Navigation Made Easy? The Promise and Perils of Electronic Navigation at Sea

Today, about 90 per cent of world trade moves by sea.[1] This means that, on any given day, hundreds of ships are plying the world's waterways, many of them large commercial vessels carrying valuable and sometimes dangerous cargoes. These ships are part of the complex transportation system that allows billions of tonnes of goods and thousands of passengers to move safely and efficiently across the globe. This system cannot work effectively without accurate and reliable navigation. The more traffic there is, the more essential reliable navigation becomes.

Today, mariners rely on sophisticated electronic navigation technologies to find their way across featureless open oceans, to pilot their vessels through busy coastal waterways and to identify and avoid hazards that might result in collision or grounding. Electronic Chart Display and Information System (ECDIS) is the latest in a long line of advanced navigational systems that the shipping industry has embraced in an attempt to make shipping safer and more efficient without dramatically increasingly costs.

The purpose of my presentation is to explore the recent history of marine navigation in an attempt to understand both the promise and the perils of ECDIS and to suggest how lessons learned from past experience might have been used more effectively to inform the implementation of this powerful technology.

Navigation before ECDIS

Up until the late 20th century, marine navigation was largely a manual process. Mariners took readings from modern versions of 18th and 19th century instruments like the compass, sextant, chronometer, and patent log to measure direction, position, and

[1] Allianz Global Corporate and Specialty, *Safety and Shipping Review 2014*, (Munich: Allianz Global Corporate & Specialty, 2014) [consulted online in pdf format] 3.

speed on the open ocean. This allowed them to follow the safest and most expeditious course to their destination. In coastal areas, they used some of the same tools to take bearings and establish lines of position using coastal navigational aids or known physical features. They used a lead line to measure the depth of water under the ship.

Beginning after the First World War, mariners could supplement the data obtained from these instruments with bearings and lines of position taken from radio-based systems developed as part of war-related research. These included radio direction finding (RDF) and hyperbolic systems like Decca or Loran. They also had access to sonar to measure water depth and radar which could be used as both a coastal navigational tool and a collision avoidance system.

Each of these new devices produced a wealth of data but it was of little use in raw form. Officers had to analyze, correct, process and plot the information on one of many paper charts covering their planned route. Beginning in the 1970s, some of this work was automated by the application of computers that processed the data making it easier interpret and plot.[2]

Each addition to the navigator's tool kit enhanced the accuracy and reliability of marine transportation. But there were limits to what could be accomplished. The mobility of vessels was severely constrained by poor visibility, especially fog, or by the presence of other hazards like ice. In the open ocean, mariners had to reduce speed and use dead reckoning techniques to estimate their position. In ice, they had to move slowly enough to allow time to turn or stop if an iceberg moved across the ship's track. The larger and heavier the ship, the longer it took to react to a change in speed or course. In coastal

[2] A.G. Corbet, "Modern Merchant Ship Navigation," in Alastair Couper (ed.) *The Shipping Revolution: The Modern Merchant Ship* (London: Conway Maritime Press, 1992)178-80.

areas and near busy shipping lanes, slow movement was possible in fog only by careful use of radar (frequent readings and plotting), attention to fog signals and maintaining a heightened state of situational awareness by employing additional look-outs.

Also, each new device or system created additional costs. Ship owners had to purchase, install and upgrade the system when mandated by international regulation. They often had to hire specially trained officers to operate and maintain the equipment. These officers had to be added to the existing complement of highly skilled officers of the watch (OOW) required to operate any licensed vessel over a certain size or carrying a particular cargo.

At the same time that these costs were rising, shipping companies were facing new demands for service that put more and larger ships into already congested waterways and ports. Unparalleled economic growth after 1945 produced a steady increase in international trade[3] which placed a strain on existing navigational infrastructure and led to a growing number of costly accidents in busy shipping lanes such as the English Channel. This forced several nations to put elaborate traffic separation and management schemes into place to control vessel movements and reduce the risk of collisions and other accidents.

As well, the rising demand for oil, gas, and chemicals and the changing political landscape of the Middle East increased demand for tanker capacity and expanded the areas where these vessels traveled. The increased amount of potentially hazardous material moving around the world went largely un-noticed until several high-profile oil spills in the 1960s and 1970s brought the risk of serious environmental damage to the

[3] World Trade Organization, “World Trade in a Globalizing World,” (WTO, 2008)15-26.

world’s attention. Regulators reacted by putting stricter rules in place for the movement of these materials imposing higher costs on owners and operators.

The exploitation of new sources of raw materials also increased traffic in remote regions where existing navigational infrastructure was sometimes limited and charts were incomplete or dated. Ships working in these areas had to move with extreme caution. When available, they might have to employ a local pilot for long periods of time, again adding significantly to operating costs.

Moreover, as the shipping industry sought to meet growing demand for rapid and reliable movement of goods and people, it had to face new competition. Before, during and after the Second World War, many countries invested huge amounts of public funds in developing road and air transportation networks. These industries gradually took over certain types of cargo and much long distance passenger traffic, especially in North America. At the same time, the emergence of new nations and the growth of developing economies created a number of new entrants into the marine transport field, making it even more urgent for shipping companies to try to keep operating costs low.

So the shipping industry and marine authorities were anxious to find ways to move more traffic, more quickly into and out of ports. They wanted to expand the effective operating area of marine transportation to include developing regions and they wanted to reduce the number accidents. But shipping companies also wanted to remain competitive and so did not want to increase their costs significantly. Their drive to reduce costs by reducing crew numbers intersected with governmental authorities’ desire to reduce accidents by improving bridge design and operation. This gave rise to the idea of the integrated bridge.[4]

Automation and Integration

Like many other industries faced with increased competition and rising labour costs, the shipping industry saw automation and integration as a promising approach to improving efficiency without sacrificing safety. As mentioned earlier, equipment designers took the first steps towards automation in the 1960s when they developed aids like projection systems and chart overlays that helped mariners plot radar and position information. Beginning in the 1970s, when computer engineers began to produce relatively low cost microprocessors, equipment makers created the first Automatic Radar Plotting Aids (ARPA) that not only identified and tracked targets but also calculated their course, speed and the closest point of approach to own vessel.[5] This relieved the bridge officer of the laborious duty of tracking and plotting manually and allowed him to attend to other duties. Processing power applied to position-fixing systems like Omega, Decca and Loran rendered "position information in latitude and longitude format instead of the raw hyperbolic grid data." This, combined with the broad coverage these systems offered, provided the basis for automated positioning both at sea and in coastal areas.[6]

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[4] Heloise Finch-Boyer, "Chart Wars The invention of digital marine charts and the battle to map the future of navigation," (manuscript provided by author, 2010)19-26.

[5] David Tinsley, "Bridge Equipment," *Lloyd's Nautical Yearbook 1989* (London: Lloyd's of London Press, 1988)89-90; James D. Luse, "A Brief History of the Use of Marine Radar," *Journal of the Institute of Navigation*, Vol 28, No. 3 (Fall 1981)204 and T. Keith Marshall, "Incompetent Use of ARPA May Constitute Unseaworthiness," (Spring 1995)1. Consulted at http://www.maritimeconsultant.com in PDF format on 29 July 2014.

[6] Corbet, 180 and Finch-Boyer,10-14.

By the late 1970s, equipment makers were designing the first experimental systems to integrate navigational and other operational data in a series of consoles on the bridge. The goal was to make “electronic navigation equipment easy to read and manage on as few displays as possible” and eventually to make it possible for one man to manage all the ship’s functions from the bridge. Electronics companies introduced the first “one-man’ bridge systems in the mid-1980s though they were not commercially available until the 1990s.

Meanwhile, another group researchers, manufacturers and entrepreneurs were pursuing a slightly different avenue of development. They were trying “to combine position-fixing equipment not only with computers but with a visual display.”[7] Beginning in the late 1970s, several individuals sought to improve navigation in challenging coastal areas by producing digital charts and using the inputs from various navigational systems to track a ship’s progress in real-time across the display monitor.

In the years before access to reliable and accurate GPS or other satellite navigation signals, these entrepreneurs had to build up their own infrastructure to provide accurate position fixes and even do their own hydrographic surveys to create sufficiently accurate electronic charts for the display. One such system proved very effective for oil companies working around the treacherous Mackenzie River where low lying land made conventional radar useless and shifting ice prevented marking of the channel. Contracted by the oil companies, Helmut Lanziner built his Precise Navigation System. His team surveyed the area to create a much more accurate chart which they converted to digital format. He set up a network of equipment that took two separate sets of readings from the ship as it moved, sent the information to an onboard computer. The information was then

[7] Finch-Boyer, 27

displayed in real time on the electronic chart of the river. The monitor showed the ship moving across the chart and provided data on course made good and distance to channel centre. This allowed company vessels to move to and from the drilling rigs without employing pilots for weeks at a time and even gave mariners the capacity to see their docking manoeuvres on screen.[8]

Obviously, Lanziner's system, like other early entrants into the field was limited by the fact that it required specially built navigational infrastructure to enhance the quality and reliability of position fixes. Also, since there were no electronic charts available, these too had to be created either by conducting new surveys or converting existing paper charts to digital format. Nevertheless, these first system showed what could be done and how to do it. This made rapid progress towards fully integrated electronic chart display systems possible once commercial shipping gained reliable access to satellite navigation systems.

Electronic Chart Display and Information System

So what exactly is ECDIS? It is essentially an integrated computer-based navigational system in which, at a minimum, navigational inputs from a vessel's position-fixing instruments (now mainly GPS), its gyrocompass and its speed and distance measuring device are displayed in real time on an approved electronic chart. That chart contains all the information regarding coastal features, built structures, depth of water, safe channels, lights and other navigational markers, and hazards that would be available on a comparable paper chart. Many ECDIS systems also incorporate automatic

[8] Finch-Boyer, 27-28 and conversation with Hemut Lanziner, the developer of the Precise Navigation System (PNS) and its successor, the Precise Integrated Navigation System (PINS), in February 2014.

identification system (AIS), radar in the form of a radar image overlay (RIO), a voyage data recorder (VDR), Navigational Telex (NAVTEX), and meteorological inputs.[9]

This means that an ECDIS system provides a continuous display of the ship's position on the chart as it moves through the area. The officer sets up the planned route by loading all the charts for the passage and then entering the passage plan. Once entered, the system recognizes the route and uses inputs from the various navigational devices to alert the officer to any deviations from it. This active depiction of the vessel on the chart increases spatial and situational awareness and relieves the officer of the task of manually plotting position on a paper chart. Also, the system pools all the information the navigating officer needs to assess the vessel's course and progress and to identify and track possible hazards, providing a quick reference point that can indicate when a closer look at one reading or instrument might be needed. It allows for fast and accurate passage planning and offers an automated procedure for updating charts. All of this leaves the officer of the watch with more time to attend to other important duties including maintaining a proper "manual" watch.[10]

There is no doubt that ECDIS is a powerful navigational tool that, when used properly, can, and does, enhance both safety and efficiency. One of the most common forms of accident for large ships is grounding and it seems obvious that having an accurate visual display of your vessel's planned course through the waters with depth measurements and hazards marked and alarms automatically set off if the ship moves too

[9] Chris Spencer and David Tilsley, "ECDIS – Understanding the Future of Navigation," *Standard Safety* (September 20110) 6.

[10] Malcolm Instone, "ECDIS Capabilities and Limitations" published online by ECDIS Ltd., 2011; Andy Norris, "The ECDIS Mindset," *Seaways* (January 2012)9-10; Andy Norris, "Facing the Problems with ECDIS," *Digital Ship* (May 2010) 26; Chris Lo, "ECDIS: life-saving electronic navigation tech," published online at http://www.ship-technology.com , (posted 27 July 2012, consulted 28 July 2014)2 and International Hydrographic Organization, *Facts about Electronic Charts and Carriage Requirements*, IHO Publication S-66 – Edition 1.0.0 (Monaco: International Hydrographic Bureau, 2010) 7.

far from its track, would make groundings much less likely. In 2008, respected Norwegian risk management organization Det Norske Veritas (DNV) published a technical report assessing the impact of ECDIS. In the author's judgement "full implementation should reduce the incidence of grounding by between 19 and 38%."

This assessment clearly was shared by much of the international maritime community; in 2008 the Maritime Safety Committee of the International Maritime Organization (IMO) made carriage of ECDIS mandatory for all vessels covered by the International Convention for the Safety of Life at Sea (SOLAS). Phase-in began in 2012 with new passenger vessels and tankers and is continuing with ships of various sizes and build dates up to a completion date of 1 July 2018.[11]

Teething Pains?

Despite this unequivocal official endorsement and strong general support for ECDIS, wider deployment and greater experience with the system has revealed some unexpected problems. Mounting evidence from a series of incidents and the resulting official inquiries pointed to several areas of concern. Two of the most important are complexity and unquestioning trust in the system.

Like all electronic systems, ECDIS's functionality depends on a combination of hardware, software and data. It is therefore subject to all the usual problems that plague computers: need for regular updates and re-boots that take time to complete and verify, hard-drive failures, systems crashes, and frozen screens, to name just a few. Ships using

[11] Australian Maritime Safety Authority, "Electronic Chart and Display Information System (ECDIS), Frequently asked questions," (Version 2, 3 October 2012) 1. Consulted online in PDF format, June 2012.

only ECDIS must therefore have a completely independent back-up system, usually a secondary ECDIS.[12]

ECDIS is also dependent on satellite navigation systems, mainly GPS, for its position data. The partial or complete loss of a satellite signal will result in an inaccurate position being displayed on the monitor. These disruptions can be caused by any number of factors. To date most have been unintentional but authorities are aware of the possible impact of deliberate jamming of GPS signals. This may create a requirement for additional redundancy in the form of a second receiver using a different constellation of satellites.[13]

Authorities are also increasingly concerned about the fact that some ECDIS have exhibited "display and alarm behaviour anomalies" that "may affect the use of the equipment or the navigational decisions made by the user." These anomalies "came to light purely by chance as a result of routine UKHO [United Kingdom Hydrographic Office] procedures for investigating reports of maritime accidents for possible charting implications."[14] They identified 16 specific problems including "failure to display a navigational feature correctly," "failure to detect objects by 'route checking' in voyage planning mode," "failure to alarm correctly," and "failure to manage a number of alarms correctly."[15]

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[12] Norris, "Facing the Problems with ECDIS," 26.

[13] JCB, "ECDIS Part 3: Problems!!," *The Pilot The Official Journal of the United Kingdom Maritime Pilots' Association (UKMPA)*, Online Edition, (21 October 2010)16-17 and David Edmonds, "10 Things They Should Have Told You About ECDIS," paper given at TransNav 2007, Gdynia. At the time Edmonds was Managing Director, PC Maritime Ltd. UK.

[14] UKHO powerpoint presentation by Tim Lewis, Head of International Partnering (America) at XIIth MACHC conference, (December 2011) slide 2. Consulted online, June 2014.

[15] IMO SN.1/Circ.312, (9 July 2012) and Annex, 1. Included as an attachment to Australian Maritime Safety Authority FAQ.

In an attempt to address these problems, the International Hydrographic Organization (IHO) produced and distributed a list of know anomalies and created a Data Presentation and Performance Check (DPPC) dataset. This DPPC gives mariners the capacity "to check some important aspects of the operation of their ECDIS" and identify if the system displays anomalies that "need to be remedied or otherwise managed." The IMO provided 'workarounds' for each of the known anomalies and asked mariners to report any anomalies they encountered "with sufficient detail on the ECDIS equipment and ENCs [Electronic Navigation Charts] to allow analysis."[16]

In addition to these performance anomalies, mariners have to deal with the added problem of non-standard user interface. Because the development of ECDIS was led by equipment manufacturers and their engineers, "there are a bewildering number of different ECDIS with a myriad of different operating systems" available to shipping companies. Each system contains a wealth of information from the navigational data inputs, the electronic charts and any additional overlays applied to the system. Since all this information cannot be displayed on a chart that is only ¼ of the size of a comparable paper chart, it must be embedded in menus and enhanced displays and mariners must drill down, scroll and zoom to see both the bigger picture and the detailed one. Each company though, varies aspects of its operating system "in order to remain commercially competitive" creating different controls and menu structures as well as different detailed layouts of the display. This means that it is not obvious where essential information resides and how best to gain access to it.[17] Also, adding overlays that provide information like tide and weather data, sailing directions or collision parameters can create

[16] IMO SN.1/Circ.312 and Annex, 1-5.
[17] JCB, #3, 5-8,10-17. JCB quotes at length from the MAIB report on the 2008 grounding of the cargo ship *CFL Performer*; Norris, "Facing the Problems with ECDIS,"26 and Norris, "The ECDIS Mindset," 8-9.

compatibility problems if the software was not produced by the same company as the ECDIS.[18]

The second, and equally worrisome problem with ECDIS is its tendency to create a false sense of security and certainty in some of its users. Because of its sophisticated operating system and detailed display which shows the ship's position continuously on the chart, it can appear to be not only simple to use but also inherently accurate. As the Marine Accident Investigation Branch of the United Kingdom (MAIB) pointed out in its report on the grounding of the cargo ship *CFL Performer* in 2008, "there is a danger that many bridge watchkeepers will increasingly trust what is displayed without question" and overlook the need "to remain vigilant and continuously monitor a vessel's position in relation to navigational hazards."[19]

Confronted by a number of mishaps involving ECDIS-equipped vessels, marine authorities have identified lack of training as a contributing cause of the overconfidence that informed the poor navigational decisions made by the officers in charge. In addition to the grounding of *CFL Performer*, the P&O passenger ferry *Pride of Canterbury* also ran aground near the English coast in 2008. In both cases, officials determined that the cause of the accidents was the improper use of ECDIS by officers who had no training. Moreover, in identifying the watch officers' lack of knowledge of the features of the *CFL Performer*'s navigation system, the MAIB (UK) pointed out that "similar factors" had contributed "to a number of recent groundings in UK waters."[20]

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[18] JCB, "ECDIS (Electronic Chart Display and Information System): Part 1: How ECDIS Works," *The Pilot*, Online Edition, 14.
[19] JCB, Part 3, 11 and 16 and Norris, "The ECDIS Mindset," 8-10.
[20] Quoted in Chris Lo, 3. For more detailed information on the Branch's findings see JCB, "ECDIS Part 3: Problems!!," 9-10.

International maritime officials have reacted to these problems in several ways. As noted earlier, they have set up a system for identifying and addressing anomalies. They have also attempted to impose some standardization after the fact by mandating performance standards including levels of display and which information appears on each, consistent symbology, and one-key stroke access to the standard display.[21] Within the industry, some have called for more input from mariners to help design "a better, more user friendly product" that addresses the needs they have identified after years of using the equipment.[22]

Officials and equipment makers alike have also identified a need for systematic training. Beginning in January 2012, ECDIS training became "an integral part of the nautical officers training scheme" mandated by the Standards for Training and Certification of Watchkeepers (STCW). Because this training varies greatly and doesn't always include individualized simulator training or an onboard component, many in the industry believe that it is insufficient. They have argued that because of the enormous complexity of the system and the lack of standardization, there is a critical need for knowledge to be transferred directly from the ECDIS manufacturer to the navigation officer onboard the vessel.[23] According to a growing number of analysts, this type-specific training is the best way to insure that officers of the watch understand the systems they are using and can get the most out of them.[24]

Lessons Learned

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[21] David Edmonds, "10 Things They Should Have Told You About ECDIS," paper given at TransNav 2007, Gdynia. At the time Edmonds was Managing Director, PC Maritime Ltd. UK, no page numbers.

[22] Instone, summary no page numbers. At the time of writing this article, Instone was the Director of Operations and Standards for ECDIS Ltd, one of the companies that produces ECDS equipment.

[23] Bjoern Roehlich, "ECDIS Training the Past, the Present and the Future," *The Maritime Executive*, consulted online at www.maritime-executive.com , 1-2.

[24] JCB, Part 3, 3-12.

As a result of a series of accidents, the shipping community has gradually learned that ECDIS is an extraordinarily powerful tool for enhancing marine safety and efficiency but that it is not a simple, self-contained or infallible means of navigating. It requires well-trained and experienced officers to operate and configure the system properly. They must understand both the capabilities and limitations of the specific system in use and must avoid over-reliance on it or on the position information provided by GPS. Instead, they should use the time made available by automatic plotting to attend to other navigational aids and to look out the window; this provides essential comparative data that can be used to alert the officers to problems with the system or to confirm that it is functioning properly. Finally operators need to know how to manage the system by updating it and trouble-shooting any problems that arise.

Looking back at the history of marine navigation, however, these lessons learned sound eerily familiar. In the years following the Second World War, the commercial shipping industry embraced radar as a coastal navigation and anti-collision tool. Crews of naval ships had used it successfully during the war to maintain convoy formation, for manoeuvring, to find enemy submarines, and for piloting in coastal waters especially when operating at night without running lights.[25] It seemed like a tried and true technology.

Shipping companies saw radar as a way to reduce delays due to fog and to speed up vessel movement in confined or busy waterways. Ship-borne radar could be used to identify other vessels and track their positions, establish the distance to the coastline and

[25] James D. Luse, "A Brief History of the Use of Marine Radar," *Navigation: Journal of the Institute of Navigation*, Vol. 26, No. 3 (Fall, 1981) 199-202.

mark any hazards, aids to navigation or built structures that might indicate position or require avoidance manoeuvres. And it could do all of this in limited visibility.

After the war various manufacturing companies offered sets for civilian use and shipping companies began install the systems onboard. By 1953, in Britain alone there were 2800 radar-equipped ships registered. Some, perhaps even most, operators of radar used it successfully but by the mid-1950s, as more and more companies adopted the technology, problems began to emerge. The earliest systems were not compass stabilized and certain vessel movements made the readings inaccurate. Some operators only turned the system on in poor visibility and so had limited experience and missed the opportunity to familiarize themselves with what the radar display of a given coastline or ship looked like on the radar compared to what it looked like to the human eye. When they did turn the system on, it was hard for them to make sense of what they were looking at. Also many were unaware that the display showed relative motion only and that they had to plot moving targets on the chart to be sure of their course and speed. The closer they were and faster they were moving, the more plots were required and this put a strain on the manpower on the bridge. Finally, the watch officer had to deal with the disorientation that came from changing from a visual lookout to the radar. These problems were made worse by a lack of systematic training.[26]

Not surprisingly, these problems only came to the attention of the shipping industry and marine authorities after a series of high profile collisions involving the improper use of radar. The most famous of these was the collision of the liners *Andrea Doria* and *Stockholm* in 1956 but it was far from the only one. In the US, the National

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[26] Luse, 202-5; J.E.D.Williams, 216 [need full reference] and Richard Woodman, "Navigation 1900-1960," in Ambrose Greenway (ed.) *The Golden Age of Shipping: The Classic Merchant Ship*, (London: Conway Maritime Press, 1994)179-80.

Transportation Safety Board was so concerned with the number of radar-assisted collisions that it conducted two studies on the problem and possible means of prevention. The factors investigators and analysts identified were almost exactly the same as those now raised regarding ECDIS. Manufacturers produced a veritable smorgasbord of systems. There were no performance or display standards and no systematic rules for proper use of the equipment. Untrained mariners often lacked anything but a rudimentary knowledge of how radar worked and what the display did and did not show. Many were too easily persuaded that radar was indeed "the conqueror of fog" and that they need not pay as close attention to their other navigational tools as long as they attended to the radar display. Indeed, in the *Andrea Doria/Stockholm* collision neither ship slowed down despite being enveloped in fog.[27]

As the evidence mounted that lack of standards and lack of training were undermining the application of a promising new technology, marine authorities decided to act. Working with equipment manufacturers and the shipping industry, they crafted a series of standards for carriage of radar, for its performance and its appropriate use. They also established training standards for operators.

Some analysts and observers have pointed out the similarities between the introduction of radar and that of ECDIS demonstrating that there is some corporate memory of the mistakes made with radar and their applicability to the current situation. It is hard to say why this historical precedent did not have more impact on the industry and regulators given their shared desire to improve the safety and efficiency of navigation. One possible explanation is that they were so anxious to find a system that would make navigation easier without increasing long term operating or infrastructure costs, that they

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[27] Luse, 203.

overlooked the limitations of ECDIS. Also, like many mariners, they were no doubt impressed with the remarkable capabilities of the system and the apparent simplicity and compelling character of the interface. Now, after several years of active use, they seem to have re-learned the lesson taught to them by radar: no one tool, no matter how powerful, can function effectively within informed human input and management. ECDIS, like radar before it, is an aid to navigation, not a substitute for it.

Sharon Babaian, 18 August 2014.