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Integrated Navigation System: Not a Sum of Its Parts

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Abstract:

Similar to the evolutionary process for living organisms, marine navigation systems are becoming increasingly complex and sophisticated. Both by design and function, shipboard and shore-based navigation systems are no longer individual equipment components operating independently. Instead, the trend is toward integration, data fusion and synergy. One example of this are new Performance Standards being considered by IMO to achieve a "harmonized" presentation of all navigation-related information on the display of an integrated navigation system (INS). Unlike a dedicated display for ECDIS or radar, the new INS displays will be a task-oriented composite presentations that enable the mariner to configure the display for an operational situation by selecting specific chart, radar, radar plotting aids (ARPA) and AIS information that is required for the task-at-hand.

This paper gives a brief overview of the trend toward the development of INS. In addition to a brief summary of IMO performance standards for navigation equipment/systems, specific mention is made about a BSH (Germany) report on the "Functional Scope and Model of INS." A discussion is provided about the challenges of providing navigation safety information that goes beyond traditional boundaries of products and services. Currently, many agencies continue to produce individual products and services on a component basis. Hydrographic offices grapple with trying to provide multiple products and services for paper charts, raster navigational charts (RNCs) and electronic navigational charts (ENCs) while a same time, Coast Guard and Maritime Safety agencies focus on improving Aids-to-Navigation (AtoN), Vessel Traffic Services (VTS), AIS networks -- and more recently, port security. In some respects, the continued concentration on separate products and services represents an organizational reluctance to change. This in turn, results in a fragmented, sub-optimal approach to the safety-of-navigation caused by the inability to provide mariners with "seamless" information at reasonable cost. In particular, hydrographic offices must be willing to recognize that chart information can no longer be considered to be separate, individual products. When it comes to the provision and use of chart-related information for use in an INS, the focus needs to shift to what information is actually desired, how it will be provided, what other information it will be used with, and whether it is truly up-to-date.

Introduction

Similar to the evolutionary process for living organisms, marine navigation systems are becoming increasingly complex and sophisticated. Both by design and function, shipboard and shore-based navigation systems are no longer individual equipment components operating independently. Instead, the trend of manufacturers and users is toward system integration, data fusion and synergy. In the broadest sense, a "system" can be defined as: "*a group or combination of interrelated, interdependent, or interacting elements forming a collective entity*." [1] More specific to shipborne navigation, Bowditch defines an integrated navigation system (or integrated bridge system) as "*a combination of equipment and software which uses interconnected controls and displays to present a comprehensive site of navigational information to the mariner*." [2]

Given this ongoing process of integration we need to ask ourselves some basic questions: where is this integration taking us and what concerns might we have as this evolutionary process unfolds. In this paper we examine the trends in navigation system integration and the status of international standards that give guidance on how such systems should evolve. We also note a key paradox in systems development that has to be confronted in order for these developments to bear the kind of fruit they promise.

Although it appears initially as counter-intuitive, it is a given in systems theory that full system optimization can only take place when subsystems are sub-optimal. [3] A corollary would be that the more independent each subsystem is, the more sub-optimal the full system will be. This is one of the great paradoxes of systems theory. The more that each subsystem is treated independently the more dysfunctional the overall system behaves. These principles are well embedded in manufacturing and other high throughput systems where, unless well managed, subsystems create problems downstream resulting in poor overall performance. This type of evolutionary process is clearly taking place for shipboard navigation systems. As we go forward with increased integration of navigation subsystems we need to be cautious about how the subsystems will operate together and about what assumptions one subsystem makes about the behavior of another. This is particularly true for Integrated Navigation Systems for, as we show here, the subsystems were all developed independently.

Separate Equipment → Integrated Systems

During the past ten years, the International Maritime Organization (IMO) has adopted a number of performance standards for individual equipment and systems. Additionally, there have also been revised carriage requirements in the Convention for the Safety of Life at Sea (SOLAS), and new guidelines on ergonomic criteria for bridge equipment.

ECDIS - IMO Resolution A.817(19), 23 November 1995
ARPA – IMO Resolution A.823(19), 23 November 1995
Radar – IMO Resolution MSC.64(67), Annex 4, 4 December 1996
IBS – IMO Resolution MSC.64(67), Annex 1, 4 December 1996
AIS – IMO Resolution MSC.74(69), Annex 3, 12 May 1998
INS – IMO Resolution MSC.86(70), Annex 3, 8 December 1998
SOLAS Chapter V – IMO Resolution MSC.99(73), Annex 7, 5 December 2000
Ergonomic Criteria for Bridge Equipment and Layout – IMO MSC/Circ.982, 20 December 2000

ECDIS - Following a lengthy harmonization process with the International Hydrographic Organization (IHO), IMO adopted Performance Standards for ECDIS in 1995.[4] The original intention of those standards was to permit Maritime Safety Administrations to consider ECDIS as the functional equivalent of the nautical charts required for carriage by Chapter V of the 1974 SOLAS Convention, as amended.[5] The current edition of these Performance Standards includes amendments for Backup Arrangements[6] and a Raster Chart Display System (RCDS) Mode of Operation.[7]

Included in the ECDIS Performance Standards are technical standards developed by the IHO for both the format and display of electronic chart data. Special Publication No. 57 is the IHO Transfer Standard for Digital Hydrographic Data.[8] It includes an object catalog, a format for the exchange of data, a Product Specification for the Electronic Navigational Chart (ENC), and a profile for updating the ENC. The current edition (3.1) was revised in November 2000, and is now "frozen." Special Publication No. 52 is the IHO Specification for Chart Content and Display Aspects of ECDIS.[9] It includes appendices describing the means and process for updating the ENC, colour and symbol specifications for displaying the ENCS, and a glossary of ECDIS-related terms. The current edition (4.2) was revised in March 2004.

Following the adoption of the IMO Performance Standards, the International Electrotechnical Commission (IEC) developed a standard containing the operational and performance requirements, methods of testing and required test results to be used as the basis for the type-approval/certification process for an IMO-compliant ECDIS. [10] This standard included an annex that specified the navigation symbols to be used with ECDIS and included ARPA and AIS targets. The current edition (2) was published in October 2001.

Automated Radar Piloting Aid (ARPA) - At the same time they adopted Performance Standards for ECDIS, IMO adopted Performance Standards for ARPA.[11] ARPA is intended to reduce the mariner's workload by automatically providing information about multiple radar targets, contributing to an accurate, continuous and rapid evaluation for collision avoidance.

IEC published updated methods of testing and required test results used for type-approval/ certification of ARPA in 1998.[12] This standard includes the same annex for navigation symbols as the ECDIS standard.

Radar – In 1996, IMO revised the Performance Standards for Radar Equipment.[13] As defined in these standards, the intention of radar equipment is to "*provide an indication, in relation to the ship, of the position of other surface craft and obstructions and of buoys, shorelines and navigational marks in a manner which will assist in navigation and in avoiding collision.*"[14] The revision was a significant update to the previous standards, including the provision that "*selected parts of the System Electronic Navigational Chart (SENC) may be displayed,*" (i.e. from an ECDIS), along with the caveat that the "*mariner should be able to select those parts of the SENC, which can be made available and the mariner requires to be displayed.*" The mariner's ability to select specific chart information for display is a noteworthy departure from the controlled data content of the ECDIS Display Base and Standard Display.

As with the ARPA standard, when the IEC published updated performance requirements, methods of testing and required test results used for type-approval/certification of ARPA in 1999, the new standard included the annex for navigation symbols.[15]

Integrated Bridge Systems (IBS) – In 1996, IMO also adopted Performance Standards for Integrated Bridge Systems (IBS).[16] As defined in these standards, an IBS can be considered *"any combination* *of systems which are interconnected in order to allow centralized access to sensor information or command/control from workstations to perform two or more of the following operations:*

- *passage execution*
- *communications*
- *machinery control*
- *loading, discharging and cargo control*
- *safety and security"*

IEC published the standard for type-approval/certification of IBS in 1999.[17] The aim of this standard was to further specify the interfacing and interconnections of stand-alone equipment with respect to interaction (e.g., integration, within a bridge). IBS also introduces the concept of multifunction displays capable of presenting information from multiple systems. However, no manufacturer has submitted their system(s) for type-approval as an IMO-compliant IBS.

<u>Automated Identification System (AIS)</u> **-** In 1998, IMO adopted Performance Standards for Universal Automated Identification System (AIS).[18] AIS is intended to improve the safety of navigation by satisfying three functional requirements:

1. in a ship-to-ship mode for collision avoidance,
2. as a means for littoral States to obtain information about a ship and its cargo, and
3. as a VTS tool, i.e. ship-to-shore (traffic management).

IEC published the standards for type-approval/certification of AIS in 2001.[19] These standards require only a minimum display unit, because this equipment was intended to be connected to other equipment (i.e., radar/ARPA and ECDIS). As such, IMO issued additional guidelines for the presentation of AIS information to address the display of AIS target data in other stand-alone or integrated systems.[20]

<u>Integrated Navigation System (INS)</u> – In 1998, IMO also adopted Performance Standards for Integrated Navigation Systems (INS).[21] These standards are intended to apply to any combination of navigational equipment or system(s) providing functionality beyond that specified in its individual Performance Standards. The purpose of an INS is to allow manufacturers to provide "added value" to their system(s) by improving interfacing and interconnectivity with an evaluation of data input from independent sensors along with a means for establishing and monitoring the integrity of that data. Integrity monitoring is an intrinsic function of the INS. The INS also makes use of the multifunction display by allowing a single visual display unit to simultaneously present information from more than one system. The INS aims to ensure that, by taking human factors into consideration, the workload is kept within the capacity of the Officer-of-the-Watch (OOW). This is done to ensure safe and expeditious navigation while at the same time, compensating for human limitations.

Although the IEC has been working on a testing standard for type-approval/certification of INS since 1996, their work has never progressed beyond a Committee Draft. This is largely due to the issues surrounding the display of navigation-related information. In 2001, the IEC submitted a report to the IMO Sub-Committee on the Safety of Navigation (NAV) making a case that since there was "no overall standard for navigation displays," and since the requirements for and implementation of the displays for individual systems and equipment "differ significantly in many aspects," it has become "necessary to harmonise/standardise the elements and human interface for presentation of navigational information."[22]

Revised SOLAS V - The IMO revised SOLAS Chapter V in 2000. The revision encourages the installation of IBS and INS, including the use of multifunction displays intended to improve safety and reduce operator workload.[23] While ECDIS was mentioned as being capable of meeting chart carriage requirements, it is listed as an optional, non-mandatory system.

Ergonomic Criteria for Bridge Equipment and Layout - Adopted by IMO in 2000, these guidelines were developed to encourage successful design intended to improve navigation.[24] They contain ergonomic requirements for a functional layout of the bridge in order to realize consistent, reliable and efficient operations.

Separate Equipment ® Integrated Systems

While IMO's overriding goal is to advance the safety of navigation, the standards for the various systems and equipment, carriage requirements/allowances and guidelines were developed independent of one another. As such, there is a lack of uniformity and consistency with respect to what information is considered to be critical, what is (or should be) the source of that information, how should that information be assimilated into the system(s) (i.e., displayed), and how should it be interpreted by the mariner. The conflicts and inconsistencies between the performance standards for the individual systems and equipment, as well as the lack of real guidance with respect to the use of multifunction displays (i.e., in place of the displays for the individual systems and equipment) often results in information overload. The solution, in most cases, is the intelligent integration of information from various sources.

Provision and Organization of Navigation-related Information

The advent of "integrated navigation" has resulted in a more sophisticated approach to systems in terms of increased functional capabilities. However, the increased degree of integration between previously independent systems and equipment means that there are complex linkages, dependencies and inter-relationships with an INS. These can present a significant challenge to both the user and the type-approval authority. The German Federal Maritime and Hydrographic Agency, Bundesamdt für Seeschiffahrt und Hydrographie (BSH), recognized this in their report on the "Functional Scope and Model of Integrated Navigation Systems."[25] The report was prepared for BSH by the Institute for Shiphandling and Simulation (ISSUS) to develop a framework for testing INS. It is divided into three parts:

Part A – Functional analysis of navigation operation
Part B – Functional model of integrated navigation process
Part C – Test requirements for INS

Part B includes a highly useful model of the integrated navigation process derived from the functional analysis in Part A. The various functions and information flows within an INS are identified and graphically represented in terms of input and output information. In particular, network diagrams are provided that represent the information flows that occur between the various functional units in an INS. One of the major implications is that integrated navigation is a network of processes that must communicate with one another. Another is that information necessary to accomplish a specific task will change depending on the navigational situation and the task-at-hand. An example might be the difference in the amount or chart-related information required for voyage planning and route monitoring. As shown in Figure 1, this can be illustrated by a data flow diagram contained in the report that represents the functional dependencies between processes and the flow of information required for various situations and tasks.

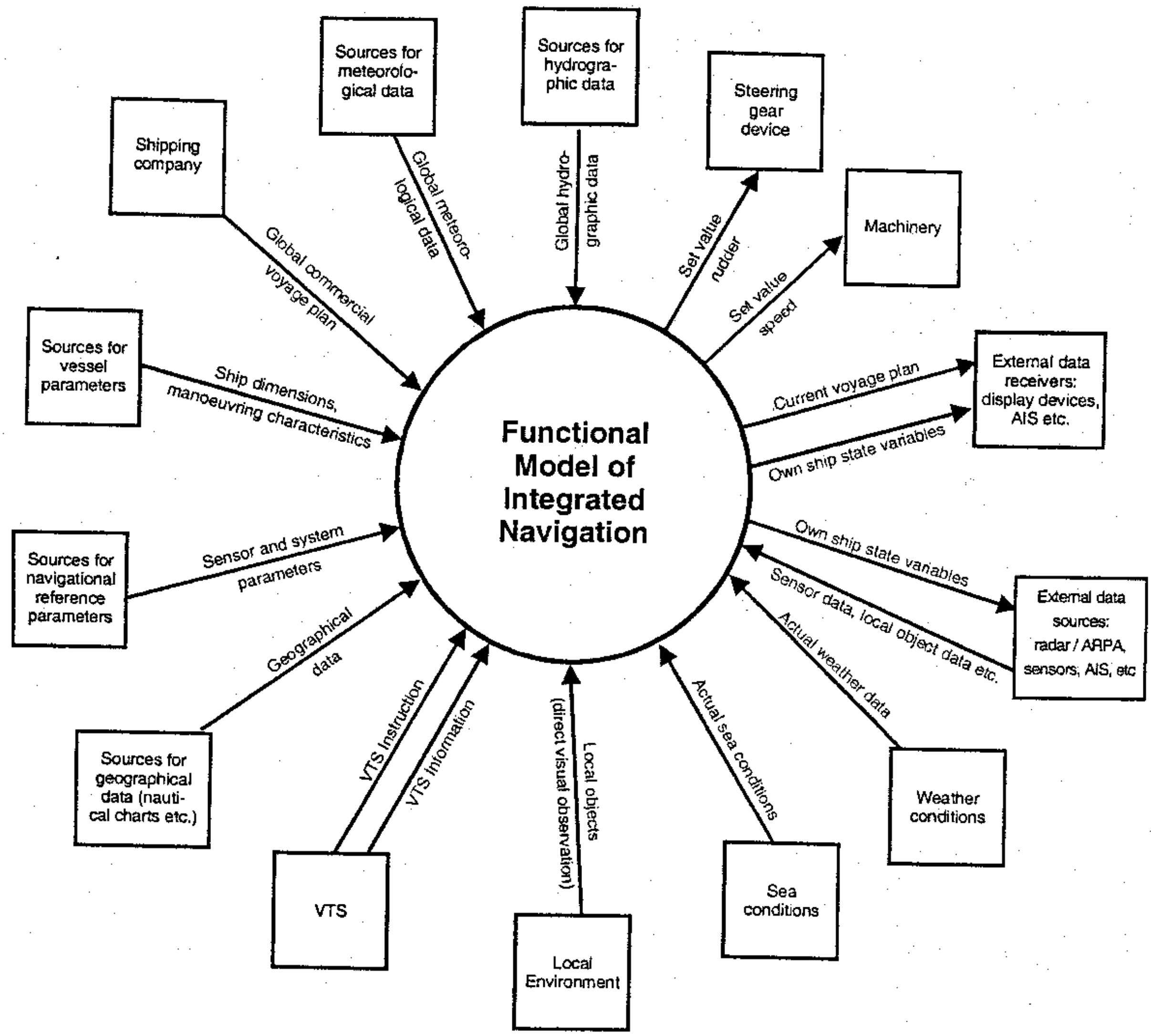

Figure 1 - Context diagram of process task "integrated navigation" [from *Functional Scope and Model of Integrated Navigation Systems*, BSH Report Nr.28/2001

While the source, content and format of the data available for input to an INS may be fixed, the level of information selected for display by the operator must be flexible. Unlike with paper nautical charts, Raster Navigational Charts (RNCs), or even ECDIS, it is inappropriate for the IMO, IHO or IEC to decide, beforehand, what charted information must be displayed in an INS. Depending on the navigation situation or task-at-hand, the level of charted information to be displayed in ECDIS can vary from Base Display, Standard Display to any combination of "All Other Information." Increasingly, this information must also be viewed and interpreted along with many other types of "navigation-related" information (e.g., ownship, radar, ARPA, AIS, MIO, etc.).

Performance Standards for Display of Navigation-related Information

At present, there is no overall standard for the display of navigation-related information on the bridge of a ship. The performance standards for each system or equipment deal with presentation and display differently. For this reason, in 2001 IMO NAV, at their 47th session, invited the IEC to establish a Working Group to develop an overall standard for the presentation of navigational information.[26] In particular, NAV47 requested that the new performance standards harmonize the following:

- display and interaction objects
- multifunction displays
- co-location, merging processing and fusion of graphical information
- indication of quantity, status, integrity and accuracy of information.

NAV47 also requested that the work take into account ergonomics and human factors.

In 2002, IEC reported to IMO NAV 48 that it had established a new Working Group (IEC TC80 WG13) to address the "Display and Presentation of Navigation-Related Information."[27] This Working Group analyzed the display requirements contained in existing IMO performance standards for ECDIS, radar, ARPA, AIS, IBS and INS, along with the carriage requirements in SOLAS Chapter V Regulations 15 and 19.5. In addition, WG13 also considered supplemental information, generally referred to as marine information objects (MIOs). MIOs consist of navigation-related information, including some charted information, that supplement the minimum information required by ECDIS. [28] As it relates to ENC data, MIOs are additional, non-mandatory information not addressed by existing IMO, IHO, or IEC standards. Such information includes ice coverage, tides and water levels, current flow, meteorological data, oceanographic data, and marine habitats. IEC's report to NAV 48 demonstrates that chart-related, operational, and MIO are all considered to be a subset of navigation-related information.

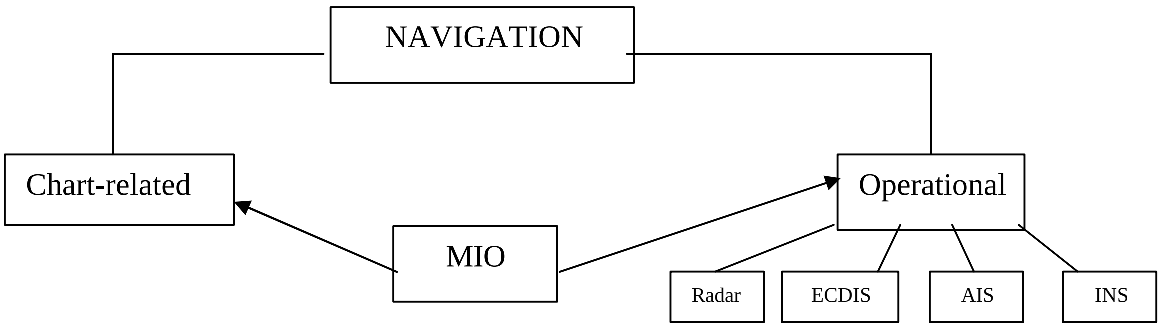

Figure 2 – Relationship of chart- and operational to Navigation-related information [from IEC Report to IMO NAV48/4/1]

In 2003, IEC submitted draft Performance Standards for the "Presentation of Navigation Related Information" to IMO NAV at their 49th session. The draft standards included annexes for the harmonization of terms and symbols used to present navigation-related information. IMO NAV 49 decided that the more detail was needed to resolve conflicts and inconsistencies between individual performance standards, and established a Correspondence Group to further progress the work.[29] Also, IMO NAV 49 felt that new performance standards should take precedence over existing equipment performance standards when conflicts regarding presentation issues occur. This past March, the Correspondence Group submitted new draft Performance Standards for the Presentation of Navigation-related Information to IMO for consideration at the 50th session of NAV. The new version contains more detailed requirements for the presentation of navigation-related information and is accompanied by two draft Safety of Navigation Circulars (SN/Circ.) related to Terms and Abbreviations and Symbology. If adopted at IMO NAV50 these harmonized terms and symbols would replace those contained in existing equipment performance standards.

Looking to the Future

While the trend for shipboard equipment and systems to become more integrated should be evident, there are still major challenges to provide information for safe navigation that can go beyond traditional products and services. Currently, most government organizations continue to provide individual products and services on a sub-component basis. HOs grapple with trying to provide various chart products (e.g., paper nautical charts, RNCs, ENCs) and services (e.g., NtoMs as well as RNC and ENC updating), while Coast Guard and Maritime Safety agencies focus on improving aids-to-navigation (AtoN), VTS, and shore-based AIS. Each agency seems to view its mission as "doing the same thing as we have always done - but better." Unfortunately, this view may well represent a reluctance to change that creates a fragmented "system" of products and services. The inability of government agencies to provide maritime users with information that is seamless and readily-available and at a reasonable cost is obviously less than optimal. Hydrographic offices must be willing to recognize that hydrographic information can no longer be regarded in terms of how it is produced and who issued it, but rather how it will be used, and whether it is up-to-date.

<u>Implications for ECDIS</u>

One could argue that ECDIS is already an INS. After all, it is capable of using different types of data, has different display modes (e.g., Display Base and Standard Display), interfaces to a number of other shipboard systems and equipment, and it provides indications/alarms. However, the reality is that ECDIS is too tightly defined by the IMO Performance Standards and in IHO S-57 and S-52 addressing data and display. For example, an ECDIS is an ECDIS *if and only if* a long list of conditions apply (e.g., suitable backup arrangements, a full suite of official ENCs, standardized monitor and display, updating mechanism, etc.).[30] Failure to meet all of these conditions reduces the ECDIS to an expensive and overly complex system that by default operates as a simple Electronic Chart System (ECS). This has, unfortunately, actually constrained the implementation and market success of ECDIS.[31] The result is that the future of ECDIS as a stand-alone system is limited. It is gradually being overtaken by the need to have an integrated navigation display, controlled by the mariner, with selected information taken from a number of systems.

During the work of IEC TC80 WG13 and the IMO Correspondence Group, it was noticed that the existing performance standards for ECDIS contain some inconsistencies and are lacking in the area of the operational requirements for chart data processing. Some examples include:

- What should be the content of the Standard Display?
- Should there be a Display Base?
- Should the background colours remain black/white?
- Should the display priority of charted data be higher than the priority of user data?
- How should supplemental chart and navigation-related information (e.g. MIOs) be displayed?

One of the recommendations that will be made at IMO NAV 50 is to review the Performance Standards for ECDIS.

Task-Oriented Composite Display

One of the more important aspects of the proposed IMO Performance Standards for the Display of Navigation-related Information is the concept that the current situation or task influences what information the mariner requires. The navigation situation refers to the conditions that currently exist which directly influence a mariner's workload and/or task. Examples include: voyage planning, grounding avoidance, collision avoidance, and restricted visibility. The navigation situation can be relatively static (e.g., ocean navigation) or quite dynamic (e.g., during harbour and approach). Information required to make informed decisions in the bridge of a ship is provided by two general classes of displays: dedicated and task-oriented. A dedicated display refers to equipment that presents information provided by a specific type navigation system or equipment (e.g., shipborne radar, ECDIS, plotting aids, etc.). The overall content of information to be displayed is pre-determined and is normally specified in individual equipment performance standards adopted by IMO (e.g., radar, ECDIS, AIS, etc.). task-oriented composite display would be equipment that simultaneously displays selected information from one or more navigational systems or equipment, and/or other information sources (e.g., maritime safety information).

Integrated displays should support task-oriented presentations appropriate to specific navigational situations by simultaneously presenting selected information from one or more navigational system or equipment, and/or other information sources such as maritime safety information (MSI). An example of a task-oriented presentation might be a Conning Display (or Conning Information Display) that arranges information according to the navigational situation and the specific mariner's task of manoeuvring a ship. Information that could be displayed on a Conning Display might be selected from Appendix 2 of the *Guidelines on Ergonomic Criteria for Shipborne Equipment and Layout*, [24] such as:

- gyro compass heading
- speed
- propeller revolutions
- pitch of controllable pitch propeller
- rudder angle
- rate-of-turn
- depth of water

To support of the concept of task-oriented presentations, navigation-related information could be organized according to specific circumstances surrounding navigational situations:

- Ownship
- Target tracking
- Radar
- Chart
- Supplemental (e.g., MIOs)

Need for Better Inter-Agency Coordination

Hydrographic Offices and Coast Guard agencies need to cooperate more in providing comprehensive, consolidated Notice-to-Mariners (NtoM) and chart updating services for both RNCs and ENCs. In principle, once new AtoN information is known, it should be provided to maritime users without delay. To do so, it should be based on information contained in the ATON database, and then issued as Notice-to-Mariners and RNC/ENC updates. Further, it should be provided as a coordinated service (i.e., simultaneous NtoM and RNC/ENC updates). For mariners relying on INS, having up-to-date navigation-related information is crucial for safety of navigation. Any more than it is prudent to rely on out-of-date operational information from radar, ARPA, or AIS, this same principle should apply to chart-related information as well.

Additionally, the type and amount of chart and navigation-related information is increasing. Some examples include:

- Environmentally Sensitive Sea Areas (ESSAs)
- Particularly Sensitive Sea Areas (PSSAs)
- Marine Information Objects (MIOs)
- 3-D data (e.g., bathymetry, land topography, shoreline features, etc.)

Vessel Traffic Services (VTS) and AIS offer a means to provide the maritime community a wide variety of supplemental navigation-related information capable of improving overall navigation safety, port security, and operational efficiency. This includes:

- ice coverage
- tides and water levels (including forecast, nowcast, and real-time)
- current flow
- wave heights
- wind speed and direction
- weather/meteorological

There are many examples of this type of government information in existence. The main challenge is to establish the necessary infrastructure and relationship between the government and the private sector to provide this service to maritime users. Since mariners know that this information exists, they want it to be provided in an efficient, cost-effective manner. They are rarely concerned about which government agency actually provides the data. They also expect that this information will be made available in a data format that is compatible for use in existing shipboard equipment and systems. They do not want to hear that different government agencies are unable (or unwilling) to establish the necessary infrastructure or agree to intra-agency cooperation in order to provide it. One-stop shopping and compatible data formats are already expected.

Since no one agency is responsible for providing all of the diverse information we suggest that the private sector is best suited to compete to provide this service.

In Summary

As Figure 1 shows, the model for an INS is extremely complex and is reliant upon a multiplicity of semi-autonomous subsystems as diverse as from weather information systems to AIS or from nautical charts to steering gear sensors. This information need not only to be assembled together, but also checked for validity and then filtered for presentation. The task is non-trivial and will take some time to evolve.

A key problem we point out is that many of the underlying information systems are provided by independent agencies each trying to “do things better”. This agency-by-agency optimization takes place within that domain each agency controls and thereby misses the “big picture” the overall system is trying to manage. Somehow each agency has to review the service and products it provides through the collective lens of an integrated system rather than as individual products or services. How the information will be used in an integrated system is the key design requirement, not how has it been produced in the past. Timeliness of data is of crucial importance as systems become more integrated and capable of real-time operation.

HOs need to take the lead in a new effort at re-evaluating the information service they provide. They need to see how their products are to be used in a much broader context than was the case with paper charts. For an INS to provide the benefits its proponents claim, agencies like HOs have to see themselves, not as ends in themselves, but as part of a larger whole.

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