation in route or schedule. In many ports in the United States, frequent users of the waterway know that the dinner boats sail at 7 p.m., are off Point A at 8 p.m., off Point B at 8:30 p.m., and back at their dock at 9:30 p.m., for example.

Offshore Industry Vessels

Several thousand boats are engaged in the support of offshore marine industry. These vessels are sleek, highly maneuverable, powerful, and often equipped with the latest navigational and communication equipment. They operate in both inland and offshore environments. In U.S. ports and harbors their voyages require interaction with both shallow-draft non-SOLAS vessels and deep-draft SOLAS vessels. They also interact with SOLAS vessels in international waters. The size and power of offshore industry vessels are dictated by their particular function. Generally, these vessels fall into one of three categories: crew boats, offshore supply vessels, and utility vessels.

Crew boats are fast and used primarily to transport offshore oil rig crews and light supplies to and from offshore rigs. These vessels range from 30 to 100 feet in length.

Supply boats carry all the supplies that an offshore rig or platform needs to operate—drilling equipment, mud, tubulars, cement, auxiliary machinery, oil and lubricants, and sufficient food and water for the workers on the platform. They are equipped to operate in all weather conditions. They are typically shaped like a tug with a high foredeck and are powered by two strong diesel engines. Many of these vessels will also double as towing/anchor-handling vessels and are used to move the rig when the need occurs. Most supply vessels are between 300 and 500 gross tons and can be as long as 800 feet.

Utility vessels are generally between crew boats and supply boats in size. They are the less sophisticated and lower-powered members of the supply boat family and are used to transport rig crews and supplies to and from an offshore oil field. They work with pipe-laying barges, shuttling fresh tubulars out from the shore or attending the operations of divers or subsea engineers. They also serve as standby or emergency evacuation vessels.

Public Vessels

SOLAS exempts warships, naval auxiliaries, and ships owned or operated by governments for public rather than commercial uses from the requirement to carry AIS. In the United States the largest number of vessels in this category are military vessels.

U.S. military vessels are owned and operated by the United States government as public vessels. Every service of the armed forces owns or operates waterborne vessels of some type. They range from small outboard motorboats to the largest Navy aircraft carriers. As part of the military fleet, these vessels are largely exempt from SOLAS convention agreements. However, Navy and other services' policy guidance requires compliance with all SOLAS and other International Maritime Organization (IMO) requirements to the extent possible. Accordingly, although there are currently no legal obligations for military vessels to carry and use AIS, the benefits of doing so are being investigated and recognized by the military leadership.

AIS is considered to provide vital safety and operational information that should be at the disposal of the public ship operator and shared with other shipping traffic in nonhostile, piloting navigation situations. Public vessels are an integral, and in many localities not an insignificant, component of vessel traffic. Thus, the inclusion of public vessels into the overall AIS field of vision can only increase the utility and effectiveness of AIS for all users.

AIS, when installed on military vessels, and particularly on the larger, newer, high-value military vessels, can be interfaced with electronic chart display information systems (ECDIS), ARPA, voyage data recorders, and other bridge equipment making up an integrated bridge system. Requirements addressing which specific vessels will ultimately need to carry AIS, and when, are still being developed. To the extent consistent with their missions and without adversely affecting their operational capabilities and readiness or compromising force protection requirements, military vessels should be identified by AIS. Within the Navy, the Office of the Navigator of the Navy is working closely with USCG to develop policies and procedures to this end.

Potential issues and concerns identified to date by the military in the course of deliberations on AIS are not unique or very different from those expressed by other segments of the maritime population and include the following:

- Security and force protection concerns arising from open, unrestricted broadcast of AIS data;
- Costs associated with implementation, regardless of the benefits;

- The accuracy and reliability of the system and the information conveyed; and
- The degree to which operators can control and manipulate AIS data and the potential for misuse.

Efforts to fully understand the implications of these issues and concerns within the military context are continuing.

TYPICAL BRIDGE OPERATIONAL ENVIRONMENTS

While there are good arguments for finding the optimal configuration for AIS display, in reality the existing wheelhouse or bridge environment will have a large impact on display design and effectiveness. For smaller vessels, which will make up the bulk of AIS-equipped vessels, this means that the size, placement, and configuration of the AIS equipment must conform to tight quarters. The wheelhouses of inland towing vessels vary in size and configuration and may be as small as 50 square feet. Some of the wheelhouses on larger river vessels may be several hundred square feet. In this space fits the non-SOLAS vessel's radar, radios, steering mechanism (commonly referred to as "sticks"), a swing meter, compass, and other equipment such as a fax machine, computer, and electronic chart unit.

AIS units will need to fit within this space and remain in the mariners' peripheral vision while not interfering with their view of the outside or other equipment. AIS visual displays will need to find a balance between being large enough to convey the necessary information and small enough to fit unobtrusively among other equipment. In some cases, vessel operators will find it advantageous to combine AIS with other charting and radar equipment. In other cases, operators may simply add AIS to an already existing piece of equipment. This is likely to be dictated by individual needs and existing onboard equipment.

One consideration that must be factored into AIS display issues is the limited opportunities available for mariners to input data into the system. Towing vessels and most other inland vessels operate a one-person wheelhouse. The vessel operator will of necessity have at least one hand occupied steering the vessel. (See Figures 2-1, 2-2, and 2-3 for pictures of three types of wheelhouses.) This will make it impractical and perhaps unsafe to require the operator to type information into the AIS unit. Any system that requires

FIGURE 2-1 Wheelhouse of a small towing vessel. (Photo courtesy of Kirby Corporation.)

the operator to scroll through information or search through data fields may also be impractical.

Passenger vessels cover a wide range of technology, service, manning, and training. From the sophisticated high-speed ferry (see, for example, Figure 2-3) to a vessel with the simplest of equipment (see, for example, Figure 2-1), the application of AIS will pose a challenge to the operator as well as the regulator and the designer. Domestic regulations for small passenger vessels take into account their sizes and unique operations.

Unlike the larger oceangoing vessels, many domestic vessels are not required to carry much of the equipment with which AIS would need to interface for proper operation. For small passenger vessels, the only navigation equipment required under U.S. regulations is a radar and a magnetic compass. An electronic position-fixing device is only required for vessels with an oceans route endorsement. A ferry on an inland river or a vessel on

FIGURE 2-2 Wheelhouse of a medium towing vessel. (Photo courtesy of Kirby Corporation.)

a short, restricted route can be exempted from the requirement to be fitted with a radar (46 CFR 121). Thus, AIS carriage requirements for domestic, non-SOLAS vessels should consider the range of operating conditions, available space, and available electronic equipment likely to be encountered on different vessels.

In the bridge or wheelhouse environment of a non-SOLAS vessel, audible alarms of AIS activities, such as approaching vessels or potential meeting situations, are of limited value. The background noise of the non-SOLAS vessel, combined with radio monitors and the proliferation of cellular telephones, would all compete with audible alarms. In addition, every vessel meeting situation in any congested port or river is a potential collision, and alarms could sound so often as to be ignored or turned off.

In critical situations, text messages sent to operators of non-SOLAS vessels via AIS could negatively affect vessel safety, especially if the mariner

FIGURE 2-3 Wheelhouse of the *Victoria Clipper*, a high-speed ferry. (Photo courtesy of David Natali, Clipper Navigation, Inc.)

were required to respond. For instance, a number of vessel information systems are currently used by inland vessel operators. Most have a function that allows for text messaging between the vessel and shoreside offices. In general, vessel operators are encouraged to respond to these text messages only when they are not busy with other tasks.

NEED FOR EFFECTIVE SHIPBOARD AIS DISPLAYS

As an important source of navigational information, AIS displays should be tailored to facilitate operator use of the transmitted information in decision making. Several major areas of concern have been identified,[1] two of which are discussed below.

[1] See Lee (2002) for a representative discussion of the issues in professional journals.

"The seduction of safety" is a phrase apparently coined by the International Electrotechnical Commission (IEC) and used as early as 1999 as a shorthand means to express the sometimes false sense of precision and completeness conveyed to mariners by electronic navigational displays. Problems described by this phrase stem from such things as failure to appreciate errors inherent in such systems, which causes what is depicted to be accepted as reality without cross-checking with other sources of information. The resulting dangers were recognized, for example, in the investigation following a 2000 collision between two ships in Canadian waters, as shown by the following quotation from the subsequent report (Transportation Safety Board of Canada 2000).

> Given the immediate goal of passing the "LADY SANDALS," the OOW focused on the apparently precise representation of the area provided by the ECS system, and did not appreciate the variance between its representation and the visual cues.

The NTSB (1997) report on the *Royal Majesty* provides another example of this.

Another potential area of concern is the issue of "stand-alone presentation of information," which refers to the present-day situation in which mariners must draw and correlate data from a number of independent sources to develop information for decision making—typically a combination of visual cues, one or more radars, paper and electronic charts (ECDIS or ECS), conventional instruments such as compass, speed log, communications, machinery, instrumentation, and alarm panels. Mariners must not only correlate the data provided by these diverse sources but also resolve the differences between the various inputs and determine what is valid within a safety- and time-critical period.

This difficulty is compounded by the lack of commonality in bridge layouts of commercial vessels, even those of the same class. A typical layout of the bridge of an 8- to 15-year-old tank ship is shown in Figure 2-4. As can be seen, not only is there a variety of instrumentation, but also the locations are such that the OOW must constantly move between locations to receive all of the data provided.

Such movement is distracting and can introduce delays in decision making, particularly when a pilot is unfamiliar with the bridge layout. The prob-

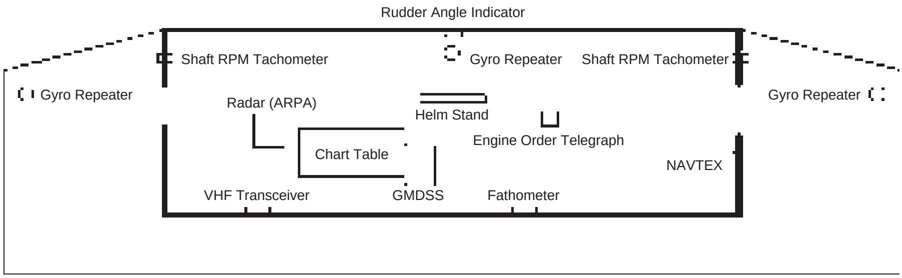

FIGURE 2-4 Typical wheelhouse layout of older ships. (GMDSS = Global Maritime Distress and Safety System.)

lem is well recognized worldwide. For example, a 1991 Finnish study (Haapio 1991) reported that pilots, who in the course of their duties may be responsible for several ships a day, find it particularly difficult to adapt to the many different types of equipment on and layout of ships' bridges.[2] Ill-considered placement can also contribute to stress during operations in close quarters or low visibility and can increase fatigue. These problems may be exacerbated by the lack of instrumentation standards, particularly in the layout of controls for critical equipment such as radars, DGPS receivers, and the like. The literature dealing with marine accidents contains many examples of the casualties that result.[3]

Bridge layout standards have been developed by individual nations and classification societies,[4] but those standards have yet to be applied on an international scale to new construction or retrofitted on existing ships. For the past several years IMO has been in the process of developing integrated bridge standards. Unlike aircrews, whose equipment certifications are related to specific types of aircraft, marine pilots and shipboard personnel

[2] For a more recent discussion of this and related problems see the report of an interview of the president of the International Maritime Pilots Association (*Professional Mariner* 1997).

[3] There are many supporting investigation reports. MSA MAIB (1993, 12–13) reports a typical example in which a watchstander, unfamiliar with the clutter controls of a radar, set that feature in a way that precluded detection of an anchored vessel and subsequently collided with it. In another case, a collision of the *Ever Decent*, a containership operated by Evergreen Marine, and the *Norwegian Dream*, a 2,400-passenger cruise ship, took place in clear visibility and light winds in the English Channel 20 miles from Margate. The proximate cause was inattention of the cruise ship's watch officer, and the probability is that he was distracted by an "administrative task."

[4] Examples include *Ship's Bridge Layout and Associated Equipment; Requirements and Guidelines* (British Standards Institution 1995).

are not licensed for specific vessel models.[5] Consequently, pilots and ships' officers may be assigned to ships in which they have no experience. Under those circumstances nonstandard bridge layouts impede the familiarization process.

The need to bring order to this chaotic condition has long been recognized, but it was not until July 2000 that IMO (2000) moved to establish a work item "to harmonize the presentation of navigational information" in such a way as "to avoid confusion in the display of such information." It is noteworthy that the IMO action was triggered by the new carriage requirement for AIS. IEC has established a Working Group (WG13) to develop specific standards. The group's approach appears to be governed by several general principles (Lee 2002):

- The present arrangement, under which information is distributed among numerous sources, is unsatisfactory.
- Information overload is dangerous.
- Co-locating information on a single display can lead to cluttered results, and performance can be degraded by displaying information in a manner that masks or obscures it.

Unfortunately, the results of the IEC working group are still several years away. In addition, it must be recognized that a significant number of international standards already apply to shipboard displays, which must also be considered in specifying AIS display requirements.

With respect to AIS, the shipboard operating environment is shaped by a number of factors, among which are[6]

- The range of data that will be transmitted, particularly the safety-related elements transmitted by shore stations to ships;
- The areas or routes used by the vessels equipped with AIS displays;
- The work environment, tasks, and workload of the shipboard bridge watchstanders charged with the safety of navigation;

[5] Unlike aircraft, ships are usually constructed individually to a custom design. Marine licensing tends to be categorized by vessel tonnage, area of operation, and type of carriage, or some combination thereof.
[6] The listing is not in order of importance.

- The skill level of the shipboard personnel who will use the AIS displays, and the training and qualifications required to use the displays effectively;
- The role technology should play, given prevailing and anticipated shipboard workload and skill levels, in converting AIS data into useful and timely information (this factor incorporates consideration of the limits of current "off-the-shelf" display technology);
- The benefits derived from mandated displays in comparison with the cost of fitting and maintaining the displays, including associated personnel costs (which encompass training); and
- The size of the crew and the number of bridge team members.

The issue of displays is also made more complex by the present stage of AIS development. The current body of work published by IMO and the International Association of Aids to Navigation and Lighthouse Authorities, among others, addresses in detail the data to be provided and transmitted by vessels via the AIS medium. The same cannot be said for the shore-to-ship data flow. Absent clear definition, including specification of which shore-to-ship data sets will be in mandatory use for maritime safety, display requirements will remain in a state of flux. Considerable effort is necessary to define the shore-to-ship data flow to the same degree of precision as now exists for ship-originated data. Since those data will play a role in determining display requirements, early resolution is required before definitive requirements for displays can be generated. A related issue is the necessity for oversight and control by national-level "competent authorities" of those shoreside entities generating AIS-transmitted data to ensure consistency among the various waterways and that required shipboard components are not overburdened.

COST CONSIDERATIONS

One of the realities affecting the imposition of AIS displays through a carriage requirement is cost, in terms of both the overall impact of the requirement on the national economy and the affordability of the requirement by the individual user. From the U.S. regulatory standpoint, the rulemaking process must include an analysis of the economic and any other relevant consequences of each of these alternatives (USDOT 1980). In terms of the national interest, the cost–benefit analysis requirement is broadly stated as follows:

> Analyses should include comprehensive estimates of the expected benefits and costs to society based on established definitions and practices for program and policy evaluation. Social net benefits, and not the benefits and costs to the Federal Government, should be the basis for evaluating government programs or policies that have effects on private citizens or other levels of government. Social benefits and costs can differ from private benefits and costs as measured in the marketplace because of imperfections arising from: (i) external economies or diseconomies where actions by one party impose benefits or costs on other groups that are not compensated in the market place; (ii) monopoly power that distorts the relationship between marginal costs and market prices; and (iii) taxes or subsidies. (OMB 1992)

In terms of the individual user—vessel owner, operating company, and so forth—the benefits of having a specified AIS display should outweigh the cost of acquisition, installation, operation, and maintenance. Operating costs encompass training and staffing issues as well as supplies, electrical power, and so forth.

The issue of cost raises a number of concerns, the primary one stemming from the fact that increased capability imposes escalating costs. With respect to AIS unit cost, USCG is using $10,000 for both SOLAS and domestic installations through 2003. However, for 2007, the estimated AIS unit cost for SOLAS vessels is $8,000 to $10,000, and for non-SOLAS vessels it is $3,000. However, this is not the cost of an AIS display. Separate display costs have not yet been estimated by USCG. The upper range of costs may be viewed as prohibitive for some vessel classes or particular routes where such capabilities are either not needed or amount to "overkill."

SUMMARY

Many types of vessels operate on U.S. waters, and even within a class of vessels, there is a lack of commonality in operating environments, bridge designs and layouts, equipment, and mariner experience and capabilities. Display designs and operator needs will vary for the near and the long term and from vessel to vessel, waterway to waterway, and traffic situation to traffic situation. Standards and guidelines for display technology must recognize the variability and complexity of the system and provide adequate flexibility over time.

The overall characteristics and operating environments for four generic types of vessels that might carry AIS displays when in U.S. waters—SOLAS vessels, coastal and inland vessels, offshore vessels, and public vessels—were reviewed. The overwhelming majority of SOLAS vessels that are subject to IMO carriage requirements are engaged in U.S. international trade and are registered under foreign flags. The prevalence of these vessels in U.S. waters underscores the need to work with international bodies to harmonize standards and guidelines for displays. Inland and coastal vessels represent the largest numbers of U.S.-registered vessels and are subject only to USCG regulation. Thus, USCG must develop standards and guidelines for AIS displays that meet the unique needs of these operators. Vessels in the offshore industry will need to be considered in the future when they operate in regions where AIS coverage and participation become important for traffic management and control. Finally, public vessels are mostly military, and decisions about their use of AIS will be made by the military. However, coordination with USCG and other waterway users will be necessary to ensure the safety of all waterway users and to gain other security benefits of AIS.

Cost issues were considered only briefly because of lack of data. It is clear, however, that the cost of AIS displays will be a factor, especially for many inland and small vessel users. USCG is keenly aware of this factor and is required to consider cost impacts in any future rulemaking process.

REFERENCES

Abbreviations

IMO	International Maritime Organization
MSA MAIB	Maritime Safety Agency, Marine Accident Investigation Board (United Kingdom)
NTSB	National Transportation Safety Board
OMB	Office of Management and Budget
USCG	U.S. Coast Guard
USDOT	U.S. Department of Transportation

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3 Recent Experience with Automatic Identification Systems and Shipboard Displays

Despite the fact that carriage requirements for automatic identification systems (AIS) are recent, there is significant experience relevant to the display of AIS data aboard ship. The committee reviewed this experience by investigating a number of AIS operational testing programs and pilot projects in the United States and abroad to better understand requirements for AIS displays. The programs investigated generally fit into two categories: those evaluating or using systems that meet the ITU-R M.1371-1 standard for AIS (ITU 2001), the International Maritime Organization (IMO) universal AIS standard (referred to as 1371 standard AIS) (IMO 2002); and non-1371 standard AIS (referred to as "transponder systems"). Only the 1371 standard is applicable to the committee's work, but few operational tests of the universal AIS are extant. The committee therefore reviewed operational experiences and tests of both 1371 and non-1371 standard AIS programs and projects in its work.

None of the trials and projects examined were rigorously structured to permit evaluation of data and display needs. Therefore, much of the information in this chapter is anecdotal, and preferences expressed may be local rather than global. The limitations of taking user preferences into account in developing display designs without careful evaluation must be recognized because incorporation of user preferences may or may not translate into enhanced user performance.

The committee investigated a number of existing applications and benefited from the experience of three of its members in the development and use of such systems in the lower Mississippi River, Tampa Bay, and San Francisco. In examining current projects, the minutiae of display technology were avoided, and the focus was on broader lessons that might apply. Although they were outside the committee's charter, the experiences with symbology, display colors, arrangements of controls, and so forth may well become germane and can be applied at the proper stage of the display design process.

Perhaps the single most important lesson learned from examination of existing applications is that the technology is gaining acceptance by mariners, with commonality developing concerning both the basic information that should be presented and the form it should take. As mariners become accustomed to the technology and to the benefits of accurate, real-time navigational data, skepticism appears to diminish rapidly. In the lower Mississippi, for example, local mariners now recognize AIS technology as a tool that vastly improves the quality of navigational information available to them, simplifying the retrieval of that information in the process.

One of the most frequently cited issues is information overload. Mariners are concerned about the sheer volume of data becoming available to them, and the problems of extracting from that data in a timely manner the information needed in a form directly applicable to decision making. This suggests the introduction of filtering technology, the imposition of limits on the data flow from the vessel, or a combination of the two.

The operational tests and pilot projects underscore the need for clear indicators of when systems are functioning properly so that mariners recognize and understand the inherent limitations in both the data and the systems generating and displaying them. This touches on two critical factors: education and standardization. Both of these areas require considerable research, particularly in evaluating the degree to which AIS-related skills need to be incorporated into the provisions of the Standards for Training, Certification, and Watchkeeping. While standardization is actively being pursued with respect to the display of navigational information, an effort to standardize the details of the information itself may become necessary as an adjunct to the vast increases in data flow made possible by AIS.

Although it is still in progress, the European initiative to develop a "river information system," which will enhance the effectiveness of inland waterway transportation, may offer significant information about the use of AIS for vessel traffic management and the safety of navigation. As envisioned by the project, AIS is an essential element in an information system designed to maximize the effectiveness of water transport with the goal, among others, of limiting the rate of growth of cargo transport by road. Under sponsorship of the European Union, the river information system intends to apply AIS both autonomously for vessel safety and in combination with shore-based facilities for lock queuing and regulating passage of waterway restrictions.

TABLE 3-1 Existing Systems Considered

System	Type
International Tug of Opportunity System	Transponder
Lower Mississippi VTS	Transponder
Panama Canal	Transponder
San Francisco Bay	Transponder
Tampa Bay	Transponder
British Columbia AIS Evaluation Program	Transponder
St. Lawrence Seaway	AIS
Swedish Maritime Administration	AIS
Warnemunde VTS	AIS
European River Information System	AIS

Note: "AIS" systems are fully compliant with ITU Recommendation M.1371.1. "Transponder" systems use similar technology but are not fully M.1371.1 compliant. VTS = vessel traffic service.

The project is well documented, and it is expected that the results of operational testing will be similarly available.[1]

The case studies from which the information in this section was drawn are shown in Table 3-1. Both ITU-compliant 1371 standard AIS programs and non-1371 standard transponder programs were reviewed. Each project is discussed in the following sections, and key results are provided, if available.

1371 STANDARD AIS PROGRAMS

St. Lawrence Seaway AIS Project

In 2001, the St. Lawrence Seaway implemented an AIS project integrated with the seaway's traffic management system. A team that includes the U.S. Saint Lawrence Seaway Development Corporation, the Canadian St. Lawrence Seaway Management Corporation, and marine transportation

[1] An entry point for information about the project is "INDRIS—The Final Report," which is available at europa.eu.int/comm/transport/extra/final_reports/waterborne/Indris.pdf. INDRIS is the acronym for "Inland Navigation Demonstrator for River Information Services."

interests is conducting this ongoing project, which was formally inaugurated on September 5, 2002. The AIS was developed by the U.S. Volpe National Transportation Systems Center and reached initial operational capability in July 2002. The necessary shoreside communications stations were installed, signal coverage areas were determined, and transmission frequencies were obtained. AIS transponders will be mandatory on all commercial vessels transiting through the seaway traffic sectors from St. Lambert (Montreal) to mid–Lake Erie beginning with the seaway opening on March 25, 2003, in advance of the IMO International Convention for the Safety of Life at Sea (SOLAS) schedule (Great Lakes St. Lawrence Seaway System 2001).

Through agreements with the Canadian Shipowners Association and the Shipping Federation of Canada, the cost of implementing AIS is being shared equally by commercial carrier users and the two seaway management corporations, Canadian and American. Shipowners will contribute $0.06 Cdn per gross registered tonne, applied to transits of the four segments of the seaway—upbound Montreal/Lake Ontario section, downbound Montreal/Lake Ontario section, upbound Welland Canal, and downbound Welland Canal. All ships have been required to pay this levy beginning May 1, 2001. The maximum annual contribution per ship is $5,000 Cdn (Great Lakes St. Lawrence Seaway System 2001).

Final testing and initial operational capability of the AIS were completed in July 2002. Two evaluations of the St. Lawrence Seaway AIS project are currently scheduled—one a comparison of AIS use and electronic chart display and information system (ECDIS) use on the seaway and the other a study of the technical, organizational, and safety impact of AIS implementation on the seaway. Both studies began in July 2002 and involved nine Great Lakes vessels from four participating shipping companies and four AIS manufacturers—Japan Radio Company, Ltd., Marine Data Systems, Saab TransponderTech AB/ICAN, Ltd., and Transas USA. Nine fixed AIS units were installed aboard participating vessels, and two portable AIS units for deep-sea vessels transiting the seaway were procured in July 2002. Data gathering for both operational tests began in August 2002, and reports of the evaluations are scheduled in 2003 (St. Lawrence Seaway Development Corporation, personal communication, July 11, 2002).

European AIS Experiences

Several countries in Europe have conducted operational tests of AIS, the most notable of which are Germany and Sweden. In 2002, the German

Waterways and Shipping Directorate in Kiel completed a series of conformity trials on 1371 AIS Class A and Class B units from a number of equipment suppliers. These tests were done to evaluate how well the equipment conformed to the specifications and requirements established by international standards and how the systems operated within the AIS environment in German coastal waters. However, the tests did not include any evaluation of shipboard displays beyond the minimum keyboard standard.

The German Federal Hydrographic and Maritime Agency in Hamburg is also in the process of conducting laboratory certification tests of Class A AIS shipboard equipment in preparation for issuing certificates for carriage on German-flag vessels, but again, no shipboard displays are involved in the tests. AIS equipment is installed on some vessels that regularly transit German coastal waters, however, and German shore-based vessel traffic control centers have experience with shore displays of AIS signals. Even though this work does not include shipboard displays, such shore-side experience may be useful to take into account. In addition, German researchers are investigating the feasibility and operability of integrating radar and AIS vessel-tracking information on one shipboard display. Research on how to best display this information is under way, with results expected in the near future. Appendix B summarizes information gathered from a visit by a small group of the committee to the German Waterways and Shipping Directorate in Kiel, Hamburg, Warnemunde, and the Kiel Canal.

The committee also received useful information from the Swedish Maritime Administration during its New Orleans Workshop (see Appendix A) and from a visit with Capt. Pettersson, Senior Nautical Advisor, on board coastal ferries in Sweden. About 150 of these passenger vessels in Sweden are fitted with AIS units, and most include shipboard displays. Operational tests of these systems have resulted in reports of beneficial use by Swedish mariners, but the reports are mostly anecdotal, with few analytical evaluations available for use to help determine design requirements.

Mariners involved in Swedish tests have preferences with regard to the type of data presented and the format in which they are presented (Pettersson 2002). For example, the preference for electronic charts over alphanumeric displays is almost universal. Also, most mariners want an accurate heading sensor on AIS displays because heading is quite possibly the most important part of a navigational message. Most also agree that heading needs to be sent at a high update rate and is more useful than rudder angle information, which can be misleading or ambiguous. These views have been expressed by many who have witnessed the test operations and could be used in the future to provide expert input to design requirements.

NON-1371 STANDARD AIS PROGRAMS

Panama Canal AIS Project, 1998

In 1998, the Panama Canal began an AIS project designed to evaluate the utility of AIS information to traffic controllers and shipboard personnel transiting the canal. The AIS units were developed by the U.S. Volpe National Transportation Systems Center. Two hundred sixty Panama Canal pilots and many vessels participated in the AIS evaluation project. The Panama Canal authority made available portable AIS units for vessels, because there was no carriage requirement for AIS in effect at the time of the test. As a result of the evaluation, which began in October 1998, the Panama Canal authority will mandate carriage of AIS units for passage through the canal coincident with the IMO SOLAS carriage requirement schedule. Permanent installation of an AIS unit will be required, as will a three-prong, 20-volt AC pilot plug, which is mandated to be installed at the primary pilot station for use by pilots with carry-aboard AIS (St. Lawrence Seaway Development Corporation, personal communication, July 11, 2002).

British Columbia Operational Tests

The Canadian Coast Guard and three Princess Cruises' ships participated in a non-1371 standard AIS evaluation project that was partially funded by the Western Marine Community's Pacific Coast Marine Review Panel in the summers of 1999 and 2000. The objective of the project was to gain operational experience with AIS and to formulate recommendations on ways to integrate AIS into bridge team operations in British Columbian waters.[2] The transponders used in the test were made by Meteor Communications Corporation of Kent, Washington; the transponders sent out updates every 30 seconds. All observations were of ship-to-ship communications.

Despite interference from cliffs 200 or more meters high in Seymour Narrows that impeded radar detection, initial AIS position updates were being received more than 1 hour before rendezvous at a range of 30 to 40 nautical

[2] Most of the information in this section is derived from www.uais.org/AISEvaluationVersion2_1.htm.

miles. All participants were receiving updates at a regular 30-second interval about 30 minutes before rendezvous at a range of 14 to 16 nautical miles.

Bridge teams in the summer 1999 tests expressed a preference for receiving reliable AIS updates about 30 minutes before time of closest point of approach (TCPA), irrespective of the speed of the target. Although there was no consensus as to how to label AIS targets in these trials, all bridge teams agreed that the labels should be short to minimize on-screen clutter. One of the bridge teams preferred to use some of the ECDIS screen to show an AIS target's rate of turn, if available, followed by P or S (port or starboard), particularly for targets with TCPAs of less than 10 minutes. Most bridge teams, however, preferred to avoid this clutter. The option to curve the course over ground (COG)/speed over ground (SOG) vectors emanating from an AIS target to reflect its rate of turn was rejected by project participants mostly because bridge teams felt uncomfortable with curved vectors.

Bridge teams in the British Columbia project also believed that AIS information superimposed on an ECDIS being used for route planning would provide information that was too unreliable to be worth cluttering the ECDIS screen. To reduce clutter on an active ECDIS screen, bridge teams preferred three levels of information about AIS targets:

- *On a normal active working ECDIS screen:* An AIS target icon includes position, course, and speed vector. For target tracking and to assist with contacting vessels by VHF radio, AIS targets were labeled with their call signs or a short abbreviation of their name in small print.
- *Target highlights:* By clicking on the label of a target on the active ECDIS screen, a small new window was opened, preferably on a part of the ECDIS screen not being used by the active chart, with the course, speed, range, bearing, CPA, TCPA, rate of turn, ship type, overall length, and full name, as well as a "more" button.
- *Target particulars:* Clicking on the "more" button provided target highlight information including voyage data such as destination, estimated time of arrival (ETA), draft, hazardous cargo information, unusual maneuvering limitations, towed barge information, and so forth, and the vessel's own particulars.

Bridge teams in the British Columbia project thought it would not be appropriate to dead reckon an AIS target to place it on the screen in its most likely position for more than just a few seconds from its last reported position, COG, SOG, and rate of turn. In addition, to reduce screen clutter, bridge teams preferred that automatic radar plotting aid (ARPA) A, ARPA B, and AIS icons of the same target be consolidated into a single icon. To avoid operator error, rule-based automatic consolidation was generally preferred over manual selection of icons to be consolidated.

Finally, intership electronic mail was tested in summer 1999. Mariners could pick from a list of short, traffic situation–oriented messages ("intend to pass you port-to-port") that appeared in a window as soon as an AIS target was selected with a mouse click. Messages were preformatted and did not require keyboard entry to select or send. Messages were sent to AIS target ships as soon as one of the messages was selected and the selection confirmed.

Blinking circles around the icon of the e-mail sender were used to indicate arrival of an incoming traffic message from an AIS target. Clicking within this circle sent a confirmation of receipt to the sender and opened both the message and the pick list of standard replies ("OK"). Standard replies appeared on a pick list depending on the nature of the original message. Replies referenced the original message. Standard messages were used in this test of intership e-mail, and replies were not customizable so as to avoid "chat."

Bridge teams in the summer 1999 British Columbia project believed that intership e-mail might reduce the need for intership and ship-to-VTS reporting VHF communications. However, bridge teams unanimously believed that the use of e-mail messaging could not be allowed to distract the officer of the watch (OOW) from accomplishing required tasks. Bridge teams also noted that adding another task to the duties of an already-busy OOW was undesirable.

Bridge teams believed that it would be useful to display new hazards, out-of-place buoys, and demarcation of traffic separation zones on screen. These "stationary icons" were recommended to be of a different type and to be identified as such on the ECDIS screen. Bridge teams also believed that AIS should be used to provide them with real-time visibility and wind data as well as currents observed at surface in critical passes. Bridge watch teams believed that ECDIS should show a special type of icon where actual real-time conditions are available.

In follow-up tests in summer 2000, participants in the British Columbia project made the following recommendations concerning AIS displays:

- To minimize clutter on an active screen, unselected targets, be they radar or AIS, should not be labeled and should not have a vector emanating from them.
- Unselected radar targets should be represented by the echo of the target, as should consolidated ARPA/AIS targets for boats smaller than 20 meters in overall length that have a TCPA of more than 5 minutes. The OOW should be able to select whether the latter should be displayed as an echo or as a diamond.
- Targets to be monitored for collision avoidance purposes should be selectable individually and by setting a guard zone. Selected AIS and consolidated targets should be displayed in the same fashion as unselected targets. Again, depending on the preferences of the OOW, icons for targets representing boats smaller than 20 meters in overall length that have TCPA of more than 5 minutes should be suppressed.
- The predicted path over ground should be displayed for selected targets. A maximum of 10 characters should be used to label each target. The label should default to the first 10 characters of the full name but should be editable.
- Collision avoidance forms, target information forms, own ship collision avoidance forms, and own ship information forms, with required information types, were defined and recommended by test participants.
- Test participants developed traffic control display recommendations.
- Display preference profiles were recommended that would allow individual users to set and edit their own display preferences in a profile document.
- SOLAS ships should have a fail-over capability, meaning that dual transponders should be carried and operational. If the primary transponder were not performing properly, an alarm should be sounded automatically on the bridge and a switchover accomplished to the backup transponder.[3]

[3] See www.uais.org/AISRecommendations.htm.

In general, bridge teams in both the 1999 and 2000 British Columbia AIS project were pleased with AIS performance. Bridge teams noted differences in range and bearing between AIS and ARPA targets of the same ship, which reinforces the need for consolidation and avoidance of screen clutter. AIS "really shone," however, when it came to filling in the many radar blind spots in Alaskan and British Columbian waters (Pot 2000).

AIS on the Lower Mississippi River

The U.S. Coast Guard (USCG), in cooperation with local mariner organizations and pilots, sponsored a project on the lower Mississippi River to introduce AIS shipboard transponder systems into the maritime operations in the region beginning in 1998 and continuing through 2002. The project was part of an overall effort to upgrade and modernize vessel traffic systems on the lower Mississippi, and the operational experience with the shipboard units was used by USCG to help with the development of international standards for AIS. The shore-based component of this AIS was implemented by USCG through a task order with Lockheed-Martin in 1998. Also, in 1998, USCG issued a task order to Ross Engineering for the supply of 52 shipboard AIS transponders. USCG established formal agreements with local mariner and pilot organizations in the region to use these transponders and the AIS during their normal operations. The AIS operational test bed with this system was completed in mid-2002.[4]

Although no formal evaluation report is available concerning the lower Mississippi River tests of AIS, anecdotal information was collected by committee members through informal discussions with mariners who are familiar with the operations. Impressions and views from those discussions are presented in this section.

When AIS was first introduced in the lower Mississippi, it was met with skepticism among local mariners, who were concerned that the new technology would only add a level of complexity to an already complex system. However, as mariners became accustomed to the technology and the benefits of accurate, real-time navigational data, the skepticism diminished. For example, mariners recognize the value of AIS technology in improving the quality of navigational information and simplifying the retrieval of that infor-

[4] Personal communications with Sandra Borden, USCG Procurement Division, Sept. 19, 2002.

mation because much information was automatically relayed to them. They also learned that AIS technology does not reduce the importance of such existing navigational tools as radio, ARPA, radar, and simply looking out the window.

Mariners on the Mississippi have noted that AIS technology improves bridge resource management and enhances safety and efficiency. For example, AIS can provide a real-time visual representation of the entire relevant waterway system, not just a particular vessel's immediate vicinity, and this can enhance knowledge of traffic situations over a wide region as well as help with more efficient use of the waterway. As more vessels participate in the overall system, mariners foresee even more operational advantages.

In addition to praise for the benefits of AIS, mariners also voiced some concerns about the new technology. One is that of information overload, because with so much data readily available, mariners must learn how to recognize priority information without being distracted by peripheral "chatter." They must know how to effectively use the data provided to enhance bridge resource management. They must know who should monitor what equipment and what information to relay to whom. It is also vital that mariners learn to recognize when the system is fully functional and when to verify data. For example, it was determined in this study that the AIS targets based on the Global Positioning System (GPS) are considerably more accurate than radar targets. The tendency, therefore, would be for mariners to rely heavily on AIS data to the exclusion of other sources. However, AIS data quality suffers when satellite contact is lost and the system switches into memory mode. The mariner might then be unknowingly relying on extrapolated rather than real-time positioning data.

Mississippi River mariners have noted that they must also be able to screen out information at various times, quickly and easily. For example, while AIS can generate a picture of the entire waterway system, mariners are generally more concerned with events and conditions in their immediate vicinity. They also need a way to filter out various alarms that do not require their immediate attention.

These mariners also voiced some concern about education and standardization. Since AIS data must be presented in a "common language" of symbols, colors, and sounds that is readily understood, all mariners who use the system must learn that common language, and education is necessary to improve the skill level of all AIS users. Not only do mariners need commonality of available information, they also need instrumentation and data readouts that "speak a common language." Information overload is only exacerbated if the information is presented in different ways at different times on different vessels.

Mariners trained on IMO-standard charts reported confusion when confronted with non-IMO chart products. There was almost universal agreement that colorization on electronic charts, AIS target and information symbology, and information retrieval procedures should be standardized according to guidelines established by IMO. Local pilots also suggested that pilot carry-ons use symbology and color codes that match a vessel's onboard system.

Mississippi River mariners also expressed a preference for having all navigational equipment, including AIS, situated close together so that critical information is conveniently available. This is especially important in situations where the mariner must verify information from several redundant sources and for vessels carrying minimal keyboard displays. These alphanumeric displays are roughly the size of a shoebox and could easily be tucked in an obscure location, which would present difficulties for manual plotting and cause delays during critical times.

Mississippi River mariners generally agree that AIS should not be used to convey additional communications messages because that would overtax the system and distract the mariners from critical navigational alerts. They agree that text messaging in general would be most appropriately relegated to a separate, parallel system, operating concurrently with AIS but focusing on important nonnavigational data such as cargo and crew list. Regardless of the technology used, text messaging will require some kind of policing, perhaps with locally defined, allowable text messages.

The mariners involved in the lower Mississippi River AIS tests have concluded that several issues need to be addressed before the full value of the technology can be realized. For example, a common language of symbology, chart colorization, and alarms needs to be established, and existing electronic charts must be resurveyed to reflect accurate data. Radar accuracy in general needs to be improved. Equipment standards and procedures need to be established, and bridge personnel need formal training so that they can make use of all available tools.

While these results have neither been formalized nor compiled in a comprehensive evaluation report, they will be useful in informing future designs. However, considering the extensive AIS testing that has been done on the lower Mississippi River with a large segment of the mariner community, the committee believes that it would be appropriate to capture these observations in an overall evaluation and prepare a report on lessons learned.

Tampa Bay Vessel Traffic Information System with Shipboard/Carry-Aboard Displays

The transponder-based pilot carry-aboard units incorporated into the Tampa Bay Vessel Traffic Information System (VTIS) provide another example of a display of AIS-type data tailored to the user's needs that can be used to inform the development of future standards and guidelines. Tampa Bay is a large body of shoal water about 30 by 7 miles. The dredged main channel extends from the entrance over 40 miles to the Port of Tampa and varies in width from 400 to 700 feet. The channel is well marked, but navigational safety is frequently impaired when ranges and buoys are obscured by low visibility. Thunderstorms often occur, which generate high winds that affect ship handling and reduce visibility to near zero in heavy rain. In addition, rain can block most radar. The narrowness of the channel also requires planning of transits to avoid meetings in narrow reaches of the waterway.

In the 1980s the Tampa Bay Pilots Association considered using portable precision navigation equipment to assist navigation during low visibility. In 1995, the state of Florida established the Tampa Bay VTIS Consortium, and steps were taken to implement a concept with state-provided funding. The consortium worked with a manufacturer and developed pilot carry-aboard units, which combined electronic chart displays with transponder-based vessel positioning and identification. The system was intended to assist pilots with the navigational challenge presented by low visibility and with passage planning.

The carry-aboard unit consists of a VHF-FM transceiver, a Differential GPS (DGPS) receiver, a battery power pack with integral "universal" charger, an antenna, and a laptop PC. The antenna must be positioned on an external portion of the ship, free from interference. The charger will accept input from a variety of voltages, and the battery pack provides for about 6 hours of use.

The operator may select a series of different screens for display on the laptop, each conveying somewhat different information. An intermediate-scale display provides a general overview of the immediate area. One portion of the screen depicts the channel boundaries, and a pointer indicates the ship's relationship to the channel centerline. There is also a digital readout of the distance left or right of the centerline. Other information displayed includes distance to the next significant navigational point, own ship's course and speed over ground, geographic position in latitude and longitude, and data about the DGPS positioning used. Data about the closest other ship appears in a box in the lower right of the screen. Provision is also made for the transmission and display of data from the area's Physical Oceanographic Real Time System, which is available from the National Oceanographic and Atmospheric Administration.

Experience and lessons learned from this program in Tampa Bay could provide valuable information for the development of future standards and designs of shipboard AIS displays.

San Francisco Bay AIS Project

In 1998, the state of California provided the San Francisco Marine Exchange with funds for a research project to develop new technologies to improve regional navigation and environmental safety. San Francisco Bay was selected as the test area because of its unique mix of navigational challenges such as varying weather patterns, high winds and fog, strong currents, and a moderately large tidal range. It has open water approaches, a relatively large bay, and many miles of narrow channels and rivers that require precision navigation and present diverse vessel traffic situations.

The project began by establishing a Joint Planning Partnership with representatives of ferryboat operators, tug companies, barge operators, container and tanker vessel operators, and the San Francisco Bar Pilots to oversee administration. Two committees were responsible for establishing the scope of work and project development and making periodic progress reports. The San Francisco AIS committee set up the criteria for acceptance of participants for the AIS evaluation. It identified a cross section of local port stakeholders and included those most active in both transits and geographic scope. Twenty-three vessels were designated to evaluate AIS in the following five areas of interest: vessel traffic management, vessel navigation safety, reduced visibility/night navigation, bridge resource management, and overall vessel operations. Tug escort vessels, ship assist tugs, several high-speed ferries, a high-capacity passenger tour boat, a large commercial tanker, a large tug and tank barge, and an oil spill recovery vessel were included in the test.

The San Francisco committee's primary focus was to evaluate the effectiveness of AIS as an aid in the practice of pilotage. Four units from different manufacturers were evaluated, and their individual strengths and weaknesses as a tool for the pilot were identified. Eight San Francisco Bar Pilots were designated to conduct the evaluations and submit their findings and recommendations.

Participants in the project concluded that the technology, although in its infancy, has the potential to develop into an effective navigational tool. "Universal AIS standards" were basic standards, or a starting point from which the AIS and linked technology could be developed on a regional or as-needed basis. Vessels at sea and vessels coasting have requirements different from those of vessels transiting port areas. Dissimilar vessel types and those in different services may also have particular requirements. The informational needs of pilots controlling large, deep-draft vessels in pilotage waters are different from those piloting other vessels and indeed may differ between pilotage districts. International, national, and regional regulatory agencies and other shoreside entities also may have requirements that could be met through the use of AIS and related technology. A concern of the mariner is the potential overload of the system with administrative information that could be transmitted by other means, which would negatively affect its use as a bridge information navigational tool.

The most common AIS features found useful by the San Francisco project evaluators were the following (in order of priority):

1. Radar target identification,
2. Position in traffic lane or narrow channel,
3. Vessel target information (i.e., speed and course),
4. Route planning,
5. Ability to make navigation decisions earlier,
6. Target destination, and
7. Ability to see around corners.

The San Francisco mariners involved in this project also had a number of common criticisms of the AIS they were using: the night screen was too bright, not all vessels were participating, there was screen clutter in areas of congestion, the system failed too often, and the navigation charts were poor.

A focus group of the AIS users was convened to discuss the usefulness of AIS and how it might affect the operation of their vessels or their particular area of interest. The group listed five goals for the development of AIS as a mature tool for the mariner and suggested topics to achieve each.

Goal 1. Vessel traffic management: To achieve this goal, the group decided that it would be necessary to integrate the system with radar, improve electronic charts, develop better icons, and develop an improved night screen.

Goal 2. Vessel navigation safety: To achieve this goal, the group suggested improvements in electronic charts, night screens, true heading displays, and illuminated keyboards.

Goal 3. Reduced visibility/night navigation: To achieve this goal, the group also suggested improvements in night screens, radar integration, and target vector features, and suggested that more vessels participate.

Goal 4. Bridge resource management: The group suggested that radar target integration would be the key improvement needed to achieve this goal.

Goal 5. Overall vessel operations: The group suggested many of the same improvements as above to achieve this goal.

Selected members of the San Francisco Bar Pilots tested four portable pilot units, each manufactured by a different company. The evaluators were asked to appraise the units and AIS in the same interest areas as the AIS group (i.e., vessel traffic management, vessel navigation safety, reduced visibility/night navigation, bridge resource management, and overall vessel operations) and to submit the same evaluation report. A synthesis of the comments indicated that the units need further development before they become a reliable tool in which the San Francisco Bar Pilots can have complete confidence. The following are the minimum requirements that these evaluators thought necessary for portable pilot units in the future:

- The vessel's true heading must be displayed.
- They must weigh less than 10 pounds.
- Electronic charts must be much more accurate to support the accurate positioning technology.
- The units must interface with the vessel AIS source information (position, course, speed) through a "universal plug."
- The units should include a wireless Internet access to receive local meteorological, hydrological, and other notices of interest to the mariner.
- Nautical software developers should work with local mariners to incorporate features to meet their needs. Such features as route planning, continuous calculations of ETA at waypoints and selected locations, and position and time of meeting between selected vessels should be included.

The focus group unanimously agreed that continuing development of AIS and related technology should be strongly encouraged in the future. The results of this test and evaluation program provide many useful insights and can benefit the development of AIS display standards and guidelines.

SUMMARY

A number of public and private organizations in the United States, Canada, and Europe have conducted operational tests and evaluations of AIS, many of which have included experience with shipboard displays. These tests were reviewed in order to understand how they might inform decisions about future requirements for displays aboard all types of vessels in U.S. waters. Most of the tests were part of research or pilot projects and used nonstandard versions of systems, usually known as "transponder systems." Only a few of the tests used systems that met the IMO 1371 standard. Nevertheless, the results provide a general notion of how mariners have used shipboard displays and what benefits they might bring to a variety of operational and geographical situations.

In general, the tests did not use rigorous procedures to measure system performance on the basis of predetermined standards or requirements. Rather, the test results were mostly anecdotal; the comments by test participants reflected local views and applied to local conditions. Therefore, the tests are not suitable for analytical evaluation of display design performance, but they do offer useful insights into mariner needs, preferences, and concerns about systems they have used in operational situations.

Mariners in a variety of U.S. port regions such as San Francisco, New Orleans, St. Lawrence Seaway, and Tampa Bay have gained considerable confidence from this recent experience as well as a degree of enthusiasm for the potential of AIS. Their initial skepticism diminished as they became accustomed to the technology and realized the benefits of accurate, real-time navigational data from AIS displays. In the lower Mississippi River tests of pilot carry-aboard AIS units, skepticism about the technology among local mariners diminished sharply after they became accustomed to the system and recognized the benefits that it offered. Similar results were noted among participants in the San Francisco Bay research project. The evaluation group from these tests strongly encouraged continuing development and noted the promise of future benefits. Across the Atlantic, extensive operational testing of shipboard AIS displays in Sweden resulted in enthusiastic support of further development within many international forums. These conclusions indicate that AIS can bring benefits that are recognized by mariners, especially when user needs are integrated into the design and development process.

The test results discussed in this chapter have also shown that designers must carefully consider such factors as reduction of information overload, effective integration of multiple bridge displays, training, and standardization. For example, information overload concerns were common among mariners who participated in test projects at all locations. The large volume of data that is typically available from multiple sources can be overwhelming, and all tests showed that excessive time is needed to extract pertinent information in a form applicable to decision making. This common problem supports the application of human factors principles by first considering the capabilities and needs of users and then designing and integrating all systems to meet those needs. Many of the test projects also showed that training and standardization are critical factors leading to successful outcomes. Both the Mississippi River and the Tampa Bay tests were used by USCG to help develop international standards for AIS.

To date, it appears that all AIS trials have been conducted in local areas by skilled operators with a common language and culture. Most have been done in pilotage waters where the operators are already familiar with the area and traffic patterns. Thus, there is inadequate experience to predict how multilingual, multicultural crews with the lowest acceptable standards of training will react to AIS information.

The experience with all of the test projects, in general, shows that shipboard AIS displays can now enter the next phase of development with confidence that the technology can bring safety and operational benefits to mariners if it is properly designed and implemented. The projects also show that the next phase of development would benefit from more rigorous operational evaluations using lessons from these tests.

REFERENCES

Abbreviations

IMO	International Maritime Organization
ITU	International Telecommunication Union

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4 Determining Requirements for Shipboard Display of Automatic Identification System Information

Displays fulfill different purposes depending on the operators who use them and the displays' operational settings. The purposes are often identified by display designers and developers in requirements documents that define the functionality, services, and support that must be provided by a display. Requirements are derived from many sources—a display's users, customers, designers, regulators, developers, and operating and technical environment. Each source may provide a different view of the functionality, services, and support required of a display. Requirements documents, thus, are the aggregate of those views, identified by source, and prioritized to reflect a composite view of what a display must do or provide.

Existing requirements for shipboard display of automatic identification system (AIS) information are described in this chapter, and an analysis of the requirements inventory with respect to three types of conceptual AIS is given. A catalog of existing requirements for shipboard display of AIS information is provided in Appendix C.

DETERMINING REQUIREMENTS FOR SHIPBOARD DISPLAY OF AIS INFORMATION

System design and development processes have evolved considerably over the past 50 years and generally follow the steps outlined in Figure 4-1. Problem and requirements analysis is a traditional first step in system design and development. Next, conceptual or logical models of the system are developed. The conceptual models are then compared with, or mapped to, the requirements to identify any needed changes. Improvements to the conceptual models are identified, and physical prototypes or designs are developed. The design is then developed into a system, implemented, maintained, and supported, as seen in Figure 4-1.

These steps are followed in the design and development of new displays, as well as in analysis, design, or review of existing displays such as AIS. Following such a process with an existing display can provide insights about

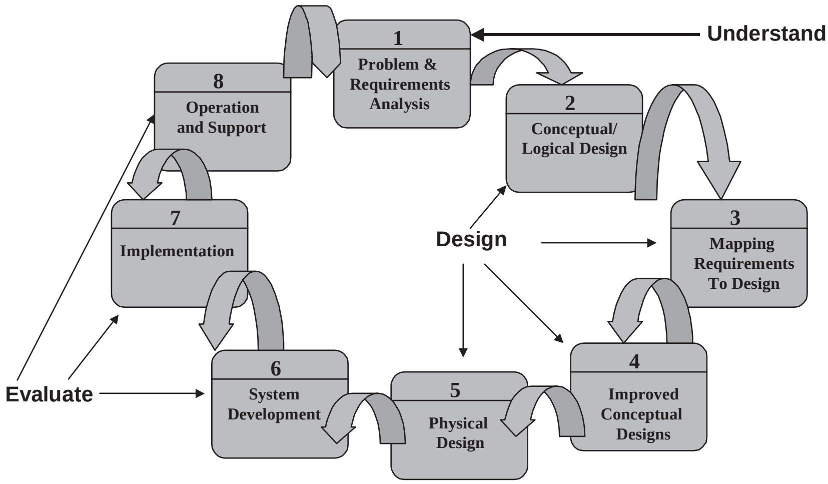

FIGURE 4-1 System design and development process.

missing, conflicting, or infeasible requirements, and can identify disconnects between requirements for the display and existing designs. Improvements or modifications of existing designs and requirements may result from these analyses.

The core elements of the human factors design process—understand the user and the demands of the operational environment, design a system on the basis of human factors principles, and evaluate the system to ensure that it meets the needs of the user—are outlined in Chapter 5. These human factors design activities are integral elements of the overall system design and development process, as shown in Figure 4-1. Comprehensive system design and development processes incorporate system and human factors design activities to design and develop robust, effective, and useful systems.

The committee performed an inventory of existing AIS display requirements (Step 1 in the design process). Requirements for high-level conceptual models for AIS display—Class A, Class B, and Class A derivative AIS—have been articulated by the International Electrotechnical Commission (IEC) (IEC 2001) and other standards bodies. These were the conceptual designs utilized in Step 2 of the design process. The inventoried AIS shipboard display requirements were then mapped to the AIS conceptual designs (Step 3), and insights resulting from the analysis provided input to committee deliberations about shipboard display of AIS information (Step 4).

Following such a process offered a number of advantages:

- An aggregate view of existing AIS display requirements was developed.
- The process provided a mechanism for determining missing, conflicting, overlapping, or infeasible requirements, as well as patterns and similarities in requirements and conceptual designs.
- Because the steps and the outputs associated with the process are standardized, the process is replicable, which suggests that the reliability of the analysis and results may be enhanced.
- Finally, the process provides a mechanism to trace changes in requirements over time. This is particularly useful when system requirements are changing and when many parties provide input to the design of a system, as in the AIS development process.

Performing an inventory of existing AIS display requirements provided an archive of articulated AIS display needs. Identifying sources for those requirements enhances auditability and accountability, so that changes in AIS display requirements and their sources can be tracked over time. Analysis of AIS display requirements with respect to AIS conceptual designs permits consideration of the importance of different requirements in different operational settings [e.g., International Convention for the Safety of Life at Sea (SOLAS) and non-SOLAS vessel use of AIS]. Missing, needed, infeasible, costly, or unresponsive requirements could thus be identified.

The use of conceptual or logical AIS display models assists in identifying the adequacy of display requirements for different conceptual designs (e.g., Class A, Class B, and Class A derivative AIS) rather than the adequacy of a particular manufacturer's display. The use of conceptual display models broadens the generality of the recommendations and allows those recommendations to extend beyond the current suite of AIS displays to future systems by considering interface, display, and control options independent of existing physical displays.

The committee did not independently develop requirements for shipboard display of AIS information, but rather surveyed existing requirements to determine their adequacy. Although international standards bodies and manufacturers, among others, have developed AIS displays and requirements for those displays, there is need to supplement, revise, and reconsider the existing requirements as well as to develop new requirements.

Computer-aided software engineering (CASE) tools are useful in display design and development as electronic repositories for system requirements, as well as for logical and physical design models. The use of CASE tools promises to improve the quality of the designs and systems developed, increase the speed of design and development, improve the ease and integrity of analysis and modeling through automated checking, and improve the quality and completeness of system documentation (Hoffer et al. 2002). Moreover, CASE tools allow reuse of frequently utilized requirements, standards, and models. Thus, capturing system requirements and models electronically is a desirable goal, particularly for regulatory agencies with technology development and management responsibilities. The use of CASE tools can significantly reduce requirements, data, and model redundancy; permit requirements and model analysis across different vessel types, hardware, and software platforms; improve the economy of system models and requirements determination; and encourage component and system reuse. The U.S. Coast Guard (USCG) should utilize CASE tools in future requirements and standards specification activities.

INVENTORY OF EXISTING AIS REQUIREMENTS

The existing AIS display requirements, listed in Appendix C, are grouped into six categories:

- *Information and task requirements*—requirements that define the nature and type of information to be handled by the AIS display and the tasks to be supported by that information. Requirements in this category identify the nature, type, volume, and size of information to be displayed; minimum information requirements are included. The category also describes target discrimination and message requirements.
- *Operational and organizational requirements*—shipboard display requirements that result from the operating environment, culture, and expectations within which the AIS display will be used. Requirements for display of different port or waterway information, traffic management or vessel traffic service (VTS) information, and information to satisfy any re-

gulations or security requirements in effect are included. The category includes requirements to provide display support for different types of waterway users—for example, deep-sea ships and inland vessels. Another example in this category would be differing requirements for display of security, privacy, and safety information in different operational settings. The category includes organizational requirements—those requirements related to needs of the AIS host or parent environment and requirements related to local, state, national, or international policies and procedures.

- *Technical display requirements*—display requirements dictated by AIS display and control technologies: hardware, software, databases, networks, storage, and processing requirements. This category includes requirements for display performance, accuracy, reliability, maintainability, availability, integrity, loading, and clutter. The category also includes requirements for future AIS displays.

- *Display format requirements*—requirements for the appearance and configuration of AIS displays. Visual presentation, display options, symbology, display synchronization, presentation priority, and alarm requirements are included in this category. The category also includes requirements for display location (in *X*–*Y* space or superimposed), color, dimensionality (planar versus perspective, mono versus stereo), motion, intensity (display brightness), coding (color, size, and shape; analog and digital coding; analog and graphics versus text), modality (vision versus audition), contrast, and labeling (Wickens et al. 2003). The category covers requirements to support user expectations, user control, user help and error support, display customizability, and user interaction styles (e.g., menus, links, dialog boxes). Formats for navigation displays include requirements for route lists or command displays, chart legibility and clutter, position representation, chart orientation and scale, and support for planning and visualization (Wickens et al. 2003).

- *Physical layout requirements*—requirements for physical engineering and appearance of the display, including numbers and types of displays and display surfaces; display integration; display controls; and requirements for display lighting, sound and noise, thermal conditions, heating, and ventilation, for example.

- *Environmental requirements*—requirements for robustness of AIS display packaging with respect to environmental conditions. Requirements for displays to pass packaging, emission, vibration, humidity, temperature, ruggedability, pollution, and contamination tests are included.

Four types of information about the requirements are contained in Appendix C:

- A categorization of the type of requirement (information and task, operational and organizational, etc.);
- A description of the requirement;
- An operationalization or definition of the requirement in the form, "The AIS display shall . . ."; and
- An indication of the source of the requirement.

Each display requirement described in Appendix C is numbered sequentially and is identified by source, which provides identification, traceability, and auditability for the requirements (Wiegers 1999). Traceability is helpful because the AIS display requirements were inventoried from several sources. A bibliography of sources is provided in the references to the requirements table in Appendix C. The AIS display requirements describe the functionality and information to be provided by different types of AIS displays, as well as the context and constraints within which the displays will operate. The following section contains an analysis of those requirements.

REQUIREMENTS ANALYSIS

The inventory of requirements for shipboard display of AIS information was analyzed with respect to three AIS conceptual designs:

- Class A SOLAS vessel displays,
- Class A derivative displays [e.g., personal pilot units (PPUs)], and
- Class B (non-SOLAS vessel) displays.

The purpose of the analysis was to assess the adequacy of existing requirements for shipboard display of AIS information, which is discussed in the following sections.

Information and Task Requirements

Information and task requirements define the nature and type of information to be handled by the AIS display and the tasks to be supported by that information. Requirements in this category identify the nature, type, volume, and size of information to be displayed; minimum information requirements are included. The category also describes target discrimination and message requirements.

Some of the information to be transmitted by AIS may be available in existing navigational equipment aboard the bridges of ships. Thus, determining the information requirements for AIS displays is an important first step in developing effective displays. Future activities for the determination of AIS information should consider the overlap in available information among existing and future navigational equipment and appropriate integration or information allocation strategies.

Functional Requirements

Displays of AIS information are to be used to assist in collision avoidance, to provide information about the vessel and its cargo, and to assist in vessel traffic management. As described previously, at a minimum, three types of core, representative information are to be displayed by AIS: static information, dynamic information, and voyage-related information.

Static information is the relatively permanent information that pertains to a particular vessel—its name, call sign, merchant marine station identifier (MMSI) number, type of ship, and so forth. Static information can be used for identification [vessel name, call sign, MMSI number, type of ship, International Maritime Organization (IMO) number, etc.], for collision avoidance (length, beam, antenna location), and for vessel traffic management (length, beam, antenna location) (see Figure 4-2).

The AIS information transmitted can support several functions; for instance, vessel length and beam information can be used for identification as well as for collision avoidance. Moreover, static, dynamic, and voyage-related information may be categorized differently in different operational settings. For instance, in inland waters, "static" information such as vessel length, beam, or cargo may change by port call, thus becoming "dynamic" information. As a result, assumptions about the nature and type of static,

AIS Data Elements

Functions

Information Type

Static Information	Dynamic Information	Voyage-related Information	Functions
Beam Length Antenna location	Navigational status Weather	Hazardous cargo Draft ETA* Route plan*	**Vessel Traffic Management**
Antenna location Length/beam	Course Heading Speed Position Rate of turn* Length/beam	Draft	**Collision Avoidance**
Vessel name Call sign/MMSI Type of ship/IMO # Cargo	Cargo on board	Cargo on board	**Identification**

*** Optional information**

FIGURE 4-2 Representative AIS data elements, functions, and information.

dynamic, and voyage-related information may be different in different operational settings.

Dynamic information provides the vessel and waterway context that permits the mariner to maintain orientation in the harbor, accurately fix and track the vessel's position, understand other vessels' movements and tracks, appreciate how other vessels' characteristics can affect maneuvering or a transit, and understand and anticipate the dynamic characteristics of the environment. Dynamic information can be used for vessel identification (cargo), collision avoidance (course, heading, speed, position, length/beam, rate of turn), and vessel traffic management (navigational status, weather) (see Figure 4-2).

Voyage-related information is acquired before and during a particular transit. It includes data on the vessel, the environment, the waterway, and their interactions under the conditions of a specific transit. Voyage-related information can be used for identification (cargo), collision avoidance (draft), and vessel traffic management [hazardous cargo, draft, estimated time of arrival (ETA), and route plan]. The use of these three types of information is essential to ship navigation (Huffner 1978; Farnsworth and Young 1988; Hutchins 1995; Grabowski and Wallace 1993; Grabowski and Sanborn 2001).

Other information may also be transmitted as required by a port or waterway or by prevailing circumstances that require transmission of important information to the mariner, in addition to the static, dynamic, and voyage-related information just described. Other AIS information, such as real-time weather, environmental, and surface data, as well as local port security notices, is currently ill defined. This information may be particular to a port, waterway, environmental condition, or a port state, and further definition is needed.

Table 4-1 summarizes the inventory of AIS requirements. As indicated in Table 4-1, eight functional requirements for Class A AIS information were identified: a Class A AIS is intended to provide identification, navigation information, and vessel's current intentions to other ships and to shore. As such, the AIS must autonomously and continuously provide ship-to-ship collision avoidance information, as well as positional and maneuvering information at a data rate adequate to facilitate accurate track-keeping. Class A AIS units must be capable of sending ship information such as identification, position, course, speed, ship length, draft, ship type, and cargo information to other ships and aircraft and to the shore. They must also be able to receive and process information from other sources, including information from a competent authority and from other ships. Class A AIS units must respond to high-priority and safety-related calls with a minimum of delay. No functional requirements for Class B were identified by the committee.

Two functional requirements for Class A derivative AIS were identified, but the requirements are lacking: Class A derivatives are not clearly defined in any of the AIS-related documents. Class A derivatives may be the result of any local or international development of AIS for particular uses—for example, in inland and coastal navigation, in PPUs, and in harbors for service vessels such as tugs, buoy tenders, hydrographic ships, and pilot vessels. Class A derivatives are intended to use the same functionality and reporting rate as the Class A stations on the VHF data link (VDL) message level. The main difference between Class A and Class A derivative AIS is that not all mandatory components of Class A AIS stations must be included. However, these

TABLE 4-1 Requirements by AIS Class

Requirement Type	Class A	Class B	Class A Derivative
1.0 Information and Task Requirements			
1.1 Functional	X (8)		X (2)
1.2–1.4 Minimum keyboard and display	X (27)	X (2)	X (3)
1.5 Target discrimination	X (3)		
1.6 Additional information	X (5)		
1.7 Messages		X (2)	
1.7.1 Short safety-related	X (7)		
1.7.2 Aids to navigation	X (3)		
1.7.3 Advice to VTS/route plan	X (3)		
1.7.4 Class B			
2.0 Operational and Organizational Requirements			
2.1 Operational	X (8)		
2.2 Security			
2.3 Privacy			
2.4 Port/waterway			
2.5 Organizational			
2.6 Regulatory			
3.0 Technical Display Requirements			
3.1 Display performance			
3.2 Display accuracy			
3.3 Display reliability			
3.4 Display maintainability			
3.5 Display availability			
3.6 Display integrity			
3.7 Display loading			
3.8 Display hardware, software, networks, etc.			
3.9 Future displays—growth			

(continued on next page)

TABLE 4-1 *(continued)* Requirements by AIS Class

Requirement Type	Class A	Class B	Class A Derivative
4.0 Display Format			
4.1–4.3 Visual presentation	X (15)	X (1)	X (2)
4.4 Display options	X (18)		
4.5 Symbology	X (5)		
4.6 Display synchronization	X (1)		
4.7 Presentation priority	X (6)		
4.8 Display alarms	X (3)		
4.9 Display location			
4.10 Use of sound and color			
4.11 Display dimensionality			
4.12 Display motion			
4.13 Display intensity			
4.14 Display coding			
4.15 Display modality			
4.16 Display contrast			
4.17 User interaction style			
4.18 User help and error support			
4.19 Display labeling			
4.20 User control			
4.21 User expectations			
4.22 Display customizability			
4.23 Chart legibility			
4.24 Chart decluttering			
4.25 Position representation			
4.26 Chart orientation			
4.27 Chart scale			
4.28 Visualization support			
4.29 Planning support			

TABLE 4-1 *(continued)* Requirements by AIS Class

Requirement Type	Class A	Class B	Class A Derivative
5.0 Physical Layout Requirements			
5.1–5.2 Display integration	X (6)		X (1)
5.3 Display lighting			
5.4 Display and control surfaces			
5.5 Sound and noise			
5.6 Thermal conditions			
5.7 Screen display			
6.0 Environmental Requirements			
6.1 Packaging			
6.2 Emission			
6.3 Vibration			
6.4 Humidity			
6.5 Temperature			
6.6 Ruggedability			
6.7 Contamination			
6.8 Pollution			

requirements are silent on the type of information and functionality that is to be provided by Class A derivative displays.

Thus, information and functional requirements for Class B and Class A derivative AIS displays need to be defined. This is an important first step for Class B and Class A derivative AIS displays; absent a definition of their functionality, it is difficult to develop additional display requirements for them.

Minimum Display Requirements

Twenty-seven Class A minimum keyboard and display (MKD) requirements were identified, as shown in Table 4-1. Class A AIS units must present a minimum of three lines of 16 alphanumeric characters sufficient to obtain a target vessel's identity and position, using target bearing, range, and ship name.

Class A AIS minimum displays must also indicate alarm conditions and provide a means to view and acknowledge alarms. Other ship data can be displayed on Class A minimum displays by horizontal scrolling, but scrolling of bearing and range is not permitted; vertical scrolling can also show other ships known to AIS. Class A minimum displays are also required to indicate state/condition changes, display safety-related messages, and indicate when safety-related messages have been received. Class A minimum displays are required to be able to initiate or cancel a reply to long-range interrogation (LRI), to respond to and acknowledge LRI automatically or manually, and to indicate when LRI is in automatic or manual mode.

Class A minimum displays are required to display Global Positioning System (GPS) position when the internal Global Navigation Satellite System (GNSS) receiver is operating as the backup position source for AIS reporting and to continuously display GPS position when the internal GPS is used for position reporting. Class A minimum displays may be used to input voyage-related information, such as cargo category, maximum preset static draft, number of persons on board, vessel destination, ETA, and navigational status. They may also be used to input static information such as MMSI number, IMO number, ship's call number, ship's name, length and beam, position reference points for GNSS antenna, and type of ship. Class A minimum displays may be used to input safety-related messages, change the AIS unit mode of response to LRI, and control AIS channel switching. Class A minimum displays may be password protected.

Few Class A derivative (three) or Class B (two) MKD requirements were identified. Class B or Class A derivative MKDs may not be required, and non-SOLAS vessels can use the Class B or Class A derivative AIS as a black box connected to a more or less sophisticated display [e.g., electronic charting systems, electronic charting and display information systems (ECDIS)], or as another external system for special applications to see and present own position and other AIS targets in relation to the environment. Both Class B and Class A derivative MKDs must have at least one means to program the units with static data. The Class A MKD units may not be required on Class B vessels or on pleasure craft.

The MKD requirements, by definition, contain a limited amount of information. However, the committee believes that the size and limited nature of the text-only display, coupled with the operator manipulation and information transposition required (e.g., the requirement for operators to transpose text information from the MKD into spatial information for decision making), render the MKD inadequate to meet the needs of mariners in different operational settings. As a result, USCG should determine such needs and revise the minimum display requirements accordingly.

Target Discrimination Requirements

Three target discrimination requirements for Class A AIS displays were identified. Class A AIS units require target discrimination: target data from radar and AIS should be clearly distinguishable as such, and if more than one target is selected, the source of the data (e.g., AIS, radar) should be clearly indicated. Furthermore, correlation between primary radar targets and AIS targets is likely to be required. No target discrimination requirements for Class B or Class A derivative AIS were identified; such requirements are needed for both.

There are unresolved issues in target discrimination between radar and AIS targets, particularly with target swap in close waters. In some cases, radar or AIS targets can "drop" from the display, sometimes without notice to the operator. Radar manufacturers should be encouraged to address this difficulty by increasing radar accuracy, and the development of data fusion techniques required to resolve open target discrimination, target swap, and target drop issues should be encouraged. USCG's display standards should resolve discrimination errors between radar and AIS targets.

Message Requirements

Thirteen Class A and two Class B AIS message requirements were identified. No Class A derivative AIS message requirements were identified by the committee; thus, such requirements need to be identified. Seven short safety-related Class A message requirements were identified. These messages can be used as an additional means to broadcast maritime safety information, and they can either be addressed to a specified destination (i.e., MMSI) or broadcast to all AIS ships fitted in the area. They can include up to 160 six-bit ASCII characters but should be kept as short as possible. They can be fixed or free-form text messages and should be relevant to the safety of navigation. Operator acknowledgment of short safety-related messages may be requested by a text message. No Class B or Class A derivative short safety-related message requirements were identified.

There are three Class A aid to navigation message requirements. Aid to navigation messages can provide information on the location and identification of hazards and marks used for navigation, as well as information of a meteorological or oceanographic nature. They can also provide information on the operational status of aids to navigation. No Class B or Class A derivative aid to navigation message requirements were identified.

There are three Class A advice to VTS waypoints/route plan message requirements and no such requirements for Class B or Class A derivative AIS. Thus, in general, message requirements for Class B and Class A derivative AIS displays need to be defined, and message requirements for Class A AIS displays need to consider the range and type of operating conditions that different vessels will encounter. In general, more work is needed to define message requirements for all classes of AIS displays.

In addition, the concept of safety-related messages for any class of AIS was ill defined. Thus, in its standards-setting process, USCG should define requirements for safety-related messages. Avoiding overload of AIS with safety-related messages that might better be sent through alternative media is a desirable goal. USCG should consider the appropriateness of different modes and media for transmission of safety-related information. In addition, USCG's standards-setting process should consider the importance of local information in safety-related messages in a particular port or waterway. Short safety-related messages have the potential to distract operators from their primary duties. USCG should consider appropriate message traffic types, levels, loading, and communication requirements associated with transmission of safety-related messages.

Operational and Organizational Requirements

Operational display requirements that affect shipboard display of AIS information include requirements that result from the operating environment, culture, and expectations within which the AIS operates. They include display requirements for different port or waterway settings or for any regulations in effect; security and privacy requirements; and company, union, or other organizational requirements for shipboard display of AIS information. Eight Class A operational requirements for AIS displays have been defined: AIS shall operate autonomously and continuously and shall provide information without involvement of ship's personnel. AIS should always be in operation unless the master believes, in sea or in port, that continued operation of AIS might compromise the ship's safety or security, at which point the AIS may be switched off. If the AIS is switched off, static and voyage-related data should be retained. Finally, if the gyro fails to provide data, the AIS should automatically transmit a "data not available" value.

Operational display requirements for the other classes of AIS should be defined for various operational environments. USCG should develop such requirements for different waterway operators and all classes of AIS displays in consultation with appropriate stakeholders. Privacy and security requirements for shipboard display of AIS information should be identified, as should any port or waterway and any organizational or regulatory display requirements.

Technical Display Requirements

Technical display requirements for shipboard display of AIS information include requirements dictated by AIS display and control technologies: hardware, software, databases, networks, storage, and processing requirements. They include requirements for display performance, accuracy, reliability, maintainability, availability, integrity, and loading. They also include requirements for future AIS displays.

Although a number of AIS displays are produced by various manufacturers, the committee found no specific AIS technical display requirements for any class of AIS in its inventory of existing AIS requirements. In addition, no discussions of future capabilities or growth of AIS displays, such as trends toward smaller, lighter, embedded, and wearable computer interfaces (MIT 2002), or of future energy sources and processors (Rifkin 2002), were found. AIS technical display requirements are needed for all classes of current and future AIS, in varying operational settings; such requirements should accommodate future growth in technologies, displays, controls, and interfaces. USCG should develop technical display requirements for shipboard display of AIS information as part of its standards-setting process.

Display Format Requirements

Display format requirements include requirements for the appearance and configuration of AIS displays, including visual presentation, display options, symbology, display synchronization, presentation priority, and alarms, as well as requirements to meet user expectations, user control, user help and error support, display customization, and user interaction styles (e.g., menus, links, dialog boxes). They also include requirements for display location (in *X–Y* space or superimposed), color, dimensionality (planar versus perspective, mono versus stereo), motion, intensity (display brightness), coding (color, size, and shape; analog and digital coding; analog and graphics versus text), modality (visual, auditory, haptic, etc.), contrast, and labeling (Wickens et al. 2003). Display formats for navigation displays include requirements for route lists or command displays, chart legibility and clutter, position representation, chart orientation and scale, and support for planning and visualization.

Forty-eight Class A display format requirements, 1 Class B display format requirement, and 2 Class A derivative display format requirements were identified. Most (36) were visual presentation and display option requirements. Additional display format requirements are needed, especially those that reference or follow existing international standards and guidelines for visual display terminals (ANSI 2002). No international standards or guidelines were referenced by existing AIS documentation and standards. As can be seen in Table 4-1, display format requirements for all classes of AIS displays are needed. USCG should develop display format requirements for shipboard display of AIS information after its assessment of mariner information needs, referencing existing international human factors and display format standards where applicable.

Visual Presentation Requirements

Fifteen Class A visual presentation requirements were identified. They state that if Class A AIS information is presented graphically, at least the following information shall be provided:

- Vessel position,
- Course over ground,
- Speed over ground,
- Heading, and
- Rate of turn (or direction of turn).

Moreover, Class A AIS visual presentation requirements state that if Class A AIS information is presented graphically on a radar display, radar signals should not be masked, obscured, or degraded. The graphical properties of other target vectors must be equivalent to those of the AIS target symbols, and the type of vector presentation (radar plotting symbols or AIS symbols) should be selectable by the operator. Active display modes on Class A AIS units should be indicated on graphical displays, and a common reference point for superimposition of AIS symbols with other information on the same display and for calculation of target properties [i.e., closest point of approach (CPA), time to CPA (TCPA)] should be utilized.

Class A AIS positional information must be displayed relative to the observing vessel, and indications should be provided if own AIS is out of service or switched off. More capable Class A displays are encouraged in the requirements because of the greater functionality provided by such displays, but selection of display types is dependent on the user requirements and options offered by manufacturers. Visual overloading of AIS display screens is to be avoided.

Other visual presentation requirements for Class A shipboard AIS displays are needed. For instance, although requirements exist for the transmission of waypoint data from shore stations to ships, there are as yet no requirements for the visual presentation of that information. Visual presentation requirements for Class A AIS units should be defined following completion of USCG's assessment of mariners' information needs for shipboard display of AIS information.

Two Class A derivative requirements for visual presentation exist. First, there is no requirement for Class A derivative AIS units to carry the same presentation interfaces as Class A stations. Second, the position information for Class A derivative stations may be derived from the internal (D)GNSS receiver. These are clearly inadequate requirements for visual presentation of Class A derivative AIS information. Similarly, a single Class B AIS visual presentation requirement was identified: there may be other equipment on board non-SOLAS vessels with interfaces that are noncompliant with IEC 61162-1 standard (i.e., RS-232). Thus, there is also a need to develop visual presentation requirements for shipboard display of AIS information for Class B and Class A derivative AIS. These requirements should be defined after completion of USCG's assessment of mariners' information needs for shipboard display of AIS information.

Display Option Requirements

Eighteen Class A display option requirements but no Class B or Class A derivative display option requirements were identified. On Class A AIS units, operators may choose to display all or any AIS targets for graphical presentation. When they do so, the mode of presentation should be indicated. If color fill is used in display of AIS target symbols, no other information should be masked or obscured. On Class A units, AIS symbols for activated targets may be replaced by a scaled ship symbol on a large scale/small range display. Furthermore, means should be provided to select a target or own ship for display of its AIS information on request, and if more than one target is selected, the relevant symbols, corresponding data, and source of the data (e.g., AIS, radar) should be clearly identified.

If zones or limits for automatic target acquisition for Class A AIS are set, the requirements state that they should be the same for automatically activating and presenting any targets, regardless of their source. In addition, the vector time set should be adjustable and valid for presentation of any target, regardless of its source. If radar plotting aids are used for display of AIS information on Class A units, they should be capable of calculating and displaying collision parameters equivalent to the available radar plotting functions.

Class A AIS display option requirements also state that if the calculated CPA and TCPA values of an AIS target are less than the set limits, a target of concern symbol should be displayed. Means to recover data for a number of last acknowledged lost targets may be provided; preferably, the ability to recover data for targets may be applied to any AIS target within a certain distance. Class A AIS units should permit operators to make reasonable changes to the default parameters of automatic selection criteria, and means should be provided to display alarm messages from own AIS stations.

Further display option requirements are needed. Display option requirements for Class A, Class B, and Class A derivative AIS should be defined after completion of USCG's assessment of mariners' information needs for shipboard display of AIS information.

Symbology Requirements

Class A AIS symbology requirements are simply stated: if AIS information is graphically presented, the symbols described in the appendix to IMO SN/Circular 217 (IMO 2001) and repeated in the Appendix 4-1 of the International Association of Aids to Navigation and Lighthouse Authorities (IALA)

AIS guidelines (IALA 2001) should be applied. However, no Class A derivative or Class B AIS symbology requirements were defined. If the intent is to extend Class A AIS symbology requirements to Class A derivative or Class B AIS units, or both, that extension should be made explicit. If exceptions to the Class A AIS symbology requirements are to be made for Class A derivative and Class B AIS units, those exceptions should also be so noted. In any event, further work is required to define symbology requirements for all classes of AIS.

The committee identified symbology requirements for ship targets during its inventory, but not symbology requirements for other types of AIS information—vessel tracklines, for instance. IEC Technical Committee 80 Working Group 13 (IEC 2001), among others, is working on the development of additional AIS symbology, and much work in chart and map symbology has been done in other domains. AIS symbology requirements should leverage this earlier and ongoing work as requirements for shipboard display of Class A, Class B, and Class A derivative AIS information are developed.

USCG should participate in international discussions on developing standards for AIS symbology. USCG should integrate standards as guides to developing symbology requirements for shipboard display of AIS information in different operational environments. These symbology requirements should conform to international and other standards for symbology. USCG should leverage earlier work in symbology development and follow international procedures [i.e., ISO TR 7239 (ISO 1984)] in developing symbology requirements.

Display Synchronization, Presentation Priority, and Alarm Requirements

One display synchronization, six presentation priority, and three alarm requirements were identified for Class A AIS, but no such requirements were identified for Class B or Class A derivative AIS units. The single Class A AIS display synchronization requirement states that if AIS information is graphically displayed on a radar, the equipment should be capable of appropriately stabilizing the radar image and the AIS information.

Six Class A presentation priority requirements were identified. The presentation of AIS target symbols, except for sleeping or lost targets, should have priority over other target presentations within the display area. Automatic display selection functions may be provided to avoid presentation of two target symbols for the same physical target. If target data from AIS and radar plotting functions are available and the automatic selection criteria are fulfilled, then the activated AIS target symbol should be presented. In contrast, if target data from AIS and radar plotting functions are available and the automatic selection criteria are not fulfilled, the respective symbols should be displayed separately. The Class A AIS requirements further specify that mariners should be able to select additional parts of information from AIS targets, such as ship's identification (at least the MMSI); those additional parts of information should be presented in the data area of display. An indication should be given if the additional information from AIS targets is incomplete.

The three Class A AIS alarm requirements identified indicate that alarms should be provided if the calculated CPA and TCPA values of an AIS target are less than the set limits, as well as when the signal of an AIS target of concern is not received for a set time. Means should be provided to acknowledge alarm messages from own Class A AIS.

No Class B or Class A derivative requirements for display synchronization, presentation priority, or alarms were identified. Thus, such requirements must be developed. In addition, alarm requirements for all classes of AIS displays should be reviewed, because existing requirements for AIS display alarms focus on the visual and auditory senses. USCG should consider alternative modes for alarms and consider alarm design in the context of existing alarms and ambient noise on the bridges of ships in different operational settings. Target discrimination, display synchronization, presentation priority, and alarm requirements for all classes of AIS should be developed by USCG.

The committee did not find any requirements for configuration of AIS displays, including display location, color, dimensionality, motion, intensity, coding, modality, contrast, user expectations, user control, user help and error support, user interaction style, or display customizability. Furthermore, display format requirements for navigation displays, such as chart legibility or decluttering, position representation, and chart orientation and scale, and for support for visualization and planning were not found. These requirements are well-known needs for display format and need to be developed for all classes of AIS displays (Wickens et al. 2003; ANSI 2002). Thus, USCG should develop requirements for all of these display format items for all classes of shipboard AIS.

Physical Layout Requirements

General

Physical layout requirements include requirements for physical engineering and appearance of the display, including numbers and types of displays and display surfaces; display integration; display controls; and requirements for display sound and noise, lighting, thermal conditions, heating, and ventilation, for example. Only six display integration requirements for Class A AIS and one Class A derivative display integration requirement were found. No other physical layout requirements for shipboard display of AIS information were identified. Thus, USCG should develop physical layout requirements, including display integration requirements, for all classes of AIS.

Display Integration Requirements

The Class A AIS integration requirements stipulate that AIS displays should be integrated with one of the existing graphical displays on the bridge or presented on a dedicated graphical display. Ideally, AIS would be displayed on the ship's radar, ECDIS, or a dedicated display. Per existing integration requirements, Class A AIS display integration options may include connections to external GNSS/DGNSS equipment and sources of navigational information from ship's equipment. The shipboard AIS is required to be connected to a power source, an antenna, and a variety of shipboard equipment, or to the integrated navigation system.

Class A derivative AIS units are described in the IALA AIS guidelines as a pilot workstation combined with portable AIS that is used primarily to provide marine pilots with the capability to carry on board an AIS station when they are piloting vessels not fitted with an AIS. Such a pilot pack contains GNSS/DGNSS, AIS (optional), heading sensor, and a workstation. Class A derivatives were considered to be portable AIS units carried aboard a vessel for the purpose of meeting the vessel's AIS carriage requirements, while PPUs brought aboard vessels for a pilot's personal use, not to satisfy an AIS carriage requirement, were not considered to be covered by requirements for Class A derivatives.

There is a proliferation of stand-alone electronic navigation equipment aboard the bridges of modern vessels. Under such conditions, operators must integrate information from different sources, scales, and sensors, and they must make decisions on the basis of that information in time-critical situations. Equipment randomly placed in available space on the bridge can increase mariners' difficulty in accessing needed information and can add to operator distraction. International committees are currently exploring standards and guidelines for integrated bridge systems. These trends highlight the need to identify and consider mariners' information needs in different operational settings when display integration requirements are developed. Such requirements are needed; USCG should develop them.

Environmental Requirements

Environmental requirements include requirements for robustness of AIS display packaging with respect to environmental conditions. Requirements for displays to pass packaging, emission, vibration, humidity, temperature, ruggedability (i.e., robustness), pollution, and contamination tests are included. No such requirements exist; thus, USCG should develop them for all classes of shipboard display of AIS information.

SUMMARY

Table 4-1 summarizes the inventory of existing requirements for shipboard display of AIS information by class of AIS. The table indicates that some information and display format requirements have been developed for Class A AIS, but much work remains to be done. The committee did not independently develop requirements for shipboard display of AIS information. Instead, it surveyed existing requirements, standards, and guidelines to determine whether they are adequate to cover all aspects of design and meet the needs of a display user. Although international standards bodies and manufacturers, among others, have been developing AIS displays and requirements for them, most need to be supplemented, revised, or reconsidered. In addition, new requirements for shipboard display of AIS information are needed for different vessel classes and operating environments.

In the analysis, CASE tools that are useful in display design and development were identified. CASE tools provide an electronic repository for system requirements, as well as for logical and physical design models. The use of CASE tools can significantly reduce requirements, data, and model redundancy; permit requirements and model analysis across different vessel types, hardware, and software platforms; improve the economy of system models and requirements determination; and encourage component and system reuse. USCG could also use CASE and other electronic requirements and modeling tools in its requirements and standards specification activities.

Some of the information to be transmitted by AIS may be available in other existing navigational equipment aboard the bridges of ships. Thus, determining the information requirements for AIS displays is an important first step in developing effective displays. This indicates that USCG can also consider the overlap in available information among existing and future navigational equipment and develop appropriate integration or information assignment strategies in its standards-setting process.

The MKD requirements, by definition, contain a limited amount of information. However, the committee believes that the size and limited nature of the text-only display, coupled with the operator manipulation and information transposition required (e.g., the requirement for operators to transpose text information from the MKD into spatial information for decision making), render the MKD inadequate to meet the needs of mariners in different operational settings. These limitations, and others, suggest that USCG should determine such needs and revise or reevaluate the minimum display requirements accordingly.

There is also a need to develop visual presentation requirements for all classes of shipboard AIS displays. For example, although requirements exist for the transmission of waypoint data from shore stations to ships, there are no requirements for how that information is to be presented visually. In the same manner, there is a need to develop display option requirements for shipboard displays.

International bodies have been working on the development of additional AIS display symbology. In addition, much work in chart and map symbology has been done in other domains. However, symbology requirements for shipboard display of Class A, Class B, and Class A derivative AIS information are not now completed, and much more work is needed. USCG could participate in international discussions on developing standards for AIS symbology. It could also integrate standards as guides to developing symbology requirements. Symbology requirements should conform to international and other standards. USCG could leverage earlier work in symbology development and follow international procedures in developing symbology requirements.

Existing requirements for alarms and alerts for shipboard display of AIS information focus on the visual and auditory senses only. A body of work outside the marine field has investigated and applied alternative human interface modes (e.g., by utilizing senses other than, or in addition to, the visual and auditory senses). USCG could consider alternative modes for alarms and consider alarm design in the context of existing alarms and ambient noise on the bridges of ships in different operational settings.

Another important topic is display integration requirements. Stand-alone units of electronic navigation equipment are proliferating aboard the bridges of modern vessels. Under such circumstances, operators must integrate information from different sources, scales, and sensors, and they must make decisions on the basis of that information in time-critical situations. Equipment randomly placed in available space on the bridge can increase the difficulty in accessing needed information and can add to operator distraction. International committees are currently exploring standards and guidelines for integrated bridge systems. These trends highlight the need to identify and consider mariners' information needs in different operational settings when integration requirements for shipboard display of AIS information are developed.

There is a need to define requirements for safety-related messages more carefully to avoid overload of AIS with messages that might better be sent through other media. USCG should consider the appropriateness of different modes and media for transmission of such information. USCG's standards-setting process should consider the importance of local information in safety-related messages in a particular port or waterway. Short safety-related messages have the potential to distract operators from their primary duties, and therefore USCG should consider appropriate message traffic types, levels, loading, and communication requirements.

Information may be categorized differently in different operational settings. For instance, in inland waters, "static" information such as vessel length, beam, or cargo may change by port call. Thus, assumptions about the nature and type of static, dynamic, and voyage-related information may be different in different operational settings. Some of the information to be transmitted by AIS may be available in other existing navigational equipment aboard the bridges of ships. Thus, determining the information requirements for AIS displays is an important first step in developing effective displays.

Given these factors, USCG activities for the determination of requirements for AIS information should consider the overlap in available information among existing and future navigational equipment and appropriate integration or information assignment strategies.

No current or future technical display requirements were found for any class of AIS. AIS technical display requirements also include requirements to accommodate future interfaces, displays, and technology. AIS technical display requirements are needed for all classes of AIS and for different operational settings. Thus, USCG should develop technical display requirements as part of its standards-setting process. USCG should investigate future display requirements as part of its research program. USCG standards-setting and requirements processes should be flexible in order to accommodate and adjust to future capabilities, displays, controls, and technology.

Finally, no display format, physical layout, or environmental display requirements for shipboard display of AIS information for any type of vessel or class of AIS exist. Therefore, such requirements are needed.

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Abbreviations

ANSI	American National Standards Institute
IALA	International Association of Aids to Navigation and Lighthouse Authorities
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ISO	International Standards Organization
MIT	Massachusetts Institute of Technology

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5 Human Factors Considerations for Automatic Identification System Interface Design

From the perspective of the human operator of automatic identification systems (AIS), the "interface" is defined as the display and control mechanisms that enable the exchange of information between the person and the AIS. The interface includes not only the display of information, such as cathode ray tube graphics and auditory warnings, but also data entry and control elements, such as a keyboard or switches.

Developing an effective AIS interface requires a systematic process that considers the capabilities of the users and the demands of the operational environment. Although several researchers have investigated mariner collision avoidance and navigation strategies and information needs, no one has systematically evaluated how AIS can support these and other information needs (Hutchins 1990; Laxar and Olsen 1978; Lee and Sanquist 1993; Lee and Sanquist 2000; Schuffel et al. 1989). To date, neither the design of AIS controls nor the information needs of the mariner and the method of displaying that information have been defined and evaluated sufficiently well. Thus, a focus on human factors considerations for AIS interfaces is needed.

Once a system has been designed, manufactured, and put in service, it must be maintained. The goal of human factors in maintenance, as in design, is to enhance safe, effective, and efficient human performance in the system. In recent years it has become apparent that human factors methodology has as much to contribute to maintenance as it does to design. In the aviation and process control industries, for example, structured human factors methods (e.g., Maintenance Error Decision Aid) are being applied to maintenance with some success (Johnson and Prabhu 1996; Maurino et al. 1998; Reason and Maddox 1998). According to the National Aeronautics and Space Administration (NASA 2002), four primary activities are undertaken in maintenance human factors: (*a*) human factors task/risk analysis, (*b*) procedural improvements, (*c*) maintenance resource management skills and training, and (*d*) use of advanced displays (to clarify procedures and to make information resources more accessible without task interruption). Because of the changing nature of the workplace and required tasks, especially given the increasing use of automation in maintenance, workers in these jobs must acquire new skills for tasks that will not necessarily reduce their workloads. In addition, issues of software version control and data maintenance (e.g., updated chart information, updated cargo information) may require special procedures and training as well as more specialized personnel. As will be seen in the discussion below, many of these types of activities are relevant to AIS shipboard displays. Although maintenance issues are important and merit consideration and comprehensive evaluation before implementation of a specific AIS, these system-level (not display-specific) issues were beyond the scope of this report.

Some of the key human factors considerations important in interface design are outlined in this chapter. A description of the human factors design process is given first. How the three stages of understand–design–evaluate might be applied to the design of AIS interfaces is then discussed. A number of human factors guidelines that can assist in the design of current and future AIS interfaces are also provided.

CORE ELEMENTS OF THE HUMAN FACTORS DESIGN PROCESS

Human factors design activities are an integral element of the overall systems analysis and design process described in Chapter 4. The focus of human factors design is on the interaction between the design and the human. Thus, human factors design processes can be simplified into three major phases: *understand* the user and the demands of the operational environment, *design* a system on the basis of human factors engineering principles and data, and *evaluate* the system to ensure that the system meets the needs of the user (Woods et al. 1996) (see Figure 5-1). These steps are mapped to the systems analysis and design framework outlined in Chapter 4 and shown in Figure 5-2. To begin with, a task or work analysis can be used to provide the initial data to understand the user and the demands of the operational environment (Kirwan and Ainsworth 1992; Vicente 1999). This understanding and the requirements that result are combined with human factors engineering guidelines and principles to create initial design concepts. As shown in Figure 5-1, design often begins by building on findings from the evaluation of an existing system rather than by starting with a blank slate. This is

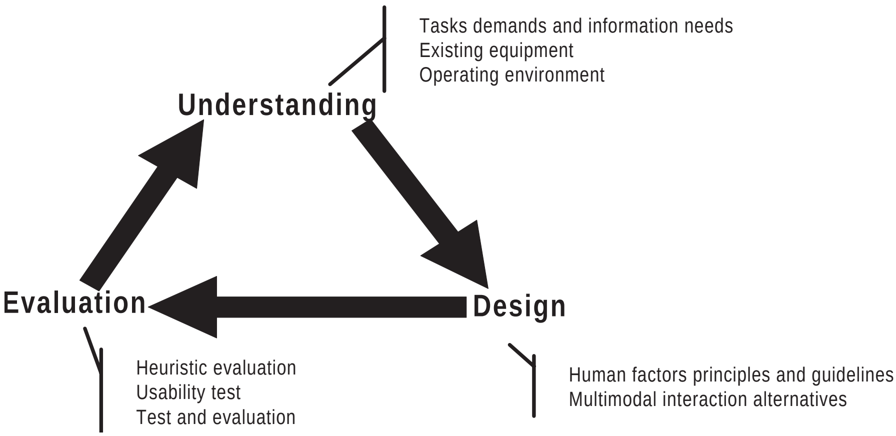

FIGURE 5-1 Iterative cycle of system development. (Adapted from Woods et al. 1996.)

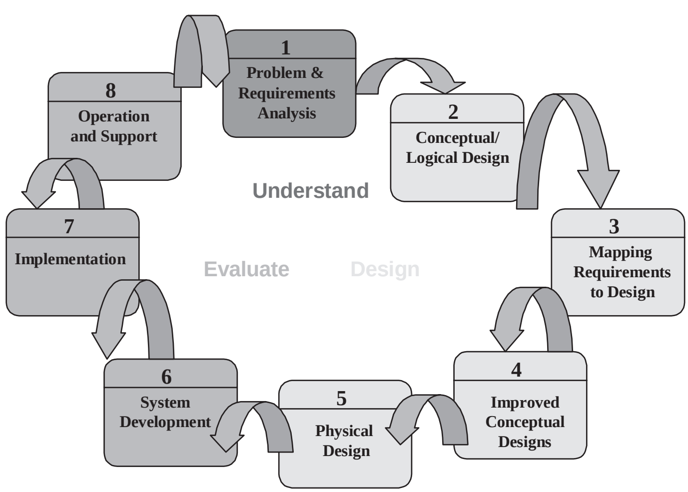

FIGURE 5-2 Systems analysis and design framework.

true also for AIS. AIS design will occur in the context of previously developed navigation, communication, and planning aids. After these initial concepts are developed, designers conduct heuristic evaluations and usability tests with low-fidelity mock-ups or prototypes (Carroll 1995). Usability evaluations in realistic operational contexts are particularly useful because they often help designers better understand the users and their needs.

AIS deployment may result in mariners using the technology in ways that were not anticipated during the initial design. For this reason, analysis of how mariners interact with prototypes is critical to a better understanding of system requirements. This enhanced understanding can then be used to refine design concepts. When the system design becomes more defined, it may be placed in an operational environment for comprehensive testing and evaluation. This final evaluation can be considered to be the final step of system development. It can also be considered as the first step in developing a better understanding of the user for the next version of the prototype or product. For this reason, it is important to consider AIS design and the associated standards and certification development as a continuous process that evolves as more is learned about how mariners use AIS and how AIS affects the maritime industry. This continuous cycle is reflected in the link between evaluation, which ends one iteration, and understanding, which begins the next iteration of the design cycle. Some of the more critical elements of each of these three phases are described in the remainder of this chapter.

The most obvious focus of the design process is the physical display and controls that make up the operator interface. However, with complex technologies such as AIS, training and documentation also represent important elements of design. Ignoring documentation (manuals, instruction cards, help systems) and training can lead to errors, poor acceptance, and ineffective use of the system.

UNDERSTANDING THE NEEDS OF THE OPERATOR

New technology can change demands on the bridge crew dramatically. If they are properly developed, technological advancements should make operators more efficient and safe. Under proper conditions, workload declines and performance improves with the introduction of new navigation technology, even when the number of crew members declines (Schuffel et al. 1989). Other studies, however, have shown significant performance declines with the introduction of new technology, particularly under medium- and high-stress conditions (Grabowski and Sanborn 2001). Studies in other domains suggest that poorly designed automation may reduce workload under routine conditions but can actually *increase* workload during stressful operations (Wiener 1989; Woods 1991). One possible explanation for these apparently contradictory findings has been suggested by Lee and Sanquist (2000), who point out that the evaluation of modern technologies often addresses only routine performance and does not consider more stressful and nonnormal conditions where new technology can actually impair performance. (A fuller discussion of automation-related issues and their potential impact on operator performance is given in the section "Human/Automation Performance Issues.")

In addition, new technology can introduce new cognitive demands, such as the need to monitor more ships during collision avoidance, to form mental models of the new technology, and to perform complex mental scaling and transformations to bridge the gap between the data presented and the information needed by the operator. Although problems abound, properly implemented technology (such as AIS) promises to enhance ship safety as it eliminates time-intensive, repetitive, and error-prone tasks. To realize the promise of new maritime technology requires a clear understanding of the needs of the operator.

Historical data concerning shipping mishaps indicate that many navigation errors result from misinterpretations or misunderstandings of the signals provided by technological aids (NTSB 1990). Moreover, Perrow (1984) notes that poor judgment in the use of radar contributes to many maritime accidents. In some situations the mariner may receive so many targets and warnings that it may be impossible to evaluate them, and that display may be ignored. In addition, production pressures could force mariners to use the devices to reduce safety margins and operate their vessels more aggressively. The demands and pressures that new technology can place on mariners can induce unanticipated errors. These findings suggest that poorly designed and improperly used technology may jeopardize ship safety. In addition, AIS may eliminate many tasks, make complex tasks appear easy at a superficial level, and lead to less emphasis on training and design. AIS may also introduce new phenomena that affect mariner decision making, such as automation bias and overreliance on a single source of information to guide collision avoidance and navigation. In this situation, if the display fails to contain the information necessary to specify operator actions, errors will result (Rasmussen 1986; Vicente and Rasmussen 1992). This is particularly problematic with AIS because it may provide information on only a subset of the vessels the operator must consider in navigating a safe course. Thus, it is clearly important to understand the cognitive tasks involved with AIS to guide design and training.

As a demonstration of this process, the committee conducted a preliminary task analysis using observations of a towing vessel representative of those that operate on the upper Mississippi River and its tributaries. This type of inland towing operation involves transiting locks and relatively long voyages. This compares with fleeting vessels, which operate in a relatively small area of the river, and vessels operating on the lower Mississippi, which may rarely encounter locks. Although towing vessels on the lower Mississippi might not encounter locks, they tend to have a much larger cargo and are likely to interact with deep-draft vessels. The towing vessel observed was also a technological leader that already uses electronic charts. Although many towing companies have adopted electronic charts, many smaller companies have not. The towing industry includes many types of vessels and operations, which may lead to different applications of AIS, particularly compared with the application of AIS for deep-draft vessels. To understand the nature of these differences, preliminary observations and a task analysis were conducted. Similar analyses should be performed for other classes of vessels as well.

A simple way to organize observations of navigation and communication activity is according to *information, functions,* and *events* (see Figure 5-3). A complementary approach would be to address the underlying constraints of the work domain on behavior (Vicente 1999). Both approaches would be useful in a comprehensive analysis of how AIS could support mariners. *Information* refers to categories of information that the pilots and captains use to guide their actions. In some cases, such as "lock ticket," the information is contained on a piece of paper, but the information could be in the form of radio communications that update this information, so "lock ticket" represents more than the physical piece of paper. For each information

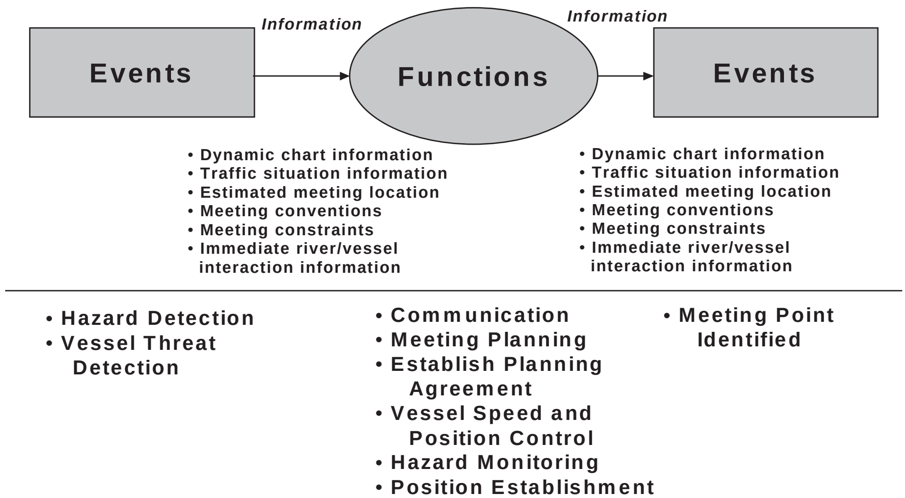

FIGURE 5-3 Towing vessel meeting example.

category, Table 5-1 shows the different activities and their descriptions, including a source for the activity, such as radio communication or visual observation. *Functions* are the information transformation processes that achieve system goals. These capture what people and technology do in the pilothouse. As shown in Figure 5-3, each function takes information as an input and generates it as an output. The functions are triggered by events and they also initiate events. *Events* are the triggers that initiate functions and the state changes that are a consequence of the information transformation and activities associated with a function. Table 5-1 shows a sample of representative information, functions, and events.

An example of the relationships between functions, events, and information can be seen in the towing vessel meeting diagram shown in Figure 5-3. In this example, a towing vessel meeting another vessel experiences at least two events—hazard detection (e.g., fixed-object hazards) and vessel threat detection. The two events result in functions being performed aboard the towing vessel: communication, meeting planning, establishment of a planning agreement, vessel speed and position control, hazard monitoring, and position establishment. Those functions result in another event—identification of a meeting point. Figure 5-3 also shows that the information being used

TABLE 5-1 Representative Information, Functions, and Events

Activity	Description
Type of Activity: Information	
Event log	Documents progress along the river, anomalies, and crew changes. This information is stored and communicated using a computer, note pad, and formal paper log.
Lock ticket	Data needed to coordinate lock passage (e.g., 600- versus 1,200-ft locks). Tow configuration, length, draft, cargo, barge numbers and types. This information is stored and communicated using paper ticket and note pad; changes are communicated by radio.
Vessel/tow configuration	Information that affects safe passage through channels, locks, and bends. This information includes draft readings, leaks and water in barges, tow length (visual inspection, notes).
Equipment calibration	Depth estimated by second vessel, physical state of depth gauge, confirmation with vessel/river interaction. This information is communicated by radio, visual observation, vessel response.
Lock waiting location	Array of vessels stopped along bank before lock. This information is communicated by radio.
Informal chart data	Addresses lack of detail in charts. Fleeting areas, location of private docks, steepness of bank, type of bank and bottom, eddies. Critical for picking an appropriate place to stop and identifying upcoming river hazards (visual confirmation, local knowledge, general river knowledge, radio communication, e-mail).
Dynamic chart information	Addresses changing features of the river. River height, sandbars, current, lock status, obstacles, and hazards. This information is stored and communicated using daily USCG updates on the radio, e-mail, and radio communication with other boats.
Traffic situation	Number, distance, and distribution of approaching boats. This information is communicated and tracked using radio and visual and radar targets.
Estimated meeting location	Point where vessels are likely to pass on the basis of estimated speed and distance. This information is communicated using radio and a chart.

TABLE 5-1 *(continued)* Representative Information, Functions, and Events

Activity	Description
Meeting conventions	Southbound has right-of-way, Ohio River convention for southbound vessel to take outside of curve. Subsequent vessels of a sequence follow the first. Opposite for lower Mississippi. This information is communicated by radio.
Meeting constraints	Space available for passage, intended track, mechanical problems of vessel. This information is stored and communicated using the charts and radio.
Immediate river/vessel interaction	Depth of water below barges, response of tow to control input. This information is based on the actual compared with the expected rate of turn, behavior of lead barges, cavitation, speed/rpm relationship, and current. This information is communicated through visual cues, haptic cues (vibration), and auditory cues.
Lock coordination	Configure tow, loading to match lock capacity. Share tow information and any changes with lock manager to establish lock type and order.
Type of Activity: Functions	
Meeting planning	Broadcast position and intention to identify relevant forward vessels (northbound responsibility). Use estimated speed, distance, and location of hazards to establish a meeting location.
Establishing passing agreement	Agreeing where and how the vessels will pass (port-to-port or starboard-to-starboard).
Fleeting area and service coordination	Plan for support services, such as maintenance personnel boarding and fleet boats.
Speed and position control	Moment-to-moment control of the vessel course through the water.
Identify waiting location	Determine availability and suitability of places where tow can be temporarily stopped against the riverbank.
Stopped at riverbank	Stopped, waiting for fog to lift or for turn through lock.
Hazard monitoring and detection	Scanning the river to identify hazards, which include other vessels, upcoming turns, sandbars, and recreational boaters.

(continued on next page)

TABLE 5-1 *(continued)* Representative Information, Functions, and Events

Activity	Description
Type of Activity: Events	
Hazard detected	Detection that a hazard is present.
Upcoming vessels detected	Realizing that other vessels are in the vicinity.
Meeting point identified	Determining location at which vessels will meet.
Passing agreement made	Agreement made between vessels as to where and manner in which they will meet.
Lock delay identified	
Change in river height	Changes in water depth.
Lock approached	
Lock passed	Have gone through the lock.

for the functions includes dynamic chart information, traffic situation information, estimated meeting locations, meeting conventions, meeting constraints, and immediate river/vessel interaction information, among other items. This simple example provides an idea of the relationships between information, functions, and events in a towing vessel meeting situation. Note that the relationship between events and functions is sequential: events trigger functions, and functions result in changes in events. Note also that information is a critical input to functions; information is needed for functions to occur.

The relationships between information, functions, and events can be modeled in a variety of ways: for instance, by using data flow diagrams (Hoffer et al. 2002), the Unified Modeling Language for object-oriented software and hardware (Kobryn 1999), data modeling (DATE 2002), transition matrices, and input/output matrices. Computer-aided software engineering tools, as described earlier, are electronic repositories for each of these different types of models that can be used for analysis, design, and development activities. Each of these models and approaches focuses on the use of information to facilitate activities in response to and in order to successfully execute or anticipate events in a domain. The patterns evidenced by different events, information, and functions in a domain provide important clues as to appropriate technology design and development strategies to assist human operators.

The variety of functions that AIS might support and the variety of information sources demonstrate the challenge of integrating AIS into the mariner's decision-making process. The variety of information, events, and functions also demonstrates the vessel- and operation-specific nature of AIS display design. While some of the elements of navigation, communication, and planning tasks remain constant across different types of vessels and operating environments, others change.

Thus, systematic analysis of the information, functions, and events that describe mariner activities is needed to derive AIS display and control requirements. The results of this analysis might include a transition matrix that identifies the potential challenges that might interfere with the functions occurring. This can also identify the interface strategies that could help AIS in supporting these transitions (e.g., separate alarms versus integration with other displays). Another result could be an input/output matrix that describes the information flow between functions and whether the information is an input or an output of each function, as well as the data entry and data flow requirements. Unneeded data entry should be avoided, and data output should be organized to avoid overwhelming the operator. An input/output matrix can help identify how AIS outputs can be integrated, combined, and formatted to support the functions with minimal data entry and cognitive transformations. An input/output analysis can also result in specific strategies for supporting efficient manipulation and use of the information and can identify potential breakdowns in information flows and functions. For instance, the initial observation of towing operations identified several considerations for AIS implementation in the inland towing industry:

- Combining a radar overlay may clutter the electronic chart and require substantial adjustments to avoid inconsistencies in electronic chart orientation. AIS information can further complicate these tasks if it is not carefully integrated.
- Geographic constraints make meeting point coordination an important task for inland towing.
- The variable speed and intention of other vessels make meeting location estimation for towing vessels difficult. Any AIS implementation should consider how to address this challenge.

- The preview of some electronic charts, as commonly used by inland operators, is only 3 miles and may make transit planning difficult. AIS displays should consider the planning horizon of the mariner.
- Current, imperfect radio communication due to intentional silence, failure to hear due to ambient noise, and being on a different channel present important opportunities for AIS to improve the mariner's knowledge of his or her domain.
- Data must be entered in the time available (e.g., picking up a radio is easier than navigating a menu system). AIS may be most effective as a supplement to radio communication rather than as a replacement.
- Many vessels have computers on the bridge, which can pose a distraction. AIS could exacerbate this risk.
- Updating vessel status and configuration data could be a substantial task and is potentially subject to high risk of error. For example, towing vessel length and beam measurements change as cargo is picked up and delivered. Some of this data entry could be eliminated if the data were linked to the locking ticket.
- Information that is static for deep-draft vessels may be dynamic for towing vessels (e.g., adding barges changes "vessel" length).

These preliminary observations do not represent a comprehensive set of considerations for AIS implementation but instead demonstrate why a task analysis can be helpful in identifying display requirements for AIS.

Integration of AIS with Other Bridge Systems

A strong tendency in technology development in the maritime industry is to create stand-alone systems that require the mariner to integrate the information from each system to make decisions. One strategy for AIS development is to treat AIS as a separate system that is independent of the automatic radar plotting aids (ARPA), electronic chart, radio, and other communication and navigation equipment. A stand-alone AIS simplifies the AIS design process but may place a substantial burden on the mariner and severely undermine the utility of the AIS. The mariner may be forced to mentally integrate the information—a process that can be effortful and subject to error. In addition, the mariner may need to resolve differences in data about the same fixture—target vessel and so forth—presented by different instruments or displays. Only people can make judgments, and the information should be configured in a way that supports judgments.

Another strategy is to integrate AIS information into the displays and controls of existing bridge equipment. The design must consider the type of judgments the mariner must make and the type of constraints under which the mariner must operate; the display needs to support these judgments and make the constraints visible. The specific integration of information and controls depends on a deep understanding of the demands and constraints of the maritime environment and the capabilities of various sensor and data sources. The development of an integrated system faces technological and display design challenges but could dramatically enhance the benefits of the AIS.

Frequently, new systems are developed without careful consideration of how they integrate with current capabilities. For example, navigation aids are installed on ships (Lee and Sanquist 2000), functions are added to flight management systems (Sarter and Woods 1995), and medical device displays are combined (Cook et al. 1990a), often without careful attention to how the information from these systems should be integrated. The general concept of functional integration has significant potential for enhancing human–system performance. Functional integration involves analysis of the information required by each function and the information produced by each function. The information inputs and outputs of the various system functions define links between functions that can either be identified and supported by designers or discovered and accommodated by operators. Operators who are forced to “finish the design” (i.e., to provide necessary links between functions) may experience increased cognitive load, frustration, and dissatisfaction with the system. Without careful consideration, AIS may be poorly integrated and may subject users to the task of finishing the design, which is laborious and prone to error.

As an example, problems can exist with personal pilot units that have the “attitude display” of own ship when only one antenna is used or there is no connection to the ship’s source of true heading (from gyro or Differential Global Positioning System). In this circumstance, own ship’s attitude transmitted to other ships will be in the direction of movement of the ship’s center of gravity, not its true compass heading. This mistaken display of heading gets worse as ship speed slows or cross-channel winds or currents affect own ship's movement so that it has to "crab" its way down the channel. While those on the bridge of the ship will probably be aware of this, mariners on bridges of other ships receiving this display of attitude will get faulty information for such a target vessel. This is particularly problematic because some ships will have gyro heading information and will broadcast the actual ship orientation, and other ships that do not have gyros will broadcast heading information that does not match their actual heading.

Graphics are frequently used to document information flows and identify how systems can be integrated. However, graphics of complex systems are often incomprehensible and at best provide only a qualitative description of the system. Typically, each function is represented by an ellipse labeled with the function name. Information flows are usually designated with arrows. These graphics provide a visual representation that can sometimes promote intuitive insight; however, as they become more complex, they grow harder to draw effectively and to comprehend. Alternatively, an information flow may be represented as a matrix in which information flows between functions are summarized as functions arrayed against functions. In each instance where information flows from one function to another, the cell in the matrix contains a "1," otherwise it contains a "0." A benefit of the matrix approach is that it easily scales to accommodate increasingly complex systems, in contrast to graphical representations, which can quickly become unmanageable. A matrix representation makes possible a range of mathematical analyses that can reveal relationships that may not be obvious in graphic representation. This representation makes it possible to apply well-established graph theory techniques developed to study engineering systems and social networks (Borgatti et al. 1992; Luce and Perry 1949; Wasserman and Faust 1994) and optimize engineering design (Kusiak 1999; Lee and Sanquist 1996). The complex set of navigation, planning, and communication tasks that AIS may support makes it important to consider systematic approaches to integrate AIS with existing bridge technology.

Translating Data into Information

New technology has the potential to overload people with data. AIS is no exception. To avoid this danger AIS design must carefully evaluate the tasks and decisions AIS is to support and then integrate, transform, and present data in a form that is most cognitively consistent with the tasks it is meant to support. If the AIS design does not address these considerations, the mariner will need to mentally integrate and transform the data. This burden may lead to errors and misunderstandings. For example, the minimum keyboard and display (MKD) forces mariners to translate numeric data concerning the latitude and longitude of surrounding vessels into a visual representation and assessment of collision hazard.

Mariners have developed successful strategies that rely heavily on representing the data in a format that makes perceptual judgments of collision potential possible (Hutchins 1990; Hutchins 1995b). For example, relative motion vectors of ships on a collision course point toward the mariner's ship.

Also, a well-designed AIS display should provide attentional guidance to mariners by, for example, highlighting changes and events (such as changes in the status or behavior of a nearby vessel), which may otherwise be missed as they appear in the context of a dynamic data-rich display. Data need to be put in context and presented in reference to related data to transform them into meaningful information. For example, simulations of possible avoidance maneuvers on the screen are useful only if they can be viewed in the context of a map depicting surrounding land masses or water depths. Finally, not all AIS information may be required at all times. Depending on task and task context, the information that is presented may change automatically, or, in a more human-centered design, mariners should be enabled to tailor the information content and display to their changing needs (Guerlain and Bullemer 1996).

Operational Differences and Implications for AIS Interface Design

AIS may be used in a range of operational environments and vessel types. The ideal AIS interface for an oceangoing tanker may be quite different from an interface for a towing vessel on an inland waterway. The operational differences have implications for the way in which AIS may be integrated with other bridge systems and how data are combined into useful information. For example, AIS for a towing vessel on inland waterways that have numerous locks should consider the information that needs to be transferred and the vessel coordination associated with locks. AIS for these vessels must also consider the demands of coordinating passing situations in narrow channels. To maximize the utility of AIS, the human interface must be designed for the particular demands of each operational environment. A useful AIS interface for oceangoing vessels may not be the same as a useful interface for inland towing vessels.

HUMAN/AUTOMATION PERFORMANCE ISSUES

Automation such as AIS has tremendous potential to extend human performance and improve safety. However, recent disasters indicate that it is not uniformly beneficial. In one case, pilots failed to intervene and take manual control even as the autopilot crashed the Airbus A320 they were flying (Sparaco 1995). In another instance, an automated navigation system malfunctioned and the crew failed to intervene, allowing the *Royal Majesty* cruise ship to drift off course for 24 hours before it ran aground (Lee and Sanquist 2000; NTSB 1997). On the other hand, people are not always willing to rely on automation when appropriate. Operators rejected automated controllers in paper mills, which undermined the potential benefits of automation (Zuboff 1988). As information technology becomes more prevalent, poor partnerships between people and automation will become increasingly costly and catastrophic (Lee and See in press). For this reason it is important to consider the problems with automation that might also plague AIS if it is not implemented with proper concern for supporting the mariner.

Such flawed partnerships between automation and people can be described in terms of misuse and disuse (Parasuraman and Riley 1997). Misuse refers to the failures that occur when people inadvertently violate critical assumptions and rely on automation inappropriately, whereas disuse signifies failures that occur when people reject the capabilities of automation. Misuse and disuse are two examples of inappropriate reliance on automation that can compromise safety and profitability. Understanding how to mitigate disuse and misuse of automation is a critically important problem for AIS development. When it is first introduced, AIS is likely to suffer from disuse because mariners may be hesitant to trust it. After several years mariners may come to depend on AIS and AIS may suffer from misuse as mariners trust it too much and become complacent about potential failures.

Several more specific problems that underlie the general problems of misuse and disuse have been identified (Bainbridge 1983; Lee and Sanquist 1994; Norman 1990; Sarter and Woods 1994; Wickens et al. 1997; Wiener and Curry 1980). The following are specific problems with automation that seem relevant to AIS development and implementation:

- Trust calibration,
- Configuration errors,
- Workload,
- Skill loss and training, and
- Disrupted human interactions.

In the following sections each of these issues will be described briefly, its connection to AIS identified, and considerations for interface design and training identified.

Trust Calibration

Trust has emerged as a particularly important factor in understanding how people manage automation (Lee and Moray 1992; Lee and Moray 1994). Just as trust guides delegation and monitoring of human subordinates, trust also guides delegation and monitoring of tasks performed by an automated system (Sheridan 1975). Trust has been defined as the attitude that will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability (Lee and See in press).

Trust in automation is not always well calibrated: sometimes it is too low (distrust), sometimes too high (overtrust) (Lee and See in press; Parasuraman and Riley 1997). Distrust is a type of mistrust: the person fails to trust the automation as much as is appropriate. For example, in some circumstances people prefer manual control to automatic control, even when both are performing equally well (Liu et al. 1993). A similar effect is seen with automation such as AIS that enhances perception. People are biased to rely more on themselves than on automation (Dzindolet et al. 2002). The consequence of distrust is not necessarily severe, but it may lead to inefficiency. In the case of AIS, distrust may lead mariners to ignore the AIS and therefore fail to benefit from the technology.

In contrast to distrust, overtrust of automation, also referred to as complacency, occurs when people trust the automation more than is appropriate. It can have severe negative consequences if the automation is imperfect (Molloy and Parasuraman 1996; Parasuraman et al. 1993). When people perceive a device to be perfectly reliable, there is a natural tendency to cease monitoring it (Bainbridge 1983; Moray 2003). As AIS becomes commonplace and mariners see it work flawlessly for long periods, they may develop a degree of complacency and fail to monitor it carefully.

Configuration Errors

Another problem with automation, and one that is likely to plague AIS use, is configuration errors. Configuration errors occur when data are entered or modes are selected that cause the system to behave inappropriately. The mariner may incorrectly "set up" the automation. As an example, nurses sometimes make errors when they program systems that allow patients to administer periodic doses of painkillers intravenously. If the nurses enter the wrong drug concentration, the system will faithfully do what it was told to do and give the patient an overdose (Lin et al. 2001). With AIS a similar problem could occur if the mariner entered the wrong length for the vessel. The AIS might then indicate a meeting point as being safe even though it is not. To combat this problem, data entry should be minimized, and the entered data should be displayed graphically so that typographical errors are easy to identify.

Workload

Automation is often introduced with the goal of reducing operator workload. However, automation sometimes has the effect of reducing workload during already low-workload periods and increasing it during high-workload periods. In this way, clumsy automation can make easy tasks easier and hard tasks harder. For example, a flight management system tends to make the low-workload phases of flight (such as straight and level flight or a routine climb) easier, but it tends to make high-workload phases (such as maneuvers in preparation for landing) more difficult; pilots have to share their time between landing procedures, communication, and programming the flight management system (Cook et al. 1990b; Woods et al. 1991). AIS may be prone to the same problems of clumsy automation, particularly if there is a high level of text messages during the already high-workload periods associated with transiting restricted waters or coming into a port. Clumsy automation can be avoided by minimizing data entry and configuration requirements and reducing the number of adjustments the mariner might need to make in high-workload periods.

Skill Loss and Training

Errors can occur when people lack the training to understand the automation. As increasingly sophisticated automation eliminates many physical tasks, complex tasks may appear to become easy, leading to less emphasis on training. The misunderstanding of new radar and collision avoidance systems has contributed to accidents (NTSB 1990). One contribution to these accidents is training and certification that fail to reflect the demands of the automation. An analysis of the examination used by the U.S. Coast Guard (USCG) to certify radar operators indicated that 75 percent of the items assess skills that have been automated and are not required by the new technology (Lee and Sanquist 2000). Paradoxically, the new technology makes it possible to monitor a greater number of ships, which enhances the need for interpretive skills such as understanding the rules of the road and the automation. These are the very skills that are underrepresented on the test. Furthermore, the knowledge and skills may degrade because they are used only in rare, but critical, instances (Lee and Sanquist 2000). Training programs and certification that consider the initial and long-term requirements of AIS can help combat potential problems of skill loss and the additional demands that AIS may put on mariners.

Disrupted Human Interactions

Crew interactions and teamwork are critical for effective navigation. In the aviation domain many problems have been traced to poor interactions between crew members (Helmreich and Foushee 1993). There are many circumstances in which subtle communications, achieved by actions or voice inflection, convey valuable information. Sometimes automation may eliminate these information channels. A digital datalink system is being developed that shares several similarities to the AIS. Datalink is proposed to replace air-to-ground radio communications with digital messages that are typed in and appear on a display panel that will eliminate informal information that is currently conveyed by voice inflection (Kerns 1991). Controllers may no longer be able to detect stress and confusion in a pilot's voice, nor will pilots be able to hear the sense of urgency in the tone of a controller's voice commanding immediate compliance (Wickens et al. 1997). In addition, the physical interaction between the crew members and the equipment can enhance communication and error recovery. In maritime navigation the way the position is plotted can indicate its accuracy (Hutchins 1995a); this indication may be lost with AIS, where every target is plotted with apparently the same accuracy. The physical movements of team members, such as reaching for a switch, can communicate intentions. Automation can eliminate such communication by channeling multiple functions and activities through a single panel (Segal 1994). To counteract these potential problems, it might be useful for AIS design to consider the joint information of the interacting crew in addition to the needs of each individual crew member.

SKILL REQUIREMENTS

The successful introduction of AIS depends on understanding the capabilities and training requirements. While AIS has certain unique features and operating functions, it is one of many tools intended to assist the mariner in accomplishing a myriad of ship operational tasks. As such, it should be treated as part of the total bridge navigational system in deciding how best to provide operator training. Operator training is a complex subject in itself, and the committee has not fully investigated it, but its importance is clear.

Most of the deep water mariners who will be using AIS will not be subject to U.S. flag jurisdiction. Thus, their capabilities and training will be overseen by international agreements or the national regulations of the flag of the vessel. In contrast, as previously noted, the majority of the U.S. inland mariners who will be expected to use AIS are those who are employed aboard U.S.-flag commercial towing vessels, coastal traffic and tug/barges, passenger vessels, ferryboats, and offshore supply vessels, which are subject to USCG regulations. The capabilities and training needs among all of these mariners are as varied as the vessels they operate. However, because they share the same waterway, there are certain basic training principles concerning the use of AIS that may be common and may be important to consider.

For example, a number of chart display units are in active use on U.S. ports and waterways, and the experience of the mariners who use these systems is a reasonable gauge of the level of training needed to operate AIS units. Electronic chart systems are in general use on a number of vessel types. AIS-like units have been in use in New Orleans, Tampa, and San Francisco; AIS are being used on the St. Lawrence Seaway as well.

Because commercial towing vessels and other inland waterway vessels are equipped with modern radar, VHF/FM radios, magnetic compasses, and rate-of-turn indicators, current operators must receive adequate training with these systems. Many are also fitted with one or more of the following: GPS, chart plotters, or electronic charting systems (ECS). Interestingly, as more mariners use this equipment in day-to-day operations, it may be that the addition of AIS will not present too large a burden of additional training so long as the display is appropriate and the operator has adequate skills with existing systems. The particular training requirements will depend on the functionality of the AIS display.

Under present USCG regulations, masters and mates of towing vessels over 26 feet are required to attend radar training as a condition of licensing. Refresher training is required on a 5-year cycle. Because of this requirement, the addition of AIS training might be considered as an adjunct to the radar endorsement. In the past, certification examinations have not always changed to reflect the introduction of new technology (Lee and Sanquist 2000). It would be useful to review all vessel operator training and certification requirements to see how the introduction of AIS might be used to modify present standards rather than introduce new ones.

There will undoubtedly be a phase-in period to facilitate AIS carriage requirements; this period could also be useful to phase in any new requirements for training. Any AIS-specific training could be synchronized with the mariner's normal radar training cycle. For example, mariners could satisfy AIS training requirements concurrently with the first renewal of a radar certificate, following the implementation of the carriage requirements. This approach would allow mariners to better meet carriage requirement deadlines and ease the burden on examination centers. While the committee believes that training will always be an important factor in the successful introduction of AIS displays, it also believes that a training program will be most useful when it is integrated with a regular, comprehensive operator training program.

DESIGNING THE AIS INTERFACE USING HUMAN FACTORS PRINCIPLES

While it will be important ultimately to tailor the AIS interface design to its intended uses, users, and context, certain general principles should be applied to its design and evaluation. For example, Smith and Mosier (1986) offer 944 such guidelines, Brown (1988) discusses 302 guidelines, and Mayhew (1992) includes 288 guidelines. Probably the most widely recognized usability heuristics are those based on a factor analysis of 249 usability problems by Nielsen and Levy (1994), which resulted in a concise list of 10 heuristics. This large body of guidelines can help direct AIS interface design, but some are more critical for AIS design than others. In the following sections human factors design principles that appear to be particularly critical for AIS design are identified, and recent trends in information representation that may complement the traditional reliance on visual displays are discussed.

Human Factors Considerations for AIS Interface Design

The following paragraphs briefly discuss some of the best-known and widely accepted heuristics and design principles (from Nielsen and Levy 1994; Shneiderman 1998; Wickens et al. 1997) that should, at a minimum, be applied to the evaluation of proposed AIS shipboard interfaces. The shipboard environment presents several critical considerations that differentiate it from typical desktop and control room situations in which the following human factors guidelines are typically applied. Shipboard displays must consider illumination so that they can be operated in both day and night, and their displays must be visible but not excessively bright at night. Shipboard interfaces should also be designed so that they are operable in heavy seas, wet conditions, and high-vibration situations. The physical layout of the bridge should also influence shipboard design. The shipboard operator is not likely to be monitoring displays constantly, and the placement of shipboard displays relative to other navigation and communication aids may influence their utility. Beyond these general considerations, the following 13 specific interface principles should be taken into account in AIS design:

- *Ensure visibility of system status and behavior:* The system should always keep the user informed about its status and activities through timely and effective feedback. This heuristic is essential to a user-centered design paradigm and vital for effective coordination and cooperation in a joint human–machine system. Yet, it is one of the most frequently violated principles. Many current interfaces focus on the presentation of status information but fail to highlight changes and events. They are often characterized by data availability rather than system observability, under which the machine plays an active role in supporting attention allocation and information integration. In the context of AIS, for example, it has been proposed that in the event of system overload, some targets will drop out. It will be important to provide clear indications of such changes in display mode.

- *Create a match between the system and the real world:* The system should speak the user's language. It should follow conventions in the particular domain and use words, phrases, and concepts that are familiar to the mariner rather than system- or engineering-oriented terms. This will reduce training time because it avoids the need for mariners to adapt to the system, and it will help avoid errors (e.g., formatting errors in data entry) and misunderstandings between the system and the mariner. This also means that menu options and error messages should use terms that are meaningful to the mariner rather than terms that are familiar to the software developers. This requires a high degree of familiarity with the tasks and existing navigation tools of the mariner. The developers should identify and use the measurement units of the mariner.
- *Support user control and freedom:* Users sometimes choose system functions by mistake. In those cases, they need a clearly marked "emergency exit" to leave the unwanted state without having to go through a lengthy dialogue. For example, the system should support the easy reversal of actions through "undo" and "redo" functions. This will be especially important in the context of high-tempo operations. However, in general, it will be important to adhere to this design principle to ensure that the mariner's attentional focus is not on operating the system rather than performing the task at hand. In other words, attention should be focused on vessel navigation, not on how to use or interact with the device being used to send or receive information. Such inappropriate attentional fixations have been observed in other domains, where they have contributed to incidents and accidents. The need to support user control and freedom also concerns the changing conditions the mariner faces and the need to allow the mariner to adjust the features of the AIS to accommodate these conditions. One simple example is the need to adjust the display to reflect the changes in lighting from day to night.
- *Ensure consistency:* This principle calls for the use of identical terminology for menus and help screens and for the consistent use of colors and display layout. Users should not have to wonder whether different words, situations, or actions mean the same thing, and where they can find information or controls. Instead, designers should attempt to capitalize on user

expectations that are derived from learned patterns. Compliance with this heuristic requires not only consideration of each individual display but also of the environment in which it will be used. Users learn certain color-coding schemes or symbols, and it is likely that they will transfer their interpretation of information from known to new displays. As mentioned in Chapter 4, one problem with proposed AIS designs that has been identified already is that symbology requirements have not yet been fully harmonized across different electronic navigation platforms. Using accepted approaches to symbol development could make AIS symbols more visible and interpretable (ISO 1984).

- *Support error prevention, detection, and recovery:* For many years, the focus in design has been on error prevention through training and design. More recently, it has been acknowledged that, despite the best intentions, errors will continue to occur and that it is critical to support operators in detecting when an error has been made, why the error occurred, and how it can be corrected. Systems can support these three stages of error management by various means, such as (*a*) expressing error messages in plain language (no codes); (*b*) clearly indicating the nature of, and reasons for, the problem; and (*c*) suggesting promising solutions to the problem.
- *Require recognition rather than recall:* The designer should place explicit visible reminders or statements of rules and actions in the environment so that they are available at the appropriate time and place. This principle helps reduce the need for memorization and is essentially a rephrasing of Norman's (1988) call for "putting knowledge in the world rather than the head" of the user. One example where this principle applies in the context of AIS is the need for officers to enter manually information related to the navigational status of the ship. In the absence of external reminders, this requirement can easily be forgotten by the officer who faces a wide range of competing attentional demands.
- *Support flexibility and efficiency of use:* Flexibility and efficiency of use can be supported by enabling experienced users to employ shortcuts or accelerators (that may be invisible to the novice user), such as hidden commands, special keys, or abbreviations. While this principle suggests that the user should be allowed to tailor the interface for frequent actions, it is important to note that this principle does not apply in all contexts. Support for tailoring can create difficulties in collaborative environments (i.e., environments where several operators use the same piece of equipment, such as on a ship's bridge), where it can lead to misunderstandings

and confusion and should be used sparingly. Thus, an analysis of the appropriate level (or levels) of AIS display flexibility and efficiency may be warranted.

- *Avoid serial access to highly related data:* In many cases, operators need to access and integrate related data to form an overall assessment of a problem or situation. It is desirable to avoid requiring that these data be accessed in a serial fashion because this imposes considerable memory demands on the part of the operator. This principle calls for the integration of AIS information with existing related information on the bridge [such as the electronic charting and display information systems (ECDIS) display].

- *Apply the proximity compatibility principle:* If two or more sources of information must be mentally integrated to complete a task, they should be presented in close display proximity. In contrast, if one piece of information should be the subject of focused attention, it should be clearly separated from other sources of information. Proximity can be created by spatial proximity or through configuring data in a certain pattern or by using similar colors for these elements. This principle is related to the heuristic of minimizing information access costs. Frequently accessed sources of information should be positioned in locations where the cost of traveling between them is minimal. In other words, the user should not be required to navigate through lengthy menus to find information.

- *Avoid new interface management tasks at high-tempo, high-criticality times:* A common problem with many automated systems is that they require operators to enter or access data at times when they are already very busy. This has been referred to as "clumsy automation"—automation that helps the least or gets in the way when support is needed the most. In the context of AIS, for example, it can be problematic to expect the officer of the watch to update information on the navigational status of the vessel when the change in status also requires the execution of other actions more directly related to safety.

- *Support predictive aiding:* Many tasks require the anticipation of future states and events. A predictive display can aid the user in making predictions and reduces the cognitive load associated with performing this task in an unaided fashion. Humans have difficulty combining complex relationships of dynamic systems to predict future events, particularly when there are delays in feedback (Brehmer and Allard 1991). For this reason, AIS should support mariners in simulating and thus evaluating possible evasive maneuvers by visualizing them as part of a graphic AIS display or as part of an integrated AIS-ARPA/ECS/ECDIS/radar interface.

- *Create representations consistent with the decision to be supported:* Operator decision making often depends on the visual representation of information. In particular, graphical integration of data makes it possible for people to see complex relationships that might otherwise be overlooked (Vicente 1992). Relative and absolute motion vectors illustrate the power of representation. Relative motion vectors make potential collisions obvious, whereas absolute vectors show the same information but make collisions more difficult to detect. Understanding the format of the information presented by a given display and how that information must be considered is essential for it to be useful in decision making. Text display of position and motion vector data would make collision detection extremely difficult. Some graphical representations, such as misaligned maps, however, can also be misleading and induce errors (Rossano and Warren 1989). Graphical displays that show position information with precision that exceeds the resolution of the underlying data can easily be misinterpreted. Thus, the resolution of the display should match the precision of the underlying data. The MKD demonstrates a mismatch between display representation and the decision to be supported. Anecdotal information from active mariners who have used MKDs suggests that using the MKD digital readouts of latitude and longitude to make hazard assessments and collision avoidance decisions is much more difficult than using an appropriate graphic display of these data.
- *Consider the principle of multiple resources:* The proposed introduction of new systems and interfaces to highly complex and dynamic environments, such as the modern ship bridge, has raised concerns about possible data overload. One promising approach to facilitate the processing of large amounts of data is to distribute information across multiple modalities (such as vision, hearing, and touch) rather than rely increasingly and almost exclusively on presentation of visual information. This principle is discussed in more detail in the following section.

Multimodal Shipboard AIS Displays

The introduction of computerized systems to a variety of domains has increased the potential for collecting, transmitting, and transforming large amounts of data. However, the ability of human operators to digest and interpret those data has not kept pace. Practitioners are bombarded with data, but they are not supported effectively in accessing, integrating, and interpreting those data. The result is data overload. One of the main reasons for observed problems with data overload is the increasing, almost exclusive, reliance on visual information presentation in interface design. The same tendency can be observed in the development of proposed AIS displays. Presenting information exclusively on a dedicated visual display or integrated with existing visual interfaces may create difficulties for the mariner, whose current tasks already impose considerable visual attentional demands.

Multimodal information presentation—the presentation of information via various sensory channels such as vision, hearing, and touch—is one means of avoiding resource competition and the resulting performance breakdowns. The distribution of information across sensory channels is a means of enhancing the bandwidth of information transfer (Sklar and Sarter 1999). It takes into consideration the benefits and limitations of the various modalities. For example, visual representation seems most appropriate for conveying large amounts of complex detailed information, especially in the spatial domain. A related advantage of visual displays is their potential for permanent presentation, which affords delayed and prolonged attending. Sound, in contrast, is transient and omnidirectional, thus allowing information to be picked up without requiring a certain user location or orientation. Since people cannot “close their ears,” auditory presentation is well suited for time-dependent information and for alerting functions, especially since urgency mappings and prioritization are relatively easy to incorporate in this channel (Hellier et al. 1993).

Auditory alerts and warnings are the most commonly developed auditory display, but recent research suggests that sound can be used in other ways. Sonification contrasts with traditional auditory warnings in that it can convey a rich array of continuous dynamic information. Examples include the static of a Geiger counter, the beep of a pulse oxymetry meter, or the click of a rate-of-turn indicator. Several recent applications of sonification demonstrate its potential. It has reduced error recovery times when tied to standard user interface elements (Brewster 1998; Brewster and Crease 1999). Sonification has also aided in understanding how derivation, transformation, and interpolation affect the uncertainty of data in visualization (Pang et al. 1997). More generally, sonification has shown great potential in domains as diverse as remote collaboration, engineering analyses, scientific data interpretation, and aircraft cockpits (Barrass and Kramer 1999). These applications show that sonification can convey subtle changes in complex time-varying data that are needed to promote better coordination between people and automation. Because sound does not require the focused attention of a visual display, it may enable operators to monitor complex situations. Just as with visual displays, combining sounds generates a gestalt from the interaction of the components (Brewster 1997). The findings support a theoretical argument that sonification can be a useful complement in visual displays.

Another sensory channel that is still underutilized is the haptic sense. The sense of touch shares a number of properties with the auditory channel. Most important, cues presented via these two modalities are transient in nature and difficult to miss, and thus are well suited for alerting purposes. The advantage of tactile cues over auditory feedback is their lower level of intrusiveness, which helps avoid unnecessary distractions. Also, like vision and hearing, touch allows for the concurrent presentation and extraction of several dimensions, such as frequency and amplitude in the case of vibrotactile cues. The distribution of information across sensory channels is not only a means of enhancing the bandwidth of information transfer; it can support the following additional functions:

- Redundancy, where several modalities are used for processing the same information. Given the independence of error sources in different modalities, redundancy in human–computer interaction can support error detection and reduce the need for confirmation of one's intention, especially in the context of safety-critical actions. For example, the AIS could have a redundant auditory alert for important warnings that are displayed on the screen.
- Complementarity, where several modalities are used for processing different chunks of information that need to be merged. It has been suggested that such a complementary or synergistic use of modalities is in line with users' natural organization of multimodal interaction.
- Substitution, where one modality that has become temporarily or permanently unavailable is replaced by some other channel. This may become necessary in case of technical failures or changes in the environment (e.g., high ambient noise level). For example, the AIS could read text

messages to the mariner, making it possible for the mariner to keep watching the surrounding vessels rather than reading messages on the display.

In summary, the design of a multimodal AIS interface may be a means of avoiding problems related to data overload. It may allow a reduction in competition among attentional resources and thus support effective attention allocation. For example, a graphic representation of the traffic situation can be combined with speech output or other AIS-specific auditory and tactile alerts that capture the officer's attention in potential traffic conflicts or other critical events that may be missed because visual or auditory attention is focused on other tasks. In addition to creating multisensory system output, it will be desirable to consider different modalities for providing input to AIS. For example, in some circumstances, the use of a keyboard for AIS data entry may not be possible or desirable. In those cases, voice input or a touch screen could serve as alternatives.

Thus, the benefits and limitations of the combined use of input and output modalities should be explored, as well as the need for the adaptive use of modalities. An adaptive approach to the design of multimodal interfaces may be appropriate for various reasons. Factors that vary over time and that may require a shift in modality usage include the abilities and preferences of individual mariners, environmental conditions, task requirements and combinations, and degraded operations that may render the use of certain channels obsolete. For example, the responsiveness to different modalities appears to shift from the visual to the auditory channel if subjects are in a state of aversive arousal (Johnson and Shapiro 1989). Also, modality expectations and the modality shifting effect play a role.

The feasibility of multimodal interfaces also needs to be carefully evaluated. If a person expects information to be presented via a certain channel, on the basis of either agreements or frequency of use, then the response to the signal will be slower if it appears in an unexpected channel. If people have just responded to a cue in one modality, they tend to be slower to respond to a subsequent cue in a different modality (Spence and Driver 1997). Environmental conditions also affect the feasibility or effectiveness of using a certain modality. For example, high levels of ambient noise may make it impossible for the mariner to use the auditory channel and thus require a switch to a different modality that would otherwise be less desirable.

Human factors design principles and promising multimodal display alternatives may help define useful AIS displays and control designs; however, no research has addressed specific design parameters for AIS. Likewise, multimodal display alternatives seem promising, but research is needed to verify their effectiveness in conveying AIS information.

EVALUATION

Heuristic Evaluation of AIS Interface

Heuristic evaluation, first proposed by Nielsen and Molich (1990), is a low-cost usability testing method for the initial evaluation of human–machine interfaces. The goal of heuristic evaluation is to identify problems in the early stages of design of a system or interface so that they can be attended to as part of an iterative design process. Heuristic evaluation involves having a small set of evaluators examine the interface and judge its compliance with recognized usability principles (the "heuristics"). Each evaluator first inspects the interface independently. Once all evaluations have been completed, the evaluators communicate and aggregate their findings. Heuristic evaluation does not provide a systematic way to generate fixes to the observed problems. However, because heuristic evaluation aims at explaining each observed usability problem with reference to established usability principles, many usability problems have fairly obvious fixes as soon as they have been identified.

Interestingly, a typical human–computer interface expert will identify about a third of the problems with a particular interface using this technique. Another expert, working independently, will tend to discover a *different* set of problems. For this reason, it is important that two to four experts evaluate the system independently. Heuristic evaluation tends to catch common interface design errors but may neglect more severe problems associated with system functionality. For this reason, usability tests are needed to evaluate whether the system is actually useful.

Heuristic evaluation relies on design principles that tend to be formulated in a context-independent manner. Thus, while it is important to ensure that a new system interface meets those general guidelines and common practices for human–computer interaction, some problems cannot be uncovered without examining device use in context (Woods et al. 1994). As suggested by

Norman (1991, 1): "Clumsiness is not really in the technology; clumsiness arises in how the technology is used relative to the context of demands and resources and agents and other tools." Thus, it is critical to understand that heuristic evaluation is a necessary but not a sufficient first step in the evaluation of any new system.

Usability Tests and Controlled Experiments

Although heuristic evaluations can identify many human interface design problems, testing and experimentation are required to understand how people actually use the system. This is particularly true with AIS because it has the potential to substantially change the operators' tasks in ways that cannot be predicted. In addition, relatively little research has addressed AIS interface design. Usability testing has become a standard part of the design process for many major software companies, and the safety-critical nature of AIS makes it important for usability testing to be a part of AIS design.

Operational Test and Evaluation

Usability testing typically involves relatively few people using relatively few functions in a controlled environment. These limits mean that important design flaws may go unnoticed until the system is deployed on actual ships. For this reason, operational test and evaluation is a critical element of the design and evaluation process. Operational test and evaluation places the AIS interface in an actual operational environment to assess how it supports the operator in the full range of conditions that might be encountered. The committee did not identify many examples of operational test programs for AIS interfaces; thus, such operational test and evaluation programs are needed.

ENSURING GOOD INTERFACE DESIGN: DESIGN, PROCESS, AND PERFORMANCE STANDARDS

Good interface design can be guided by three general types of standards: design, process, and performance. Design standards specify the range or value of design parameters. These might take the form of very specific guidance concerning the color and size of display elements or more general guidelines, such as the 13 human factors design principles described above. Although design standards are attractive because they can specify equipment precisely, they can also be vague and conflicting, which could lead to poor designs (Woods 1992). Adherence to design standards does not guarantee a good design.

Process standards define the required design and evaluation process but do not define any of the features or characteristics of the device. For AIS interface design, process standards might mandate a process that begins with a task or work domain analysis, involves the application of human factors guidelines during design, and culminates in an operational evaluation.

Performance standards define the required efficiency of the human–AIS interface and do not specify the interface features or the design process. Performance standards require a comprehensive test and evaluation process that evaluates how AIS supports the operator in a variety of situations. Performance standards can be complex and costly to administer and may not guarantee a good design because it is impossible to test all possible use scenarios. No one type of standard will guarantee an acceptable AIS interface. A combination of design, process, and performance standards may be necessary to promote effective AIS displays and controls.

SUMMARY

Human factors considerations of AIS span a broad range that includes standards development, operational testing, training and certification, and research and development. The rapid pace of navigation technology development and the limits of traditional design standards make it likely that process and performance standards could be useful mechanisms to address the human factors considerations of AIS display development. Performance standards require operational test and evaluations. These evaluations provide useful information that can help refine process and design standards. Too frequently system design focuses on the physical system and its operation and fails to consider training and certification programs as part of the overall system design. Training and certification can have an important effect on overall system performance and should be considered with the same care as the development of display icons and color schemes.

Shipboard navigation and communication technology is changing quickly. In addition, there are many different operating environments, each with unique requirements for the AIS interface. More important, AIS may be used in a variety of novel ways that cannot be anticipated until mariners start using it. For these reasons, it is critical to remain flexible and not to mandate a single interface standard. At the same time, the success of AIS depends on developing interfaces that are compatible with the capabilities of the operator and the demands of the operator's tasks. These factors all argue for a continuing process of understanding the user, design, and evaluation that continues after the initial deployment of AIS. A combination of design standards, process standards, and performance standards is needed to ensure adequate interface design without interfering with the ability of designers to create effective AIS interfaces in the context of rapidly changing technology. These standards should evolve as the mariners' use of AIS changes over time. Currently, the effect of AIS on the mariner is not well understood. General guidelines, such as the 13 heuristics described above, can help guide design, but research into the following issues is needed:

- Design, process, and performance standards for the human factors considerations of AIS;
- The potential benefits of multimodal interfaces to support mariner's attention management;
- How technology development and trends in other fields, such as aviation, might influence AIS design; and
- How interface design can help address the trade-off between information requirements and the associated cost of complex shipboard displays of AIS information.

REFERENCES

Abbreviations

DATE	Design, Automation, and Test in Europe
ISO	International Standards Organization
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board

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6 Conclusions and Recommendations

Automatic identification systems (AIS) technology, which has been under development for almost two decades, provides a means of exchanging a precisely defined range of data between ships and between ships and shore facilities under the oversight of competent authorities. It holds the promise of providing accurate and reliable data while reducing the need for radio communications among ships and shore stations, but there are also the possibilities of misuse and unintended negative consequences. Although the implementation of International Convention for the Safety of Life at Sea (SOLAS) carriage requirements has already begun for oceangoing vessels, the requirements do not specify any shipboard display parameters for use by the mariner beyond minimal basic numerical identification data.

In this chapter, the committee's conclusions and recommendations derived from its investigations and analyses of the key issues affecting the design, development, and implementation of shipboard AIS displays are presented. The conclusions and recommendations address the U.S. Coast Guard's (USCG's) request for guidance about how to proceed with the AIS regulatory process for AIS displays aboard ships and how to ensure that these displays, when they are developed, will provide sufficient benefits to all mariners and enhance navigational safety and effectiveness in general. They also address the process that USCG will need to follow and the display-related technical and human factors aspects of producing and implementing an effective system aboard vessels.

NEED FOR A SYSTEMATIC IMPLEMENTATION PLAN

USCG has sponsored and conducted pilot tests of AIS in selected regions and has supported the introduction of AIS technology to enhance vessel traffic management and safety. However, USCG does not have a systematic plan for implementation of AIS in U.S. waterways or AIS displays aboard U.S. vessels. Such a plan is needed because there are important steps in the process that depend on each other to ensure that the vessel operator will derive the expected benefits from an onboard AIS and its display. For example, many of the requirements for shipboard display of AIS information focus on vessels with existing integrated navigation systems, sophisticated hardware, and electronic suites. Requirements for shipboard display of AIS information for small inland and coastal vessels are not well defined and need more analysis. In addition, integration requirements for AIS information with other electronic navigation systems information such as radar, automatic radar plotting aids, electronic charts, and so forth have not been well developed. Additional work in display integration is required to determine how to best integrate existing and new systems.

While AIS display requirements in support of vessel maneuvering and collision avoidance are under development, additional work is required before they can be fully adopted. For example, it has been difficult to integrate AIS displays with other bridge displays in a way that presents clear and unambiguous data to the mariner. In addition, AIS display requirements need further development to support the practice of good seamanship in multiple vessel collision avoidance and other emergency conditions.

Finally, USCG needs an AIS display implementation process to ensure that the underlying research will be accomplished to demonstrate the viability of the display requirements and that the resulting system will meet the needs of the mariners who use it.

Recommendation 1: USCG should establish an implementation plan and schedule for AIS shipboard display standards in consultation with stakeholders. Key elements of the plan should include

- Research in technical and human factors,
- Requirements determination and analysis, and
- Development of international and domestic standards.

AIS AND ITS RELATIONSHIP TO SHIPBOARD DISPLAYS

In the United States, AIS (as experimental or prototype technology) is in the early stages of implementation and is just beginning to become available within certain port and waterway regions. At the same time, international shipboard carriage requirements for oceangoing vessels under SOLAS have begun to be adopted for the world fleet of merchant vessels. The initial carriage requirements for SOLAS vessels, in the United States and worldwide, will not specify any shipboard display for use by the mariner except for minimal basic numerical identification data. Thus, the implementation schedule for true AIS shipboard displays is uncertain.

The introduction of onboard displays of AIS information represents an opportunity for significant improvements in available knowledge and awareness of waterway and vessel traffic situations for all mariners, which should bring safety and efficiency benefits. If AIS displays are introduced carefully and thoughtfully so that the needs of mariners are met without overburdening them with inessential information, the benefits may be considerable. However, the dangers and limitations of this technology could overshadow such benefits, and users and authorities must guard against them. The committee is both encouraged at the prospects for major improvements for vessel operations with the use of AIS and cautious about the problems that could result from less than careful planning.

Even though this report addresses only shipboard displays and not the full AIS, the committee understands that the challenge of AIS displays is but one of several facing AIS development in general. For example, while AIS, and displays in particular, complements traditional aids to navigation, it does not replace the need for them. With today's technology, the prudent mariner should never rely on AIS alone. AIS does not substitute for good judgment or replace the need to use all available means appropriate to the prevailing circumstances to establish vessel position.

Not all vessels will carry AIS, which will hinder its effectiveness. Thus, in a typical waterway with mixed traffic, all vessels cannot be located or identified by AIS technology. The unique nature of AIS is that it requires a functioning and reliable transmitter on each target that is part of the system and thus requires each carrier of AIS to participate and cooperate with the protocol.

To the extent that AIS provides additional valuable information to the mariner, it will be useful. The current capabilities of AIS provide for the support of three specific functions as defined by a resolution of the International Maritime Organization (IMO): (*a*) to assist in *collision-avoidance* while the system is operating in the ship-to-ship mode, (*b*) to provide *information* *about a ship and its cargo* to local authorities who oversee waterborne trade, and (*c*) to assist authorities engaged in *vessel traffic management.* As AIS technology and its applications evolve, they will become capable of additional support for vessel navigation and operations.

At the current state of development, each of the three broad functions of AIS noted above will affect shipboard display requirements differently. To assist in collision avoidance, an AIS display would be necessary as a direct tool feeding information to the mariner for use while maneuvering in close quarters or planning a meeting and passing situation. With regard to the second function—providing ship and cargo information to local authorities—a shipboard display probably would have little use. With respect to the third function—assisting vessel traffic management—a shipboard display may have a significant role, depending on the nature and design of specific traffic management systems. For example, shore-based data could be transmitted to vessels in a given waterway and then displayed as a means of communicating overall traffic situations and data concerning specific vessels within the area.

While the introduction of AIS in both domestic and international settings has been based on these three functions, the initial emphasis has been on the shipboard transponder and the system to ensure accurate identification and location transmissions. Only recently has much attention been given to shipboard display issues. Consequently, much development remains to be done in the form and display of both ship- and shore-originated AIS messages. Although displays can be considered the means by which AIS data are converted into useful information for the operator, little has been done to define the information needs and priorities that would establish display parameters.

Different types of information require different display strategies. The design of an AIS display interface needs to consider appropriate strategies for delivering information to the mariner. AIS information will be displayed in many different operating environments: rivers and inland waterways, high-density ports with mixed traffic, coastal waterways, urban harbors with scheduled ferry and passenger vessel operations, and major commercial ports accommodating large deep-sea vessels. In the United States, by far the largest segment of operators who may be required to use AIS are tugs, towing vessels, passenger ferries, and other non-SOLAS vessels.

Because of the variety of operating environments, one AIS requirement will not fit all situations, particularly in domestic operations, and implementation plans need to reflect that reality. The operating environment will greatly affect the configuration of displays that are appropriate as well as the operator training that is adopted. And, unlike large oceangoing vessels, many smaller domestic vessels may not carry all of the equipment (such as gyrocompass or satellite navigation) with which an AIS needs to interface for proper operation.

The AIS international carriage requirements for oceangoing vessels that came into force during 2002 refer to equipment that is designated as "Class A." The international bodies have defined two other classes that would be designated for other uses: (*a*) "Class A derivatives," which are portable units similar to the carry-aboard equipment now generally used by pilots in several U.S. ports and waterways; and (*b*) "Class B" units, which have less stringent requirements and are intended for use by domestic, inland, and coastal vessels (e.g., towboats, passenger ferries).

The Class A derivative units have received the most attention in the United States because of their similarity to those that pilots have used as carry-aboard units. The definition, role, and display requirements for Class A derivative units are incompletely specified at the present time, and this affects display requirements for such units. Carry-aboard AIS units could be used to fill the gap for vessels that do not have permanently installed AIS equipment. Therefore, there is a near-term need to develop Class A derivative display requirements before full implementation of AIS. Class B units, which are intended for coastal and inland vessels, are also not well defined, and the information display requirements for these units have not been specified. Much more analysis will be necessary on Class A derivatives and Class B before specific display requirements for these units can be established.

Recommendation 2: USCG should establish requirements for shipboard display of AIS information in U.S. navigable waters by

- Defining mariner information needs,
- Defining key functions for AIS displays aboard different types of vessels and in different operating environments,
- Developing appropriate requirements for each major vessel class that take into consideration the wide differences in operating environments,

- Involving the key stakeholders in the entire process, and
- Developing a new requirement for minimum information display of AIS.

USCG should take a leadership role in establishing display requirements for AIS information and work with appropriate international organizations in this process to ensure compatibility with international requirements.

DEVELOPMENT OF DOMESTIC AND INTERNATIONAL STANDARDS

Display standards are intended to ensure that designs meet user needs, that key requirements are understood, and that a proper certification process can be instituted for all operational units. Standardization of AIS equipment is critical to the safety of navigation and the facilitation of commerce, because shipping is an international business and it is essential that mariners find the same information displayed wherever they sail.

International standardization has come late in the development process for AIS. Efforts to standardize technology have been undertaken after many stand-alone systems were already in use throughout the world. This has caused difficulties in producing functional and reliable systems that provide information the mariner can use with ease. In addition, the evaluation of operational tests of AIS equipment has been hindered because no consistent performance standards are available with which to measure results.

The process of setting standards and certifying AIS equipment is under way within international bodies for the Class A units specified in current carriage requirements for SOLAS vessels. However, no such standards-setting process has begun for AIS displays either internationally or in the United States.

Recommendation 3: USCG should recognize the evolving nature of AIS display technology in its requirements process and allow for technological change, growth, and improvements in the future.

HUMAN FACTORS IN THE DISPLAY DESIGN PROCESS

For AIS to meet its stated objective of promoting safe vessel navigation, an effective onboard interface with the vessel's operator is essential. To provide an effective interface, the focus of the design process must be on the best means of exchanging information between the person and the AIS. Although the term “display” is usually used in this report in referring to this interface, it should be noted that, from the perspective of the human operator, the “interface” includes both the display and control mechanisms that allow the exchange of information between the operator and the rest of the system. The interface includes not only the display of information through such means as a cathode ray tube, graphics, and auditory warnings, but also data entry and control elements such as keyboards or switches. Development of an effective human interface for AIS requires a systematic process that considers the capabilities of users and the demands of the operating environment.

Three core elements make up a typical design process with human factors as a focus: understanding, design, and evaluation. The process is circular and continues from one element to the next as new factors and inevitable changes are recognized.

Within the element of understanding is the notion that advanced technology can increase errors and risk even when appearing to be beneficial. This reinforces the need for attention to the human interface. It is also clear that AIS data must be translated into decision-relevant information for the mariner. Thus it is important to understand how each task of the mariner is performed and how AIS data can support that task and, in turn, overall performance. There are substantial operating differences among the range of vessels that may be equipped with AIS, and it is clear that interface design needs to reflect that range of variation if it is to adequately support operator needs.

The second element, design, follows from the first and begins with incorporation of the large body of knowledge about human factors interface guidelines that already exists. Thirteen human factors principles are particularly relevant to AIS interface design. Among them are ensuring that system behavior is completely visible to the operator, avoiding interface management tasks during high-tempo situations, and realizing that the representation of AIS data (e.g., graphic versus numeric) can greatly affect interpretations. Multimodal display alternatives should be considered in addition to graphics and text.

Finally, the evaluation element represents the step that tests a design and its performance and leads to either initial adoption or redesign to correct a problem. Heuristic evaluation with multiple evaluators is a very useful approach in identifying design problems. In addition, usability testing and operational evaluation are complementary approaches in identifying problems.

Selection of an effective design process will have a large impact on how well a shipboard display and control system provides the promised benefits and avoids unexpected consequences. A combination of design, process, and performance standards is needed to ensure effective designs. Maritime technology and AIS applications will always be difficult to predict. Thus, designers must have the freedom to adapt to changes as they occur or are identified. USCG needs to allow for this in its standards-setting process.

Recommendation 4: In its standards, USCG should specify that design, process, and performance standards be used in combination to promote adequate shipboard AIS display design.

SYSTEM LIMITATIONS

For a shipboard AIS display to function adequately and provide necessary information to the mariner, the overall AIS and supporting infrastructure must also function reliably and accurately. The following are some of the limitations in current systems:

- The systems are not fail-safe. If the equipment is not operating on board a carrying vessel, it can disappear from the surveillance picture without notice.
- The systems require the cooperation of the vessels being tracked. A decision not to carry the required equipment or to disable it or otherwise turn it off removes the vessel from the display.
- The integrity of the data that must be provided by the carrying vessel is not assured. Some data, including data identifying the carrying vessel, are manually entered by an operator and so can be changed or could contain errors.
- Multiple shipboard sensors (e.g., radar and AIS) can result in multiple displays of single targets. The resulting target ambiguity needs to be resolved through a sorting process, which has not yet been fully developed.

The available system capacity for transmitting messages of varying priority and time sensitivity is another factor that may need attention in the overall AIS context because of its effect on shipboard displays. Although AIS has substantial messaging capability, it is not infinite, and the shore-based infrastructure needs to be designed to match traffic volume, message demands, and messaging priorities. Additional message demands due to mariner needs for AIS information could be a key factor in overall system design.

Several other infrastructure issues also affect the display of AIS information: transponder coverage and the spacing of shore-based repeater stations, the adequacy and accuracy of digital charting in a given waterway, the availability of existing vessel instrumentation, and the need for standardized interfaces between existing equipment. International standards development efforts have inadequately considered such infrastructure issues and have not considered the impact of infrastructure issues on shipboard display of AIS information.

In addition to infrastructure, it is important to consider shipboard operating environments that will shape shipboard display of AIS information, particularly in terms of

- The range of data that will be transmitted, especially the safety-related elements transmitted by shore stations to ships;
- The areas or routes used by vessels equipped with AIS displays;
- The work environment, tasks, and workload of the shipboard bridge watchstanders charged with the safety of navigation;
- The skill levels of shipboard personnel using the AIS displays and the training and qualifications required to use the displays effectively;
- The role technology should play, given prevailing and anticipated shipboard workload and skill levels, in converting AIS data into useful and timely information (this factor incorporates consideration of the limits of current "off-the-shelf" display technology); and
- The benefits derived from mandated displays compared with the cost of fitting and maintaining the displays, taking into consideration training and other associated personnel costs.

These and other operating environment factors affect AIS performance in general, and especially the design and implementation of shipboard displays.

For example, a potential problem with the use of AIS displays aboard vessels is that the human interfaces can, in some cases, mislead operators into believing that a complex system is well represented by a simple display (sometimes referred to as "the seduction of safety"). Some of this risk can be addressed by good display design. However, the general problem suggests that operator training may be needed in the theory of communication systems, AIS capabilities and limitations, and AIS operations. These and other factors suggest that specific AIS training will be needed and that stakeholders, such as vessel operators, equipment manufacturers, and vessel traffic managers, should be involved in developing training guidelines.

> ***Recommendation 5:*** USCG should identify critical AIS limitations and infrastructure requirements and coordinate them with display requirements. USCG should establish a mechanism to inform all users about system limitations if they cannot be readily corrected.

> ***Recommendation 6:*** USCG should work with stakeholders to develop appropriate training and certification guidelines for AIS users that will lead to effective use and an understanding of system functions and limitations.

NEED FOR ONGOING RESEARCH ON HUMAN INTERFACES

The development of AIS displays requires a full consideration of human interface attributes that affect what information to display, how to present it to the operator, how to integrate other displays or other bridge information systems, and how to give the operator what is most needed to perform critical tasks. The term "AIS display" connotes a visual presentation of data; however, there are many different methods to provide an effective human interface for information that is vital to the mariner.

AIS interface design should be subject to further analysis and critical investigation. For example, the system image and its physical representation will determine its use. A key consideration is whether AIS data will be presented to the operator separately or will be integrated with other existing equipment and information flows. This is a key research area and has received little attention to date. On board certain vessels, AIS units need to fit within existing operational configurations to remain within the mariner's peripheral vision while not interfering with his or her view of the outside or other equipment. This condition might suggest that different types of AIS interfaces could be adopted, such as wearable computing devices, enhanced binoculars, or a mix of tactile and auditory devices. In addition, AIS interfaces could consider multimodal approaches in order to adequately address competing attention demands. Aboard smaller vessels, AIS visual displays will need to balance the need to be large enough to convey the necessary AIS information and small enough to fit unobtrusively among other equipment. Another consideration aboard small inland vessels is the noise level in the wheelhouse that might interfere with audio interfaces.

Another area of necessary research relates to whether and how mariners need to input data into the AIS during the normal conduct of vessel operations and how this might interfere with other duties. Some mariners may have limited opportunities to input data into the system, given competing demands for operational task performance and decision making, particularly on board smaller vessels with one-person wheelhouses. Different types of information may require different data input strategies.

Symbology for visual displays is a fertile area for research and development. While some display symbology requirements have been articulated by international bodies, they have not been harmonized across different shipboard electronic navigational displays. This is especially critical for smaller inland and coastal vessels. Furthermore, little work has been done in differentiation of symbols for Class A from Class B and Class A derivatives. The integration of radar and AIS symbols also needs attention and evaluation.

Another research area is the cost–benefit trade-off associated with AIS: whether the benefits associated with improved identification and maneuvering/collision avoidance information are worth the cost. For example, do the decision-making and human performance advantages associated with AIS outweigh the human costs in terms of mariner attention management, workload, and vigilance? Studies are also needed to define the information needs for maneuvering and collision avoidance that can be fulfilled by AIS technology.

There are several human factors interface research topics that are particular to the operation of smaller inland and coastal vessels, including the evaluation of competing operator attention demands on board vessels with one operator, high noise levels, multiple communications links, and needs for multiple operational tasks. This leads to the need to consider requirements for specific operating environments rather than universal requirements for all vessels. A challenge for shipboard display design is to find the appropriate balance between the amount of information needed to inform the decision maker in a way appropriate to the decision without overloading the information-handling capabilities of the mariner.

The process of determining the proper shipboard display of AIS information will be dynamic and reflect the needs and requirements of differing operating areas. Integration requirements for shipboard display of AIS information raise questions about appropriate task and function allocation between technology and people. For example, designers must strike the right balance between human integration and information processing and automation support for each key task. In addition, shore-based AIS information transmission should be directly linked to the identified mariner needs for that information. There is little commonality in bridge layouts, even for vessels of the same class, and the lack of standardization affects potential shipboard displays of AIS information. Locating shipboard AIS information on a single display can lead to cluttered results, and the value of that information can be degraded by masking or obscuring relevant navigational information.

Recommendation 7: USCG should establish an ongoing research program to investigate information displays and controls that might be appropriate for AIS. The research program should consider AIS use with other navigational and communication technologies. The research program should include

- Human factors aspects of interface design and the subsequent process of determining requirements, setting standards, and evaluating performance;
- Evaluation of multimodal interfaces (tactile, auditory) that could effectively support mariners' needs for attention management;
- Allowance for technological change and leverage of lessons learned from other fields (such as aviation) and related applications of similar technology; and
- Investigation of trade-offs between information requirements and the associated cost for shipboard display of AIS.

NEED FOR CONTINUED OPERATIONAL TESTING OF AIS DISPLAYS

USCG and other authorities have conducted a number of operational tests of AIS technology in the United States and abroad. Most of these tests have demonstrated benefits and limitations of the equipment used and shown the operators how it might be used within their operational environments. However, none of the tests with displays has resulted in clear evaluations of performance measured against specific standards. Also, few of the tests on displays have been performed on AIS equipment that was built to IMO standards, and no other standards are available.

The committee reviewed several operational tests of shipboard AIS equipment. Most of these tests have not resulted in evaluation reports that clearly and critically document the functioning and usefulness of displays. Anecdotal reports from certain operations using AIS displays (e.g., Sweden and Tampa Bay, Florida) suggest that operators have gained confidence in the systems and used them successfully as navigational aids. From this experience, it appears that the entire maritime community would benefit from more rigorous AIS operational testing with clear functional requirements against which to measure performance, followed by critical evaluations.

> ***Recommendation 8:*** USCG should sponsor continuing operational tests, evaluation, and certification of new display and control technology in consultation with stakeholders and prepare test and evaluation reports. To conduct tests and evaluations, USCG should develop standards for human performance with display and control technology. It should use heuristic evaluation, where multiple designers assess how well a design conforms to human factors rules of thumb or heuristics. It should also incorporate usability tests and operational evaluations as complementary approaches to assess how well AIS displays and controls support mariner performance.

SUMMARY

The introduction of AIS technology with effective displays aboard vessels operating in U.S. waters can enhance the safety of vessel operations and the prudent management of waterway traffic. The benefits to the maritime community and the nation as a whole will depend on how well the industry, government authorities, and mariners work together to design effective systems, establish comprehensive standards and guidelines, and implement technologies that provide useful tools for the vessel operator. USCG should take specific actions to ensure an implementation process that meets safety improvement goals. These actions include preparing an implementation plan, establishing requirements for displays and their functions, including human factors in the display design process, addressing system limitations and shortfalls, developing training guidelines, establishing human performance standards, establishing a focused research program, and conducting operational tests and evaluations of display systems.

USCG cannot ensure that this new technology will bring the promised benefits to all without the involvement and cooperation of all stakeholders, and without formal evaluation of such systems. Manufacturers, mariners, and the maritime industry as a whole need to be a part of the process to develop effective systems and to successfully implement this technology. While the focus of this report is on shipboard display of AIS information, the process of implementation and the use of human factors principles have wider application to many systems used aboard vessels operating in U.S. waters.

Appendix A

Workshop to Explore Automatic Identification System Display Technology and Human Factors Issues

Sponsored by the
TRB/Marine Board Committee for
Evaluating Shipboard Display of
Automatic Identification Systems

April 3–4, 2002, New Orleans, Louisiana

The Committee for Evaluating Shipboard Display of Automatic Identification Systems (AIS) sponsored a workshop on April 3–4, 2002, to solicit detailed information from experts and stakeholders about human factors and technical aspects of shipboard display systems. The workshop explored a number of issues related to future guidelines for AIS shipboard display parameters. It stressed the collection of current and accurate information and included suppliers, researchers, and ship operators with experience in using AIS or related systems. Each participant presented relevant views and expertise. The committee used the information and the subsequent discussions among participants to help analyze the problem and report results.

The presentations and discussions at the workshop are summarized in the following sections. Emphasis is given to the major points related to opportunities for use of AIS displays aboard vessels and limitations of the technology and human factors.

The workshop agenda with presenters and moderators identified, a list of workshop attendees, and a list of vendors who exhibited their equipment are provided at the end of this appendix.

INTRODUCTORY REMARKS

Martha Grabowski, committee chair, introduced the committee and staff and presented an overview of the study goals and plans as well as the goals of the workshop. The workshop was organized to make maximum use of invited experts and their experience to inform the committee members about the state of the art in technology for AIS displays, experience in previous tests and operations, related work in other fields, and pertinent studies and analyses.

Jorge Arroyo, from the U.S. Coast Guard (USCG), sponsor of this study, presented the group with a background of USCG's development of AIS and its regulatory process for specifying carriage of AIS aboard vessels in U.S. waters. He pointed out that a notice of proposed rulemaking for AIS was under development and would be issued during summer 2002. So far no standards have been developed for AIS shipboard displays.

PANEL I, TECHNICAL FACTORS: SUMMARY POINTS

Panel I consisted of three presenters with committee member *Robert Moore* acting as facilitator:

- *Holger Ericsson*, Director of Marketing, Saab Transponder Tech AB (STT);
- *George B. Burkley*, Head, Applied Research Department at the Maritime Institute of Technology and Graduate Studies (MITAGS); and
- *William Nugent*, U.S. Navy Space and Naval Warfare (SPAWAR) Systems Center, San Diego, California.

The purpose of Panel I was to acquaint the committee with the limitations of AIS and display technology. To help the presenters focus on those limitations, they were each provided with a list of questions and areas of committee interest before the meeting. The material presented by Mr. Burkley and Mr. Nugent generally addressed the questions; Mr. Ericsson focused on the products offered by Saab. Mr. Moore stated at the start that AIS as now envisioned is a vehicle capable of transmitting a great deal of information and it is likely that its messaging capability will grow to fill its capacity. He asked the group to help focus the discussion on what needs the shipboard display of this information should meet and what displays would be the most beneficial to the mariner.

Mr. Ericsson stated that there are limits to AIS messaging capacities even though they are large. The preferred method of accommodating those limits is to subdivide geographic regions into "cells," each of which is served by an AIS "base station." Of the three internationally agreed functions of AIS [ship-to-ship for collision avoidance, awareness by coastal states of vessels within their areas of interest, and use by a vessel traffic service (VTS) as a traffic management tool], the most data intensive is VTS use for traffic management. That information permits a conclusion that a major determinant of shipboard display requirements is the data intended to be provided shore-to-ship within a VTS area of responsibility. Mr. Ericsson concluded that there are implementation schemes for AIS that can protect against or compensate for the known limitations of AIS messaging capacity and that STT has significant experience with such implementations. Mr. Ericsson also presented a real-time demonstration of vessel situations in Swedish waters projected on an electronic charting and display information systems (ECDIS) chart to show one display option now available.

Mr. Burkley's presentation focused on the differences between radar [specifically, automatic radar plotting aid (ARPA)] and AIS technologies as they relate to display issues. A conclusion supported by his material is that the integration of AIS data in an ARPA display increases the possibilities of confusion and misinterpretation, and he did not indicate that such integration would be desirable. Mr. Burkley concluded that AIS information should not be displayed on a radar screen because it would be more confusing than helpful to the mariner. Portable piloting units for AIS displays, separate from other shipboard displays, have become common and useful, even though Mr. Burkley believes that AIS and ARPA are not compatible.

Mr. Nugent presented many of the inherent capabilities of display technologies. The capabilities generally exceed those desirable for use aboard commercial vessels. He emphasized the need to focus on simplicity and clarity in order to limit training requirements and avoid the necessity for increased staffing. Mr. Nugent's accounting of the Navy's experiences proved that any level of complexity that is desired can be had and that there are situations in which added capabilities, at the cost of complexity, might be justified. He also provided information on display techniques and practices to be avoided, as learned from Navy and other military experiences. Mr. Nugent concluded that significant research work already exists on the topic of display design and that the integration of display technology with human factors, within the context of the intended application, is critical.

During the discussion session after the first panel presentations, several general points were made by presenters and participants:

- Even though AIS has high capacity for data exchange, limits are needed with regard to large geographical areas and large numbers of vessels that might participate.
- There is a need to manage the data on a display so that information will not overwhelm the operator—the use of overlays and lessons from the Navy's symbology work may be valuable.
- Displays can handle certain combinations of system inputs, such as ECDIS and AIS, while other combinations may be problematic (ARPA and AIS).
- Any future requirements for AIS displays that might be contemplated need to be considered in the light of what other displays are required (or not required—such as ECDIS).
- AIS displays must be designed to meet end users' needs.
- A variety of AIS user need categories must be sorted out—navigation, collision avoidance, situation awareness, voyage planning, vessel traffic management, and so forth.
- At present most AIS manufacturers are striving to meet International Maritime Organization standards with the addition of small graphical displays with minimal complexity.
- The AIS in any given waterway will be affected by the total capability of the traffic management system in that waterway.

PANEL II, HUMAN FACTORS: SUMMARY POINTS

Panel II consisted of three presenters with committee member *John Lee* acting as facilitator:

- *Nadine Sarter*, The Ohio State University;
- *Kim Vicente*, University of Toronto; and
- *Edwin Hutchins*, University of California, San Diego.

The purposes of Panel II were (*a*) to explore a range of human factors research and development work that might be applied to the problem of AIS displays and (*b*) to acquaint the committee with human factors information relevant to shipboard and related bridge operations, the types of information systems used, and typical operator needs and capabilities. The panel was asked to comment on lessons from process control, cockpit information, and air traffic control situations that might apply to AIS. Questions included, What are recent findings related to interface alternatives (e.g., tactile vibration or sonification)? What human information processing limits might be critical to consider? What considerations with regard to the organization and combination of information might be useful to include? How should organizational, social, or teamwork considerations influence AIS interface designs?

Nadine Sarter presented highlights of her recent research in human factors in airline operations. She emphasized that any display should alert the operator to updated information and indicate where to find it. She also noted that many options are available for other than visual displays and that some of them may be preferable, especially for occasional warnings. The options include auditory displays, tactile channels (vibrations on skin) for getting the attention of the operator, and peripheral vision channels. These options may be especially useful for mode change detection. She concluded that there are automation and mode transformation lessons to be learned from aviation experience.

Kim Vicente presented relevant information from his research on integrated system designs for power plants and other control stations. He pointed out that too many detailed rules get in the way of sensible operator functions. When the operator must work to the rule, nothing gets done. Control systems must be designed for adaptation. Another point was that the biggest threats to safety are the unfamiliar and the unanticipated. He stressed that human cognitive ability is very adaptive and that complexity is in the eye of the beholder. His main conclusion was that tests and task analyses of which systems work best under real operating conditions shed much light on how to select an optimum design, and designers should not always display raw data but rather should develop the most useful interpretation of data. He also stressed that how people manage attention (when to look at what) has a huge impact on display design.

Ed Hutchins presented information on how human factors research can improve the design and safe operations of all systems. Key factors that must be considered include how to monitor system status; what alerts work best; how to avoid skill atrophy; how to avoid overreliance on electronic displays when other, more direct, information is available (look out the window); how to avoid complacency; and how to build trust in the most accurate information. Another point is that the display designer must know what level of precision is needed for an operator to do a specific task—not what precision is possible. A final remark was that AIS should only provide information that an operator cannot get in another way.

PANEL III, CASE STUDIES: SUMMARY POINTS

Panel III consisted of three presenters with committee member *Elizabeth Gedney* acting as the facilitator:

- *Lee Alexander*, University of New Hampshire;
- *Jeff McCarthy*, San Francisco Marine Exchange; and
- *Tom Hill*, Master Mariner, SeaRiver Maritime.

The purpose of Panel III was to acquaint the committee with case studies involving AIS equipment and with successes and failures of tests or related systems developments. The last presenter discussed real operational factors on existing vessels on the basis of experience with AIS equipment that did not have any shipboard display. Information was sought from the presentations concerning how designs were selected and implemented, how user needs were evaluated, and what technical and human factors aspects were included.

Lee Alexander recommended that the committee take advantage of a number of past studies, tests, and reports that illustrate the gradual development of AIS technology and operations over a number of years. He emphasized that navigation and other important functions that AIS can facilitate should be addressed separately and with the end use in mind. For example, in ship-to-ship collision avoidance, AIS can supplement other data available to the mariner but must be tempered with knowledge about what vessels participate and what traffic management systems are in force. With regard to symbols that can be used on displays, standards (i.e., for ECDIS) have already been set for certain areas and situations. Therefore AIS can be and has been incorporated with ECDIS in some areas. For example, in the

St. Lawrence Seaway, AIS trials are beginning in July 2002, and several manufacturers will participate in these trials with three types of AIS and three types of ECDIS.

Mr. Alexander discussed his view of what factors are the most important for a suitable AIS display from the mariner's perspective. He stated that the display should have a single background color scheme; it should be simplified in presentation, with only the critical information shown; the designer should strive for the most information with the least clutter; and the user should be able to select what information is important for the task at hand and set the display to provide that information.

The next presenter, Jeff McCarthy, described the history and lessons learned from an extensive AIS testing program over several years in the San Francisco Bay area.

The final presenter was Tom Hill, an experienced ship's captain who has sailed worldwide for over 25 years on tankers for Exxon Shipping and now for SeaRiver Maritime. He described his experience from the standpoint of navigational equipment that he has used and how that experience might help in the selection of an AIS display system for the future. He has seen the rate at which new technologies become available accelerate in recent years, but the new technologies do not always increase operational effectiveness. He noted that radar does not usually work well when overlaid on ECDIS, and therefore operators shy away from that combination. He thinks that AIS has a better potential to overlay on ECDIS and provide more information. He thinks that AIS has the potential to do things that radar cannot (see around corners, improve target acquisition).

Captain Hill made the following observations in his presentation:

- AIS displays should have simple graphics and be easy to read—especially considering the aging mariner labor pool.
- Displays should filter out information that is not needed.
- Pilot carry-aboard equipment adds no benefit to the ship's crew because it is not usually available to the rest of the bridge team.
- Too many mode changes are confusing and can lead to inoperability.
- Alarms must be integrated into the rest of a ship's systems. New types of alarms (tactile) may be useful because they do not just add to the multitude of audible alarms that tend to all go off at once.

- Most ships are old and equipment is added piecemeal—it is hard to find the right place for everything.
- Reliability and simplicity are most important. If a system is too complex, it will not be used.
- Regulations and technology often are not compatible. Some equipment might help operations but not help meet regulations (ships with ECDIS still must keep hand records on paper charts to satisfy regulators).

During the question and answer session for this panel, several issues were discussed.

- Many participants believe that AIS must be better designed to meet user needs and designers must better understand what information and displays will most improve overall safety of navigation.
- The notion of not having an AIS display was discussed. The questions that should be addressed are, How much should AIS be relied on? How specifically does USCG need to require a system?
- AIS is needed the most when conditions are bad and looking out the window is not the best option.
- Simplicity of operation and display should be stressed, and the importance of operator training should be recognized.

PANEL IV, OPERATIONS: SUMMARY POINTS

Panel IV consisted of four presenters with committee member *Douglas Grubbs* acting as the facilitator:

- *Benny Pettersson*, Swedish Maritime Administration and Passenger Vessel Pilot;
- *Allison Ross*, Bay Pilot with the Association of Maryland Pilots;
- *Mark Stevens*, Inland Barge Operator with Ingram Barge, Inc.; and
- *Jorge Viso*, Pilot with Tampa Bay Pilots Association.

The purpose of this panel was to present and discuss the needs of various operators for AIS displays to aid in making the best navigational decisions. The participants were asked to discuss pitfalls that should be avoided, lessons that have been learned from recent tests and operations, and how overall vessel operational tasks might change with the introduction of AIS. The panel members include mariners from key industry sectors who will be directly affected by the introduction of AIS displays aboard vessels.

Captain Pettersson described the status of AIS usage in Europe, especially Sweden. He stated that AIS does not replace existing navigation inputs (radar, etc.). However, AIS can give more accurate data than can radar, and it can give some data that radar cannot. In some modes, radar gives the wrong information, especially with regard to turning vessels and their heading, and this can be corrected by AIS. In Swedish tests it has been shown that minimal symbols on an electronic chart can give intuitive information about ship position in a turn. Over a few years of Swedish tests and operations with AIS, the pilots and mariners have become comfortable with the technology and confident of the information provided to them. This trust is hard to gain but is a highly important factor.

Captain Ross indicated that in Chesapeake Bay, security concerns are fast changing the pilots' operational procedures and the way all technologies (including AIS) are being used. She stressed that the best AIS display should present the basic data in a simple way and in one place so that the mariner need not go from place to place on the bridge to get information. There is too much ARPA and other clutter already on most bridges, and that should not be increased.

Mark Stevens presented the inland waterways situation and its unique needs for AIS-type data and displays. He stated that it is important to have an easy-to-operate system that can be integrated into currently used systems. Inland tug operators do not usually have radar, do not plot charts, and do not need latitude and longitude information. However, AIS displays should integrate easily into electronic charts that are in use with minimal clutter of data. Systems must also work on all 25,000 miles of inland waterways and on 4,500 operating vessels. Designers must recognize that inland vessels are confined in available space and have limited time to make navigational decisions. Some electronic charts are problematic because of frequent water level changes. Operators also need very simple displays directed to their operating environment.

Captain Viso described the recent test usage of AIS in Tampa Bay by ship's pilots, other vessel operators, and traffic managers. Pilots have used carry-aboard units since 1998. The system displays a chart with own-ship and other vessel data overlaid. The vessel traffic system can pick up ships up to 70 miles offshore. Environmental data (PORTS) is also displayed as a pop-up on the AIS. Text messages can be sent between vessels. AIS has been a useful tool for traffic management in Tampa Bay, which has a long, narrow, and restricted channel. In their 3.5 years of experience Tampa pilots have verified the usefulness of AIS and now can trust the equipment in fog and storms. Most pilots now use it to look over the entire bay—not just in a passing situation. They have verified what information is most important to transmit and display, and they have become strong proponents of its benefits. Captain Viso stressed that AIS has proved most useful as a planning tool for meeting situations. He noted that an important future improvement would be harmonization of formats with other systems.

WORKSHOP CONCLUDING COMMENTS

Committee Chair Martha Grabowski led the concluding discussion of all participants at the workshop. The USCG representative noted that USCG is in the process of rulemaking on AIS carriage requirements and that the public can bring any concerns to its attention through its website: www.uscg.mil/vtm.

Several comments were made in general to the committee and all other participants. One was that the committee should carefully separate policy on early AIS development from that needed to implement an up-to-date system. Another pointed out that all affected nations should work together on international standards rather than implementing individual national standards. Another participant noted that committee members should see some actual systems in operation.

Some concluding main points from the workshop follow:

- Available AIS units can display a large range and amount of information, including target IDs, traffic situations, navigation predictions, and depictions. They have been integrated with ECDIS in several tests. However, integration with ARPA displays appears to be problematic.
- Portable AIS units have been most widely used (by pilots) in the United States, and they have not been integrated with any existing bridge systems.

- Significant research by the U.S. Navy on display systems can inform future design of AIS displays and most appropriate symbols.
- There is no universal agreement on the amount of information that should be included in an AIS shipboard display. There is general concern about too much information or clutter that would make for operator confusion and inhibit interpretation. Display information should be matched to the mariner's tasks and to the operational needs for navigation safety or other appropriate functions.

WORKSHOP AGENDA
National Academy of Sciences
Transportation Research Board

COMMITTEE FOR EVALUATING SHIPBOARD DISPLAY OF AUTOMATIC IDENTIFICATION SYSTEMS
Hyatt Regency
New Orleans, Louisiana

April 3–4, 2002

Meeting Objectives

- Receive panel presentations relative to the committee's charge
- Examine AIS display systems being developed by various manufacturers

OPEN SESSION

Wednesday, April 3, 2002

8:00–8:30 a.m. Introduction and Welcoming Remarks
Martha Grabowski, Chair
Beverly Huey, Study Director
- Introduction of Committee Members and Staff
- Overview of Study
- Workshop Goals
- Overview of Agenda

8:30–8:45 a.m. Remarks on U.S. Coast Guard's Expectations and Needs
Jorge Arroyo, USCG

8:45 a.m.–noon	Panel I: Technical Factors *Facilitator: Robert Moore, Member* Holger Ericsson, SAAB George Burkley, MITAGS Bill Nugent, SPAWAR Systems Center UCDT
Noon–2:00 p.m.	*Lunch and AIS Manufacturer Exhibits*
2:00–5:00 p.m.	Panel II: Human Factors *Facilitator: John Lee, Member* Nadine Sarter, The Ohio State University Kim Vicente, University of Toronto Edwin Hutchins, University of California, San Diego
5:00–6:30 p.m.	*AIS Manufacturer Exhibits*
7:00–9:00 p.m.	*Reception*

Thursday, April 4, 2002

8:00–10:00 a.m.	Panel III: Case Studies *Facilitator: Elizabeth Gedney, Member* Lee Alexander, University of New Hampshire Jeff McCarthy, San Francisco Marine Exchange Tom Hill, SeaRiver Maritime
10:30 a.m.–12:30 p.m.	Panel IV: Operations *Facilitator: Douglas Grubbs, Member* Benny Pettersson, Swedish Administration Jorge Viso, Tampa Bay Pilots Allison Ross, Association of Maryland Pilots Mark Stevens, Ingram Barge
12:30–12:45 p.m.	Closing Remarks *Martha Grabowski, Chair*
12:45 p.m.	*Adjourn*

WORKSHOP ATTENDEES
Committee for Evaluating Shipboard Display of Automatic Identification Systems

Hyatt Regency
New Orleans, Louisiana

April 3–4, 2002

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LeMoyne College and Rensselaer Polytechnic Institute

Carl E. Bowler, Member
San Francisco Bar Pilot

Elizabeth J. Gedney, Member
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Douglas J. Grubbs, Member
Crescent River Port Pilots Association

Don K. Kim, Member
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Beverly Huey, Study Director
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TRB, National Research Council

Sponsor

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U.S. Coast Guard

David DuPont
U.S. Coast Guard

Edward LaRue
U.S. Coast Guard

Mike Sollosi
U.S. Coast Guard

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Lee Alexander
University of New Hampshire

George B. Burkley
Maritime Institute of Technology and Graduate Studies

Holger Ericsson
Saab Transponder Tech AB

Tom Hill
SeaRiver Maritime

Edwin Hutchins
University of California, San Diego

Jeff McCarthy
San Francisco Marine Exchange

Bill Nugent
SPAWAR System Center

Benny Pettersson
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Allison Ross
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Mark Stevens
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Kim Vicente
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Jorge Viso
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Speschel Interest Group/SAAB

Mark Pfeiffer
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Technologies GmbH

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Christopher R. Brown
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Ted Lillestolen
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Kenneth Mills
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Lower Mississippi River

Michael Morris
Houston Pilots

LTC Franklin Morrison
USACOE, Liaison to USCG

Steve Nicoulin
New Orleans Steamboat Co.

Mike Nesbitt
Maritrans, Inc.

Scott Nesbitt
Quality Positioning Services, Inc.

Nick Van Overdam
Kongsberg-SIMRAD, Inc.

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Appendix B

Report on Committee Subgroup Trip to Europe, July 25–August 4, 2002

Two members of the committee and one staff member visited locations in the United Kingdom, Germany, and Sweden between July 25 and August 4, 2002. The members were Douglas Grubbs and Bob Moore, and the staff member was Peter Johnson. All three took part in site visits and meetings with officials in northern Germany for 3 days—July 29, 30, and 31. Bob Moore had meetings with Captain C. K. D. Cobley, Secretary-General of Comité International Radio-Maritime (CIRM); Mr. Michael Rambaut, Deputy Secretary-General of CIRM; and Mr. C. Julian Parker, Secretary of the Nautical Institute, in London before this visit. Doug Grubbs went on to Sweden after the German trip.

Discussions with Captain Cobley and Mr. Rambaut focused on the goals and progress of International Electrotechnical Commission Working Group 13 and the pros and cons of establishing parameters for data transmitted by automatic identification systems (AIS). The latter discussions included comments about the work of the International Association of Aids to Navigation and Lighthouse Authorities (IALA) Vessel Traffic Service (VTS) Committee and the results of their work as published in IALA's *Guidelines*.

It was clear that manufacturers would seek to incorporate unique features in their shipboard AIS displays but that both industry and maritime users would benefit by regulatory measures that established the limits, or meets and bounds, for the AIS data to be transmitted—particularly by shore stations. By implication, efforts such as those of Working Group 13 and establishment of AIS data parameters would drive displays toward a commonality of presentation that would improve safety.

The chief topic discussed with Mr. Parker was the AIS seminar held in London jointly by the International Maritime Organization (IMO) and IALA in July 2002. The discussion included a review of comments submitted to the Nautical Institute about the seminar by various individuals.

On the basis of the discussion and the written comments reviewed, it seems clear that active mariners have little knowledge of AIS or of the intentions of governmental agencies for its use, particularly as a vessel traffic management tool. As a result, there had been little input from users concerning the data to be transmitted by AIS or traditional data sources that should not be changed. There appeared to be some feeling that implementation of AIS beyond ship-to-shore applications should be delayed until data content and display requirements were established.

FACILITIES VISITED AND MEETINGS HELD WITH GERMAN OFFICIALS

- In Kiel at the Waterways and Shipping Directorate for Baltic and North Sea coastal areas and ports and river entrances (for Kiel, Kiel Canal, Travemunde, Warnemunde, Rostock, Hamburg and River Elbe, Bremen and Bremerhaven); with Jan-Hendrik Oltmann, deputy head of division, and Hendrik Eusterbarkey, engineer. Had presentations on the organization of the waterways agencies and their mission, the recent AIS conformity trials in the Baltic Sea, issues and concerns about AIS implementation in Germany and the development of the complete system, and the status of AIS implementation in Germany.
- In Warnemunde at the entrance to Rostock harbor. Visit to the newest German vessel traffic center (VTC) under the waterways and shipping directorate in Warnemunde. Had presentations on the operation of the VTS and integration of AIS data with radar data from certain vessels on traffic monitoring and control; had discussions with operators.
- In Warnemunde at ship training simulator center for the new institute there under the Wismar University of Technology. Saw demonstrations of the simulators and training technology. Presentations by Dr. Christoph Felsenstein, director of the institute, described simulator technology and training programs.
- In Hamburg at the German Federal Hydrographic and Maritime Agency (BSH), the agency that oversees the approvals of shipboard technical equipment (AIS and displays) to meet IMO standards and that experiments with shipboard technology improvements. (This agency also incorporates the equivalent of the National Oceanic and Atmospheric Administration Ocean Survey.) Presentations by Dr. Ralf-Dieter Preuss and staff addressed AIS equipment testing by this office, work on integrating radar (ARPA) with AIS displays, and philosophy regarding overall approach to bridge

navigational displays. Also visited the laboratory where AIS equipment undergoes type testing.

- In Brunsbuttel at the VTC for managing traffic in the Kiel Canal. A presentation by Mr. Heesch described the new system incorporating AIS technology being developed and implemented by Kiel Canal traffic management. All vessels will carry AIS; those not equipped with it will be lent a unit for canal transit. Visited traffic center under existing operation and discussed new system with operators.

MAJOR ISSUES AND POINTS RELATED TO AIS DISPLAY STUDY FROM GERMAN VISIT

- Regarding AIS introduction in general, there are concerns about total system integration, the integrity of all units on board vessels and on shore, and the need for repeaters and knowledge on message conformity.
- At present there are no plans in Germany to require anything other than minimal IMO onboard display.
- German waterways now have extensive radar coverage; AIS will supplement but not replace radar—total system facilitates traffic and efficiency.
- Germany plans to use AIS to enhance traffic monitoring.
- German VTS operation now has no problem with voice communications.
- Pilots are used within VTCs and aboard vessels.
- With AIS, there are concerns about the fact that the receiver of information has no control over the quality of information sent; therefore, VTC must monitor integrity of all transmitted information.
- There is a need to design the entire AIS with attention to source, sink, and links; much work is needed to complete system implementation.
- At Warnemunde VTC modern radar coverage is available, and AIS signals can be integrated within radar displays.
- At long distances (20 miles) there is a significant difference between radar and AIS location.
- At BSH, the laboratory performs tests and certification of all AIS devices (type approval) with the manufacturer contributing the equipment for

these tests and covering the cost of the tests. It is not clear whom the U.S. Coast Guard will use to perform similar approval work in the United States.

- The position of the German authorities is that the minimal IMO display is not suitable for shipboard navigation or other functions but is useful only for checking the operability of the system. For any navigation or collision avoidance function, a more sophisticated display will be necessary.
- The BSH authorities believe that AIS is usually displayed in electronic chart format because that is the easiest solution at present. However, for a display to be useful to the mariner, it should be either a close-in collision avoidance device or a longer-range strategic voyage-planning device. Two displays may be best (one for each purpose). The close-in display might integrate ARPA and AIS data to show other vessel locations, ID, tracking, and so forth. The strategic display might incorporate electronic charts with long-range traffic data.
- BSH is now experimenting with techniques for integrating AIS and ARPA data in one display.

Appendix C

Shipboard Display of Automatic Identification System Requirements

Requirement Number	Operationalization	Source
Requirement Type: Information and Task Requirements (Requirement No. 1.0)		
1.1.1	Description: Class A Functional Requirements	
1.1.1.1	The shipboard AIS is designed to provide identification, navigation information, and vessel's current intentions to other ships.	IALA AIS Guidelines, Oct. 31, 2001, 2.4
1.1.1.2	AIS shall provide ship-to-ship collision avoidance information.	IALA AIS Guidelines, Oct. 31, 2001, 1.2.2
1.1.1.3	AIS shall receive and process information from other sources, including that from a competent authority and from other ships.	IALA AIS Guidelines, Oct. 31, 2001, 1.2.2
1.1.1.4	AIS shall respond to high-priority and safety-related calls with a minimum of delay.	IALA AIS Guidelines, Oct. 31, 2001, 1.2.2
1.1.1.5	AIS shall provide positional and maneuvering information at a data rate adequate to facilitate accurate track-keeping.	IALA AIS Guidelines, Oct. 31, 2001, 1.2.2
1.1.1.6	AIS shall be capable of sending ship information such as identification, position, course, speed, ship's length, draft, ship type, and cargo information to other ships and aircraft and to the shore.	IALA AIS Guidelines, Oct. 31, 2001, 1.2.2
1.1.1.7	AIS can have an aid to navigation transmit its identity, its state of "health," and other information such as real-time tidal height, tidal stream, and local weather to surrounding ships or back to the shore authority.	IALA AIS Guidelines, Oct. 31, 2001, 3.3.3
1.1.1.8	AIS can convert radar target information from a VTS center and retransmit it to AIS-fitted vessels in the area as pseudo-AIS targets.	IALA AIS Guidelines, Oct. 31, 2001, 3.4.2

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Requirement Number	Operationalization	Source
1.1.2	Description: Class A Derivative Functional Requirements	
1.1.2.1	Class A derivatives are not defined in any of the AIS-related documents (IMO, ITU, IEC, IALA). Class A derivatives may be the result of any local or international development for particular groups of users. Examples are inland and coastal navigation, development of personal pilot units, and the use of AIS in harbors for service vessels like tugs, buoy tenders, hydrographic ships, pilot vessels, and so forth.	IALA AIS Guidelines, Oct. 31, 2001, 12.6
1.1.2.2	Class A derivatives are intended to use the same functionality and reporting rate as Class A stations on VDL message level. The main difference between Class A and Class A derivatives is that not all mandatory components of Class A stations must be included.	IALA AIS Guidelines, Oct. 31, 2001, 12.6
1.2	Description: Minimum Display Requirements—Class A	
1.2.1	The AIS display shall provide at least three lines of 16 alphanumeric characters, sufficient to obtain the target vessel's identity and position.	IEC TC 80 Test Standard IEC 61993-2, June 2001
1.2.2	The minimum mandated display provides not less than three lines of data consisting of bearing, range, and name of a selected ship.	IALA AIS Guidelines, Oct. 31, 2001, 4.2
1.2.3	The minimum keyboard and display indicates alarm conditions and means to view and acknowledge the alarm.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.4	When the minimum keyboard and display AIS unit gives an alarm, the display indicates to the user that an alarm is present and provides a means to display the alarm.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.5	When an alarm is selected for display on the minimum keyboard and display, it is possible to acknowledge the alarm.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.6	Other data of the ship can be displayed on the minimum mandated display by horizontal scrolling of data, but scrolling of bearing and range is not possible.	IALA AIS Guidelines, Oct. 31, 2001, 4.2
1.2.7	Vertical scrolling on the minimum mandated display will show all other ships known to AIS.	IALA AIS Guidelines, Oct. 31, 2001, 4.2

Requirement Number	Operationalization	Source
1.2.8	The unit will be fitted with, at least, a minimum keyboard and display or a dedicated dynamic display that interfaces with the AIS.	IALA AIS Guidelines, Oct. 31, 2001, 4.1
1.2.9	A dedicated dynamic display that interfaces with the AIS shall display the unit's operational status (which should be regularly checked).	IALA AIS Guidelines, Oct. 31, 2001, 4.1
1.2.10	A dedicated dynamic display that interfaces with the AIS shall display target information.	IALA AIS Guidelines, Oct. 31, 2001, 4.1
1.2.11	The minimum keyboard and display shall indicate the state/condition change inside the AIS and provide a means to view the state/condition change message.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.12	The minimum keyboard and display may be used to input voyage-related information, such as cargo category, maximum preset static draught, number of persons on board, destination, ETA, and navigational status.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.13	The minimum keyboard and display may be used to input static information such as MMSI number, IMO number, ship's call number, ship's name, length and beam, position reference points for GNSS antenna, and type of ship.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.14	The minimum keyboard and display displays safety-related messages. The minimum keyboard and display will indicate to the operator when a safety-related message has been received and display it on request.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.15	The minimum keyboard and display may be used to input safety-related messages. It is possible to input and send addressed (message 12) and broadcast (message 14) safety-related messages from the minimum keyboard and display.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.16	The minimum keyboard and display may change the AIS unit mode of response to long-range (LR) interrogations.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.17	The minimum keyboard and display sets the AIS to automatically or manually respond to LR interrogations. The mode (LR or default) the AIS unit is in will be displayed where appropriate.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.18	The minimum keyboard and display indicates LR interrogations when in automatic mode and provides a means to acknowledge these indications.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4

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Requirement Number	Operationalization	Source
1.2.19	The minimum keyboard and display indicates LR interrogations when in manual mode.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.20	The minimum keyboard and display provides a means to initiate a reply or cancel a reply to an LR interrogation.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.21	When in manual mode to an LR interrogation, the minimum keyboard and display will indicate that the system was LR interrogated until the operator has replied to the interrogation or canceled the reply.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.22	The minimum keyboard and display may be used to control the AIS channel switching.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.23	It is possible to change the AIS operational frequencies and power settings from the minimum keyboard and display.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.24	The minimum keyboard and display displays GPS position when the internal GNSS receiver is operating as the backup position source for the AIS reporting.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.25	When the AIS is using the internal GPS for position reporting, that position must be continuously displayed.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.26	The AIS unit has an option where it uses the internal GPS receiver position information for position reporting. When in this mode, the position that is transmitted by the AIS will be available on the minimum keyboard and display.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.2.27	Some of the above minimum keyboard and display functions can be password protected.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.3	Description: Minimum Display Requirements—Class B	
1.3.1	The minimum keyboard and display unit, as on Class A stations, may not be required on pleasure craft. They may use the Class B station as a black box (to be seen) or connected to a more or less sophisticated display (e.g., ECS/ECDIS) to see and present own position and other AIS targets in relation to the environment.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4
1.3.2	The minimum keyboard and display for Class B stations must have at least one means to program the station with static data during the configuration.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4

Requirement Number	Operationalization	Source
1.4	Description: Minimum Display Requirements— Class A Derivative Stations	
1.4.1	The minimum keyboard and display for Class A derivative stations may not be required.	IALA AIS Guidelines, Oct. 31, 2001, 12.6
1.4.2	Non-SOLAS vessels can use the Class A derivative station configured as • A black box (to allow the vessel to be seen only), • Connected to a more or less sophisticated display (i.e., ECS/ECDIS), or • Other external system for special applications to see and present own position in relation to the environment.	IALA AIS Guidelines, Oct. 31, 2001, 12.6
1.4.3	There must be at least one means to program Class A derivative stations with static data.	IALA AIS Guidelines, Oct. 31, 2001, 12.6
1.5	Description: Target Discrimination Requirements	
1.5.1	Target data derived from radar and AIS should be clearly distinguishable as such.	IMO SN/Circ 217, July 11, 2001, 2.1.7; IALA AIS Guidelines, Oct. 31, 2001, 4.7.6
1.5.2	If more than one target is selected, the source of the data (e.g., AIS, radar) should be clearly indicated.	IMO SN/Circ 217, July 11, 2001, 2.1.8; IALA AIS Guidelines, Oct. 31, 2001, 4.7.7
1.5.3	Correlation between primary radar targets and AIS targets is likely to be required.	IMO SN/Circ 217, July 11, 2001, 2.1.13
1.6	Description: Additional Information Requirements	
1.6.1	If an AIS target is marked for data display, related data from other target sources may be available for display upon operator command.	IMO SN/Circ 217, July 11, 2001, 2.2.6
1.6.2	Mariners should be able to select additional parts of information from AIS targets.	IMO SN/Circ 217, July 11, 2001, 2.1.4; IALA AIS Guidelines, Oct. 31, 2001, 4.7.3

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Requirement Number	Operationalization	Source
1.6.3	Additional parts of information available from AIS targets should be presented in the data area of display.	IMO SN/Circ 217, July 11, 2001, 2.1.5; IALA AIS Guidelines, Oct. 31, 2001, 4.7.4
1.6.4	Additional parts of information should be available from AIS targets and should include the ship's identification (at least the MMSI).	IMO SN/Circ 217, July 11, 2001, 2.1.5; IALA AIS Guidelines, Oct. 31, 2001, 4.7.4
1.6.5	If the additional information available from AIS targets is incomplete, this should be indicated.	IMO SN/Circ 217, July 11, 2001, 2.1.5; IALA AIS Guidelines, Oct. 31, 2001, 4.7.4
1.7	Description: Message Requirements	
1.7.1	Description: Short Safety-Related Message Requirements	
1.7.1.1	Short safety-related messages can be either "addressed" to a specified destination (MMSI) or "broadcast" to all AIS-fitted ships in the area.	IALA AIS Guidelines, Oct. 31, 2001, 2.3
1.7.1.2	Short safety-related messages can include up to 160 six-bit ASCII characters in the text of the message but should be kept as short as possible.	IALA AIS Guidelines, Oct. 31, 2001, 3.2.7
1.7.1.3	Short safety-related messages can be fixed- or free-format text messages.	IALA AIS Guidelines, Oct. 31, 2001, 3.2.7
1.7.1.4	Short safety-related messages should be relevant to the safety of navigation (e.g., an iceberg sighted or a buoy not on station).	IALA AIS Guidelines, Oct. 31, 2001, 3.2.7
1.7.1.5	Operator acknowledgment of short safety-related messages may be requested by a text message.	IALA AIS Guidelines, Oct. 31, 2001, 3.2.7
1.7.1.6	If operator acknowledgment of a short safety-related message is requested, a Binary Acknowledgement Message will be used.	IALA AIS Guidelines, Oct. 31, 2001, 3.2.7
1.7.1.7	Short safety-related messages are an additional means to broadcast maritime safety information.	IALA AIS Guidelines, Oct. 31, 2001, 3.2.7

Requirement Number	Operationalization	Source
1.7.2	Description: Aid to Navigation Message Requirements	
1.7.2.1	Aid to navigation messages can provide information on the location and identification of hazards and marks used for navigation.	IALA AIS Guidelines, Oct. 31, 2001, 3.2.7
1.7.2.2	Aid to navigation messages can provide information of a meteorological or oceanographic nature of benefit to the mariner.	IALA AIS Guidelines, Oct. 31, 2001, 3.3.3
1.7.2.3	Aid to navigation messages can provide information on the operational status of the aid.	IALA AIS Guidelines, Oct. 31, 2001, 3.3.3
1.7.3	Description: Advice of VTS Waypoints/Route Plan Message Requirements	
1.7.3.1	IFM 18 (Advice of VTS Waypoints/Route Plan Message) is used by a VTS center to advise ships of the waypoints and route plans used in that particular VTS area.	IALA AIS Guidelines, Oct. 31, 2001, 3.3.3
1.7.3.2	When transmitting the Advice of VTS Waypoints/Route Plan Message, the VTS center can include up to 12 Advised Waypoints, if available, and a route specified by textual description.	IALA AIS Guidelines, Oct. 31, 2001, 3.4.4
1.7.3.3	If waypoints are transmitted in the Advice of VTS Waypoints/Route Plan Message, a recommended turning radius can be included for each waypoint.	IALA AIS Guidelines, Oct. 31, 2001, 3.4.4
1.7.4	Description: Class B Message Requirements	
1.7.4.1	The following messages or usage of messages are optional for Class B stations: • Send and receive binary message, • UTC and date inquiry and response, • Send and receive safety-related messages, and • Interrogate other vessels.	IALA AIS Guidelines, Oct. 31, 2001, 3.4.2
1.7.4.2	The following messages shall not be sent from Class B stations: • Message 1, 2, 3: Position reports for Class A; and • Message 5: Ship static and voyage-related data for Class A.	IALA AIS Guidelines, Oct. 31, 2001, 12.4.4

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Requirement Number	Operationalization	Source
Requirement Type: Operational and Organizational Requirements (Requirement No. 2.0)		
2.1	Description: AIS Operational Requirements	
2.1.1	AIS shall operate in autonomous and continuous modes.	IALA AIS Guidelines, Oct. 31, 2001, 1.2.2
2.1.2	AIS shall provide information automatically and continuously without involvement of ship's personnel.	IALA AIS Guidelines, Oct. 31, 2001, 1.2.2
2.1.3	AIS should always be in operation.	IALA AIS Guidelines, Oct. 31, 2001, 4.2.1
2.1.4	Whether the ship is at sea or in port, if the master believes that continued operation of AIS might compromise the ship's safety or security, the AIS may be switched off.	IALA AIS Guidelines, Oct. 31, 2001, 4.2.1
2.1.5	If the AIS is switched off, the equipment should be reactivated as soon as the source of the danger has disappeared.	IALA AIS Guidelines, Oct. 31, 2001, 4.2.1
2.1.6	It may be necessary to switch off the AIS or to reduce the transmission power during some cargo-handling operations.	IALA AIS Guidelines, Oct. 31, 2001, 4.2.1
2.1.7	If the AIS is shut down, static data and voyage-related information remain stored.	IALA AIS Guidelines, Oct. 31, 2001, 4.2.1
2.1.8	If no sensor is installed or if the sensor (e.g., the gyro) fails to provide data, the AIS automatically transmits the "not available" data value.	IALA AIS Guidelines, Oct. 31, 2001, 4.2.1
2.2	Description: Security Requirements	
2.3	Description: Privacy Requirements	
Requirement Type: Technical Display Requirements (Requirement No. 3.0)		
Requirement Type: Display Format Requirements (Requirement No. 4.0)		
4.1	Description: Visual Presentation Requirements–Class A	
4.1.1	If AIS information is made available for graphical display, at least the following information shall be provided: vessel position, course over ground, speed over ground, heading, and rate of turn (or direction of turn).	IMO SN/Circ 217, July 11, 2001, 2.1.1; IALA AIS Guidelines, Oct. 31, 2001, 4.7
4.1.2	AIS positional information is displayed relative to the observing vessel.	IALA AIS Guidelines, Oct. 31, 2001, 2.3

Requirement Number	Operationalization	Source
4.1.3	If AIS information is graphically presented on a radar display, radar signals should not be masked, obscured, or degraded.	IMO SN/Circ 217, July 11, 2001, 2.1.2; IALA AIS Guidelines, Oct. 31, 2001, 4.7.1
4.1.4	Whenever graphical display of AIS information is enabled, the graphical properties of other target vectors should be equivalent to those of the AIS target symbols.	IMO SN/Circ 217, July 11, 2001, 2.1.3; IALA AIS Guidelines, Oct. 31, 2001, 4.7.2
4.1.5	Whenever graphical display of AIS targets is enabled, the type of vector presentation (radar plotting symbols or AIS symbols) may be selectable by the operator.	IALA AIS Guidelines, Oct. 31, 2001, 4.7.2
4.1.6	Whenever graphical display of AIS targets is enabled, the active display mode should be indicated.	IALA AIS Guidelines, Oct. 31, 2001, 4.7.2
4.1.7	A common reference should be used for superimposition of AIS symbols with other information on the same display.	IMO SN/Circ 217, July 11, 2001, 2.1.6; IALA AIS Guidelines, Oct. 31, 2001, 4.7.5
4.1.8	A common reference should be used for the calculation of target properties (i.e., TCPA, CPA).	IMO SN/Circ 217, July 11, 2001, 2.16; IALA AIS Guidelines, Oct. 31, 2001, 4.7.5
4.1.9	Indication should be given if own AIS is out of service or switched off.	IMO SN/Circ 217, July 11, 2001, 2.2.7; IALA AIS Guidelines, Oct. 31, 2001, 4.8.7
4.1.10	Greater functionality will be provided by a more capable display, but selection of the type of display is dependent on the user requirement and options offered by manufacturers.	IALA AIS Guidelines, Oct. 31, 2001, 2.3
4.1.11	The danger of overloading the screen would need to be considered.	IALA AIS Guidelines, Oct. 31, 2001, 2.3
4.1.12	AIS vessels can view all VTS-held radar targets and AIS targets as well as those tracks held on their own radar(s) using a proven application of AIS, variously termed “radar target broadcasting” or “VTS footprinting” (the process of converting radar target information from a VTS center and retransmitting it to AIS-fitted vessels in the area as pseudo-AIS targets).	IALA AIS Guidelines, Oct. 31, 2001, 3.4.2

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Requirement Number	Operationalization	Source
4.1.13	IFM 18 (Advice of VTS Waypoints/Route Plan Message) is used by a VTS center to advise ships of the waypoints and route plans used in that particular VTS area.	IALA AIS Guidelines, Oct. 31, 2001, 3.4.4
4.1.14	In order to avoid a situation whereby AIS-fitted vessels incorrectly believe that a VTS authority is receiving data being transmitted via the AIS, all VTS authorities will need to publish by appropriate means their status in respect of AIS.	IALA AIS Guidelines, Oct. 31, 2001, 8.8
4.1.15	Where possible, the date on which a VTS authority intends to incorporate AIS should be promulgated well in advance.	IALA AIS Guidelines, Oct. 31, 2001, 8.8
4.2	Description: Visual Presentation Requirements—Class A Derivatives	
4.2.1	There is no mandatory requirement for Class A derivative stations to carry the same presentation interfaces as Class A stations.	IALA AIS Guidelines, Oct. 31, 2001, 12.6
4.2.2	The position information for Class A derivative stations may be derived from the internal (D)GNSS receiver. In this case, the position information may be displayed and used outside the AIS station for external applications.	IALA AIS Guidelines, Oct. 31, 2001, 12.6
4.3	Description: Visual Presentation Requirements—Class B	
4.3.1	There may be other equipment on board non-SOLAS vessels with interfaces that are noncompliant with IEC 61162-1 standard (ie., RS-232).	IALA AIS Guidelines, Oct. 31, 2001, 12.6
4.4	Description: Display Option Requirements	
4.4.1	The operator may choose to display all or any AIS targets for graphical presentation.	IMO SN/Circ 217, July 11, 2001, 2.1.9
4.4.2	When operators choose to display all or any AIS targets for graphical presentation, the mode of presentation should be indicated.	IMO SN/Circ 217, July 11, 2001, 2.1.9; IALA AIS Guidelines, Oct. 31, 2001, 4.7.8
4.4.3	If color fill is used in display of AIS target symbols, no other information should be masked or obscured.	IALA AIS Guidelines, Oct. 31, 2001, Appendix 4-1

Requirement Number	Operationalization	Source
4.4.4	If the display of AIS symbols is enabled, removing a dangerous target should only be possible temporarily as long as the operator activates the corresponding control.	IMO SN/Circ 217, July 11, 2001, 2.1.10; IALA AIS Guidelines, Oct. 31, 2001, 4.7.9
4.4.5	The AIS symbol for an activated target may be replaced by a scaled ship symbol on a large-scale/small-range display.	IMO SN/Circ 217, July 11, 2001, 2.1.11; IALA AIS Guidelines, Oct. 31, 2001, 4.7.10
4.4.6	If the COG/SOG vector is shown, the reference point should be either the actual or the virtual position of the antenna.	IMO SN/Circ 217, July 11, 2001, 2.1.12; IALA AIS Guidelines, Oct. 31, 2001, 4.7.11
4.4.7	Means should be provided to select a target or own ship for the display of its AIS information on request.	IMO SN/Circ 217, July 11, 2001, 2.1.13; IALA AIS Guidelines, Oct. 31, 2001, 4.7.12
4.4.8	If more than one target is selected, the relevant symbols, corresponding data, and source of the data (e.g., AIS, radar) should be clearly identified.	IMO SN/Circ 217, July 11, 2001, 2.1.13; IALA AIS Guidelines, Oct. 31, 2001, 4.7.12
4.4.9	If zones or limits for automatic target acquisition are set, they should be the same for automatically activating and presenting any targets, regardless of their source.	IMO SN/Circ 217, July 11, 2001, 2.2.1; IALA AIS Guidelines, Oct. 31, 2001, 4.8.1
4.4.10	The vector time set should be adjustable and valid for presentation of any target regardless of its source.	IMO SN/Circ 217, July 11, 2001, 2.2.2; IALA AIS Guidelines, Oct. 31, 2001, 4.8.2
4.4.11	If radar plotting aids are used for the display of AIS information, they should be capable of calculating and displaying collision parameters equivalent to the available radar plotting functions.	IMO SN/Circ 217, July 11, 2001, 2.2.3; IALA AIS Guidelines, Oct. 31, 2001, 4.8.3

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Requirement Number	Operationalization	Source
4.4.12	If the calculated CPA and TCPA values of an AIS target are less than the set limits, a dangerous target symbol should be displayed.	IMO SN/Circ 217, July 11, 2001, 2.2.4; IALA AIS Guidelines, Oct. 31, 2001, 4.8.4
4.4.13	The preset CPA/TCPA limits applied to target data derived from different sensors should be identical.	IMO SN/Circ 217, July 11, 2001, 2.2.4; IALA AIS Guidelines, Oct. 31, 2001, 4.8.4
4.4.14	Means to recover the data for a number of last acknowledged lost targets may be provided.	IMO SN/Circ 217, July 11, 2001, 2.2.4; IALA AIS Guidelines, Oct. 31, 2001, 4.8.5
4.4.15	Preferably, the ability to recover data for targets may be applied to any AIS target within a certain distance.	IMO SN/Circ 217, July 11, 2001, 2.2.5; IALA AIS Guidelines, Oct. 31, 2001, 4.8.5
4.4.16	An automatic display selection function may be provided to avoid the presentation of two target symbols for the same physical target.	IMO SN/Circ 217, July 11, 2001, 2.2.5; IALA AIS Guidelines, Oct. 31, 2001, 4.8.6
4.4.17	The operator should have the option to make reasonable changes to the default parameters of automatic selection criteria.	IMO SN/Circ 217, July 11, 2001, 2.2.6
4.4.18	Means should be provided to display alarm messages from own AIS.	IMO SN/Circ 217, July 11, 2001, 2.2.6
4.5	Description: Symbology Requirements	
4.5.1	If AIS information is graphically presented, the symbols described in the Appendix to SN/Circ 217, July 11, 2001 (repeated in IALA AIS Guidelines, Oct. 31, 2001, Appendix 4-1) should be applied.	IMO SN/Circ 217, July 11, 2001, 2.2.7
4.5.2	Whenever graphical display of AIS information is enabled, the type of vector presentation (radar plotting symbols or AIS symbols) should be selectable by the operator.	IMO SN/Circ 217, July 11, 2001, 2.1.2; IALA AIS Guidelines, Oct. 31, 2001, 4.7.1

Requirement Number	Operationalization	Source
4.5.3	If the calculated CPA and TCPA values of an AIS target are less than the set limits, a dangerous target symbol should be displayed.	IMO SN/Circ 217, July 11, 2001, 2.1.3
4.5.4	If the signal of a dangerous AIS target is not received for a set time, a lost target signal should appear at the latest position.	IMO SN/Circ 217, July 11, 2001, 2.2.4; IALA AIS Guidelines, Oct. 31, 2001, 4.8.5
4.5.5	The lost target symbol should disappear after the generated alarm has been acknowledged.	IMO SN/Circ 217, July 11, 2001, 2.2.5; IALA AIS Guidelines, Oct. 31, 2001, 4.8.5
4.6	Description: Display Synchronization Requirements	
4.6.1	If AIS information is graphically displayed on a radar, the equipment should be capable of appropriately stabilizing the radar image and the AIS information.	IMO SN/Circ 217, July 11, 2001, 2.2.5
4.7	Description: Presentation Priority Requirements	
4.7.1	The presentation of AIS target symbols, except for sleeping or lost targets, should have priority over other target presentations within the display area.	IALA AIS Guidelines, Oct. 31, 2001, 2.3
4.7.2	If an AIS target is marked for data display, the existence of the other source of target data may be indicated.	IMO SN/Circ 217, July 11, 2001, 2.1.4; IALA AIS Guidelines, Oct. 31, 2001, 4.7.3
4.7.3	An automatic display selection function may be provided to avoid the presentation of two target symbols for the same physical target.	IALA AIS Guidelines, Oct. 31, 2001, 4.8.6
4.7.4	The operator should have the option to make reasonable changes to the default parameters of the automatic selection criteria.	IALA AIS Guidelines, Oct. 31, 2001, 4.8.6
4.7.5	If target data from AIS and from radar plotting functions are available, then the activated AIS target symbol should be presented, if the automatic selection criteria are fulfilled.	IMO SN/Circ 217, July 11, 2001, 2.1.4; IALA AIS Guidelines, Oct. 31, 2001, 4.7.3, 4.8.6

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Requirement Number	Operationalization	Source
4.7.6	If targeted data from AIS and from radar plotting functions are available and the automatic selection criteria are not fulfilled, the respective symbols should be displayed separately.	IMO SN/Circ 217, July 11, 2001, 2.2.6; IALA AIS Guidelines, Oct. 31, 2001, 4.8.6
4.8	Description: Alarm Requirements	
4.8.1	If the calculated CPA and TCPA values of an AIS target are less than the set limits, an alarm should be given.	IMO SN/Circ 217, July 11, 2001, 2.1.5; IALA AIS Guidelines, Oct. 31, 2001, 4.7.4
4.8.2	If the signal of a dangerous AIS target is not received for a set time, an alarm should be given.	IMO SN/Circ 217, July 11, 2001, 2.2.4; IALA AIS Guidelines, Oct. 31, 2001, 4.8.5
4.8.3	Means should be provided to acknowledge alarm messages from own AIS.	IMO SN/Circ 217, July 11, 2001, 2.2.5; IALA AIS Guidelines, Oct. 31, 2001, 4.8.7
Requirement Type: Physical Layout Requirements (Requirement No. 5.0)		
5.1	Description: Display Integration Requirements—Class A	
5.1.1	AIS should be integrated to one of the existing graphical displays on the bridge or a dedicated graphical display.	IMO SN/Circ 217, July 11, 2001, 2.2.7
5.1.2	Ideally, AIS would be displayed on the ship's radar, electronic chart display and information system, or a dedicated display. This would provide the greatest benefit to the mariner.	IALA AIS Guidelines, Oct. 31, 2001, 2.3
5.1.3	AIS has the facility to send its information to an external display medium such as radar, electronic chart display and information system, or an integrated navigation system.	IALA AIS Guidelines, Oct. 31, 2001, 2.3
5.1.4	Most of the vessels that are piloted will be fitted with AIS according to the SOLAS convention. The onboard AIS has a pilot/auxiliary input/output port that provides the facility to forward the own vessel's GNS/DGNSS information, heading, and (optional) rate of turn continuously, independently of (i.e., faster than) the standard AIS reporting rate.	IALA AIS Guidelines, Oct. 31, 2001, 7.5

Requirement Number	Operationalization	Source
5.1.5	Options for AIS may include connection to external GNSS/DGNSS equipment and sources of navigational information from ship's equipment.	IALA AIS Guidelines, Oct. 31, 2001, 2.4
5.1.6	The shipboard AIS is connected to a power source, an antenna, and a variety of shipboard equipment, or to the integrated navigation system.	IALA AIS Guidelines, Oct. 31, 2001, 4.1
5.2	Description: Display Integration Requirements—Class A Derivatives	
5.2.1	A pilot workstation combined with portable AIS is used primarily to provide marine pilots with the capability to carry on board an AIS station when piloting vessels not fitted with AIS. Such a pilot pack contains GNSS/DGNSS, AIS, (optional) heading sensor, and a workstation.	IALA AIS Guidelines, Oct. 31, 2001, 7.5
5.3	Description: Display Lighting Requirements	
5.4	Description: Display and Control Surface Requirements	
5.5	Description: Sound and Noise Requirements	
5.6	Description: Thermal Condition Requirements	
Requirement Type: Environmental Requirements (Requirement No. 6.0)		

SOURCES

Abbreviations

ANSI	American National Standards Institute
IALA	International Association of Aids to Navigation and Lighthouse Authorities
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ISO	International Standards Organization
NRC	National Research Council

ANSI. 1998. *American National Standards for Human Factors, Human Computer Interaction Standards.* ANSI HFES HCI 200.

ANSI. 2001. *American National Standards for Human Factors, Engineering of Visual Display Terminal Workstations.* ANSI HFS 100.

ANSI. 2002. *American National Standards for Structured Query Language.* ANSI SQL.

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Study Committee Biographical Information

Martha R. Grabowski, *Chair,* is Director of the Information Systems Program at Le Moyne College, as well as a Research Professor at Rensselaer Polytechnic Institute, where she earned a Ph.D. in management/information systems, an M.S. in industrial and management engineering, and an M.B.A. in management information systems. She earned a B.S. in nautical science and marine transportation from the U.S. Merchant Marine Academy at Kings Point. She holds a U.S. Coast Guard Merchant Marine license (Second Mate, Unlimited Tonnage, Any Oceans, Radar Observer) and retired as a Lieutenant Commander in the U.S. Naval Reserve. Her teaching and research interests cover the design and development of advanced technology systems, particularly embedded intelligent real-time systems; human and organizational error; risk mitigation in safety-critical systems; and the impact of technology on people and organizations in large-scale systems. Dr. Grabowski teaches, lectures, and is widely published in these research areas in journals, conference proceedings, reports, working papers, and books. She is a member of the American Bureau of Shipping and a member of the Marine Board; she has served on various Marine Board committees. Dr. Grabowski is also a member of the National Research Council's standing Committee on Human Factors.

Carl E. Bowler, a 1959 graduate of the California Maritime Academy, served as an unrestricted line officer aboard U.S. Navy vessels. After his military service, he returned to the merchant marine and sailed in all licensed deck officer capacities for United States–flag companies, ending his offshore seagoing career as Master for States Steamship Company. For more than 26 years, Captain Bowler has served as a California State Licensed Pilot for San Francisco Bay and tributaries, including the inland river ports of Sacramento and Stockton. In addition, he has acted as the San Francisco Bar Pilots' liaison to the U.S. Army Corp of Engineers, the U.S. Coast Guard, the National Ocean Service of the National Oceanic and Atmospheric Administration, and other state and local agencies dealing with navigation matters in San Francisco Bay. He served for many years as Chair of both the Navigation and Technical Committee of the American Pilots Association, a professional association of state licensed marine pilots, and the San Francisco Bar Pilots Technology Committee. During his tenure, he was involved in the evaluation and implementation of emerging technologies useful to the practice of piloting. Captain Bowler is a member of a number of professional associations, including the American Pilots Association, the Council of American Master Mariners, and the Nautical Institute.

Elizabeth J. Gedney works for Victoria Express. She is a former Vice President of Marine Operations for Clipper Navigation, Inc., an operator of high-speed passenger ferries in Puget Sound with principal routes from Seattle to Victoria, British Columbia. She is a licensed deck officer and a graduate of the California Maritime Academy. She is a member of two Coast Guard/Department of Transportation advisory committees—Merchant Marine Personnel and Navigation Safety. She is an active member of the Passenger Vessel Association and serves on its regulatory issues committee. Captain Gedney has extensive experience as a licensed officer operating offshore towing and high-speed passenger vessels. She currently manages the operations of a growing fleet of passenger and specialty cargo vessels and is responsible for all operating personnel and their training. She has also served as deck officer aboard towing vessels and passenger ferries and was responsible for the safety of operations for these vessels.

Douglas J. Grubbs is a commissioned pilot with the Crescent River Port Pilots Association (with both a Master of Rivers and a First Class Pilot's license) and serves as the congressional liaison for the association. An expert in navigation technology, Captain Grubbs was the principal architect of the New Orleans Vessel Traffic Safety System and Vessel Traffic Center. He chaired the VTS subcommittee of the Lower Mississippi River Safety Advisory Council and the American Pilots Association Gulf South Region Technical Committee for developing and evaluating pilots' portable Differential Global Positioning System navigational equipment. He was the principal architect of the watershed Memorandum of Agreement between the United States Coast Guard and New Orleans pilots establishing the first public–private partnership between the two organizations. He is an active member of the International Association of Lighthouse Authorities and the Radio Technical Committee for Maritime Services, and he is an active participant in automatic identification systems (AIS) technical training system development with the Lockheed-Martin AIS/VTS systems, SAAB Transponders, Ross Electronics AIS systems, Offshore ECDIS systems, and ICAN, Inc., software. Captain Grubbs has been awarded the Key to the City of New Orleans; the Board of Commissioners for the Port of New Orleans Award for Ship Handling; a Citation of Appreciation from the China Union Lines for heroism; the United States Department of Commerce Maritime Administration Meritorious Service Award for Heroism and Ship Handling; and, most recently, the United States Coast Guard Federal Gold Lifesaving Medal.

Don K. Kim, a registered professional engineer with AMSEC LLC, M. Rosenblatt & Son Group (MR&S), has more than 13 years of experience in the design, analysis, modification, installation, maintenance, and repair of shipboard mechanical systems, equipment, and components. He has M.E. and B.S. degrees in mechanical engineering from the University of Virginia. Mr. Kim has expertise in propulsion and auxiliary equipment, including steam, gas turbine, diesel, and electric propulsion systems; pumps; compressors; fans; valves; heat exchangers; and filters. He has conducted feasibility studies and engaged in preliminary, contract, and detailed ship design, including circular of requirements and specifications development. Mr. Kim has provided engineering technical support to NAVSEA 03 technical codes, the DDG 51 construction program, the AOE 10 contract design effort, the LPD 13 conversion program, the Program Executive Office for Aircraft Carriers, and is currently the MR&S Program Manager for the Uniform National Discharge Standards program. He also has an interest in total shipboard automation and human systems integration. Seven of the 13 years of experience that Mr. Kim has in the marine engineering industry have involved program management and project leadership.

John D. Lee is Associate Professor of Industrial Engineering at the University of Iowa. He has a background in engineering and psychology, with a Ph.D. in mechanical engineering from the University of Illinois at Urbana–Champaign. He has 10 years of research and consulting experience aimed at matching human capabilities to the demands of technologically intensive systems. Before moving to the University of Iowa, Dr. Lee was a research scientist and deputy director at the Battelle Human Factors Transportation Center. His research interests include interface design, human adaptation to technological innovation, and human performance modeling. This research addresses human error and performance in a broad range of application domains, from process control and the maritime industry to driving. His current research projects address modeling driver behavior, understanding and mitigating the distraction potential of in-vehicle technology, and trust in automation. He is the author of approximately 100 journal articles, book chapters, conference papers, and technical reports.

Robert G. Moore is the President of Coastwatch, Inc., a maritime consulting firm specializing in government and industry projects to improve safety and vessel operations as well as other coastal zone work. He has more than 40 years of experience in maritime and international affairs. He is a master mariner and a retired Coast Guard officer with special expertise in ship operations and marine navigation. Captain Moore served as military readiness/operations program manager in the Coast Guard, represented the United States at foreign conferences, managed multinational navigation systems, and was public safety advisor for the Agency for International Development to the Government of Somalia. His consulting assignments and publications cover subjects such as coastal defense missions of the Coast Guard, vessel traffic management, command and control systems, and surveillance. Captain Moore served as a member of the Marine Board Committee on Maritime Advanced Information Systems. He has a B.S. in Engineering from the U.S. Coast Guard Academy and received continuing education at the Naval War College and the Industrial College of the Armed Forces.

Roy L. Murphy is the Director of Corporate Training for Kirby Corporation. Kirby Corporation operates the largest tank barge fleet in the world. He has more than 25 years of experience instructing and directing maritime training programs. Mr. Murphy is the former Director of Training at the National River Academy of the United States. He is certified to teach a number of nautical science courses, including Radar Observer (Unlimited), Tankerman PIC (Barge) Dangerous Liquid, Mate, Towing Vessel, Navigation and Piloting, and Fire Fighting (Barge). Mr. Murphy holds a U.S. Coast Guard Masters' license, a Radar Observer (Unlimited) certification, and a Tankerman PIC (Barge) Dangerous Liquid endorsement. He has served as a member of numerous government and industry committees and subcommittees, including the Merchant Marine Personnel Advisory Committee and the Towing Safety Advisory Committee. Mr. Murphy earned a B.S. in education from Arkansas State University.

Nadine B. Sarter received her Ph.D. in Industrial and Systems Engineering from the Ohio State University in 1994. From 1996 to 1999 she was an Assistant Professor in the Institute of Aviation at the University of Illinois at Urbana–Champaign, where she held coappointments with the Departments of Psychology, Mechanical and Industrial Engineering, and the Beckman Institute. In 1999, she joined the faculty in the Department of Industrial, Welding, and Systems Engineering and the Institute for Ergonomics at the Ohio State University, where she also holds a joint appointment with the Department of Psychology. Her research interests include human–automation communication and coordination (primarily in high-risk, event-driven domains such as aviation), multimodal human–machine interfaces/interaction, error prevention and management, and attention and interruption management.