CHAPTER 14

ELECTRONIC CHARTS

INTRODUCTION

1400. The Importance of Electronic Charts

Since the beginning of maritime navigation, the desire of the navigator has always been to answer a fundamental question: "Where, exactly, is my vessel?" To answer that question, the navigator was forced to continually take fixes on celestial bodies, on fixed objects ashore, or using radio signals, and plot the resulting lines of position as a fix on a paper chart. Only then could he begin to assess the safety of the ship and its progress toward its destination. He spent far more time taking fixes, working out solutions, and plotting the results than on making assessments, and the fix only told him where the ship was at the time that fix was taken, not where the vessel was some time later when the assessment was made. He was always "behind the vessel." On the high seas this is of little import. Near shore, it becomes vitally important.

Electronic charts automate the process of integrating real-time positions with the chart display and allow the navigator to continuously assess the position and safety of the vessel. Further, the GPS/DGPS fixes are far more accurate and taken far more often than any navigator ever could. A good piloting team is expected to take and plot a fix every three minutes. An electronic chart system can do it once per second to a standard of accuracy at least an order of magnitude better.

Electronic charts also allow the integration of other operational data, such as ship's course and speed, depth soundings, and radar data into the display. Further, they allow automation of alarm systems to alert the navigator to potentially dangerous situations well in advance of a disaster.

Finally, the navigator has a complete picture of the instantaneous situation of the vessel and all charted dangers in the area. With a radar overlay, the tactical situation with respect to other vessels is clear as well. This chapter will discuss the various types of electronic charts, the requirements for using them, their characteristics, capabilities and limitations.

1401. Terminology

Before understanding what an electronic chart is and what it does, one must learn a number of terms and definitions. We must first make a distinction between official and unofficial charts. Official charts are those, and only those, produced by a government hydrographic office (HO). Unofficial charts are produced by a variety of private companies and may or may not meet the same standards used by HO's for data accuracy, currency, and completeness.

An **electronic chart system (ECS)** is a commercial electronic chart system not designed to satisfy the regulatory requirements of the IMO Safety of Life at Sea (SOLAS) convention. ECS is an aid to navigation and when used on SOLAS regulated vessels is to be used in conjunctions with corrected paper charts.

An **electronic chart display and information system (ECDIS)** is an electronic chart system which satisfies the IMO SOLAS convention carriage requirements for corrected paper charts when used with an ENC or its functional equivalent (e.g. NIMA Digital Nautical Chart.)

An **electronic chart (EC)** is any digitized chart intended for display on a computerized navigation system.

An **electronic chart data base (ECDB)** is the digital database from which electronic charts are produced.

An **electronic navigational chart (ENC)** is an electronic chart issued by a national hydrographic authority designed to satisfy the regulatory requirements for chart carriage.

The **electronic navigation chart database (ENCDB)** is the hydrographic database from which the ENC is produced.

The **system electronic navigation chart (SENC)** is the database created by an ECDIS from the ENC data.

A **raster navigation chart (RNC)** is a raster-formatted chart produced by a national hydrographic office.

A **raster chart display system (RCDS)** is a system which displays official raster-formatted charts on an ECDIS system. Raster charts cannot take the place of paper charts because they lack key features required by the IMO, so that when an ECDIS uses raster charts it operates in the ECS mode.

Overscale and **underscale** refer to the display of electronic chart data at too large and too small a scale, respectively. In the case of overscale, the display is "zoomed in" too close, beyond the standard of accuracy to which the data was digitized. Underscale indicates that larger scale data is available for the area in question. ECDIS provides a warning in either case.

Raster chart data is a digitized "picture" of a chart comprised of millions of "picture elements" or "pixels." All

data is in one layer and one format. The video display simply reproduces the picture from its digitized data file. With raster data, it is difficult to change individual elements of the chart since they are not separated in the data file. Raster data files tend to be large, since a data point with associated color and intensity values must be entered for every pixel on the chart.

Vector chart data is data that is organized into many separate files or layers. It contains graphics files and programs to produce certain symbols, points, lines, and areas with associated colors, text, and other chart elements. The programmer can change individual elements in the file and link elements to additional data. Vector files of a given area are a fraction the size of raster files, and at the same time much more versatile. The navigator can selectively display vector data, adjusting the display according to his needs. Vector data supports the computation of precise distances between features and can provide warnings when hazardous situations arise.

1402. Components of ECS's and ECDIS's

The terms ECS and ECDIS encompasses many possible combinations of equipment and software designed for a variety of navigational purposes. In general, the following components comprise an ECS or ECDIS.

• **Computer processor, software, and network:** These subsystems control the processing of information from the vessel's navigation sensors and the flow of information between various system components. Electronic positioning information from GPS or Loran C, contact information from radar, and digital compass data, for example, can be integrated with the electronic chart data.

• **Chart database:** At the heart of any ECS lies a database of digital charts, which may be in either raster or vector format. It is this dataset, or a portion of it, that produces the chart seen on the display screen.

• **System display:** This unit displays the electronic chart and indicates the vessel's position on it, and provides other information such as heading, speed, distance to the next waypoint or destination, soundings, etc. There are two modes of display, **relative** and **true**. In the relative mode the ship

remains fixed in the center of the screen and the chart moves past it. This requires a lot of computer power, as all the screen data must be updated and re-drawn at each fix. In true mode, the chart remains fixed and the ship moves across it. The display may also be north-up or course-up, according to the availability of data from a heading sensor such as a digital compass.

• **User interface:** This is the user's link to the system. It allows the navigator to change system parameters, enter data, control the display, and operate the various functions of the system. Radar may be integrated with the ECDIS or ECS for navigation or collision avoidance, but is not required by SOLAS regulations.

1403. Legal Aspects of Using Electronic Charts

Requirements for carriage of charts are found in SOLAS Chapter V, which states in part: "All ships shall carry adequate and up-to-date charts... necessary for the intended voyage." As electronic charts have developed and the supporting technology has matured, regulations have been adopted internationally to set standards for what constitutes a "chart" in the electronic sense, and under what conditions such a chart will satisfy the chart carriage requirement.

An extensive body of rules and regulations controls the production of ECDIS equipment, which must meet certain high standards of reliability and performance. By definition, **only an ECDIS can replace a paper chart.** No system which is not an ECDIS relieves the navigator of the responsibility of maintaining a plot on a corrected paper chart. Neither can the presence of an electronic chart system substitute for good judgement, sea sense, and taking all reasonable precautions to ensure the safety of the vessel and crew.

An electronic chart system should be considered as an aid to navigation, one of many the navigator might have at his disposal to help ensure a safe passage. While possessing revolutionary capabilities, it must be considered as a tool, not an infallible answer to all navigational problems. The rule for the use of electronic charts is the same as for all other aids to navigation: The prudent navigator will never rely completely on any single one.

CAPABILITIES AND PERFORMANCE STANDARDS

1404. ECDIS Performance Standards

The specifications for ECDIS consist of a set of interrelated standards from three organizations, the International Maritime Organization (IMO), the International Hydrographic Organization (IHO), and the International Electrotechnical Commission (IEC). The IMO published a resolution in November 1995 to establish performance

standards for the general functionality of ECDIS, and to define the conditions for its replacement of paper charts. It consisted of a 15-section annex and 5 original appendices. Appendix 6 was adopted in 1996 to define the backup requirements for ECDIS. Appendix 7 was adopted in 1998 to define the operation of ECDIS in a raster chart mode. Previous standards related only to vector data.

The IMO performance standards refer to IHO Special

Publication S-52 for specification of technical details pertaining to the ECDIS display. Produced in 1997, the 3rd edition of S-52 includes appendices specifying the issue, updating, display, color, and symbology of official electronic navigational charts (ENC), as well as a revised glossary of ECDIS-related terms. The IMO performance standards also refer to IEC International Standard 61174 for the requirements of type approval of an ECDIS. Published in 1998, the IEC standard defines the testing methods and required results for an ECDIS to be certified as compliant with IMO standards. Accordingly, the first ECDIS was given type approval by Germany's classification society (BSH) in 1999. Since then, several other makes of ECDIS have gained type approval by various classification societies.

The IMO performance standards specify the following general requirements: Display of government-authorized vector chart data including an updating capability; enable route planning, route monitoring, manual positioning, and continuous plotting of the ship's position; have a presentation as reliable and available as an official paper chart; provide appropriate alarms or indications regarding displayed information or malfunctions; and permit a mode of operation with raster charts similar to the above standards.

The performance standards also specify additional functions, summarized as follows:

- Display of system information in three selectable levels of detail

- Means to ensure correct loading of ENC data and updates

- Apply updates automatically to system display

- Protect chart data from any alteration

- Permit display of update content

- Store updates separately and keep records of application in system

- Indicate when user zooms too far in or out on a chart (over- or under-scale) or when a larger scale chart is available in memory

- Permit the overlay of radar image and ARPA information onto the display

- Require north-up orientation and true motion mode, but permit other combinations

- Use IHO-specified resolution, colors and symbols

- Use IEC-specified navigational elements and parameters (range & bearing marker, position fix, own ship's track and vector, waypoint, tidal information, etc.)

- Use specified size of symbols, letters and figures at scale specified in chart data

- Permit display of ship as symbol or in true scale

- Display route planning and other tasks

- Display route monitoring

- Permit display to be clearly viewed by more than one user in day or night conditions

- Permit route planning in straight and curved segments and adjustment of waypoints

- Display a route plan in addition to the route selected for monitoring

- Permit track limit selection and display an indication if track limit crosses a safety contour or a selected prohibited area

- Permit display of an area away from ship while continuing to monitor selected route

- Give an alarm at a selectable time prior to ship crossing a selected safety contour or prohibited area

- Plot ship's position using a continuous positioning system with an accuracy consistent with the requirements of safe navigation

- Identify selectable discrepancy between primary and secondary positioning system

- Provide an alarm when positioning system input is lost

- Provide an alarm when positioning system and chart are based on different geodetic datums

- Store and provide for replay the elements necessary to reconstruct navigation and verify chart data in use during previous 12 hours

- Record the track for entire voyage with at least four hour time marks

- Permit accurate drawing of ranges and bearings not limited by display resolution

- Require system connection to continuous position-fixing, heading and speed information

- Neither degrade nor be degraded by connection to other sensors

- Conduct on-board tests of major functions with alarm or indication of malfunction

- Permit normal functions on emergency power circuit

- Permit power interruptions of up to 45 seconds without system failure or need to reboot

- Enable takeover by backup unit to continue navigation if master unit fails,

Before an IMO-compliant ECDIS can replace paper charts on vessels governed by SOLAS regulations, the route of the intended voyage must be covered completely by ENC data, that ENC data must include the latest updates, the ECDIS installation must be IMO-compliant including the master-slave network with full sensor feed to both units, and the national authority of the transited waters must allow for paperless navigation through published regulations. The

latter may also include requirements for certified training in the operational use of ECDIS.

The first type approval was earned in 1999 and since the finalization of the standards in 1998, many manufacturers of ECDIS equipment have gained such certification.

The certifying agency issues a certificate valid for two years. For renewal, a survey is conducted to ensure that systems, software versions, components and materials used comply with type-approved documents and to review possible changes in design of systems, software versions, components, materials performance, and make sure that such changes do not affect the type approval granted.

Manufacturers have been willing to provide type-approved ECDIS to vessel operators, but in a non-compliant installation. Without the geographical coverage of ENC data, the expensive dual-network installation required by ECDIS will not eliminate the requirement to carry a corrected portfolio of paper charts. These partial installations range from approved ECDIS software in a single PC, to ECDIS with its IEC-approved hardware. In these instances, plotting on paper charts continues to be the primary means of navigation. As more ENC data and updates become available, and as governments regulate paperless transits, vessel operators are upgrading their installations to meet full IMO compliance and to make ECDIS the primary means of navigation.

1405. ECS Standards

Although the IMO has declined to issue guidelines on ECS, the Radio Technical Commission for Maritime Services (RTCM) in the United States developed a voluntary, industry-wide standard for ECS. Published in December 1994, the RTCM Standard called for ECS to be capable of executing basic navigational functions, providing continuous plots of own ship position, and providing appropriate indicators with respect to information displayed. The RTCM ECS Standard allows the use of either raster or vector data, and includes the requirement for simple and reliable updating of information, or an indication that the electronic chart information has changed.

In November 2001, RTCM published Version 2.1 of the "RTCM Recommended Standards for Electronic Chart Systems." This updated version is intended to better define requirements applicable to various classes of vessels operating in a variety of areas. Three general classes of vessels are designated:

Large commercial vessels (oceangoing ships)
Small commercial vessels (tugs, research vessels. etc.)
Smaller craft (yachts, fishing boats, etc.)

The intent is that users, manufacturers, and regulatory authorities will have a means of differentiating between the needs of various vessels as relates to ECS. In concept, an ECS meeting the minimum requirements of the RTCM standard should reduce the risk of incidents and improve the efficiency of navigating for many types of vessels.

However, unlike IMO-compliant ECDIS, an ECS is not intended to comply with the up-to-date chart requirements of SOLAS. As such, an ECS must be considered as a single aid to navigation, and should always be used with a corrected chart from a government-authorized hydrographic office.

Initially, IMO regulations require the use of vector data in an ECDIS; raster data does not have the flexibility needed to do what the ECDIS must do. But it soon became clear that the hydrographic offices of the world would not be able to produce vector data for any significant part of the world for some years. Meanwhile, commercial interests were rasterizing charts as fast as they could for the emerging electronic chart market, and national hydrographic offices began rasterizing their own inventories to meet public demand. The result was a rather complete set of raster data for the most heavily travelled waters of the world, while production of man-power intensive vector data lagged far behind. IMO regulations were then amended to allow ECDIS to function in an RCDS mode using official raster data in conjunction with an appropriate portfolio of corrected paper charts. Nations may issue regulations authorizing the use of RCDS and define what constitutes an appropriate folio of paper charts for use in their waters.

In general, an ECS is not designed to read and display the S-57 format, and does not meet the performance standards of either ECDIS or RCDS. But an ECDIS can operate in ECS mode when using raster charts or when using non-S-57 vector charts. When a type-approved ECDIS is installed without being networked to a backup ECDIS, or when it is using non-official ENC data, or ENC data without updates, it can be said to be operating in an ECS mode, and as such cannot be used as a substitute for official, corrected paper charts.

1406. Display Characteristics

While manufacturers of electronic chart systems have designed their own proprietary colors and symbols, the IMO Performance Standard requires that all IMO approved ECDIS follow the International Hydrographic Organization (IHO) Color & Symbol Specifications. These specifications are embodied in the ECDIS Presentation Library. Their development was a joint effort between Canada and Germany during the 1990s. In order for ECDIS to enhance the safety of navigation, every detail of the display should be clearly visible, unambiguous in its meaning, and uncluttered by superfluous information. The unofficial ECS's continue to be free to develop independent of IHO control. In general they seek to emulate the look of the traditional paper chart.

To reduce clutter, the IMO Standard lays down a permanent display base of essentials such as depths, aids to

navigation, shoreline, etc., making the remaining information selectable. The navigator may then select only what is essential for the navigational task at hand. A black-background display for night use provides good color contrast without compromising the mariner's night vision. Similarly, a "bright sun" color table is designed to output maximum luminance in order to be daylight visible, and the colors for details such as buoys are made as contrasting as possible.

The symbols for ECDIS are based on the familiar paper chart symbols, with some optional extras such as simplified buoy symbols that show up better at night. Since the ECDIS can be customized to each ship's requirements, new symbols were added such as a highlighted, mariner selectable, safety contour and a prominent isolated danger symbol.

The Presentation Library is a set of colors and symbols together with rules relating them to the digital data of the ENC, and procedures for handling special cases, such as priorities for the display of overlapping objects. Every feature in the ENC is first passed through the look-up table of the Presentation Library that either assigns a symbol or line style immediately, or, for complex cases, passes the object to a symbology procedure. Such procedures are used for objects like lights, which have so many variations that a look-up table for their symbolization would be too long. The Presentation Library includes a Chart 1, illustrating the symbology. Given the IHO S-57 data standards and S-52 display specifications, a waterway should look the same no matter which hydrographic office produced the ENC, and no matter which manufacturer built the ECDIS.

The overwhelming advantage of the vector-based ECDIS display is its ability to remove cluttering information not needed at a given time. By comparison, the paper chart and its raster equivalent is an unchangeable diagram. A second advantage is the ability to orient the display course-up when this is convenient, while the text remains screen-up.

Taking advantage of affordable yet high-powered computers, some ECDIS's now permit a split screen display, where mode of motion, orientation and scale are individually selectable on each panel. This permits, for example, a north-up small-scale overview in true motion alongside a course-up large-scale view in relative motion. Yet another display advantage occurs with zooming, in that symbols and text describing areas center themselves automatically in whatever part of the area appears on the screen. None of these functions are possible with raster charts.

The display operates by a set of rules, and data is arranged hierarchically, For example, where lines overlap, the less important line is not drawn. A more complex rule always places text at the same position relative to the object it applies to, no matter what else may be there. Since a long name or light description will often over-write another object, the only solution is to zoom in until the objects separate from each other. Note that because text causes so much clutter, and is seldom vital for safe navigation, it is written automatically when the object it refers to is on the display, but is an option under the "all other information" display level.

Flexibility in display scale requires some indication of distance to objects seen on the display. Some manufacturers use the rather restrictive but familiar radar range rings to provide this, while another uses a line symbol keyed to data's original scale. The ECDIS design also includes a one-mile scalebar at the side of the display, and an optionally displayed course and speed made good vector for own ship. There may be a heading line leading from the vessel's position indicating her future track for one minute, three minutes, or some other selectable time.

To provide the option of creating manual chart corrections, ECDIS includes a means of drawing lines, adding text and inserting stored objects on the display. These may be saved as user files, called up from a subdirectory, and edited on the display. Once loaded into the SENC, the objects may be selected or de-selected just as with other objects of the SENC.

Display options for ECDIS include transfer of ARPA-acquired targets and radar image overlay. IMO standards for ECDIS require that the operator be able to deselect the radar picture from the chart with a single operator action for fast "uncluttering" of the chart presentation.

1407. Units, Data Layers and Calculations

ECDIS uses the following units of measure:

- **Position:** Latitude and longitude will be shown in degrees, minutes, and decimal minutes, normally based on WGS-84 datum.
- **Depth:** Depths will be indicated in meters and decimeters.
- **Height:** Meters
- **Distance:** Nautical miles and tenths, or meters
- **Speed:** Knots and tenths

ECDIS requires data layers to establish a priority of data displayed. The minimum number of information categories required and their relative priority from highest to lowest are listed below:

- ECDIS warnings and messages
- Hydrographic office data
- *Notice to Mariner*s information
- Hydrographic office cautions
- Hydrographic office color-fill area data
- Hydrographic office on demand data
- Radar information
- User's data
- Manufacturer's data
- User's color-fill area data
- Manufacturer's color-fill area data

As a minimum, an ECDIS system must be able to perform the following calculations and conversions:

- Geographical coordinates to display coordinates, and display coordinates to geographical coordinates.
- Transformation from local datum to WGS-84.
- True distance and azimuth between two geographical positions.
- Geographic position from a known position given distance and azimuth.
- Projection calculations such as great circle and rhumb line courses and distances.

1408. Warnings and Alarms

Appendix 5 of the IMO Performance Standard specifies that ECDIS must monitor the status of its systems continuously, and must provide alarms and indications for certain functions if a condition occurs that requires immediate attention. Indications may be either visual or audible. An alarm must be audible and may be visual as well.

An alarm is required for the following:

- Exceeding cross-track limits
- Crossing selected safety contour
- Deviation from route
- Position system failure
- Approaching a critical point
- Chart on different geodetic datum from positioning system

An alarm or indication is required for the following:

- Largest scale for alarm (indicates that presently loaded chart is too small a scale to activate anti-grounding feature)
- Area with special conditions (means a special type of chart is within a time or distance setting)
- Malfunction of ECDIS (means the master unit in a master-backup network has failed)

An indication is required for the following:

- Chart overscale (zoomed in too close)
- Larger scale ENC available
- Different reference units (charted depths not in meters)
- Route crosses safety contour
- Route crosses specified area activated for alarms
- System test failure

As these lists reveal, ECDIS has been programmed to constantly "know" what the navigation team should know, and to help the team to apply its experience and judgment through the adjustment of operational settings.

This automation in ECDIS has two important consequences: First, route or track monitoring does not replace situational awareness; it only enhances it. The alarm functions, while useful, are partial and have the potential to be in error, misinterpreted, ignored, or overlooked.

Secondly, situational awareness must now include, especially when ECDIS is used as the primary means of navigation, the processes and status of the electronic components of the system. This includes all attached sensors, the serial connections and communication ports and data interfaces, the computer processor and operating system, navigation and chart software, data storage devices, and power supply. Furthermore, these new responsibilities must still be balanced with the traditional matters of keeping a vigilant navigational watch.

ECDIS or not, the windows in the pilothouse are still the best tool for situational awareness. Paradoxically, ECDIS makes the navigator's job both simpler and more complex.

1409. ECDIS Outputs

During the past 12 hours of the voyage, ECDIS must be able to reconstruct the navigation and verify the official database used. Recorded at one minute intervals, the information includes:

- Own ship's past track including time, position, heading, and speed
- A record of official ENC used including source, edition, date, cell and update history

It is important to note that if ECDIS is turned off, such as for chart management or through malfunction, voyage recording ceases, unless a networked backup system takes over the functions of the master ECDIS. In that case, the voyage recording will continue, including an entry in the electronic log for all the alarms that were activated and reset during the switchover. Voyage files consist of logbook files, track files and target files. The file structure is based on the date and is automatically created at midnight for the time reference in use. If the computer system time is used for that purpose, the possibility exists for overwriting voyage files if the system time is manually set back. Allowing GPS time as the system reference avoids this pitfall.

In addition, ECDIS must be able to record the complete track for the entire voyage with time marks at least once every four hours. ECDIS should also have the capability to preserve the record of the previous 12 hours of the voyage. It is a requirement that the recorded information be inaccessible to alteration. Preserving voyage files should follow procedures for archiving data. Unless radar overlay data is being recorded, voyage files tend to be relatively small, permitting backup onto low-capacity media, and purging from system memory at regular intervals. (This form of backing up should not be confused with the network master-slave

backup system.)

Adequate backup arrangements must be provided to ensure safe navigation in case of ECDIS failure. This includes provisions to take over ECDIS functions so that an ECDIS failure does not develop into a critical situation, and a means of safe navigation for the remaining part of the voyage in case of complete failure.

1410. Voyage Data Recorder (VDR)

The purpose of the voyage data recorder VDR is to provide accurate historical navigational data in the investigation of maritime incidents. It is additionally useful for system performance monitoring. A certified VDR configuration records all data points, as per IMO Resolution A.861(20) & EC Directive 1999/35/EC. Some of the voyage data can be relayed through ECDIS. A fully IEC compliant data capsule passes fire and immersion tests.

The implementation of a secure "black box" and comprehensive Voyage Data Recorder (VDR) is now a carriage requirement on passenger and Ro-Ro vessels over 3000 GT (1600 GRT) engaged in international passages. Existing vessels must be retrofitted by July 2004, and all vessels built after July 2002 must be fitted with a VDR. Retrofit regulations for other vessels built before July 2002 are still in development. Non-RO-RO passenger vessels built before July 2002 may be exempted from carriage where an operator can show that interfacing a VDR with the existing equipment on the ship is unreasonable and impracticable. The European Union requires that all RO-RO ferries or high speed craft engaged on a regular service in European waters (domestic or international) be fitted with a VDR if built before February 2003, and otherwise retrofitted by July 2004.

VDR features include:

- Radar video capture: Radar video is captured and compressed every 15 seconds to comply with IEC performance standards.

- I/O subsystem: To collect a wide variety of data types, a sensor interface unit provides signal conditioning for all analog, digital and serial inputs. All data is converted and transmitted to a data acquisition unit via an ethernet LAN.

- Audio compression: An audio module collects analog signals from microphone preamplifiers. The data is digitized and compressed to meet Lloyds of London 24-hour voice storage requirements.

- Integral uninterruptible power supply (UPS) IEC requires a UPS backup for all components of the data acquisition unit and for the data capsule to provide two hours continuous recording following a blackout.

- Hardened fixed data capsule: IEC 61996 compliant data capsules fitted with ethernet connections provide fast download as well as fast upload to satellite links.

- Remote data recovery and shoreside playback: Options available in several systems.

- Annual system certification: The IMO requires that the VDR system, including all sensors, be subjected to an annual performance test for certification.

DATA FORMATS

1411. Official Vector Data

How ECDIS operates depends on what type of chart data is used. ENC's (electronic navigational charts) and RNC's (raster nautical charts) are approved for use in ECDIS. By definition both ENC's and RNC's are issued under the authority of national hydrographic offices (HO's). ECDIS functions as a true ECDIS when used with corrected ENC data, but ECDIS operates in the less functional raster chart display system (RCDS) mode when using corrected RNC data. When ECDIS is used with non-official vector chart data (corrected or not), it operates in the ECS mode.

In vector charts, hydrographic data is comprised of a series of files in which different layers of information are stored or displayed. This form of "intelligent" spatial data is obtained by digitizing information from existing paper charts or by storing a list of instructions that define various position-referenced features or objects (e.g., buoys, lighthouses, etc.). In displaying vector chart data on ECDIS, the user has considerable flexibility and discretion regarding the amount of information that is displayed.

An ENC is vector data conforming to the IHO S-57 ENC product specification in terms of content, structure and format. An ENC contains all the chart information necessary for safe navigation and may contain supplementary information in addition to that contained in the paper chart. In general, an S-57 ENC is a structurally layered data set designed for a range of hydrographic applications. As defined in IHO S-57 Edition 3, the data is comprised of a series of points, lines, areas, features, and objects. The minimum size of a data set is a cell, which is a spherical rectangle (i.e., bordered by meridians and latitudes). Adjacent cells do not overlap. The scale of the data contained in the cell is dependent upon the navigational purpose (e.g., general, coastal, approach, harbor).

Under S-57, cells have a standard format but do not have a standard coverage size. Instead, cells are limited to 5mb of data. S-57 cells are normally copy protected and therefore require a permit before use is allowed. These permits are delivered as either a file containing the chart

permits or as a code. In both cases the first step is to install the chart permit into the ECDIS. Some hydrographic offices deliver S-57 cells without copy protection and therefore permits are not required.

Any regional agency responsible for collecting and distributing S-57 data, such as PRIMAR for Northern Europe, will also maintain data consistency. National hydrographic offices are responsible for producing S-57 data for their own country area. Throughout the world HO's have been slow to produce sufficient quantities of ENC data. This is due to the fact that the standards evolved over several years, and that vector data is much harder to collect than raster data.

In 1996 the IHO S-57 data standard and IHO S-52 specifications for chart content and display were "frozen." It took three versions of S-57 before the issue was finally settled as to what actually comprises an ENC (i.e., ENC Product Specification) and what is required for updating (ENC Updating Profile). The ENC Test Dataset that the International Electrotechnical Commission (IEC) requires for use in conjunction with IEC Publication 61174 (IEC 1997) was finalized by IHO in 1998. It was not possible to conduct ECDIS type-approval procedures without a complete and validated IHO ENC Test Dataset.

Major areas of ENC coverage now include most of Canadian and Japanese waters, the Baltic and North Sea, and important waterways such as the Straits of Malacca, Singapore Strait, and the Straits of Magellan (Chile).

At the same time, many countries including the United States, are stepping up their production of ENC's where issues of port security require the collection of baseline data of submerged hazards. In the U.S., NOAA plans to complete its portfolio of large-scale charts of 42 ports in ENC format by mid-2003, with smaller scale chart completion by 2005. As the chart cells are completed, the data is being made available on the World Wide Web at no cost. Beginning in 2003, NOAA will post critical notice to mariner corrections without restrictions in monthly increments. At that point the status of NOAA's available ENC data will be changed from provisional to official.

ENC data is currently available from the HO's of most Northern European countries, Japan, Korea, Hong Kong, Singapore, Canada, Chile, and the United States, although the coverage and updating process is incomplete. Most ENC is available only through purchase, permits or licensing.

1412. Vector Data Formats Other Than IHO S-57

The largest of the non-S-57 format databases is the Digital Nautical Chart (DNC). The National Imagery and Mapping Agency (NIMA) produces the content and format for the DNC according to a military specification. This allows compatibility among all U.S. Defense Department assets. The DNC is a vector-based digital product that portrays significant maritime features in a format suitable for computerized marine navigation. The DNC is a general-purpose global database designed to support marine navigation and Geographic Information System (GIS) applications. DNC data is only available to the U.S. military and selected allies. It is designed to conform to the IMO Performance Standard and IHO specifications for ECDIS.

Several commercial manufacturers have developed vector databases beyond those that have been issued by official hydrographic offices. These companies are typically manufacturers of ECDIS or ECS equipment or have direct relationships with companies that do, and typically have developed data in proprietary format in order to provide options to raster charts in the absence of ENC data. HO-issued paper charts provide the source data for these formats, although in some cases non-official paper charts are used. In some cases, ECS manufacturers provide a regular updating and maintenance service for their vector data, resulting in added confidence and satisfaction among users. The manufacturer's source of the updates is through HO's. Hence, these two particular non-official formats allows for a very high degree of confidence and satisfaction among mariners using this data.

ECS systems sometimes apply rules of presentation similar to officially specified rules. Thus information is displayed or removed automatically according to scale level to manage clutter. The same indications pertinent to overscaling ENC apply to private vector data. Since the chart data is not ENC, the systems must display that non-official status when used in an ECDIS.

1413. Raster Data

Raster navigational chart (RNC) data is stored as picture elements (pixels). Each pixel is a minute component of the chart image with a defined color and brightness level. Raster-scanned images are derived by scanning paper charts to produce a digital photograph of the chart. Raster data are far easier to produce than vector data, but raster charts present many limitations to the user.

The official raster chart formats are:

ARCS (British Admiralty)
Seafarer (Australia)
BSB (U.S., NOAA/Maptech)

These charts are produced from the same raster process used to print paper charts. They are accurate representations of the original paper chart with every pixel geographically referenced. Where applicable, horizontal datum shifts are included with each chart to enable referencing to WGS84. This permits compatibility with information overlaid on the chart. *Note: Not all available charts have WGS84 shift information.* Extreme caution is necessary if the datum shift cannot be determined exactly.

Raster nautical charts require significantly larger

amounts of memory than vector charts. Whereas a world portfolio of more than 7500 vector charts may occupy about 500mb, a typical coastal region in raster format may consist of just 40 charts and occupy more than 1000mb of memory.

For practical purposes, most of a portfolio of raster charts should be left on the CD and not loaded into the ECDIS hard drive unless one is route planning or actually sailing in a given region. Of course, updates can only be performed on charts that are loaded onto the hard drive.

Certain non-official raster charts are produced that cover European and some South American waters. These are scanned from local paper charts. Additionally, some ECDIS and ECS manufacturers also produce raster charts in proprietary formats.

In 1998 the IMO's Maritime Safety Committee (MSC 70) adopted the Raster Chart Display System (RCDS) as Appendix 7 to the IMO Performance Standards. The IMO-IHO Harmonization Group on ECDIS (HGE) considered this issue for over three years. Where IHO S-57 Ed. 3 ENC data coverage is not available, raster data provided by official HO's can be used as an interim solution. But this RCDS mode does not have the full functionality of an otherwise IMO-compliant ECDIS using ENC data. Therefore, RCDS does not meet SOLAS requirements for carriage of paper charts, meaning that when ECDIS equipment is operated in the RCDS mode, it must be used together with an appropriate portfolio of corrected paper charts.

Some of the limitations of RCDS compared to ECDIS include:

- Chart features cannot be simplified or removed to suit a particular navigational circumstance or task.

- Orientation of the RCDS display to course-up may affect the readability of the chart text and symbols since these are fixed to the chart image in a north-up orientation.

- Depending on the source of the raster chart data, different colors may be used to show similar chart information, and there may be differences between colors used during day and night time.

- The accuracy of the raster chart data may be less than that of the position-fixing system being used.

- Unlike vector data, charted objects on raster charts do not support any underlying information.

- RNC data will not trigger automatic alarms. (However, some alarms can be generated by the RCDS from user-inserted information.).

- Soundings on raster charts may be in fathoms and feet, rather than meters.

The use of ECDIS in RCDS mode can only be considered as long as there is a backup folio of appropriate up-to-date paper charts.

INTEGRATED BRIDGE SYSTEMS

1414. Description

An Integrated Bridge System (IBS) is a combination of equipment and software which uses interconnected controls and displays to present a comprehensive suite of navigational information to the mariner. Rules from classification societies such as Det Norske Veritas (DNV) specify design criteria for bridge workstations. Their rules define tasks to be performed, and specify how and where equipment should be sited to enable those tasks to be performed. Equipment carriage requirements are specified for ships according to the requested class certification or notation. Publication IEC 61029 defines operational and performance requirements, methods of testing, and required test results for IBS.

Classification society rules address the total bridge system in four parts: technical system, human operator, man/machine interface, and operational procedures. The DNV classifies IBS with three certifications: NAUT-C covers bridge design; W1-OC covers bridge design, instrumentation and bridge procedures; W1 augments certain portions of W1-OC.

An IBS generally consists of at least:

- Dual ECDIS installation – one serving master and the other as backup and route planning station

- Dual radar/ARPA installation
- Conning display with a concentrated presentation of navigational information (the master ECDIS)
- DGPS positioning
- Ship's speed measuring system
- Auto-pilot and gyrocompass system
- Full GMDSS functionality

Some systems include full internal communications, and a means of monitoring fire control, shipboard status alarms, and machinery control. Additionally, functions for the loading and discharge of cargo may also be provided.

An IBS is designed to centralize the functions of monitoring collision and grounding risks, and to automate navigation and ship control. Control and display of component systems are not simply interconnected, but often share a proprietary language or code. Several instruments and indicators are considered essential for safe and efficient performance of tasks, and are easily readable at the navigation workstation, such as heading, rudder angle, depth, propeller speed or pitch, thruster azimuth and force, and speed and distance log.

Type approval by Det Norske Veritas for the DNV-W1-ANTS (Automatic Navigation and Track-Keeping

System) certification is given to ship bridge systems designed for one-man watch (W1) in an unbounded sea area. DNV also provides for the other two class notations, NAUT-C and W1-OC. The W1 specifications require the integration of:

- CDIS (providing the functions of safety-contour checks and alarms during voyage planning and execution)
- Manual and automatic steering system (including software for calculation, execution and adjustments to maintain a pre-planned route, and including rate of turn indicator)
- Automatic Navigation and Track-keeping System (ANTS)
- Conning information display
- Differential GPS (redundant)
- Gyrocompass (redundant)
- Radar (redundant) and ARPA
- Central alarm panel
- Wind measuring system
- Internal communications systems
- GMDSS
- Speed over ground (SOG) and speed through water (STW or Doppler log)

- Depth sounder (dual transducer >250m)
- Course alteration warnings and acknowledgment
- Provision to digitize paper charts for areas not covered by ENC data

The W1 classification requires that maneuvering information be made available on the bridge and presented as a pilot card, wheelhouse poster, and maneuvering booklet. The information should include characteristics of speed, stopping, turning, course change, low-speed steering, course stability, trials with the auxiliary maneuvering device, and man-overboard rescue maneuvers.

The W1-OC and W1 classifications specify responsibilities of ship owner and ship operator, qualifications, bridge procedures, and particular to W1, a requirement for operational safety standards. The W1 operational safety manual requires compliance with guidelines on bridge organization, navigational watch routines, operation and maintenance of navigational equipment, procedures for arrival and departure, navigational procedures for various conditions of confinement and visibility, and system fallback procedures. Both classifications also require compliance with a contingency and emergency manual, including organization, accident, security, evacuation, and other related issues.

MILITARY ECDIS

1415. ECDIS-N

In 1998, the U.S. Navy issued a policy letter for a naval version of ECDIS, ECDIS-N, and included a performance standard that not only conforms to the IMO Performance Standards, but extends it to meet unique requirements of the U.S. Department of Defense.

A major difference from an IMO-compliant ECDIS is the requirement that the ECDIS-N SENC must be the Digital Nautical Chart (DNC) issued by the National Imagery and Mapping Agency (NIMA). The DNC conforms to the U.S. DoD standard Vector Product Format (VPF), an implementation of the NATO DIGEST C Vector Relational Format. All of NIMA's nautical, aeronautical, and topographic vector databases are in VPF to ensure interoperability between DoD forces.

In the United States, NIMA produces the Digital Nautical Chart (DNC). It is a vector database of significant maritime features that can be used with shipboard integrated navigation systems such as ECDIS, ECDIS-N, or other types of geographic information systems. NIMA has been working closely with the U.S. Navy to help facilitate a transition from reliance on paper charts to electronic chart navigation using the DNC. The U.S. Navy plans to have all of its surface and sub-surface vessels using DNC's by 2004. NIMA has produced the DNC to support worldwide navi-

gation requirements of the U.S. Navy and U.S. Coast Guard.

To ensure that the DNC data would not be manipulated or inadvertently altered when used by different military units, a decision was made to produce a specific data software product that must be used in a "direct read" capability. As such, a DNC is really a system electronic navigational chart (SENC) that contains specified data and display characteristics. Control of the SENC provides the military with interoperability across deployed systems, which is particularly important when integrated with military data layers.

1416. Navigation Sensor System Interface (NAVSSI)

The Navigation Sensor System Interface (NAVSSI) contains the U.S. Navy's version of ECDIS, and also has significant additional capabilities for the Navy's defense missions. NIMA's Vector Product Format (VPF) DNC's are used in conjunction with NAVSSI. NAVSSI performs three important functions:

- Navigation Safety: NAVSSI distributes real time navigation data to the navigation team members to ensure navigation safety.
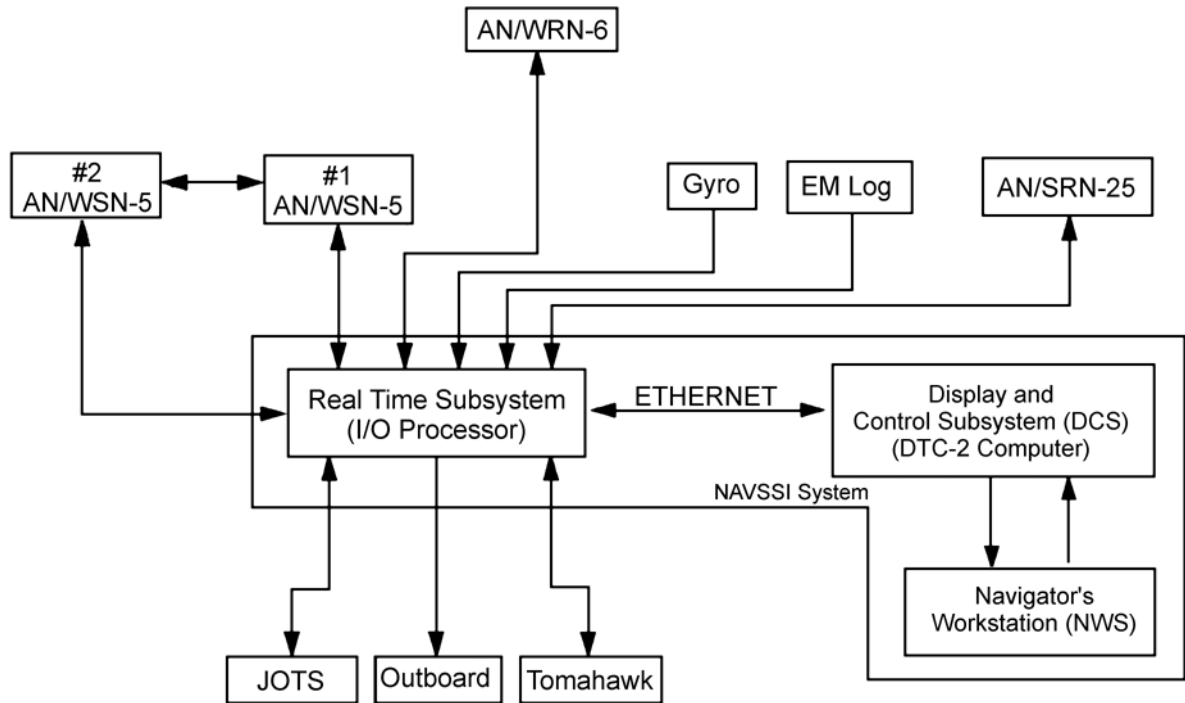- Weapons System Support: NAVSSI provides initial-

Figure 1416. Block diagram of NAVSSI.

ization data for weapons systems.

- Battlegroup Planning: NAVSSI provides a workstation for battlegroup planning.

The navigational function of NAVSSI, therefore, is only one of several tasks accomplished by the system. The navigational portion of NAVSSI complies with the IMO/IHO ECDIS standards for content and function.

The heart of NAVSSI is the Real Time Subsystem (RTS). The RTS receives, processes and distributes navigational data to the navigation display, weapons systems, and other networked vessels. This ensures that all elements of a battlegroup have the same navigational picture. Inputs come from GPS, Loran, inertial navigation systems, compass, and speed log. The bridge display consists of a monitor and control panel, while the RTS is mounted below decks. DNC's are contained in the **Display and Control Subsystem (DCS)** typically mounted in the chartroom with a monitor on the bridge. This is unlike many current commercial systems which house all hardware and software in a single unit on the bridge. A separate NAVSSI software package supports operator interface, waypoint capability, collision and grounding avoidance features, and other aspects of an ECDIS.

Figure 1416 illustrates a basic block diagram of the NAVSSI system. The RTS takes inputs from the inertial navigators, the GPS in PPS mode, the compass, the EM Log, and the SRN-25. The RTS distributes navigation in-

formation to the various tactical applications requiring navigation input, and it communicates via fiber optic network with the DCS. The DCS exchanges information with the Navigator's Workstation.

1417. The Digital Nautical Chart

NAVSSI uses the Digital Nautical Chart (DNC) as its chart database. The DNC is in Vector Product Format (VPF) and is based on the contents of the traditional paper harbor, approach, coastal and general charts produced by NIMA and NOS.

Horizontal datum is WGS 84 (NAD 83 in the U. S. is equivalent). There are three vertical datums. Topographic features are referenced to Mean Sea Level and the shore line is referenced to Mean High Water. Hydrography is referenced to a low water level suitable for the region. All measurements are metric.

The DNC portfolio consists of 29 CD-ROM's and provides global coverage between 84 degrees N and 81 degrees S. This comprises some 4,820 charts group into five libraries based on scale:

General: (>1:500K)
Coastal: (1:75K - 1: 500K)
Approach (1:25K - 1:75K)
Harbor (1 <1:50K)
Browse Index (1:3,100,000)

DNC data is layered together into 12 related feature classes:

- Cultural Landmarks
- Earth Cover
- Inland Waterways
- Relief
- Landcover
- Port Facilities
- Aids to Navigation
- Obstructions
- Hydrography
- Environment
- Limits
- Data Quality

Content is generally the same as on a paper chart. The data is stored in libraries; each library represents a different level of detail. The libraries are then stored on CD-ROM and organized as tiles according to the World Geodetic Reference System (GEOREF) tiling scheme.

A subset of the DNC is known as Tactical Ocean Data (TOD). TOD data is bathymetric in nature and intended for Naval operations.

There are 6 levels of TOD:

Level 0 - OPAREA charts
Level 1 - Bottom Contour
Level 2 - Bathymetric Navigation Planning Charts
Level 3 - Shallow Water
Level 4 - Hull Integrity Test Charts
Level 5 - Strategic Straits Charts

1418. Warship ECDIS (WECDIS)

A Warship ECDIS is an ECDIS approved by international authorities for warship use, which, while meeting the operating standards of ECDIS, may not conform exactly to ECDIS specifications.

Performance Standards for "Warship" ECDIS (WECDIS) were approved by the North Atlantic Treaty Organization (NATO) in 1999 and issued as STANAG 4564. The core functionality of WECDIS is an IMO-compliant ECDIS. Beyond the minimum performance requirements for ECDIS, WECDIS has the ability to use a variety of geospatial data from both civilian and military sources. For navigational data, WECDIS uses both IHO S-57 ENC data and data conforming to NATO Digital Geographic Information Exchange (DIGEST) Standards. This latter includes such products as Vector Product Format (VPF) and Digital Nautical Chart (DNC).

In addition to core navigation information (IHO S-57 ENC and VPF-DNC), WECDIS will also use Additional Navigation Information (ANI) provided by government hydrographic offices and military sources. Specific types of ANI data include Raster Navigational Charts (RNC's), such as Admiralty Raster Chart Service (ARCS) or NOAA's raster charts distributed and updated by Maptech, Inc. The ability to use different types of navigational data from a variety sources is often referred to as "multi-fuel."

CORRECTING ELECTRONIC CHARTS

1419. ECDIS Correction Systems

ECDIS software creates a database from the ENC data called the system electronic navigational chart (SENC) and from this selects information for display. The ECDIS software meanwhile receives and processes serial data from navigational sensors and displays that textual and graphical information simultaneously with the SENC information.

It is the SENC that is equivalent to up-to-date charts, as stated by the Performance Standards. As originally conceived, ECDIS was designed to use internationally standardized and officially produced vector data called the ENC (electronic navigational chart). Only when using ENC data can ECDIS create an SENC, and thereby function in the ECDIS mode.

Updates for ENC are installed into the ECDIS separate from the ENC data itself. For the mariner, this involves activating a special utility accompanying the ECDIS and following the on-screen prompts. Within this same utility, update content and update log files in textual form can be viewed. Once the ECDIS software itself is reactivated, the update information is accessed in conjunction with the

ENC data and the SENC database is created.

Just as ENC and updates are transformed into the SENC, so too are other data types accessed and combined. The user has the option to add lines, objects, text and links to other files supported by application. Referred to in the Performance Standards as data added by the mariner, these notes function as layers on the displayed chart. The user can select all or parts of the layers for display to keep clutter to a minimum. The mariner's own layers, however, must be called into the SENC from stored memory. As a practical matter, not only must the mariner take care to associate file names with actual content, such as with manually created chart corrections, but also must realize that the files themselves do not have the tamper-proof status that ENC and official updates have.

Within the SENC resides all the information available for the display. The Presentation Library rules such as Standard Display and Display Base define what levels of information from the SENC can be shown.

An ENC updating profile is contained within the IHO S-57 Edition 3.0 specification. This enables the efficient addition, removal or replacement of any line, feature, object

or area contained within the ENC dataset. Guidance on the means and process for ENC updating is provided in IHO S-52, Appendix 1. In terms of what is called for in the IMO Performance Standards, an ENC dataset being used in an ECDIS must also have an ENC updating service. This permits the ENC and the SENC to be corrected for the intended voyage, and thus achieves an important component of SOLAS compliance.

Accordingly, ECDIS must be capable of accepting official updates to the ENC data provided in conformity with IHO standard. Updated cells are stored in a file and transmitted by e-mail, floppy disk or CD-ROM, or satellite. For example, PRIMAR charts and updates are delivered on two CD's: the Base CD contains the PRIMAR database at the time indicated on the label and the second CD contains the updates for those charts. But the update CD also contains new charts issued since the base CD was printed. Since the operator must acquire the files and then initiate the update functions of the ECDIS software, this form of updating is referred to as semi-automatic.

Generally, ECDIS will reject updates if the update issuing authority is different from the cell issuing authority. It will also reject corrupted update files and files with an incorrect extension. ECDIS checks that updates are applied in the right sequence. If one update is missing the next update is rejected. An update CD-ROM should contain all available updates for all S57 cells. Generally, ECDIS will automatically run all updates in the right order for all cells.

For S-57 data, the content of updates in text form can be viewed from within the utility that permits the management of chart data. Generally it can only be run when ECDIS is terminated. ECDIS is also capable of showing or hiding S-57 updates on a given chart or cell. The update must first be installed via the chart utility. After restarting ECDIS, and after loading into the display the particular chart with the correction, the correction should be manually accepted. That enables the function in S-57 chart options to show or hide the symbol indicating the location of the correction.

NIMA DNC Corrections

NIMA has produced the DNC Vector Product Format Database Update (VDU) to support worldwide DNC navigation requirements of the U.S. Navy, the U.S. Coast Guard, and certain allies. NIMA does not distribute DNC to other than U.S. government agencies and foreign governments having data exchange agreements with NIMA. The DNC maintenance system will be able to apply new source materials such as bathymetry, imagery, *Notice to Mariners*, local notices, new foreign charts, etc. for inclusion in the DNC database.

The VDU system works by performing a binary comparison of the corrected chart with the previous version. The differences are then written to a binary "patch" file with instructions as to its exact location. The user then ap-

plies this patch by specifying the proper path and filename on his own ship. Every new change incorporates all previous changes, so the navigator is assured that, having received the latest change, he has all changes issued to date.

File sizes are small enough to support bandwidth limitations of ships at sea and requires only one-way communication. Patch files are posted every four weeks. Authorized commands may access DNC's and the associated VDU files through the NIMA Gateway:

OSIS http://osis.nima.mil/gidbe/index.htm
SIPRNET http://www.nima.smil.mil/products/dnc1
JWICS http://www.nima.is.gov/products/dnc1

The VDU patch files are posted to the World Wide Web monthly at:

http://www.nima.mil/dncpublic/

A separate layer within DNC provides the user with identification of where changes have been made during the updating process.

British RCS Corrections

For the British RCS system, updates for all 2700 charts affected by *Admiralty Notice to Mariners* are compiled and placed on a weekly ARCS Update CD-ROM. Applying the corrections is only semi-automatic (not fully automatic), but it is also error-free, and each CD-ROM provides cumulative updates. The CD-ROM's are available through chart agents.

NOAA Corrections

In the U.S., NOAA has contracted with Maptech, Inc. to provide updating of all NOS raster charts using information from the USCG, NIMA and the Canadian Hydrographic Service (CHS). Maptech uses a "patch technique" to update only those parts of a given chart identified as needing correction. The method compares the existing chart file and its corrected counterpart on a pixel-by-pixel basis. The software creates a "difference file" that is associated with the existing raster file to which it applies. This difference file is then compressed so that a typical patch contains only a few kilobytes of data. Ninety-nine percent are under 10kb. Typical downloads for a chart take 15 seconds to 5 minutes depending on modem speed.

The raster chart is updated as the patch file alters the pixels on the original chart. Update patches are available by download, and are cumulative for the all the charts packed on a given source folio CD. Further refinement will permit the separate storage of the RNC and update patches, so that as the patch is applied dynamically in real time, the user will be able to view the correction. The dynamic patching is similar to ENC updating in that the original chart data is

not altered. Presently the service is a subscription service with weekly updates at a nominal cost. Information is available at http://chartmaker.ncd.noaa.gov.

Commercial Systems

There are a variety of ECS's available for small craft, often found aboard fishing vessels, tugs, research vessels, yachts, and other craft not large enough to need SOLAS equipment but wanting the best in navigation technology. Given that these systems comprise a single aid to navigation and do not represent a legal chart in any sense, it is probably not a critical point that correction systems for

these products are not robust enough to support regular application of changes.

In fact, often the only way to make changes is to purchase new editions, although the more sophisticated ones allow the placement of electronic "notes" on the chart. The data is commonly stored on RAM chips of various types, and cannot be changed or without re-programming the chip from a CD-ROM or disk containing the data. If the data is on CD-ROM, a new CD-ROM is the update mechanism, and they are, for the most part, infrequently produced. Users of these systems are required to maintain a plot on a corrected paper chart.

USING ELECTRONIC CHARTS

1420. Digital Chart Accuracy

As is the case with any shipboard gear, the user must be aware of the capabilities and limitations of digital charts. The mariner should understand that nautical chart data displayed possess inherent accuracy limitations. Because digital charts are necessarily based primarily on paper charts, many of these limitations have migrated from the paper chart into the electronic chart. Electronic chart accuracy is, for the most part, dependent on the accuracy of the features being displayed and manipulated. While some ECDIS and ECS have the capability to use large-scale data produced from recent hydrographic survey operations (e.g., dredged channel limits or pier/terminal facilities) most raster and vector-based electronic chart data are derived from existing paper charts.

Twenty years ago, mariners were typically obtaining position fixes using radar ranges, visual bearings or Loran. Generally, these positioning methods were an order of magnitude less accurate than the horizontal accuracy of the survey information portrayed on the chart. For example, a three-line fix that results in an equilateral triangle with sides two millimeters in length at a chart scale of 1:20,000 represents a triangle with 40-meter sides in real-world coordinates.

A potential source of error is related to the system configuration, rather than the accuracy of electronic chart data being used. All ECDIS's and most ECS's enable the user to input the vessel's dimensions and GPS antenna location. On larger vessels, the relative position of the GPS antenna aboard the ship can be a source of error when viewing the "own-ship" icon next to a pier or wharf.

In U.S. waters, the Coast Guard's DGPS provides a horizontal accuracy of +/-10 meters (95 percent). However, with selective availability off, even the most basic GPS receiver in a non-differential mode may be capable of providing better than 10 meter horizontal accuracy. In actual operation, accuracies of 3-5 meters are being achieved. As a result, some mariners have reported that when using an electronic chart while moored alongside a pier, the vessel

icon plots on top of the pier or out in the channel.

Similarly, some mariners transiting a range that marks the centerline of a channel report that the vessel icon plots along the edge or even outside of the channel. Mariners now expect, just as they did 20 years ago, that the horizontal accuracy of their charts will be as accurate as the positioning system available to them. Unfortunately, any electronic chart based on a paper chart, whether it is raster or vector, is not able to meet this expectation.

The overall horizontal accuracy of data portrayed on paper charts is a combination of the accuracy of the underlying source data and the accuracy of the chart compilation process. Most paper charts are generalized composite documents compiled from survey data that have been collected by various sources over a long period of time. A given chart might encompass one area that is based on a lead line and sextant hydrographic survey conducted in 1890, while another area of the same chart might have been surveyed in the year 2000 with a full-coverage shallow-water multibeam system. In the U.S., agencies have typically used the most accurate hydrographic survey instrumentation available at the time of the survey.

While survey positioning methods have changed over the years, standards have generally been such that surveys were conducted with a positioning accuracy of better than 0.75 millimeters at the scale of the chart. Therefore, on a 1:20,000-scale chart, the survey data was required to be accurate to 15 meters. Features whose positions originate in the local notice to mariners, reported by unknown source, are usually charted with qualifying notations like position approximate (PA) or position doubtful (PD). The charted positions of these features, if they do exist, may be in error by miles.

As of 2002, over 50 percent of the depth information found on U.S. charts is based on hydrographic surveys conducted before 1940. Surveys conducted many years ago with lead lines or single-beam echo sounders sampled only a tiny percentage of the ocean bottom. Hydrographers were unable to collect data between the sounding lines. Depending on the water depth, these lines may have been spaced at

50, 100, 200 or 400 meters. As areas are re-surveyed and full-bottom coverage is obtained, uncharted features, some dangerous to navigation, are discovered quite often. These features were either: 1) not detected on prior surveys, 2) objects such as wrecks that have appeared on the ocean bottom since the prior survey or 3) the result of natural changes that have occurred since the prior survey.

In a similar manner, the shoreline found on most U.S. charts is based on photogrammetric or plane table surveys that are more than 20 years old. In major commercial harbors, the waterfront is constantly changing. New piers, wharves, and docks are constructed and old facilities are demolished. Some of these man-made changes are added to the chart when the responsible authority provides as-built drawings. However, many changes are not reported and therefore do not appear on the chart. Natural erosion along the shoreline, shifting sand bars and spits, and geological subsidence and uplift also tend to render the charted shoreline inaccurate over time.

Another component of horizontal chart accuracy involves the chart compilation process. For example, in the U.S. before NOAA's suite of charts was scanned into raster format in 1994, all chart compilation was performed manually. Projection lines were constructed and drawn by hand and all plotting was done relative to these lines. Cartographers graphically reduced large scale surveys or engineering drawings to chart scale. Very often these drawings were referenced to state plane or other local coordinate systems. The data would then be converted to the horizontal datum of the chart (e.g., the North American 1927 (NAD 27) or the North American Datum 1983 (NAD 83). In the late 1980's and early 1990's, NOAA converted all of its charts to NAD 83. In accomplishing this task, averaging techniques were used and all of the projection lines were redrawn.

When NOAA scanned its charts and moved its cartographic production into a computer environment, variations were noted between manually constructed projection lines and those that were computer generated. All of the raster charts were adjusted or warped so that the manual projection lines conformed to the computer-generated projection. In doing so, all information displayed on the chart was moved or adjusted.

Similar processes take place during NIMA's digital chart production, but involving more complexity, since NIMA cartographers must work with a variety of different datums in use throughout the world, and with hydrographic data from hundreds of official and unofficial sources. While much of NIMA's incoming data was collected to IHO standards during hydrographic surveys, many sources are questionable at best, especially among the older data.

Today, when survey crews and contractors obtain DGPS positions on prominent shoreline features and compare those positions to the chart, biases may be found that are on the order of two millimeters at the scale of the chart (e.g., 20 meters on 1:10,000-scale chart). High accuracy

aerial photography reveals similar discrepancies between the true shoreline and the charted shoreline. It stands to reason that other important features such as dredged channel limits and navigational aids also exhibit these types of biases. Unfortunately, on any given chart, the magnitude and the direction of these discrepancies will vary by unknown amounts in different areas of the chart. Therefore, no systematic adjustment can easily be performed that will improve the inherent accuracy of the paper or electronic chart.

Some mariners have the misconception that because charts can be viewed on a computer, the information has somehow become more accurate than it appears on paper. Some mariners believe that vector data is more accurate than paper or raster data. Clearly, if an electronic chart database is built by digitizing a paper chart, it can be no more accurate than the paper chart.

The most accurate way to create an ENC is to re-compile the chart from all of the original source material. Unfortunately, the process is far too labor intensive. In the U.S., NOAA has used original source material where possible to compile navigation critical information such as aids to navigation and channel limits. The remaining data are being digitized from the largest scale paper charts.

Once ENC's are compiled, they may be enhanced with higher-accuracy data over time. High-resolution shoreline data may be incorporated into the ENC's as new photogrammetric surveys are conducted. Likewise, depths from new hydrographic surveys will gradually supersede depths that originated from old surveys.

1421. Route Planning and Monitoring

Presumably, route planning takes place before the voyage begins, except in situations where major changes in the route are called for while the ship is underway. In either case, both ECDIS and ECS will allow the display of the smallest scale charts of the operating area and the selection of waypoints from those charts. ECDIS requires a warning that a chosen route crosses a safety contour or prohibited area; ECS will not necessarily do so. If the data is raster, this function is not possible. Once the waypoints are chosen, they can be saved as a route in a separate file for later reference and output to the autopilot.

It is a good idea to zoom in on each waypoint if the chart scale from which it is selected is very small, so that the navigational picture in the area can be seen at a reasonable scale. Also, if a great circle route is involved, the software may be able to enter the waypoints directly from the great circle route file. If not, they will have to be entered by hand.

During route monitoring, ECDIS must show own ship's position whenever the display covers that area. Although the navigator may chose to "look-ahead" while in route monitoring, it must be possible to return to own ship's position with a single operator action. Key information pro-

vided during route monitoring includes a continuous indication of vessel position, course, and speed. Additional information that ECDIS or ECS can provide includes distance right/left of intended track, time-to-turn, distance-to-turn, position and time of "wheel-over", and past track history.

As specified in Appendix 5 of the IMO Performance Standard, ECDIS must provide an indication of the condition of the system and its components. An alarm must be provided if there is a condition that requires immediate attention. An indication can be visual, while an alarm must either be audible, or both audible and visual.

The operator can control certain settings and functions, some of the most important of which are the parameters for certain alarms and indications, including:

- Cross-track error: Set the distance to either side of the track the vessel can stray before an alarm sounds. This will depend on the phase of navigation, weather, and traffic.

- Safety contour: Set the depth contour line which will alert the navigator that the vessel is approaching shallow water.

- Course deviation: Set the number of degrees off course the vessel's heading should be allowed to stray before an alarm sounds.

- Critical point approach: Set the distance before approaching each waypoint or other critical point that an alarm will sound.

- Datum: Set the datum of the positioning system to the datum of the chart, if different.

1422. Waypoints and Routes

In the route planning mode, the ECS or ECDIS will allow the entry of waypoints as coordinates of latitude and longitude, or the selection of waypoints by moving a cursor around on the charts. It will allow the creation and storage of numerous pre-defined routes, which can be combined in various ways to create complex voyages.

For example, one might define a route from the inner harbor to the outer harbor of a major port, a route for each of two or more channels to the sea, and several more for open sea routes to different destinations. These can then be combined in different ways to create comprehensive routes that will comprise entire dock-to-dock voyages. They may also be run in reverse for the return trip.

When selecting waypoints, take care to leave any aids to navigation marking the route well to one side of the course. Many navigational software programs contain databases listing the location of the aids to navigation in the United States and other countries. This list should NOT be used to create routes, because the accuracy of today's navigation systems is good enough that to do so invites a collision with any aid whose actual position is entered as a

waypoint. Always leave a prudent amount of room between the waypoint and the aid.

Some published routes exist, also a feature of certain software programs. The wise navigator will not use these until he has verified the exact position of each waypoint using the best scale chart. Using pre-programmed routes from an unknown source is the same as letting someone else navigator your vessel. Such a route may pass over shoal water, under a bridge, or through an area that your own vessel might find hazardous. Always check each waypoint personally.

Many electronic chart systems will also allow the coupling of the navigation system to the autopilot. Technically, it is possible to turn the navigation of the vessel over to the autopilot almost as soon as the vessel is underway, allowing the autopilot to make the course changes according to each waypoint. While this may be possible for small craft in most inland, harbor and harbor approach situations, the larger the vessel, the less advisable this practice is, because autopilots do not take advance and transfer into account. The large ship under autopilot control will not anticipate the turn in a channel, and will not begin the turn until the antenna of the positioning system, presumably GPS and often located in the stern of the ship, is at the exact waypoint. By this time it is too late, for the turn should likely have been started at least two ship lengths previous. It is perfectly prudent to allow autopilot control of course changes for vessels in the open sea if the proper parameters for maximum rudder angle have been set.

1423. Training and Simulation

In 2001, the IMO issued guidelines for training with ECDIS simulation. The guidelines stipulate that ECDIS training should include simulation of live data streams, as well as ARPA and Automated Information System (AIS) target information, and a Voyage Data Recorder (VDR) interface. But the IMO has not specifically required ECDIS training other than as a general substitution in the Standards of Training, Certification, and Watchkeeping (STCW) 95 code for navigation with paper charts.

Also in 2001, the USCG approved the country's first STCW-compliant five day ECDIS training course in the U.S. Long-term STCW 95 training and education programs are presently in development. The two levels of competency defined by STCW are operational (OIC or 3rd mate / 2nd mate) and management (CCM or 1st officer / Master). It is likely that for mariners sailing since August 1998, training and education in navigation at both the OIC and CCM levels will include the five day competency-based ECDIS training course.

Accordingly, certified training in the operational use of ECDIS should consist of a five day course making use of simulation equipment for a real-time operating environment appropriate for tasks in navigation, watchkeeping and maneuvering. The primary goal is that the trainee should be

able to smoothly operate the ECDIS equipment, use all of its navigational functions, select and assess all relevant information, respond correctly in the case of a malfunction, describe common errors of interpretation and describe potential errors of displayed data. The trainee should follow structured practice in the following: setting up and maintaining the display; operational use of electronic charts including updating, route monitoring, route planning, handling alarms; work with motion parameters and position correction; work with log records and voyage files; and operate interfaces with radar, ARPA, AIS transponders, and VDR's.