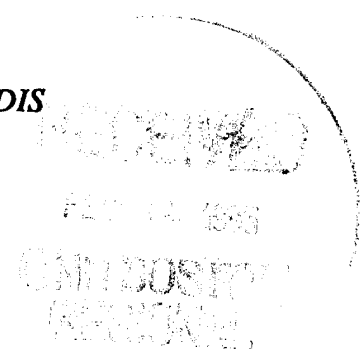


U.S. ECDIS Test Bed Project

Evaluation of Proposed IMO Performance Standard for ECDIS

(HGE draft version 2, September 1992)

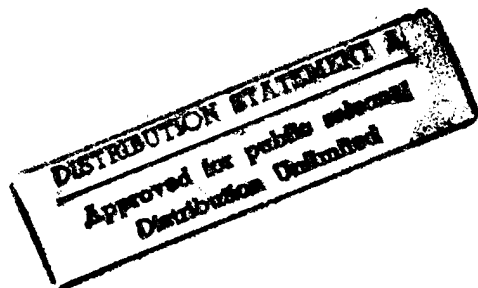


by the

Marine Policy Center
Woods Hole Oceanographic Institution



March 1993



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INFORMATION PROCESSING AND DECISION SUPPORT
IN THE MARINE ENVIRONMENT:
ELECTRONIC CHART DISPLAY AND INFORMATION SYSTEM (ECDIS)
TEST AND DEMONSTRATION PROJECT

Evaluation of Proposed IMO Performance Standards for ECDIS

(HGE draft version 2, September 1992)

Submitted to

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24 March 1993

by the

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Table of Contents

	<i>page</i>
Executive Summary	2
1. Introduction	4
2. Background and History of U.S. ECDIS Test Bed Project	5
3. Methodology for Evaluation of the Proposed IMO Standard	8
1. Overview	8
2. Theory of standards	9
3. System analysis of navigational safety	9
4. Development of SRS and SDS	10
5. Assembly of a compliant ECDIS	10
6. Sea trials of Intergraph ECDIS	10
7. Commercial ECDIS user interviews	11
8. Expert commentary on DPS	12
4. Findings and Recommendations	13
1. General	13
2. Recommendations and Comments on IMO DPS	15
3. Concluding remarks	36
5. References	38
App. A Intergraph SRS and SDD	
App. B Intergraph ECDIS Documentation	
App. C Sea Trials Test Plan and Questionnaire	
App. D Sea Trials Data	
App. E Membership of U.S. ECDIS Test Bed Project Consultative Group	

(Appendices are available on request from the Marine Policy Center, WHOI.)

Executive Summary

The U.S. ECDIS Test Bed Project has undertaken the evaluation of a proposed IMO performance standard for electronic charts (ECDIS). This work is based on three major premises, which set it apart from other efforts to evaluate the proposed standard: (1) the need to supplement existing practical experience by designing, constructing, and testing a device that could actually meet (or exceed) the requirements of the proposed standard; (2) the importance of direct evaluations by those with practical experience in the use or manufacture of electronic chart devices; and (3) the need to stand back from the details of the proposed standard far enough to capture potential missing elements and alternative (better) approaches.

The Test Bed Project has conducted research to support its evaluation of the standard over the course of more than two years. This research effort consists of the following: (1) the theory of technological standards and their effects in marine electronics; (2) system analysis of navigational safety and the potential contribution of electronic charts; (3) development of system requirement and system design specifications for a standard-compliant ECDIS; (4) assembly of a compliant ECDIS; (5) sea trials using a compliant ECDIS; (6) interviews with users of commercially available electronic chart systems; and (7) expert commentary on the proposed standard.

Because of delays in the delivery of critical government funds, much of the operational testing and sea trials remain to be done as of March 1993. Nonetheless, considerable progress has been made toward our objectives, and the Test Bed Project at this time is in a position to make recommendations to IMO, IHO, and HGE regarding the proposed standard, based upon four major findings of the project's research efforts to date:

(1) The main legitimate objective for the standard is to ensure that ECDIS contributes to safety of navigation, primarily by safeguarding against potentially hazardous performance features that are not readily obvious to buyers/users of the equipment. Other legitimate objectives for the IMO ECDIS standard -- reference in carriage requirements, stability in requirements, etc. -- are secondary to the primary objective and will follow readily if the primary objective is accomplished.

(2) Within the above constraint, the standard should be as non-restrictive as possible. IMO's intention to make this a "minimum performance" standard is appropriate; the standard should not specify anything that is not absolutely necessary ("minimum"), and it should focus firmly on "performance" and not on design parameters or operational instructions.

(3) The major safety gain from ECDIS comes from its application to "route monitoring," i.e. the real-time graphical presentation of position, heading, and track against charted hazards in the vessel's vicinity on a display that is readily accessible to the conning officer.

(4) Realistic expectations of availability of official, government hydrographic authority data sets, as well as backup requirements, suggest that the "equivalence" provision in the proposed standard ought to be reformulated to enable the "sanctioned" use of ECDIS for route monitoring with interim (publicly or privately supplied) data sets.

(5) Work on the proposed standard should continue in an HGE-like setting until the issues raised in this report have been resolved. With continued, diligent effort, it should be possible to complete the necessary revisions of the proposed standard in time for an IMO assembly vote in 1995.

Broadly, these major findings suggest that the proposed standard can be made less restrictive. At the present stage of operational experience with electronic chart systems on large vessels, the cause of safety at sea can benefit from operational experience with alternative designs for electronic chart systems. The minimum performance standard should assure that safety is not degraded in the process. It should also assure that what we know with some certainty to be the primary safety-enhancing features of ECDIS are incorporated in any equipment that may be mandated. This perspective, together with expert/user commentary on the standard, forms the basis for our comments and recommendations regarding specific provisions in this report.

It is important that the provisions of the standard to which we draw attention in our comments and recommendations be considered carefully before a standard is adopted that -- despite the best intentions of IMO and IHO -- hinders the interest of safety of navigation by restricting ECDIS to sub-optimal designs, or by delaying the realization of its safety benefits through unattainable data requirements.

1. Introduction

Only time and the law will ultimately decide what type of ECDIS display constitutes 'the legal equivalent to the paper chart.' It may even evolve that there are a whole range of 'legal equivalents' depending on the situation, e.g. maneuvering the ship alongside, negotiating a congested harbor, approaching a coastline, or well away from land. Since so few even rudimentary ECDIS exist today and it will be many years before their role progresses from Navigation Aid toward something approaching 'the legal equivalent of the paper chart', it is probably best for the next few years to (a) encourage a continuation of the discussions among the mariners, hydrographers and manufacturers that are presently taking place, and (b) continue the experimentation and field testing that is going on in various parts of the world.

Report of the IHO/COE Working Group on
Updating the Electronic Chart, Appendix 1
to IHO Special Publication 52, 1990,
Section 7.10

The Electronic Chart Display and Information System (ECDIS) is a shipboard information management tool that carries significant promise for improved safety and efficiency of ship handling. The technology can bring together in a single electronic display much crucial information about charted and uncharted hazards as well as a real-time display of ship's position and velocity. This combined with a display of the ship's intended route provides a new and strongly graphic means for monitoring the adherence of the ship to a known safe route of passage.

ECDIS technology has become feasible because of a) advances in desktop and workstation computer technology including powerful graphics processing software capabilities; 2) precise and automatic electronic navigation systems with wide geographic coverage, such as the NAVSTAR satellite navigation facility; and 3) advances in electronics miniaturization, packaging, and reliability that allows routine applications of electronics at sea. Although adoption of this technology by the maritime transportation industry seems inevitable (it was adopted by the aeronautical industry many years ago) there remains a need for the setting of uniform, safe performance standards for ECDIS, as well as eventual introduction of national carriage requirements. This report addresses an international performance standard for ECDIS.

The project was funded by the U.S. Coast Guard using monies transferred to the Office of Naval Research (ONR), which agency administered the program. The project, though formally self-standing, is related to a much larger effort known as the U.S. ECDIS Test Bed Project. For the purpose of adherence to the ONR grant schedule it is necessary to make the distinction, but in preparing this report we have drawn freely from the larger effort to elaborate as fully as possible on goals identified at the outset for the smaller project. In effect, the U.S. Coast Guard and ONR thereby receive the benefit of a total investment that is about an order of magnitude greater than the funds which directly supported this report.

2. Background and History of U.S. ECDIS Test Bed Project

Discussion surrounding the U.S. ECDIS Test Bed Project began in 1988 and has evolved in response to many factors: the formal request by the International Maritime Organization (IMO) in 1989 for member states to evaluate the Provisional Performance Standards for ECDIS (IMO 1989); heightened attention in 1989 to maritime safety and environmental pollution following the Prince William Sound oil spill; increased and diversified attention to maritime transportation safety in the U.S. Congress, as manifested in the Oil Pollution Act of 1990 and the Vessel Safe Navigation and Marine Environment Protection Act of 1991 (Hochbrueckner, 1991); heightened priority assigned to maritime transportation safety by government agencies responding to Congress; and individual interests and priorities of public and private Project participants in the project as the capabilities and implications of ECDIS technology broaden and take on new perspective. Sea trials conducted elsewhere on ECDIS-like equipment, commercial developments in ECDIS, and changes in the provisional or draft IMO performance standards are other factors affecting the course of the Project.

The U.S. ECDIS Test Bed Project is a non-commercial, cooperative effort among government, private, and academic organizations to support and assess the international adoption of electronic chart technology by the maritime transportation industry. Many public and private participants are working together on the ECDIS Test-Bed Project (see Table 1). The Project is

Table 1: Contributors to the U.S. ECDIS Test Bed Project (as of January 1993).

ORGANIZATION AND COORDINATION	DIGITAL DATABASES
Woods Hole Oceanographic Institution, Marine Policy Center Radio Technical Commission for Maritime Services U.S. Coast Guard (G-NSR) U.S. National Ocean Service (NOAA)	U.S. National Ocean Service/NOAA (DX-90) Australian Hydrographic Office (DX-90) U.S. Defense Mapping Agency (VPF) Japan Maritime Safety Agency (DX-90)
FUNDING	ENGINEERING & TECHNOLOGY
American Petroleum Institute U.S. Coast Guard Exxon Shipping Company U.S. Defense Mapping Agency Australian Hydrographic Office Hellenic Marine Environment Protection Association U.S. Army Corps of Engineers Lloyd's Register of Shipping American Telephone and Telegraph Marine Spill Response Corporation	Raytheon Marine Company RACAL DECCA Marine Electronics Company COMSAT Maritime Services Magnavox Electronic Systems Company
PRINCIPAL CONTRACTORS	SHIPS-OF-OPPORTUNITY
Intergraph Corporation Digital Directions Co., Inc.	Exxon Shipping Company (tank vessel) American President Lines (container ship) Hapag-Lloyd (container ship) Woods Hole, Martha's Vineyard & Nantucket Steamship Authority (ferry) Pacific & Oriental Lines (ferry) U.S. Coast Guard (buoytender) U.S. Maritime Administration (research vessel)

coordinated by the Woods Hole Oceanographic Institution's Marine Policy Center (MPC). The principal motive behind the project is improved safety of ship operation, including reduced loss of valuable and hazardous cargos, and improved marine environmental protection. Most immediately, the Project supports the U.S. Coast Guard in formulating a U.S. position on the Draft Performance Standards for ECDIS taking shape within IMO.

Planning for an ECDIS test and demonstration project in the United States began in the Radio Technical Commission for Maritime Services (RTCM), a private radio technology association based in Washington, D.C. Specifically, they originated in the Special Committee 109 on Electronic Charts chaired by Mr. Mortimer Rogoff and involved the Woods Hole Oceanographic Institution beginning in 1988. Early planning accompanied the writing of RTCM Performance Standards for ECDIS (RTCM 1989), prepared partly in support of the U.S. submission to the Harmonization Group on ECDIS (HGE), a special working group of the International Maritime Organization (IMO) and International Hydrographic Organization (IHO).

Stated in its broadest context, the goal of the U.S. ECDIS Test Bed Project is to give modern electronic technology a higher priority as a proactive, economical, preventative measure in reducing the occurrence and environmental impact of maritime accidents. The objectives listed below are intended to support national and international organizations in placing greater emphasis on electronic chart technology in addressing maritime safety and environmental protection issues:

(1) Since the formal beginning of the Project, a *primary objective* has been to support the U.S. Coast Guard, the designated U.S. Delegate to IMO, in formulating a U.S. position on the performance standards for ECDIS. The adoption of a single, effective international standard is essential to the writing of carriage requirements, and in spurring the private sector to develop and produce ECDIS technology. Several offices or branches of the Coast Guard are themselves active participants in the project and have had a significant effect in steering its course and emphasis. As indicated elsewhere (Alexander and Klingler, 1992) the Coast Guard plans to incorporate additional information as well, such as results of human factors research conducted using a ship simulator facility; shipboard observations on commercially available ECDIS and ECDIS-like equipment; and cooperative research with the Canadian Coast Guard and Canadian Hydrographic Office.

(2) A *second major objective* of the Test Bed Project has been to support the National Ocean Service (Coast and Geodetic Survey) in developing its capabilities for producing electronic navigational charts (ENCs). The worldwide availability of official, standardized chart databases remains one of the most challenging aspects surrounding the introduction of ECDIS. Over the past few years, experimental digital charts have been produced by NOS according to evolving specifications of the IHO hydrographic data transfer standard, DX-90 (as defined in SP57). Over the past year, the Test Bed Project, through Intergraph Corporation, has worked interactively with NOS in the preparation of the charts needed for sea trials. The first charts available, delivered in April 1992, are for Woods Hole and adjacent waters. Eventually, charts for other port areas of the U.S. are expected to be available from NOS. In order to display the

NOS ENC's, translation software has been written by Intergraph Corporation. The experimental ECDIS unit on which the ENC's can now be displayed and manipulated has been designed and is to a great extent complete.

Other participants in the Project have prepared digital charts as well. One example is a DX-90 digital chart of Sydney Harbor prepared by the Australian Hydrographic Office. This independently prepared chart provides a valuable opportunity to evaluate aspects of the IHO data exchange standard. Another example is Vector Product Format digital nautical charts of New York Harbor and Norfolk area, completed in December 1992 by the Defense Mapping Agency (DMA). DX-90 charts of Japanese waters have been provided by the Japan Maritime Safety Agency.

(3) *A third objective* of the Test Bed Project is technology demonstration and assessment of ECDIS capabilities and applications. This objective goes back to the original discussions of a test and demonstration project in 1988. Examples of activities in this area include: the planned demonstration and assessment of radar video overlay; automatic chart updating and local warnings assessment currently in the planning stage; and assessments of integration of other data and sensors into the experimental ECDIS unit. Specific planning for research on, and at sea testing of, navigation sensor integration, and implications for manual and autopilot control of the vessel, is described by Pease (1992).

(4) *Fourthly*, we are interested in exploring solutions to ECDIS implementation problems, such as the "legal equivalency" of ECDIS to paper charts; chart and product liability; and commercial access to government chart data bases. This area of the Project has had to take a lower priority relative to the above objectives, but it is essential that progress be made on these issues.

3. Methodology for Evaluation of the Proposed IMO Standard

3.1. Overview

No-one knows with certainty what commercial electronic chart systems will look like and how they will be used a few years from now. The sparsity of operational and commercial experience with electronic charts makes standard setting at this stage difficult. The authors of draft standards for large-vessel electronic charts at IMO, IHO, and RTCM have had very few operational data on which to base their efforts. Anticipatory standard setting under such circumstances can create unexpected and undesired results (see Kite-Powell, 1992).

The U.S. ECDIS Test Bed Project's evaluation of the proposed IMO standard employs both theoretical analysis and practical experience. No test program can simulate realistically the years of operational experience necessary to obtain solid performance data for a product that, like electronic charts, will be used and manufactured in many different configurations and circumstances. However, it is possible to produce a credible critique of the proposed standard by examining the available practical experience and expert opinion through a filter of systematic analysis of how standards work, what electronic charts can contribute to maritime safety, and why an IMO standard for ECDIS might be needed.

Three fundamental premises guided the work of the U.S. ECDIS Test Bed Project:

- (1) the need to supplement existing practical experience by designing, constructing, and testing a device that could meet (and exceed) the requirements of the proposed standard;
- (2) the importance of direct evaluations of the proposed standard by those with practical experience in the use and manufacture of electronic chart devices; and
- (3) the need to stand back from the details of the proposed standard far enough to capture potential missing elements and identify better approaches.

These premises are reflected in the project's research and data collection activities, listed here and described in more detail below:

- (1) investigation of the theory of technological standards and their effects in marine electronics;
- (2) theoretical systems analysis of navigational safety and the potential contribution of electronic charts;

- (3) development of system requirement and system design specifications for a standard-compliant ECDIS;
- (4) assembly of a compliant ECDIS;
- (5) sea trials using a compliant ECDIS;
- (6) interviews with users of commercially available electronic chart systems; and
- (7) collection of expert commentary on the proposed standard.

3.2. Theory of standards

WHOI conducted an investigation into the rationale, processes, and effects of technological standards in marine electronics to determine criteria for standards evaluation and identify potential pitfalls. This work was pursued as a doctoral dissertation topic by Hauke Kite-Powell (Kite-Powell, 1992).

The dissertation includes a review of the literature on effects of technological standards, a taxonomy of standards, and a framework model of standards and their effects. Three cases drawn from marine electronics are analyzed using the model: radar/ARPA standards, EPIRB (Electronic Position Indicating Radio Beacon) standards, and ECDIS standards.

The research identifies linkages between the circumstances of standard development, technology characteristics, and the effects of the standard. It also reviews the economic rationale for various types of standards. Relevant findings are included below in section 4 (Findings and Recommendations). Complete copies of the dissertation are on file at the WHOI Marine Policy Center and at MIT.

3.3. System analysis of navigational safety

To identify the important safety-enhancing features of electronic chart devices, we consider a system model of the vessel, its operators, and its environment (see Kite-Powell, 1993a). The vessel navigational safety system is centered around the operators, who make decisions about vessel course and speed that affect the vessel's interactions with its hydrographic and marine traffic surroundings (see Wiencke et al, 1980, for a similar, previous model).

The model suggests a process of observation (perception of reality and threat detection), situation analysis and threat calibration (understanding of options), and decision (choice among options) that underlies route monitoring procedures (see Schuffel et al, 1989). Information about the reality of the hydrography and traffic in the vessel's surroundings plays a critical role both in timely threat perception and accurate threat calibration; a failure at either stage is strongly detrimental to safety. Combined with ergonomic considerations of which bridge functions can

be automated (for a range of options, see Iijima and Hagiwara, 1991, and Schuffel et al, 1989), this view of vessel safety suggests that ECDIS can contribute most significantly to safety by providing a real-time graphical display of the vessel's position and track (planned and actual) against a background of the charted navigational hazards relevant to the vessel in its vicinity. See Hederström and Gylden (1992), Grabowski (1990), and Gonin and Crowell (1992) for examples of studies that consider the problem of information for the navigator.

3.4. Development of SRS and SDD

The development of a System Requirement Specification (SRS) and a System Design Document (SDD) were necessary first steps to the development of a test bed ECDIS compatible with the proposed IMO standard. The development of SRS and SDD was undertaken by Intergraph Corporation with guidance from WHOI and Digital Direction, Inc. (see Appendix A).

The SRS sets out a composite specification based on the proposed IMO standard and IHO's SP52, as well as other relevant documents. The SDD provides the basis for hardware and software development to fulfill the requirements of the SRS. These documents proved to be valuable vehicles for development of expertise in the nuances and internal conflicts of the proposed standard. This expertise is reflected in Intergraph's assessment of the draft standard and their numerous informal advisory reports in support of the U.S. delegation to HGE.

3.5. Assembly of a compliant ECDIS

Assembly of a prototype ECDIS compliant with the proposed standard was considered a prerequisite to practical, at-sea evaluation of the standard. It also proved valuable in identifying further ambiguities within the proposed standard from the point of view of the manufacturer. For example, one prominent source of concern has been the operational integration of chart standards and performance standards. These ambiguities may give unclear guidance with the intent of leaving choices to the manufacturer's discretion, or they may indicate shortfalls in the formulation of provisions of the standard.

Many of these ambiguities have been discussed and/or resolved in the U.S. ECDIS Project "Technical Notes" (on file at the Marine Policy Center). The experience gained from the assembly of the test bed ECDIS is also reflected in Intergraph's comments on the proposed standard.

3.6. Sea trials of Intergraph ECDIS

A series of sea trials was scheduled to obtain operational experience with the Intergraph ECDIS and to conduct specific trials designed to shed light on particular issues regarding the proposed standard. A Sea Trials Test Plan was developed with extensive review and participation (see Appendix C). This plan is based not solely on the language of the draft standard, but on an independent assessment of significant issues surrounding the standard, given the objectives of the standard. A first draft was assembled from a meeting of experts on

maritime safety, ECDIS, and standards, held at Woods Hole in May 1992. That draft was refined through subsequent work by project staff and repeated review by the project's Consultative Group and independent experts.

Most of the trials described in the Sea Trials Test Plan are designed to produce three separate streams of data: (1) internal recordings of usage and performance parameters collected by the test bed ECDIS (see Test Plan), (2) project personnel observations (see Test Plan), and (3) questionnaires completed by operators (see Appendix C for a compilation of questions for all trials). Plans call for analysis based on correlation of the first two data sets, supplemented with the third.

Original plans call for sea trials aboard a variety of vessels, including a Coast Guard cutter (the USCGC *Bittersweet*), a Maritime Academy vessel, and commercial ships. Engineering shakedown voyages aboard the WHOI vessel *Eagle Mar* and the Woods Hole, Martha's Vineyard and Nantucket Steamship Authority ferry *Nantucket* have been conducted to date. Because the test bed ECDIS is still in development, no formal administration of Sea Trials Test Plan trials has taken place. However, modified versions of the questionnaire have been given to operators on the *Nantucket* following their use of the test bed equipment over a period of three months.

It is the intention of project management to conduct sea trials aboard commercial vessels as soon as possible in the near future. Companies with whom preliminary arrangements for such trials have been made include Exxon Shipping Company (tanker route between Valdez, Alaska and California), American President Lines (container vessel between U.S. west coast and Asia), Hapag Lloyd (container vessel on North Atlantic/Pacific routes), and Maritrans (tug/barge combinations on northeastern United States coastal routes). Sea trials may also be conducted aboard the USCGC *Bittersweet* and on a vessel operated by the U.S. Merchant Marine Academy in Kings Point, New York.

The results that have been obtained from sea experience with the test bed ECDIS to date are reflected in the findings described in section 4 of this report. See Appendix D and Kite-Powell (1993b) for data from *Nantucket* questionnaires.

3.7. Commercial ECDIS user interviews

Electronic chart equipment, some of it "more or less" in compliance with the proposed IMO standard, has been used on several commercial vessels in the recent past. Although these electronic charts may not be strictly compliant with the proposed standard, valuable experience with the technology has been developed aboard these vessels. A modified version of the sea trials questionnaire was given to operators on such vessels, and the resulting data used in developing the findings discussed in section 4 of this report. The data from these questionnaires were analyzed with a view to the differences and limitations imposed by the use of the respective commercial ECDIS aboard each ship.

Commercial ECDIS users included to date in this study are operators aboard the P&O ferry *European Seaway* between Dover and Zbrugge (using a Racal Decca Chartmaster ECDIS), and officers aboard USCGC *Bittersweet* out of Woods Hole, Massachusetts (using Offshore Systems Ltd. PINS 9000 and ECPINS). Results from these questionnaires are presented in Appendix D; see also Kite-Powell (1993b). In addition, Greek vessel operators and navigators have expressed their views on the prospects of ECDIS through a training seminar and questionnaire administered by the Hellenic Marine Environment Protection Association (HELMEPA).

3.8. Expert commentary on DPS

Several knowledgeable individuals, including primarily manufacturer's representatives, have spent a great deal of their professional lives becoming familiar with the proposed IMO standard for ECDIS (and with related standards). The designers of electronic chart equipment generally have their own reasons for choosing to comply or not comply with certain provisions of the proposed IMO standard. Recognizing that these choices could provide an informed perspective on the proposed standard, we asked some of these individuals to provide us with written comments on the subject. Among those who contributed their time and thought to this effort are Mr. William Pease (Raytheon, retired), Mr. David Scott (Intergraph), Mr. Alan Wheeler (Landon Consultancy and Racal Marine Electronics), Mssrs. Mark Lanziner and Kenneth Deering (Offshore Systems Ltd.), Mr. Frank Cassidy (Datamarine), and Mr. Jack Roeber (Sperry Marine & CIRM).

Finally, several experts in the areas of standard setting, marine transportation, and safety contributed their analysis of the proposed ECDIS standard in less formal ways, such as during Consultative Group meetings and smaller, focused workshops. Notable among these are Prof. Edward Wenk (University of Washington, Seattle), Prof. Charles Perrow (Yale University), Prof. Jesse Ausubel (Rockefeller University), Mr. Alan Wheeler (Landon Consultancy and Racal Marine Electronics), and Mr. Kenneth Burrows (Australian Hydrographic Office).

4. Findings and Recommendations

4.1. General

Expert and user opinion does not come to a simple consensus on many aspects of the proposed ECDIS standard. To synthesize plausible, unambiguous conclusions for this report, WHOI evaluated divergent opinions against a set of four major findings developed from research on the proposed standard. These findings are derived from the research activities described in the previous section, and they govern the recommendations we make in this report.

(1) Based on economics and societal goals, the legitimate primary objective for the standard is to ensure that ECDIS contribute to safety of navigation by safeguarding against potentially hazardous performance features that are not readily obvious to users of the equipment. The history of EPIRB and radar standards (Kite-Powell, 1992) suggests that this is a critical factor for performance standards in marine electronics. Market competition and selection are likely to be the most effective means of arriving at the optimal design of electronic chart systems (Kite-Powell, 1992). Regulatory standards, such as the ECDIS standard, interfere with the normally efficient working of the market, but are justified in so far as they redress a failure of the market mechanism.

Not all failures of the market mechanism to perform efficiently can be corrected by a performance standard. It is important to distinguish the role of a performance standard and a carriage requirement. Carriage requirements for marine electronics are designed to remedy market failures stemming from limitation of liability -- the public policy that historically has held ship owners and operators only partly liable for the damages caused by maritime vessels. Because ship operators can ignore some of the social costs of their operations as "externalities," it is to be expected that ship operators will invest less in accident prevention equipment under a regime of limited liability than society might consider optimal. Carriage requirements are intended to force operators to increase investment in safety equipment. To be enforceable, a carriage requirement for electronic charts, for example, must reference a performance standard.

The other legitimate objectives for the IMO ECDIS standard -- reference in carriage requirements, stability in requirements, compatibility, etc. -- are secondary to the primary objective and will be accomplished if the primary objective is properly attended to. The "compatibility" aspects of a performance standard for ECDIS have been the subject of much debate. Compatibility could be important to ECDIS in two areas: data formats (data bases and updates) and user interface (controls, display, and warnings). In fact, neither is a relevant concern at this time. Hydrographic offices are not yet prepared to provide digital data in a fixed, universally accepted data format (see point 4 below). For user interface standards, existing operational data are too sparse, operating conditions and requirements too diverse, and software too easily modified to justify the formulation of a concrete compatibility standard at this stage.

(2) Within the constraints of (1), the standard should be as non-restrictive as possible. IMO's intention to make this a "minimum performance" standard is appropriate; the standard should not specify anything that is not absolutely necessary ("minimum"), and it should focus firmly on "performance" and not on design parameters. Because IMO standards are stable over many years, specifying design features can lock manufacturers into technological choices which, even if optimal today, may be inefficient in a year or two. An example is the requirement in the IMO radar standard for a display size that was appropriate for phosphorescent screens, but that turned out to be excessive for a high-resolution raster display with automatic target tracking.

(3) The major safety gain from electronic charts comes from real-time graphical presentation of position, heading, and track against potential hazards in the vessel's surroundings during route monitoring. Systems analysis of vessel navigation processes suggests, and operational experience to date confirms, that the major improvements electronic charts can make to safety of navigation come from automation of position plotting, and the associated improved presentation of the vessel's navigation situation (Kite-Powell, 1993a; see also Hederström and Gylden (1992), Grabowski (1990), Iijima and Hagiwara (1991), Schuffel et al (1989), Wiencke et al, (1980), and Gonin and Crowell (1992)). This does not mean that electronic charts do not have the potential for other benefits, but it does suggest that a minimum performance standard ought to focus on this function.

(4) Realistic expectations for the availability of official data sets, as well as backup requirements, suggest that the "equivalence" provision in the proposed standard ought to be reformulated to enable the "sanctioned" use of ECDIS for route monitoring with non-IHO data sets. The original intent of the authors of the proposed standard was for ECDIS to replace the paper chart for both route monitoring and route planning, an objective based in part on overly optimistic expectations of conversion to digital hydrography. While this may indeed be a long-term outcome, it is probably not a near-term reality because of official data set availability schedules, backup requirements, and updating difficulties (it is also not clear that mariners *want* to eliminate their paper charts, particularly for route planning). Until complete and official government data sets are available for all relevant waters, ECDIS cannot be equivalent to the paper chart for route planning. More likely, therefore, ECDIS will be used for many years to come as a route monitoring *supplement* to the paper chart, which will remain for some time the primary route planning tool. To enable the use of ECDIS in commercial shipping until full official data sets are available, there is a need for an interim data set standard for public and private data providers. The use of ECDIS with data conforming to this standard would make ECDIS equivalent (i.e., "at least as effective") *for route monitoring* in the sense of I/5 of SOLAS 1974.

It should be noted that while the concept of "equivalence" has special significance in the context of IMO and SOLAS 1974, it would be a mistake to confine ECDIS entirely, through an undue emphasis on equivalence, to the same category of equipment as paper charts. As many of the authors of the proposed IMO and IHO standards for ECDIS have long realized, ECDIS presents possibilities for the performance of navigation functions that extend far beyond what

the paper chart can provide. It is likely, in fact, that ECDIS is the beginning of a new paradigm for marine navigation altogether. The equivalence "hook" to the SOLAS carriage requirement for paper charts may be useful for the adoption of an IMO standard for ECDIS, but care should be taken that it does not become a stumbling block in the evolution of this new marine navigation technology.

(5) Work on the proposed standard should continue within HGE, or in a similar setting, until the issues raised in our specific comments and recommendations have been resolved (see section 4.2 below). It should be possible to make the necessary changes to the proposed standard in time for acceptance by the IMO assembly in 1995.

Broadly, these major findings suggest that it is possible and appropriate to make the proposed standard less restrictive. At the present stage of operational experience with electronic chart systems on large vessels, safety at sea can benefit from experience with alternative designs for electronic chart systems, which will result in the selection and evolution of superior designs. The minimum performance standard should assure that safety is not degraded in the process. It can assure also that only what we know with some certainty to be the primary safety-enhancing features of ECDIS are incorporated in any equipment that may eventually be mandated for carriage.

Against this background, we present specific recommendations for the proposed IMO standard. It is important that the provisions of the standard to which we draw attention in our comments and recommendations be reconsidered and, in many cases, revised before a standard is adopted that -- despite the best intentions of IMO and IHO -- hinders the interest of safety of navigation by restricting ECDIS to sub-optimal designs, or by delaying the realization of its safety benefits through unattainable data requirements.

4.2. Recommendations and comments on IMO DPS

The following pages contain the text of the September 1992 HGE draft of the IMO DPS for ECDIS. WHOI's suggestions are inserted after each appropriate provision, preceded either by the word "Recommendation:" or by the word "Comment:".

Recommendations are critical suggestions that our findings suggest must be attended to if the standard is to succeed (see provisions 1.2, 2.1.1, 2.1.2, 2.1.3, 2.1.4, 3.8, 4, 8.1, 10.4.2.4, and Appendix 1.1.3). Comments are significant suggestions for improving the proposed standard, but they are not of the same urgency. (Note: "USETB data" refers to findings from U.S. ECDIS Test Bed Project sea trials and questionnaires.)

1. Introduction

1.1 The primary function of the ECDIS is to contribute to safe navigation.

Comment: Add language to the effect that: "The primary safety increment will likely come from the route monitoring function of ECDIS."

- 1.2 ECDIS can be accepted as the equivalent permitted by regulation I/5 of SOLAS 1974 to comply with the up-to-date chart required by regulation V/20 of SOLAS 1974.

Recommendation: Add at beginning: "For route monitoring purposes," and at end: "provided that the data set used conforms to the interim ECDIS data standard (section 4). When ECDIS is used with a full hydrographic data set originated by a national hydrographic office, it can be accepted as the equivalent permitted by regulation I/5 of SOLAS 1974 to comply with the up-to-date chart required by regulation V/20 of SOLAS 1974 for route monitoring and route planning."

- 1.3 ECDIS should be capable of displaying all chart information relevant for safe and efficient navigation, originated by, and distributed on the authority of, a national hydrographic office.

Comment: Add to end of sentence: "according to the specifications of IHO SP52."

- 1.4 ECDIS should facilitate simple and reliable updating of chart information.

- 1.5 ECDIS should reduce the navigational workload compared to using the paper charts. It should enable the mariner to execute in a convenient and timely manner all navigational routines currently performed on paper charts, including the planning of sailing routes. It should be capable of continuously plotting the ship's position.

Comment: It is not certain that route planning will be easier or more efficient with ECDIS than with a paper chart. Insert "route monitoring" before "navigational" in the first sentence.

"Continuous" is ambiguous and, if taken literally, may not be possible. Replace last sentence with: "It should be capable of plotting the ship's position at least every two seconds."

- 1.6 ECDIS should have at least the same reliability and availability of presentation as the paper chart.

Comment: It is not clear what this means; if taken literally, it may be impossible to fulfill. Should be clarified or deleted.

- 1.7 In addition to the General Requirements for Electronic Navigational Aids contained in IMO resolution A.694(17), ECDIS should comply with this minimum performance standard.

Comment: Other standards that apply to ECDIS should be identified here as well.

- 1.8 ECDIS should be designed following ergonomic principles for user-friendly operation.

Comment: "Ergonomic principles" should be identified, perhaps by reference to ISO 8468, and applicable classification society rules and regulations, if any.

- 1.9 ECDIS should provide appropriate warnings with respect to the information displayed or the status of the equipment.

Comment: Replace "or" with "and".

2. Definitions

- 2.1 Definitions of terms used in connection with this performance standard are:

- 2.1.1 *Electronic Chart Display and Information System (ECDIS)*. The navigation information system which can be accepted as the equivalent permitted by regulation I/5 of SOLAS 1974 to comply with the up-to-date chart required by regulation V/20 of SOLAS 1974. By displaying selected information from a system electronic navigational chart (SENC) with positional information from navigation sensors, ECDIS assists the mariner in route planning and route monitoring. Optionally, ECDIS can display additional navigation-related information from other nautical publications or sensors.

Recommendation: Add to first sentence: ": (a) for route monitoring when used with a data set that conforms to the interim ENC standard (section 4); (b) for route monitoring and route planning when used with a full hydrographic ENC originated by a national hydrographic office."

Comment: Switch the order of "route planning" and "route monitoring" in the second sentence, to reflect better their relative importance in ECDIS.

- 2.1.2 *Electronic Navigational Chart (ENC)*. The data base, standardised as to content, structure, and format, issued for use with ECDIS on the authority of national hydrographic offices. The ENC contains all the chart information necessary for safe navigation and may contain nautical information in addition to that contained in the paper chart (e.g., sailing directions).

Comment: Add the sentence: "Use of the ENC allows ECDIS to be used as the equivalent permitted by regulation I/5 of SOLAS 1974 to comply with the up-to-date chart required by regulation V/20 of SOLAS 1974 for purposes of route monitoring and route planning."

Recommendation: Add the following definition: "*Interim ENC*: The data base, standardised as to minimum content and accuracy, which may be issued by governments or private parties, for use with ECDIS. Use of an interim ENC allows ECDIS to be used as the equivalent permitted by regulation I/5 of SOLAS 1974 to comply with the up-to-date chart required by regulation V/20 of SOLAS 1974 for purposes of route monitoring."

- 2.1.3 *System Electronic Navigational Chart (SENC)*. The data base resulting from the transformation of the ENC by ECDIS for appropriate use, updates to the ENC by appropriate means, and other data added by the mariner. The SENC is the data base that is actually accessed by ECDIS for display generation and other

navigational functions. The SENC contains the equivalent to an up-to-date paper chart. The SENC may also contain information from other sources.

Recommendation: Replace "ENC" in both instances with "ENC or interim ENC".

- 2.1.4 *Standard Display.* The level of the SENC information that should be shown when a chart is first displayed on the ECDIS. Depending upon the needs of the mariner, the level of SENC information shown during route planning or route monitoring can be modified by the mariner. However, it should be possible to return to this display level at any time by a single operator action.

Recommendation: Add after the first sentence: "The feature content of the *standard display* is defined in Appendix 2; if an interim ENC is used, it includes only those features of the ENC standard display that are provided in the interim ENC."

Comment: The "single operator action" is not necessarily a safeguard if it can be taken by mistake, resulting in loss of information from the previous screen. Consider alternative wording, such as "by a simple and straightforward procedure."

- 2.1.5 *Display Base.* The level of SENC information which cannot be removed from the display by the mariner. This permanent level of display consists of information that would be required at all times, in all geographic areas, and under every circumstance. It is not intended to be sufficient for safe navigation, and the mariner should add SENC information as required by the actual situation.

Comment: Replace "intended to be" in the last sentence with "necessarily" to clarify the meaning of the sentence. The need for a display base provision is debatable, since operators are probably the best judges of what information should be on display for the purpose at hand.

- 2.2 Further information on definitions may be found in Appendix 1, Publication 1.4.

Comment: Add the following definitions:

Route Monitoring. The set of activities and procedures employed to ascertain the ship's position, speed, and heading, needed to determine adherence of the vessel's progress to a planned route and schedule. The primary purpose of route monitoring is to provide the mariner information needed to make changes in the vessel's heading and speed to ensure the safety of the vessel.

Route Planning. The set of activities and procedures employed to determine a safe route plan for carrying out an anticipated voyage and for subsequent use in route monitoring.

Route Editing (see 10.5.10). The modification of a route plan at a time when the same plan is in use for route monitoring. Route editing can be performed on ECDIS using either an ENC or an interim ENC data set. However, for purposes of equivalence in the sense of regulation I/5 of SOLAS 1974 to comply with the up-to-date chart required by regulation V/20 of SOLAS 1974, route editing requires the use of an ENC.

Ship's Safety Contour. Selected by the operator among the depth contours in the ENC or interim ENC that indicate depths greater than or equal to the vessel's safety depth.

3. Display of SENC Information

- 3.1 The ECDIS should be capable of displaying all SENC information.

Comment: Should "SENC" read "ENC"? If that is the intention, this provision should reference Appendix 2 or (better) distinct object catalog elements and attributes (including display priorities).

- 3.2 The SENC information to be displayed during route planning and route monitoring should be subdivided into the following three categories, Display Base, Standard Display and All Other Information, as further defined in Appendix 2.

Comment: Provide specific object catalog references for each of these features (see Appendix 2). The reference to route planning might be eliminated, since operators generally will use full display features for route planning.

- 3.3 The ECDIS should present the Standard Display at any time by single operator action.

Comment: See 2.1.4.

- 3.4 When a chart is first displayed on the ECDIS, it should provide the Standard Display at the largest scale available in the SENC for the displayed area.

Comment: The need for this provision is debatable, since this is largely an operational issue. There is no equivalent requirement for use of paper charts.

- 3.5 It should be possible for the mariner to remove selectively from the display any categories of information of the Standard Display other than the Display Base.

Comment: See 2.1.5.

- 3.6 It should be possible for the mariner to select a safety depth. The ECDIS should emphasize soundings equal to or less than the safety depth whenever spot soundings are selected for display.

Comment: This provision is not needed in a minimum performance standard.

- 3.7 The addition or removal of information should be possible with an economy of operator controls and actions.

Comment: This is rather vague and probably unnecessary in a minimum performance standard, since the market is not likely to support equipment that does not meet high standards of user friendliness.

- 3.8 The ENC and all update information should be displayed without degradation.

Recommendation: Add "or interim ENC" after "ENC". This provision needs to be clarified, possibly in SP52 (with appropriate reference here). The meaning of "without degradation" is not clear. Does it refer to storing/maintaining/displaying all attributes in the ENC, to numeric precision, to positional accuracy? A CRT screen necessarily degrades an ENC compiled to greater resolution. Perhaps add "to the resolution of the display screen" after the word "displayed". The topic of this provision is appropriate because degradation might not be obvious to the user.

- 3.9 The system should provide a method to ensure that the ENC and all update information have been correctly loaded into the SENC.

Comment: Add "or interim ENC" after "ENC". Data integrity is a relevant issue for this standard. Reference could be made to data integrity standards from the commercial computer industry, or hydrographic offices and vendors of interim ENCs might provide mechanisms (routines and/or meta data) for verifying data integrity for their data sets.

- 3.10 All other information on the display should be clearly distinguished from the ENC and updated information.

Comment: Add "or interim ENC" after "ENC".

4. Provision and Correction of Chart Information

Recommendation: Add a provision: "An interim ENC must contain at minimum the features required for the display base, derived from official hydrographic office charts or chart information products. The geographic location of these features must be represented in the interim ENC to an accuracy that permits the display built on the basis of the interim ENC to match the paper chart representation at paper chart scale to $\pm 0.5\text{mm}$."

- 4.1 The ENC information to be used in ECDIS should be the latest edition of that originated by the national hydrographic office.

Comment: This has to do with legal operation of ships, not with performance of ECDIS. Provision should be dropped.

- 4.2 The contents of the SENC should be adequate and up to date for the intended voyage to comply with regulation V/20 of SOLAS 1974.

Comment: This has to do with sailing instructions to the Master, not with performance of ECDIS. Provision should be dropped.

- 4.3 The ECDIS should be capable of accepting official updates to the ENC data provided in standard IHO format. These updates should be automatically applied to the SENC. Updates should be stored separately from the ENC.

Comment: It will be some time before IHO and national hydrographic offices

develop the format and infrastructure for digital updates. Until then, this is not a relevant issue. This provision should be declared "inactive" until that time.

- 4.4 The ECDIS should also be capable of accepting updates to the ENC data entered manually with simple means for verification prior to the final acceptance of the data. These should be stored separately from the ENC and should be distinguishable on the display from ENC information and its automatic correction and not affect its legibility.

Comment: Add "or interim ENC" after each occurrence of "ENC".

- 4.5 The system should keep a record of updates including time of application to the SENC.

Comment: Clarify the level of detail is required in this record (date and number, time of day, source of update, detailed content of update message, identity of operator, etc.).

- 4.6 It is necessary that the mariner be able to display updates both for verification and to ascertain the changes which have been made.

- 4.7 It should not be possible to alter the contents of the ENC.

Comment: Add "or interim ENC" after "ENC".

5. Scale

- 5.1 If the information is displayed at a larger scale than that contained in the ENC, a warning should be provided.

Comment: What tolerance should be used? Is even a 1% difference enough to warrant a warning? Exact scale is hard to hit with a CRT. Consider changing the provision to require "a clear indication of the scale to which the data set in use has been compiled, and the scale at which it is displayed".

- 5.2 If the ship's position is covered by an ENC at a larger scale, the ECDIS should inform the mariner.

Comment: Add "or interim ENC" after "ENC". This is a design issue, and is not necessary in a minimum performance standard.

6. Display of other Information

- 6.1 If radar information or other temporary navigational information is added to the ECDIS display, it should not degrade the SENC information and it should be clearly distinguishable from the SENC information.

Comment: "Degrade" should be clarified (see 3.8). Should it be permissible to switch precedence of chart/radar image by means of a toggle, even though some SENC information may be obscured by radar imagery in "overlay" mode?

6.2 Radar

- 6.2.1 Transferred radar information may contain both the radar image and ARPA information.

Comment: Delete the word "both" to remove the suggestion that it may contain the image and ARPA only in combination with each other.

- 6.2.2 If the radar image is added to the ECDIS display, the chart and the radar image should match in scale and in orientation.

- 6.2.3 The radar image and the position from the position sensor should both be adjusted automatically to a common reference point at the conning position.

- 6.2.4 It should be possible to adjust the displayed position of the ship manually so that the radar image matches the SENC display.

Comment: Some commentators consider this potentially dangerous. At least require a clear warning on the display when such a position offset is applied.

- 6.2.5 It should be possible to remove the radar image by single operator action.

Comment: See 2.1.4.

7. **Display Mode and Generation of the Neighboring Area**

- 7.1 It should always be possible to display the SENC in a "north-up" orientation. Other orientations are permitted.

- 7.2 ECDIS should provide at least for true motion mode.

- 7.3 When true motion mode is in use, reset and generation of the neighbouring area should take place automatically at a distance from the border of the display determined by the mariner.

- 7.4 It should be possible to change manually the chart area and the position of own ship relative to the edge of the display.

8. **Colours and Symbols**

- 8.1 Only IHO-recommended colours and symbols should be used to represent SENC information. (See Appendix 1, Publication 1.3)

Recommendation: Replace with: "ECDIS must be capable of displaying SENC information using IHO-approved colors and symbols (see Appendix 1, Publication 1.3)." Questions have been raised regarding the feasibility of early versions of IHO color tables. HGE/IMO should ensure that IHO's color specifications are achievable and repeatable in an operational bridge environment. Users should be

allowed to develop custom color and symbol schemes for their own use, so long as the equipment can return to standard colors/symbols on demand.

- 8.2 All colours and symbols other than those mentioned in 6.1 should be those in Appendix 3.

Comment: "6.1" should be "8.1". Replace with a reference to CIRM recommended symbols for use in ECDIS.

- 8.3 All SENC information should be displayed at all specified scales, with the same size of symbols, figures and letters.

Comment: This is a design issue, and should be restated to refer to a presentation library with recommended display size for numbers, letters, and figures, as well as CIRM symbols. The requirement for constant symbol size has been questioned by a number of observers (see Miller and Kreiton, 1993; Kite-Powell, 1993b). This provision should be dropped.

- 8.4 ECDIS should be capable of displaying own ship in true scale. The mariner should be able to select whether own ship is displayed in true scale or as a symbol, provided the own ship's symbol shall never be less than 6 mm. Whenever own ship is not shown to scale, this should be clearly indicated.

Comment: Does "6 mm" refer to length or beam? The use of separate symbols for scaled and non-scaled ownship makes the last sentence unnecessary. This provision goes beyond minimum performance requirements.

9. Display Requirements

- 9.1 The ECDIS should be capable of displaying information for:

.1 navigation, route monitoring, and look ahead

Comment: How does "navigation" differ from route monitoring?

.2 route planning and supplementary navigation tasks.

Comment: "Supplementary navigation tasks" should be clarified or deleted (perhaps replace "supplementary" with "associated").

- 9.2 The effective size of the chart presentation for route monitoring should be at least 270 mm by 270 mm.

Comment: This is a design issue, involving pixel size and spacing as well as well as number of pixels. In general, it is better to specify requirements in terms of operational parameters or navigation requirements, as elsewhere in this standard. Users will be keenly aware of inadequate display size.

- 9.3 The display should be capable of meeting colour and resolution recommendations of IHO.

Comment: The feasibility of these requirements under operating conditions should be assured before they are required (see 8.1).

- 9.4 The method of presentation should ensure that the displayed information is clearly visible to more than one observer in the conditions of light normally experienced on the bridge of the ship by day and by night.

Comment: This is an installation issue, and redundant given other provisions of this standard. Provision should be dropped.

10. Route Planning, Monitoring and Voyage Recording

- 10.1 It should be possible to carry out route planning and route monitoring in a simple and reliable manner.

Comment: This is not a useful provision, unless "simple" and "reliable" are defined clearly.

- 10.2 ECDIS should be designed following ergonomic principles for user-friendly operation.

Comment: See 1.8 and 3.7.

Intergraph Corp. has suggested that it might be useful to establish standard abbreviations (such as SOG, SMG, COG, CMG, XTRK, RNG, BRNG, HDG, HTS (heading to steer), DTG (distance to go), TTG (time to go)) and standard warnings for conditions such as:

- ship within restricted area
- ship within hazardous area
- ship off track
- hazardous depth area
- close to bottom
- ship symbol not to scale
- GPS unavailable
- DGPS unavailable
- Loran C unavailable
- dead reckoning in use
- gyrocompass unavailable
- depth sounder unavailable
- speed log unavailable
- radar unavailable -- offline
- radar unavailable -- scale mismatch
- radar unavailable -- manual course-up
- ARPA unavailable at radar scale
- updates available for current route
- updates received out of sequence
- overscale display

Abbreviations and warnings can be altered easily through software changes.

Rather than standardizing these here, user group(s) should be allowed to develop a recommended standard (if they want one) and communicate this to manufacturers.

- 10.3 The largest scale data available in the SENC for the area given, shall always be used by the ECDIS for all warnings of crossing the ships' safety contour and of entering a prohibited area, and for automatic notices according to Appendix 4.

10.4 Route Planning

- 10.4.1 It should be possible to carry out route planning including both straight and curved segments.

- 10.4.2 It should be possible to adjust a planned route by, for example:

- .1 Adding waypoints to a route
- .2 Deleting waypoints from a route
- .3 Changing the position of a waypoint
- .4 Changing the order of the waypoints in the route (including reversing the route).

Recommendation: The last provision (10.4.2.4) could contribute to danger of collisions if several ships make use of the same route plans. This provision should be deleted.

- 10.4.3 It should be possible to plan alternate routes in addition to the selected route. The selected route should be clearly distinguishable from the other routes.

Comment: Replace "The selected route" in the second sentence with "The route selected for route monitoring" to clarify what "selected" means.

- 10.4.4 A warning is required if the mariner plans a route across an own ship's safety contour or the boundary of a prohibited area.

- 10.4.5 Appropriate notice is required if the mariner plans a route across the boundary of a geographic area for which special conditions exist (see Appendix 4).

Comment: Interim ENCs may not include all of these geographic areas. Add to end of sentence: ", in so far as these can be identified in the data set being used".

- 10.4.6 It should be possible for the mariner to specify a limit of deviation from the planned route at which activation of an automatic offtrack warning

should occur.

10.5 Route Monitoring

10.5.1 For route monitoring, the selected route and own ship's position should appear automatically whenever the display covers that area.

10.5.2 It should be possible to display a sea area that does not have the ship on the display (e.g., for look ahead, route planning), while route monitoring. If this is done on the display used for route monitoring, the automatic route monitoring functions (e.g., updating ships position, detecting and warning of prohibited areas) should be continuous. And it should be possible to return to the route monitoring display covering own ship's position immediately by single operator action.

Comment: See 2.1.4.

10.5.3 It should be possible to detect and give a warning if, within a specified time set by the mariner, own ship will cross the safety contour or a boundary of a prohibited area.

10.5.4 It should be possible to detect and give appropriate notice if, within a specified time set by the mariner, own ship will cross the boundary of a geographical area for which special conditions exist (see Appendix 4).

Comment: See 10.4.5.

10.5.5 A warning should be given when the specified limit for deviation from the planned route is exceeded.

10.5.6 The ship's position should be derived from a continuous positioning system of an accuracy consistent with the requirements of safe navigation.

Comment: "Continuous" not possible with current NMEA standards, and requirements of safe navigation in coastal applications have not been adopted internationally. Substitute wording in keeping with modified provision 1.5: delete "continuous" and add the sentence: "The ECDIS should be capable of processing updates at least every two seconds."

10.5.7 The geodetic datum of any position-fixing system should conform with the datum of the displayed SENC.

10.5.8 A warning should be given whenever the accuracy of the primary positioning system deteriorates to a level determined unacceptable by the mariner.

Comment: This requires standards for interface, quality of position information, and passing this information to ECDIS. In the absence of these standards,

warnings issued by the position sensor itself will have to suffice, and this provision should not appear in the performance standard for ECDIS. If it is to be retained, delete the word "primary" and insert the words "(if known)" after the word "system".

- 10.5.9 In addition to the primary positioning system, a second independent positioning method of a different type should be provided. The ECDIS should be capable of identifying discrepancies between the two systems.

Comment: What exactly constitutes a "discrepancy"? Can the "second independent positioning method" be dead reckoning or visual? A requirement for a second positioning sensor would be a carriage requirement. This provision should be clarified.

- 10.5.10 It should be possible to display alternate routes in addition to the selected route. The selected route should be clearly distinguishable from the other routes. During the voyage, it should be possible for the mariner to change the selected sailing route.

Comment: Replace "change" with "edit" in the last sentence.

- 10.5.11 It should be possible to display:

- .1 time-labels along ships track manually on demand and automatically at intervals selected between 1 and 120 minutes;

Comment: Add a reference to the symbol for time labels provided by CIRM. Replace "between 1 and 120 minutes" with "determined by the operator."

- .2 the past track data for at least 8 hours on demand; and

Comment: To clarify, insert after "past track data" the words: "(planned route and course made good, for review by an oncoming watch)".

- .3 an adequate number of: points, free movable electronic bearing lines, variable and fixed range markers and other symbols required for navigation purposes as specified in Appendix 3.

Comment: It is not likely that anyone would purchase a system that is inadequate in this regard. This provision should be dropped. (Intergraph Corp. suggests that "superior" navigation tools are available to the mariner through ECDIS.)

- 10.5.12 It should be possible to enter the geographical coordinates of any position and then display that position on demand. Also, it should be possible to select any feature or position on the display and read its geographical coordinates on demand.

Comment: This does not appear to be a minimum performance requirement.

- 10.5.13 It should be possible to adjust the ship's geographic position manually, in

order to correct a positioning system error. This manual adjustment should be noted alpha-numerically on the screen and should be maintained until altered by the mariner.

Comment: Several commentators suggest that this capability is dangerous, and that the only permissible adjustments should be (1) fixed, systematic nav receiver corrections (applied at the receiver?), and (2) at ECDIS, the offset of the receiver antenna (GPS) to the conning position (not user adjustable). At least, the words "at all times" should be inserted after "on the screen" in the second sentence.

10.6 Voyage recording.

Comment: "Black box" capabilities are being addressed by a separate IMO working group. Specifications should be left to a black box carriage requirement, or at least the data requirements for this record in ECDIS should be limited.

10.6.1 ECDIS should store and reproduce those minimum elements of the display required to reconstruct the past navigation utilizing the ECDIS during the previous 8 hours.

Comment: "Minimum elements" need to be defined. USETB data suggest that they include ship's position, heading, and speed, plus possibly ARPA targets' position, heading, and speed. Should they also include chart features on display at each moment, display scale and window, color mode, warnings shown?

10.6.2 It should not be possible for the mariner to manipulate or change the recorded information.

10.6.3 In case of an accident, the record of the previous 8 hours is to be preserved.

Comment: As stated, this addresses operational policy, and not a performance standard issue. To preserve this provision as a performance requirement, replace it with "ECDIS should allow the operator to preserve the last eight hours of data."

11. Accuracy

11.1 All calculations performed by the ECDIS should be consistent with SENC accuracy.

Comment: Clarify where SENC accuracy is stated, defined, or derived. Add at end of sentence: "and the pixel resolution of the ECDIS display".

11.2 Bearings should be presented with an accuracy of +/- 0.5 degree or better.

Comment: Bearings can be displayed as lines to this accuracy on an IMO-compliant screen if they are at least 38mm long. The difference between rhumbline and great circle take-off angles may exceed this allowance in higher latitudes; can hydrographic offices provide appropriate projections for high

latitudes? Consider changing the provision to: "The contribution of the chart display to bearing error shall not exceed 0.5 degrees".

- 11.3 Distances should be presented with an accuracy of one-tenth of the chart scale in use in cm. (e.g., for a 1:50,000 scale chart, the accuracy should be within 5,000 cm = 50 m).

Comment: An IMO-compliant CRT can resolve 15 meters at 1:50,000 scale. Why not set the accuracy standard to meet the maximum capabilities of the minimum compliant CRT pixel dimension? What is the rationale for the formula used above? Can this be referred to the IEC for resolution?

Comment: A minimum data position resolution (lat/long) requirement is missing here, in part because no international standard on the topic has been adopted. The development of such a standard should be pursued (see SP52).

12. Connections with other Equipment

- 12.1 The ECDIS should not degrade the performance of any equipment providing sensor inputs. Nor should the connection of optional equipment degrade the performance of ECDIS below this standard.

13. Malfunction Warnings and Performance Tests

- 13.1 The ECDIS should provide suitable warning of system malfunction.
- 13.2 The ECDIS should be provided with either automatic or manual self-test of major functions. In case of failure, the self-test should display information to indicate which module is at fault.

Comment: Refer to test protocols being developed for ECDIS by IEC.

15. Back-up Arrangements

- 15.1 Adequate back-up arrangements should be provided to ensure safe navigation in case of ECDIS failure. See Appendix 5.

Comment: These back-up arrangements are procedural issues, and not appropriate for the ECDIS standard. They might be replaced with a reference to "traditional navigation practice" as the backup for ECDIS.

15. Power Supply

- 15.1 It should be possible to operate the ECDIS and all equipment necessary for its normal functioning when supplied by an emergency source of electrical power in accordance with the appropriate requirements of II/1 of SOLAS 1974.

- 15.2 Changing from one source of power supply to another or any interruption of the supply for a period of up to 60 seconds should not require the equipment to be manually reinitialized and should not lose information stored in memory.
Comment: Refer to appropriate specification or existing standard for ship's power supplies.

Appendix 1: Technical Extensions to this Standard from other International Organizations

The following international organizations have developed the documents listed below as technical extensions to this standard.

The latest edition of these documents should be obtained from the organization concerned.

1. International Hydrographic Organisation

Address: Directing Committee
International Hydrographic Bureau
BP 445
MC 98011 Monaco cedex
Principality of Monaco

Phone: +33 9350 6587
Fax: +33 9325 2003

Publications

- .1 Special Publication No. 52: "Provisional Specifications for Chart Content and Display of ECDIS"

- .2 SP52 Appendix 1: "Report of the IHO (COE) Working Group on Updating the Electronic Chart"

Comment: This should be a recommendation only, at least until updating infrastructure for ECDIS is in place.

- .3 SP52 Appendix 2: "Provisional Colour and Symbol Standards for ECDIS"
Recommendation: Commentators indicate that the colors definition of early versions of SP52 cannot be sustained by engineering realities in an economical manner. These requirements should be revisited to assure that the issue has been resolved.

Comment: Colors and symbols should be "recommended" only, and manufacturers and users encouraged to evaluate alternatives, until more

operational experience is available.

.4 SP52 Appendix 3: "Glossary of ECDIS-related Terms"

.5 Special Publication No. 57: "IHO Transfer Standard for Digital [Hydrographic] Data"

Comment: This should be cited as reference only, since data will not be universally available in this format for some time, and ECDIS is not required to accept data in this format only.

Other organizations will be added as necessary.

Comment: Relation of IMO DPS to other standards should be clarified and references made explicitly: IHO SP52, ISO, IEC 945 (Marine navigational equipment: General requirements -- Methods of testing and required test results).

Appendix 2

Comment: Provide specific object catalog references to these features, especially broad features such as "underwater"/"isolated" dangers (considerable room for interpretation).

Display Base, permanently retained on the ECDIS display, consisting of:

Comment: USETB data suggest that the following features generally will always be kept on display: coastline, ship's safety contour, traffic routing schemes, boundaries of fairways/channels, isolated dangers within safe water, fixed/floating aids to navigation, and prohibited/restricted areas. It is probably not necessary to include a display base requirement in a minimum performance standard.

.1 coastline (high water)

Comment: USETB data: operators concur.

.2 own ship's safety contour, to be selected by the mariner from the depth contours provided by the SENC

Comment: USETB data: operators concur.

.3 indication of isolated underwater dangers of depths less than the safety contour which lie **within the safe waters defined by the safety contour**

Comment: USETB data: operators concur.

.4 indication of isolated dangers which lie **within the safe water defined by the safety contour** such as bridges, overhead wires, etc., and including buoys and beacons whether or not these are being used as aids to navigation

Comment: USETB data: operators concur generally, but would include "bridges

and wires" more often in the standard display.

- .5 traffic routing systems

Comment: USETB data: operators concur.

- .6 indication of scale, range, orientation and display mode

- .7 units of depth and height

Comment: USETB data: operators appear not to concur, but not asked explicitly. Operators also suggest including indications of cautionary notes.

Standard Display, to be displayed when the chart is first displayed on the ECDIS, consisting of:

- .1 display base

- .2 drying line

Comment: USETB data: operators concur.

- .3 indication of fixed and floating aids to navigation

Comment: USETB data: operators concur.

- .4 boundaries of fairways, channels, etc.

Comment: USETB data: operators concur.

- .5 visual and radar conspicuous features

Comment: USETB data: operators do not concur.

- .6 prohibited and restricted areas

Comment: USETB data: operators concur.

- .7 chart scale boundaries

Comment: USETB data: operators do not concur.

- .8 indication of cautionary notes

Comment: USETB data: operators concur. Operators also suggest adding all depth contours, spot soundings, bridges & wires, details of isolated dangers, characteristics of nav aids, and indication of scale and distance to the standard display.

Supplementary information. All other information displayed individually on demand, for example:

Comment: Clean up this list with view to changes in the two lists above. Why has this particular subset of "other symbols" included here? What purpose does

it serve?

- .1 spot soundings
- .2 submarine cables and pipelines
- .3 ferry routes
- .4 details of all isolated dangers
- .5 details of aids to navigation
- .6 contents of cautionary notes
- .7 ENC edition date
- .8 geodetic datum
- .9 magnetic variation
- .10 graticule
- .11 place names

Appendix 3: ECDIS Route Monitoring Video Symbols and Control Names

Comment: CIRM proposed ECDIS symbols should be referred to as guidance, not requirement. Some of them, such as "position probability area" (11), may be proprietary to particular equipment vendors. "Position line" (13) is ambiguous and should be clarified.

The following list of symbols has been identified as being used for navigational routines:

- .1 Own ship
- .2 Past track
- .3 Heading and beam bearing
- .4 Vector for course and speed made good
- .5
 - a. Range rings
 - b. Variable range marker and electronic bearing line
- .6 Cursor mark
- .7 Waypoint
- .8 Event
- .9 Dead reckoning position (DR)
- .10 Estimated position (EP)

- .11 Position probability area (PPA)
 - .12 a. Visual fix
 - b. Astronomical fix
 - c. Radar fix
 - d. Electronic position-fixing system fix
 - .13 Position line
 - .14 Transferred position line
 - .15 Planned route
 - .16 Current vector
 - .17 Danger highlight
 - .18 Clearing line
 - .19 Distance to run
 - .20 Planned position and time
 - .21 Visual limits of lights
 - .22 Position and time of "Wheel over"
- Comment:** Add item 23: past track from second positioning method.

Appendix 4: Areas for which Special Conditions Exist

Comment: Reference should be made to specific DX-90 objects.

The following are the areas which ECDIS should detect under sections 5.3.5 and 5.4.4, with the type of notice required for each:

Comment: "5.3.5 and 5.4.4" should read "10.4.5 and 10.5.4".

1. Cautionary notice:
 - Traffic separation zone
 - Traffic routing scheme crossing or roundabout
 - Traffic routing scheme precautionary area
 - Two way traffic route
 - Deepwater route
 - Recommended traffic lane
 - Inshore traffic zone
 - Fairway
 - Restricted area
 - Caution area
 - Offshore production area
 - Areas to be avoided
 - Military practice area
 - Seaplane landing area
 - Ice area
2. Information notice:
 - Channel

Fishing ground
Fishing prohibited
Pipeline area
Cable area
Anchorage area
Anchorage prohibited
Dumping ground
Spoil ground
Dredged area
Cargo transshipment area
Incineration area

Appendix 5: Back-up Arrangements

Comment: This appendix could be eliminated (see 15.1), or kept as a "suggestion". Backup should be "traditional practice."

- .1 Adequate back-up arrangements should be provided to ensure safe navigation in case of ECDIS failure.
- .2 A failure in the ECDIS should not cause a critical situation for the ship. Failure Mode and Effect Analysis may be used to evaluate the performance during various failure modes and assist in determining the effect of system failures and provisions to be made.
- .3 If a back-up system is based on redundancy by another electronic system, this system should be fully independent and not share any components or the source of power supply with the primary system.
- .4 The switch-over to a redundant system should be simple to execute by automatic or manual operation.
- .5 A redundant system and equipment which serves as part of a back-up system should meet relevant IMO performance standards.
6. Back-up arrangement for instant take-over
 - 6.1 Facilities enabling instant and safe take over of the ECDIS functions should be provided to avoid that an ECDIS failure develops into a critical situation.
 - 6.2 If manual operation facilities cannot ensure instant and safe take over in accordance with 15.6.1, or if dangerous conditions cannot be expected to be counteracted by manual intervention, a redundant system can be

required.

- 6.3 A redundant programmable electronic system (PES) should not be considered required if an easily accessible and easily operated back-up system is provided.

7. Back-up arrangement for continuous navigation

- 7.1 A back-up arrangement facilitating means for safe navigation of the remaining part of the voyage in the case of ECDIS failure should be provided.

- 7.2 If a back-up system is based on manual plotting of the ship's position in a paper chart, the system should at least comprise:

Hard copy of the ENC, presenting sufficient information for safe navigation of the waters along the route and the planned route, Global Position System receiver and navigational aids in compliance with IMO regulations.

A hard copy of information from the ENC should comprise the information used for the initial planning of the route and at least the information specified for the Display Base, and the planned route.

4.3. Concluding remarks

Since the recommendations and comments given above are likely to require extensive discussion, IMO should continue the HGE deliberations of this standard through 1994, with a broader representation (manufacturers and users) in HGE. These deliberations should lead to the adoption of a standard for an ECDIS that can be used as the equivalent to the paper chart for route monitoring in the near term, with interim data sets, and that may replace the paper chart entirely when the availability of appropriate databases is assured. It should be possible to make the necessary changes to the proposed standard in time for acceptance by the IMO assembly in 1995.

National hydrographic offices and IHO should work with IMO to ensure that the interim ENC specification is suitable, and hydrographic offices should continue and expand their efforts to provide interim data sets (vector or raster based) for use by ECDIS vendors and data suppliers.

The subject of updating encompasses many institutional and jurisdictional issues (data management, etc.) as well as the question of transmission channels. This subject requires coordinated international attention. IMO and IHO efforts in this area should be coordinated.

It is tempting, but probably not productive, to try to use an equipment performance standard to correct deficiencies in operator training and mindset. Operator training standards and operating instructions and procedures are of great importance to maritime safety (see Hederström and Gyldén, 1992). Mariners express concern that the advent of ECDIS may lead to a further loss of manual navigation skills because of increased reliance on electronic charts (USETB data). In a display of what is sometimes called "revenge theory," operational behavior can adjust to take advantage of ECDIS' safety gains, the net result being no improvement in the safety (casualty) record. For example, the introduction of radar as a navigational aid was marked by the advent of "radar-assisted collisions," and the adoption of radar standards and carriage requirements has not lead to any clear reduction in the statistical likelihood of collisions (see Kite-Powell, 1992). These problems can only be addressed through operator training and safety-conscious operating procedures. ECDIS may prevent some accidents, but it is no cure-all for maritime safety.

We recommend that the IMO standard for ECDIS be kept flexible until more operational experience can be obtained. Experimentation in equipment design, within the parameters of the minimum performance standard, should be encouraged. The Test Bed evaluation of ECDIS technology and standards is no substitute for more extensive at-sea experience. The sea trials planned for U.S. ECDIS Test Bed Project should contribute valuable input to the deliberations on this standard into 1994.

5. References

- Alexander, L. and C. F. Klingler, 1992. U.S. Coast Guard Test and Evaluation Program for Electronic Chart Display Information Systems (ECDIS). Proceedings, MTS '92. October 19-21, 1992. Washington D.C.
- Gonin, I.M. and B. Crowell, 1992. United States Coast Guard ECDIS field trials: preliminary results. ECDIS '92 Conference (Baltimore) Proceedings.
- Grabowski, M., 1990. Decision support to masters, mates on watch, and pilots: the piloting expert system. *Journal of Navigation* 43:3, pp. 364-84.
- Hederström, H. and S. Gyldén, 1992. Safer navigation in the '90s -- integrated bridge systems. *Journal of Navigation* 45:3, pp. 369-83.
- Hochbrueckner, G.J., 1991. Vessel Safe Navigation and Marine Environmental Protection Act of 1991. H.R. 3969, 102d Congress, 1st Session.
- Iijima, Y. and H. Hagiwara, 1991. Results of collision avoidance manoeuvre experiments using a knowledge-based autonomous piloting system. *Journal of Navigation* 44:2, pp. 194-204.
- IMO (International Maritime Organization, Maritime Safety Committee), 1989. Provisional Performance Standards for Electronic Chart Display Systems (ECDIS). MSC Circular 515.
- Kite-Powell, H.L., 1993a. Economics of standards, system analysis, and sea trials data: toward an assessment of the proposed IMO performance standard for ECDIS. ECDIS '93 Conference (Baltimore) Proceedings, forthcoming.
- Kite-Powell, H.L., 1993b. Preliminary operational and user survey results from U.S. ECDIS Test Bed Project sea trials. ECDIS '93 Conference (Baltimore) Proceedings, forthcoming.
- Kite-Powell, H.L., 1992. Rationale, processes, and effects of technological standards in marine electronics. Ph.D. dissertation in Ocean Systems Management, Ocean Engineering Department, MIT, Cambridge, Massachusetts.
- Miller, P.D. and K.J. Kreiton, 1993. Presenting symbol size effectively at varying display scales. ECDIS '93 Conference (Baltimore) Proceedings, forthcoming.
- Morkve, O.T. and L.E. Mathison, 1991. ECDIS: Electronic Chart Display and Information System. *Marine Industrial Technology*, No. 4, p. 1-7.

- Pease, W., 1992. Sensor integration and autopilots in ECDIS-based navigation. Paper #28, Digital Mapping and Navigation, Proceedings of the International Conference of the Royal Institute of Navigation and the German Institute of Navigation, London, November.
- RTCM (Radio Technical Commission for Maritime Services), 1989. RTCM Recommended Standards for Electronic Chart Display and Information Systems Version 1.0. RTCM Special Committee No. 109, RTCM Paper 132-89/SC 109-72.
- Schuffel, H., J.P.A. Boer, and L. van Breda, 1989. The ship's wheelhouse of the nineties: the navigation performance and mental workload of the officer of the watch. *Journal of Navigation* 42:1, pp. 60-72.
- Scott, D.J., and A.G. Gaines, 1992. Development of the United States Electronic Chart Display and Information System (ECDIS) Test-Bed. U.S. Hydrographic Conference '92, February 25-28, 1992, Baltimore, MD.
- Wiencke, P.M., J.E. Karlsen, and S. Kristiansen, 1980. Collisions and groundings analysis: an operational model of the ship system and the navigator's functions. Proceedings of the West European Conference on Marine Technology and Sea Transport Systems in the 1980s. Sandefjord, Norway.