Article

ECDIS-GNSS COMBINED TO IMPROVE MARINE TRAFFIC SAFETY

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Abstract

This paper analyses the enhanced GNSS and ECDIS technology in the realm of maritime navigation from the user's perspective taking into account the latest changes in international regulations and standards. It is through this integration that mariners have the possibility to analyze their own ship's position related to the chart information for a safer decision-making process and where the best accuracy of the position data can be properly managed. To obtain the maximum advantage of this enhanced technology a different approach by the mariner is required and a specific training program that provides comprehensive instruction on safe equipment operation must be developed.

Résumé

Le présent article analyse la technologie GNSS et ECDIS améliorée dans le domaine de la navigation maritime, selon la perspective de l'utilisateur et en tenant compte des derniers changements intervenus dans les règles et normes internationales. C'est par cette intégration que les navigateurs ont la possibilité d'analyser la position de leur propre navire par rapport aux informations portées sur la carte en vue d'un processus de prise de décision plus sûr et lorsque la plus grande exactitude des données de position peut être gérée efficacement. Pour retirer le plus grand bénéfice de cette technologie améliorée, une différente approche est requise du navigateur et un programme de formation spécifique fournissant des instructions complètes sur le fonctionnement sûr des équipements doit être développé.

Resumen

Este artículo analiza la tecnología mejorada del GNSS y del ECDIS en el campo de la navegación marítima, desde la perspectiva del usuario, tomando en cuenta los últimos cambios en los reglamentos y las normas internacionales. Es gracias a esta integración que los navegantes tienen la posibilidad de analizar la posición de sus propios buques con respecto a la información de la carta para un proceso de toma de decisiones más seguro y en el que pueda controlarse adecuadamente la mayor exactitud posible de los datos de posición. Para obtener las máximas ventajas de esta tecnología mejorada, se requiere un enfoque diferente por parte del navegante y tiene que desarrollarse un programa de formación específico que proporcione amplias instrucciones sobre el manejo seguro del equipo.

1. Introduction

The International Maritime Organisation (IMO) introduces the issue of maritime safety as follows: Shipping is perhaps the most international of all the world's great industries - and one of the most dangerous. Ship casualties and incidents can result in serious loss of life and pollution of the marine environment as modern ship can carry over 5,000 people and over 500,000 tons of petroleum [1].
Maritime safety is of paramount importance in the new role of Global Navigation Satellite System (GNSS) and Electronic Chart Display and Information System (ECDIS). Increased safety at sea should be considered while taking into account the most critical issue of supplying the master of a vessel and those responsible for the safety of shipping ashore with modern, proven tools to make marine navigation and communications more reliable thereby reducing errors, especially those with the potential to cause equipment damage, pollution harm to the marine environment, injury and loss of life.

Maritime safety in this case means to address the particular needs of enhancing the prevention of collisions and groundings. According to statistics, the number of ship collisions and groundings has not appreciably changed over the last ten years despite the growing technology.

The European Maritime Safety Agency (EMSA) statistics show that 626 vessels were involved in 540 accidents (sinkings, collisions, groundings, fires/explosions and other significant accidents) in and around European Union (EU) waters during 2009 [2].

The majority of vessels in the 2009 EMSA survey were involved in collisions and contacts (around 47%) and groundings (around 28%), while sinkings accounted for around 4% of the total and fires and explosions for around 11% (other causes 10%).

It is acknowledged that there is evidence to show that the great majority of accidents have a human error component, and also that seafarers often make mistakes under difficult circumstances (eg. bad weather, geographical/infrastructure restrictions, fatigue, task overload, training shortcomings, etc.).

There are numerous examples of collisions and groundings that might have been avoided had there been suitable input into the navigation decision-making process.

In recent years, the enhanced GNSS has dramatically changed the way mariners, surveyors and other professional engineers measure positional coordinates.

For the scope of navigation, this development should not be considered independently, but should be viewed from a broader perspective of enhanced navigation as a result of the simultaneous improvements of existing and new navigational tools, in particular electronic tools.

Today, mariners as well as those ashore can use enhanced information derived from GNSS in a reliably and efficient way through the extensive electronic navigational and communication technologies and services available or in development, such as ECDIS, Automatic Identification System (AIS), Automatic Radar Plotting Aids (ARPA), Integrated Bridge Systems/ Integrated Navigation Systems (IBS/INS), Vessel Traffic Services (VTS), Long Range Identification and Tracking (LRIT) systems, Global Maritime Distress and Safety System (GMDSS) and the Marine Electronic Highway (MEH).

All these technologies and equipment/system needs to be connected with an Electronic Position Fixing System (EPFS) such as GNSS to perform the concerning navigational tasks they are used for. Fundamental Navigational tasks necessary to support the mariner to conduct navigation safely such as “Route monitoring”, “Collision avoidance”, “Navigation control data”, “Navigation status and data display” and “Alert management”.

This paper will discuss the enhanced GNSS technology in the realm of maritime navigation from the user’s perspective through the integration of the other navigation systems used in the decision-making process and taking into account the latest changes in international regulations and standards already in force and those under consideration.

2. GNSS maritime requirements

Since the earliest days of navigation, seafarers have sought to keep track of their direction and position.
Since the beginning an important part of IMO regulations have dealt with ship positioning and the related equipments.

The first step of IMO in radionavigation positioning occurred with the International Convention for the Safety of Life at Sea (SOLAS-1948), which required all ships over 1600 tons gross tonnage engaged on international voyages, to carry Radio Direction Finder apparatus. In 1968 the amendments to the 1960 SOLAS Convention, added requirements to carry radar. In 1988 IMO adopted an amendment which allowed ships the option to carry radionavigation equipment instead of the Radio Direction Finder. On 1st September 1984, new requirements for shipborne navigational equipment came into force, requiring large ships, especially tankers, to be fitted with ARPA.

In July 2002, new requirements for the carriage of navigation equipment come into effect following a complete revision of Chapter V of the SOLAS 1974 Convention (current situation).

After 1st July 2002, the radio direction-finding apparatus is not required anymore. With the carriage requirements currently in force all ships constructed on or after 1st July 2002 shall be fitted with a receiver for a GNSS or a terrestrial radio navigation system, or other means, suitable for use at all times throughout the intended voyage to establish and update the ship's position by automatic means. It is the first time a GNSS receiver is in the SOLAS convention.

a) GNSS minimum requirements

IMO resolutions A.953(23) and A.915(22) specified the maritime navigation requirements for GNSS. The first of these resolutions establishes operational requirements relevant to GNSS-1 (the first generation GNSS) (***Table 1***), whereas the second resolution is interpreted as being a living document specifying top-level requirements more appropriate to a future GNSS-2 (the second generation GNSS) (***Table 2***).

The IMO resolutions contain the internationally adopted maritime requirements for general navigation. These requirements are applicable to all radio-navigation systems. The maritime use of radio-navigation systems pass through the IMO recognition. The recognition by IMO of a radio-navigation system would mean that the Organization recognizes that the system is capable of providing adequate position information within its coverage area and that the carriage of receiving equipment for use with the system satisfies the relevant requirements of the 1974 SOLAS Convention.

Current first generation GNSS (GNSS-1) such as GPS and GLONASS systems have been recognized as a component of the World Wide Radio-navigation System (WWRNS) for navigational use in waters other than harbour entrances and approaches and restricted waters.

Area	Absolute horizontal Accuracy (95%)	Signal Availability	Continuity	Warning (non-availability)	Update Rate
Ocean	≤ 100 m	> 99.8% over 30 days	N/A	ASAP by Maritime Safety Information (MSI) System	< 10 s < 2 s*
harbour entrances-approaches and coastal waters with a low volume of traffic and/or less significant degree of risk	≤ 10 m	> 99.5% over 2 years	≥ 99.85% over 3 hours	< 10 s	< 10 s < 2 s*
harbour entrances-approaches and coastal waters with a high volume of traffic and/or significant degree of risk	≤ 10 m	> 99.8% over 2 years	≥ 99.97% over 3 hours	< 10 s	< 10 s < 2 s*

* If the computed position data is used for AIS, graphical display or for direct control of the ship

Table 1:
Operational requirements for a world-wide radio-navigation system (GNSS-1)

	System level parameters				Service level parameters			
	Absolute Accuracy	Integrity			Availability % per 30 days	Continuity % over 3 hours	Coverage	Fix interval* (sec)
	Horizontal (m)	Alert limit (m)	Time to alarm* (sec)	Integrity risk (per 3 hours)				
Ocean	10	25	10	10^{-5}	99.8	N/A**	Global	1
Coastal	10	25	10	10^{-5}	99.8	N/A**	Global	1
Port approach and restricted waters	10	25	10	10^{-5}	99.8	99.97	Regional	1
Port	1	2.5	10	10^{-5}	99.8	99.97	Local	1
Inland waterways	10	25	10	10^{-5}	99.8	99.97	Regional	1

*More stringent requirements may be necessary for ships operating above 30 knots.
** Continuity is not relevant to ocean and coastal navigation.

Table 2:
Future GNSS minimum maritime user requirements for general navigation (GNSS-2)

Future GNSS(s) are expected to improve, replace or supplement the current systems, which have short-comings in regard to integrity, availability, control and system life expectancy. Early identification of maritime user requirements has been developed to ensure that these requirements are considered in the development of future GNSS(s). These IMO requirements should be incorporated in GNSS plans to be accepted for maritime use. The second generation GNSS will meet the maritime user's operational requirements for general navigation, including navigation in harbour entrances and approaches and restricted waters. Furthermore the shipborne GNSS equipment should meet performance standards adopted by IMO.

The developing European Galileo have already considered these second generation GNSS requirements in order to make possible for the mariners broader and enhanced safety critical applications. Actual assessment of the Galileo navigation service requirements, as laid down in the most recent issues of the GALILEO reference documents, indicates that the IMO requirements for Oceanic, Coastal, Port approach and restricted waters operations as stated in resolution A.915(22), can be met by the GALILEO stand-alone system using the Safety Of Life service.

3. GNSS and the navigation system

The navigation system includes the GNSS and the Chart System. In order to specify the overall navigation system requirements and performance of a vessel it is necessary to consider all possible contributions to the errors in navigation.
In the navigation system context of GNSS used in the maritime environment, the sources of error affecting overall navigation performance include the GNSS signal, the user receiver, the charts and the equipment and crew (e.g., human factors) controlling the navigation of the vessel.

Therefore in determining the requirements of a GNSS used in the maritime environment, it is necessary to understand these contributing factors. The most important new equipment that needs input of GNSS data is the ECDIS.

ECDIS, as defined by IMO, is the navigation information system which with adequate back-up arrangements can be accepted as complying with the up-to-date chart required by the 1974 IMO SOLAS Convention (regulations V/19 and V/27), by displaying selected chart information derived from electronic navigational charts (ENCs) with positional information from navigation sensors to assist the mariner in route planning and route monitoring, and if required display additional navigation -related information. The electronic chart navigation with ECDIS and real-time GNSS positioning with improved performance (accuracy, integrity, availability, continuity, coverage and fix interval) is a relatively new technology that is considered to be the most important advancement in maritime navigation since the advent of radar some 60 years ago. IMO adopted, on 23^{th} November 1995, the first performance standards for ECDIS, by resolution A.817(19), recently amended on 5^{th} December 2006, with resolution MSC232(82). However, the introduction of new real-time electronic navigation has not been an easy process since the first type approved ECDIS occurred in 1999. It is not just an electronic representation of a paper nautical chart on a colour display with its own ship's position plotted on it, but it represents a new, more powerful navigation aid that significantly improves safety.

ECDIS reduces the navigational workload compared to using the paper chart. It is capable of continuously plotting the ship's position to enable the mariner to execute in a convenient and timely manner all route planning, route monitoring and positioning currently performed on paper charts.

The most important improvement is surely the real time positioning. With ECDIS plus GNSS the mariner knows for the first time where he is and not where he was a few minutes before. This represents a notable change because it allows some most effective and immediate evaluations on the route monitoring activities. At the same time it reduces the Officer Of the Watch (OOW) workload to determine and to plot the ship's position on the paper chart, leaving him increased lookout capability and more time for other evaluations and activity related to the safety of the ship.

Also of great benefit is the new ability to monitor in real time the effective movement of the ship, the Course Over Ground (COG) and Speed Over Ground (SOG), on the chart feature and in comparison to the true course steered (heading) and the speed log. It makes possible the continuous evaluation of the angular difference between COG and heading (sum of leeway and drift angle). A very important feature during route monitoring in narrow channel with bad whether as shown in ***figure 1***.

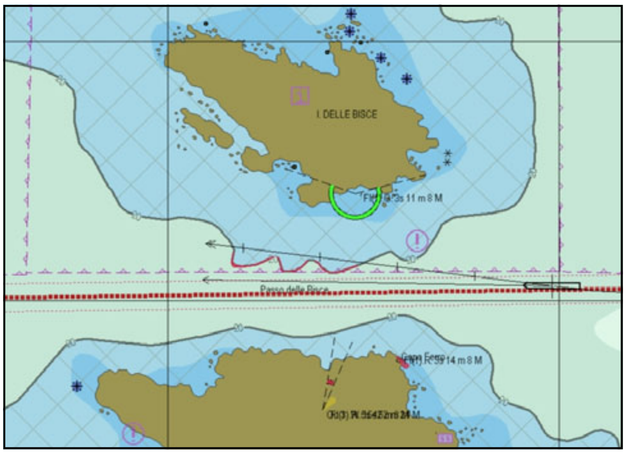

Figure 1: *COG and SOG real-time monitoring*

Moreover the GNSS integration on ECDIS makes possible the automatic generation of an alarm if, within a specified time set by the mariner, the own ship crosses the safety contour or the boundary of a prohibited area or of a geographical area for which special conditions exist.

It is in this context that mariners have the possibility to analyze in an efficient way their own ship's position related to the chart information for a safer decision-making process and where the best accuracy of the position data can be properly managed. This means that navigational risks could be reduced when using ECDIS compared to traditional paper charts.

It is for this reason that IMO has recently approved an amendment to SOLAS regulation V/19, introducing for the first time a mandatory carriage requirement for ECDIS. With the adoption of this amendment at the 86th session of the Maritime Safety Committee (MSC), in June 2009, ECDIS is no more only a mariner optional alternative to the adequate and up-to-date folio of paper nautical charts requirement.

The new ECDIS carriage mandatory requirement will have a phased implementation period from 2012 to 2018 depending on class of ship and tonnage (Table 3).

Furthermore IMO has already agreed a carriage requirement for ECDIS on board all High-Speed Craft (HSC) from 1^{st} July 2008 with a two years transition period for HSC constructed before (full mandate from 1^{st} July 2010).

ECDIS are widely expected to improve safety at sea and make life easier for the navigator. Hardware, software and standards capable of supporting ECDIS have been available for some time, but to be of use they need chart and positional information.

Ship class	Gross Tonnage (KGT*)	New Construction on or after	Existing ship not later first survey on or after
Passenger	KGT≥0.5	1 July 2012	1 July 2014
Tanker	KGT≥3	1 July 2012	1 July 2015
Cargo	KGT≥10	1 July 2013	
	3≤KGT≤10	1 July 2014	
	KGT≥50		1 July 2016
	20≤KGT≤50		1 July 2017
	10≤KGT≤20		1 July 2018

*expressed in Kilo Gross Tonnage

***Table 3* : ECDIS mandatory carriage requirement**

Both these two kinds of information are the fundamental elements that make ECDIS a safe and reliable tool. Furthermore ECDIS performances are strongly dependent on their availability, reliability and quality. These make the real difference for the mariners using ECDIS compared to paper chart for route monitoring activities and make ECDIS together with new enhanced GNSS a more powerful navigation aid that significantly improves safety.

a) ECDIS chart information

The chart information to be used in ECDIS are the latest edition ENC, as corrected by official updates, issued by or on the authority of a Government, government-authorized Hydrographic Office or other relevant government institution, and conforming to IHO standards (now S-57 and in future S-100).
The provision of chart information is a responsibility and obligation of the coastal State, so it is an issue that clearly the international rules put at the maximum level of importance. They can be derived from the previous United Nations General Assembly resolution (A/RES/53/32 -1988),

This is currently an IMO obligation under regulation 9 of the revised chapter V of the SOLAS (1974) Convention, which entered into force on 1st July 2002. Regulation related to the provision on Hydrographic services under which it is clearly stated that Contracting Governments undertake to arrange for the collection and compilation of hydrographic data and the publication, dissemination and updating of all nautical information necessary for safe navigation.

In May 2010, the IHO submitted a report to the 56th meeting of the IMO Sub Committee on the Safety of Navigation (NAV56) that provides an evaluation of ENC coverage, in comparison with corresponding paper charts, for international voyages based on available data as of the 16 April 2010 [3]. An extract of this evaluation is provided in *table 4* with the following related IHO consideration.

ENCs type	May 2010
Small scale ENCs (planning charts)	~100%
Medium scale ENCs (coastal charts)	84%
Large scale ENCs (top 800 ports)	91%

Table 4 : Comparison of ENCs with corresponding paper ***charts for international voyages***

The IHO is continuously monitoring the situation to ensure that ENCs for vessels engaged on international voyages is given the highest priority for ENC production. The IHO is aware that at the end of 2010 some small gaps will remain in Africa, Arctic routes and the Caribbean. However, in most cases, and especially in any areas frequented by significant levels of international traffic, these gaps are planned to be filled as soon as possible.

The IHO is aware that some ports used by certain classes of vessel, and in particular by cruise ships, may be of relatively low use and therefore not reflected in the busiest international routes. The IHO has been in contact with Cruise Lines International Association (CLIA) and the International Chamber of Shipping (ICS) on this matter to try and identify any such ports.

b) ECDIS positional information

Noting that the collection and dissemination of accurate and up-to-date chart information is vital to safe navigation it is also evident that this accuracy will become useless if the positional information are not of the same reliability.

The positioning requirements for ECDIS are clearly identified on the IMO Performance Standard for ECDIS (Resolution MSC232(82)). The ECDIS requirements related to positioning clearly identify the operational need to carry out the route monitoring activities in a simple and reliable manner. ECDIS is connected to the ship's position fixing system, to the gyro compass and to the speed and distance measuring device. The ship's position required is to be derived from a continuous positioning system of an accuracy consistent with the requirements of safe navigation. Whenever possible it is also required that a second independent positioning source, preferably of a different type, should be provided. In such cases ECDIS is able to identify and display discrepancies between the two sources.

Because of the fundamental importance of the position data input, ECDIS has the requirement to provide to the user an alarm when the input from position sources is lost. Furthermore it also has to repeat, as an indication, any alarm or indication passed to it from position sources.

The collection and use of positioning data is a responsibility of the mariner. It is the mariners that assess what is the safe distance from dangerous chart features and the safe under-keel clearance through a quantitative estimation of the overall related accuracy.

If ECDIS relies on GPS input only, as it is a single position fixing system without integrity information, the exclusive use of this violates the most important rule of navigation: never rely on a single source of position fixing and try always to evaluate a quality indicator through LOP redundancy. A GPS ship's position as displayed on an ECDIS or plotted on paper chart can and should be cross-referenced using a separate independent positioning system, such as radar, terrestrial electronic position-fixing systems, visual, depth sounder etc. This is nowadays much more needed for GPS because of the absence of integrity information, often absent also on DGPS .

What are the requirements for position fixing for route monitoring?

The standard method of position fixing during route monitoring close to hazard such as in coastal, restricted water and harbour approach navigation has always been by visual compass bearing while maintaining an appropriate Dead Reckoning (DR) and Estimated Position (EP) outlook. Furthermore there should be also available a backup method of fixing (usually Radar and radio-navigation), independent from the primary, which makes possible for the mariner to cross-check and monitor the standard method. Currently, most often the primary position fixing method is GNSS with visual and Radar ranges as secondary. This is particularly true in restricted visibility conditions. The mariner should always have an indicator of the reliability of the ship's position that give trust of the route made good. This old rule still works nowadays and it is its violation that most often is the cause of groundings and marine casualties.

It should also be noted that current GNSS providers do not accept liability for the service they provide. In 2007, the IMO Sub-Committee on Safety of Navigation (NAV) agreed that there was a need to provide an internationally agreed alternative system for complementing the existing satellite navigation, positioning and timing services to support e-navigation and recognised that potential back-up systems could be made available.

The new challenge for the future will be to provide the mariner "assured positioning data" to fuel all the mandatory shipborne equipments and systems as it happens for chart information (***figure 2***). The key to success on navigation safety is first of all the quality of all the concern data throughout skilled and well trained mariners.

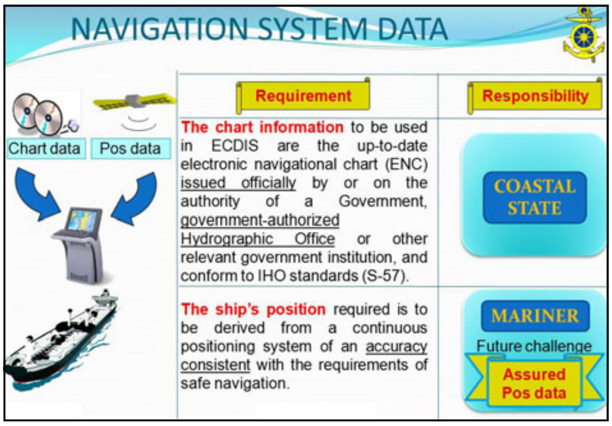

Figure 2: ECDIS+GNSS Data Requirement and Responsibility

This has been true for the past and will be true for the future besides the bridge navigation aids that make it possible for the mariners to use it better.

An important milestone towards this future challenge has been achieved recently on 12th July 2010 when the European Satellite Services Provider (ESSP SAS) of European Geostationary Navigation Overlay Service (EGNOS)' Safety-of Life Service (SoL) received a certificate of Air Navigation Service Provider according to the Single European Sky Regulation 2096/2005. The certification confirms that ESSP complies with safety criteria for operations and is a prerequisite for the company to provide navigation services to airspace users. It assessed compliance with the European Safety Requirements, and with the International Civil Aviation Organization Standards. By the end of 2010, after a successful operational period, the European Commission will be able to declare the EGNOS' SoL available to the aviation community, enabling the publication of precision approach procedures with vertical and lateral navigation guidance (APV) based on EGNOS. At that time, European air navigation service providers will be able to implement satellite-based precision approaches without needing ground equipment on the airport, and with performances similar to those of the instrument landing system (ILS Category I) currently used in the world[4].

This is an important milestone towards the "assured positioning data" that will involve in the near future also the IMO community for the provision to maritime users of the EGNOS' SoL in pan-European region and of the GALILEO' SoL and similar developing new second generation GNSS worldwide.

The GALILEO' SoL has been designed specifically for safety critical users, for example maritime, aviation and trains, whose applications or operations require stringent performance levels.
This service will provide high-level performance globally to satisfy the user community needs and to increase safety especially in areas where services provided by traditional ground infrastructure are not available.

The Safety of Life service will be provided globally according to the performances indicated in table 5. These specifications include two levels (critical level and not-critical level) to cover two conditions of risk exposure and are applicable to many applications in different transport domains, for example air, land, maritime, rail [5].

		GALILEO Safety-Of-Life Service	
Type of Receiver	Carriers	Three Frequencies	
	Computes Integrity	Yes	
	Ionospheric correction	Based on dual-frequency measurements	
Coverage		Global	
		Critical level	Non-critical level
Accuracy (95%)		H: 4 m V: 8 m	H: 220 m
Integrity	Alarm Limit	H: 12 V 20 m	H: 556 m
	Time-To-Alarm	6 seconds	10 seconds
	Integrity risk	$3.5x10^{-7}$ / 150 s	10^{-7}/hour
Continuity Risk		10^{-5}/15 s	10^{-4}/hour - 10^{-8}/ hour
Certification/Liability		Yes	
Availability of integrity		99.5%	
Availability of accuracy		99.8 %	

***Table 5* : Service Performances for the Galileo Safety of Life Service**

4. The issue of quality of data

The issue of the dissemination of data quality information has not been a big concern in the past for hydrography because of the implicit protection related to two natural barriers.

The first was the much better positioning accuracy available for hydrographic surveys compared to the one available to mariners. The second was on the means the surveyed data final product reaches the mariner end users, that was a printed paper chart with a scale of reduction. The power to control and to choose the scale of the printed chart, with its implicit limitation, makes it possible for Hydrographic Offices to include all the position errors in the graphic uncertainty (0.2 mm). The scale of the paper chart limits also the accuracy to which the mariner could plot geographic position on the chart (a plottable difference is considered to be 0.3 mm). In a common coastal purpose chart with a scale of 1:100.000 it means that the graphic uncertainty produces a positional uncertainty of 20 m and a mariner plottable difference of 30 m.

a) The positioning barrier

The first barrier has been removed in the last years with the advent of GNSS and DGNSS and the consequent availability to the mariners of the same order of position accuracy of the hydrographic surveyors. This situation will be much more real in the near future with the enhancement of GNSS performances that will be delivered to the maritime navigation users. Nevertheless, the speed up of positioning accuracy has created a gap with some old surveys that need some years before updating.

In many parts of the world, even the most recent data available may have been gathered when survey methods were less sophisticated than they are now and the achievable accuracy currently available with GPS was not possible. In these areas, GPS positions available to the navigator may be more accurate than the charted detail.

This deficiency may not be limited to sparsely surveyed waters of developing nations, but may also apply to the coastal waters of major industrial states. Fortunately, new survey technologies have improved the precision to which modern hydrographic surveys can be conducted and it is required that positions of shoreline constructions in Berthing cells should be one dimension more precise than the shipborne GPS-Position.

However, in some areas of the world there are still charts that are based on old surveys for which there is no determined geodetic datum or the datum is imprecise. Therefore in such areas, paper charts (and thus raster navigational charts - RNC) are not compatible with GNSS navigation, and it will take some time to resolve this problem. This makes it extremely difficult to accurately plot the ship's position obtained by the GNSS in relation to surrounding shoals and other dangers on such charts. The difference in the plotted position can often be significant and could lead to an accident, casualties and is a risk in restricted waters.

This has led to a specific IMO recommendation to the mariners to cross-check position using relative references such as visual or radar fixing or ECDIS radar overlay to provide for the immediate detection of datum inconsistencies in electronic charts, and immediately alert on potential positional shifts required for particular charts (SN.1/Circ.255 dated 24th July 2006 - Additional guidance on chart datums and the accuracy of positions on charts).

b) The chart scale barrier

The barrier of the paper chart scale was removed with the advent of the Electronic Chart era. With ECDIS the mariner can change the scale of the video representation of the Electronic Navigational Chart (ENC) without any limitation choosing to zoom-in and zoom-out as he wishes.

One of the most innovative aspects of digital cartography is represented by the fact, that for a vector database (ENC), it would seem to overcome the concept of representation scale ratio, since hydrographic data are stored in absolute coordinates and therefore always in real scale 1:1. The protection of the carefully selected Hydrographic Office paper chart scale has been removed and subsequently also the user plottable limited difference.

It would seem therefore improper to speak of scale of an Electronic Navigational Chart. Nevertheless this reference cannot be removed because it is no longer connected to the printed ratio of reduction but to the related content and accuracy it has been produced for.

The concept of scale still works as ENC compilation scale refers to the scale at which the ENC was designed to be displayed and is related to the chart's navigational purpose. The concept of scale remains for ENCs also because of cartographic generalization of depth areas.

It is important for the mariner to know that if he overzooms an ENC of a data compilation scale he will not get more data detail and better positional accuracy. This risk to overrate is increased in term of accuracy due to the fact that most ENCs have been produced by digitizing paper charts which were themselves designed to be used individually rather than as part of a database. ***Figures 3 and 4*** put in evidence this risk – looking at the rocks close to P.ta delle Formiche in overscale the mariner performing route monitoring with DGPS could wrongly evaluate to pass between two of them; evaluation that for sure he will not realize in 1:1 scale display [6]. The greater scale of representation gives expectation of grater detail and accuracy that instead should be experienced with a greater ENC compilation scale if available inside ECDIS storage.

Figure 3*: display scale = compilation scale*

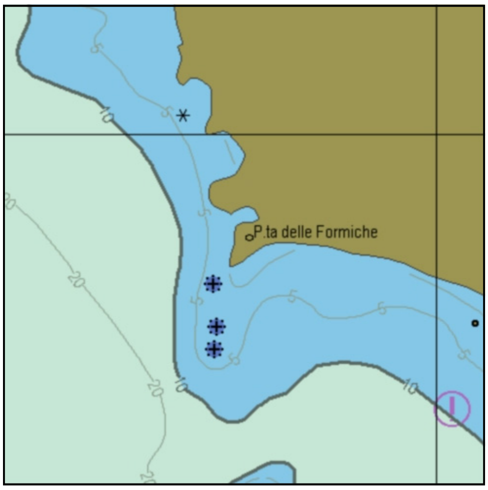

Figure 4*: display scale (1:20,000) > compilation scale (1:90,000)*

As required by IMO Performance Standards, ECDIS should warn the mariner with an overscale indication whenever he selects a display scale that is larger than the ENC compilation scale. This is a new conceptual skill required for the mariner who is an ECDIS plus GNSS user.

c) Chart data quality indicator

ECDIS combines chart and navigational information in a powerful way that, by removing these two important barriers, gives the mariner a new aid with more accuracy expectation that is not always true.

As a result, there is evidence that enhanced navigation systems (e.g. GNSS and DGNSS) may offer comparable or more accurate positioning than the one provided by the ENC data. For this reason the IHO introduced a mandatory data quality indicator in the ENC, which allows a quantitative estimate of the accuracy of important chart features, to be used in combination with estimates of position accuracy from satellite navigation in assessing safe distance from hazards, in order that the mariner may be informed of the quality of the information he uses. This is another important new safety skill required of the marine user of future integrated navigation systems using GNSS and ECDIS.

A chart data quality indicator by zones of confidence (M_QUAL - CATZOC) will cover the entire ENC (although not all data will be assessed initially). ZOC provide a simple and logical mean of displaying to the mariner the confidence that the national charting authority places on any particular selection of bathymetric data. It seeks to classify areas for navigation by identifying the various levels of confidence that can be placed in the underlying data using a combination of the following criteria:

- position accuracy,
- depth accuracy, and
- sea floor coverage (certainty of significant feature detection).

Under this concept there are six possible ZOCs value. ZOCs A1, A2, and B are generated from modern and future surveys with, critically, ZOCs A1 and A2 requiring a full area search. ZOCs C and D reflect low accuracy and poor quality data whilst ZOC U represents data which is un-assessed. ZOCs are designed to be depicted on the ECDIS electronic displays as a ready available symbol. The depth and position accuracy specified for each ZOC refer to the errors of the final depicted soundings and include not only survey errors but also any other errors introduced in the chart production process.

An example of a ECDIS displayed S-52 symbol for CATZOC in comparison with the corresponding quality information data provided to the mariners with source diagrams in paper charts are provided on **figure 5 and 6** respectively.

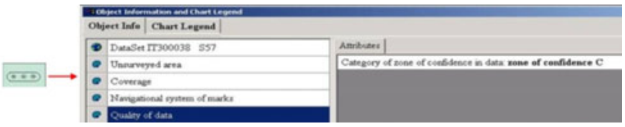

***Figure 5**: example of CATZOC symbol displayed on ECDIS and window for supplementary related information*

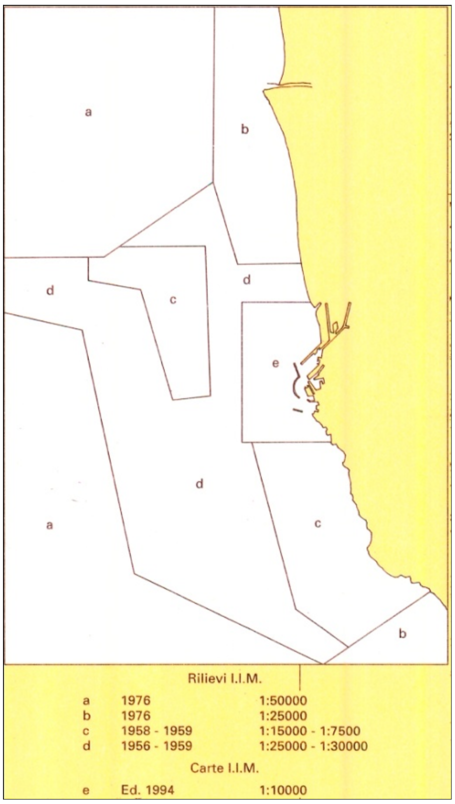

***Figure 6**: example of quality information provided on source diagram on paper chart*

Furthermore in this contest the IHO is now looking to determine whether the existing ENC data quality indicators will be appropriate or whether new indicators will need to be developed. The IHO is in fact investigating how to improve the way the quality of survey data could be better presented to the mariner.

5. ECDIS and GNSS functional status

ENC data for ECDIS are compiled for a variety of navigational purposes such as overview, general, coastal, approach, harbour and berthing (defined in the IHO ENC Product Specification, S-57 Appendix B.1). It is the responsibility of the coastal Hydrographic Offices to optimize and produce the ENC data that is most appropriate to the requirements of safe navigation in the area.
The future second generation GNSS receiver equipment should indicate to the user whether its performance is outside the bounds of requirements for general navigation in the ocean, coastal, port approach and restricted waters, and inland waterway phases of the voyage as specified in IMO resolutions.

As outlined above ECDIS and GNSS involved in the navigation system require some new important mariner skills related to the correct evaluation of quality of data. This evaluation is not an easy process and is of fundamental importance in electronic chart real-time positioning.

There is the need for a similar navigational status indicator both for the ENC and for the GNSS data. A future solution could be to make it possible for ECDIS to provide a functional status green, yellow or red light to warn the mariner performing the route monitoring of the overall navigation system situation related to the current type of navigation (coastal, approach, harbour, etc.), according to ***Table 6***.

FUNCIONAL STATUS	ENC	Positioning	
		GNSS	Other requirement
GREEN	Appropriate navigational purpose/scale for navigation available and up-to-date	Performance met the requirement for the navigational purpose	None
YELLOW	As above	Only accuracy performance met the requirement for the navigational purpose	Alternative appropriate positioning method required as integrity monitoring. Ship's position should be cross-referenced using a separate independent positioning system, such as visual, Radar, terrestrial electronic position-fixing systems, depth sounder etc
	As above	Performance not met for the navigational purpose	Appropriate positioning method required other than GNSS
RED	Appropriate navigational purpose/scale for navigation not available or not up-to date	Not applicable for ECDIS – refer to up-to-date paper nautical chart.	

***Table 6**: ECDIS +GNSS functional status*

6. The e-Navigation strategy

The rapid improvement of these new technologies and the consequent impact on maritime navigation resulted in the IMO considering in 2005 the need to develop a broad strategic vision. A new vision for incorporating the use of new technologies in a structured way and ensuring that their use is compliant with the various navigational communication technologies and services that are already available, with the aim of developing an overarching accurate, secure and cost-effective system with the potential to provide global coverage for ships of all sizes. In December 2008, the IMO Maritime Safety Committee approved the strategy for the development and implementation of e-Navigation along with a time frame and the framework for its implementation process. IMO also requested the participation of other international organizations (IHO, IALA, etc.) in the implementation of e-Navigation.

This need has been summarized by a new concept of "e-Navigation", where "e" stands for "enhanced-navigation" since the electronic navigation has already been used in the maritime navigation for some years. What is new is the proper reliable and efficient integration of these electronic system and the related profit use of the related information technology.

The concept has been well summarized in the definition of e-Navigation as the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment.

It is in this context that the new perspective and advantage of the GNSS information should be analyzed in light of the new requirements related to safety of navigation. Some of the most important requirements are:

- Information shall be automatically checked for validity and plausibility.
- Data failing these checks will trigger an alarm and should not be used by the system.
- The integrity of information should be monitored and verified automatically before being used.
- e-Navigation systems must have sufficient integrity and/or redundancy commensurate with the safety, security and environmental protection requirements.
- All navigation related information should be made available to the user in an effective manner via an integrated system.

7. Improvement of ECDIS related standard of training for seafarers

The enhanced ECDIS technology and its integration with other navigation systems used in the decision-making process has been considered in the last years by IMO in relation also to the requirements of minimum standard for seafarers training.

IMO, recognizing the importance of establishing detailed mandatory standards of competence necessary to ensure that all seafarers shall be properly educated and trained, skilled and competent to perform their duties, recently approved an important revision to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (the STCW Convention), and its associated Code. The amendments, to be known as "The Manila amendments to the STCW Convention and Code" have been adopted at a Diplomatic Conference in Manila, the Philippines, in june 2010 and are set to enter into force on 1 January 2012.
Amongst the amendments adopted, there are a number of important changes to each chapter of the Convention and Code, including new requirements relating to ECDIS use and its integration with other navigation systems. Some of the most important ECDIS new specification of minimum standard of competence for officers in charge of a navigational watch and for masters and chief mates are summarized on **table 7 and 8** respectively [7].

(FOR MORE DETAILS SEE FULL SIZE TABLES OVER PAGE)

Competence	Knowledge, understanding and proficiency	Methods for demonstrating competence	Criteria for evaluating competence
Use of ECDIS to maintain the safety of navigation	*Navigation using ECDIS* Knowledge of the capability and limitations of ECDIS operations, including: .1 a thorough understanding of Electronic Navigational Chart (ENC) data, data accuracy, presentation rules, display options and other chart data formats .2 the dangers of over-reliance .3 familiarity with the functions of ECDIS required by performance standards in force Proficiency in operation, interpretation, and analysis of information obtained from ECDIS, including: .1 use of functions that are integrated with other navigation systems in various installations, including proper functioning and adjustment to desired settings .2 safe monitoring and adjustment of information, including own position, sea area display, mode and orientation, chart data displayed, route monitoring, user-created information layers, contacts (when interfaced with AIS and/or radar tracking) and radar overlay functions (when interfaced) .3 confirmation of vessel position by alternative means .4 efficient use of settings to ensure conformance to operational procedures, including alarm parameters for anti-grounding, proximity to contacts and special areas, completeness of chart data and chart update status, and backup arrangements .5 adjustment of settings and values to suit the present conditions .6 situational awareness while using ECDIS including safe water and proximity of hazards, set and drift, chart data and scale selection, suitability of route, contact detection and management, and integrity of sensors	Examination and assessment of evidence obtained from one or more of the following: .1 approved training ship experience .2 approved ECDIS simulator training	Monitors information on ECDIS in a manner that contributes to safe navigation. Information obtained from ECDIS (including radar overlay and/or radar tracking functions, when fitted) is correctly interpreted and analysed, taking into account the limitations of the equipment, all connected sensors (including radar and AIS where interfaced), and prevailing circumstances and conditions. Safety of navigation is maintained through adjustments made to the ship's course and speed through ECDIS-controlled track-keeping functions (when fitted) Communication is clear, concise and acknowledged at all times in a seamanlike manner

Table 7: Specification of minimum standard of competence for officers in charge of a navigational watch on ships of 500 gross tonnage or more – function: Navigation at the operational level

Competence	Knowledge, understanding and proficiency	Methods for demonstrating competence	Criteria for evaluating competence
Maintain the safety of navigation through the use of ECDIS and associated navigation systems to assist command decision making	Management of operational procedures, system files and data, including: .1 manage procurement, licensing and updating of chart data and system software to conform to established procedures .2 system and information updating, including the ability to update ECDIS system version in accordance with vendor's product development .3 create and maintain system configuration and backup files .4 create and maintain log files in accordance with established procedures .5 create and maintain route plan files in accordance with established procedures .6 use ECDIS log-book and track history functions for inspection of system functions, alarm settings and user responses Use ECDIS playback functionality for passage review, route planning and review of system functions	Assessment of evidence obtained from one of the following: .1 approved in-service experience .2 approved training ship experience .3 approved ECDIS simulator training	Operational procedures for using ECDIS are established, applied, and monitored Actions taken to minimize risk to safety of navigation

Table 8: Specification of minimum standard of competence for masters and chief mates on ships of 500 gross tonnage or more - Function: Navigation at the management level

Furthermore, with the "The Manila amendments to the STCW Convention and Code", IMO approved a new recommendation guidance regarding the use of simulator specifically related on "training and assessment in the operational use of electronic chart display and information systems (ECDIS)".

Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Use of ECDIS to maintain the safety of navigation	*Navigation using ECDIS* Knowledge of the capability and limitations of ECDIS operations, including: .1 a thorough understanding of Electronic Navigational Chart (ENC) data, data accuracy, presentation rules, display options and other chart data formats .2 the dangers of over-reliance .3 familiarity with the functions of ECDIS required by performance standards in force Proficiency in operation, interpretation, and analysis of information obtained from ECDIS, including: .1 use of functions that are integrated with other navigation systems in various installations, including proper functioning and adjustment to desired settings .2 safe monitoring and adjustment of information, including own position, sea area display, mode and orientation, chart data displayed, route monitoring, user-created information layers, contacts (when interfaced with AIS and/or radar tracking) and radar overlay functions (when interfaced) .3 confirmation of vessel position by alternative means .4 efficient use of settings to ensure conformance to operational procedures, including alarm parameters for anti-grounding, proximity to contacts and special areas, completeness of chart data and chart update status, and backup arrangements .5 adjustment of settings and values to suit the present conditions .6 situational awareness while using ECDIS including safe water and proximity of hazards, set and drift, chart data and scale selection, suitability of route, contact detection and management, and integrity of sensors	Examination and assessment of evidence obtained from one or more of the following: .1 approved training ship experience .2 approved ECDIS simulator training	Monitors information on ECDIS in a manner that contributes to safe navigation. Information obtained from ECDIS (including radar overlay and/or radar tracking functions, when fitted) is correctly interpreted and analysed, taking into account the limitations of the equipment, all connected sensors (including radar and AIS where interfaced), and prevailing circumstances and conditions. Safety of navigation is maintained through adjustments made to the ship's course and speed through ECDIS-controlled track-keeping functions (when fitted) Communication is clear, concise and acknowledged at all times in a seamanlike manner

Table 7
Specification of minimum standard of competence for officers in charge of a navigational watch on ships of 500 gross tonnage or more – function: Navigation at the operational level

Competence	**Knowledge, understanding and proficiency**	**Methods for demonstrating competence**	**Criteria for evaluating competence**
Maintain the safety of navigation through the use of ECDIS and associated navigation systems to assist command decision making	Management of operational procedures, system files and data, including: .1 manage procurement, licensing and updating of chart data and system software to conform to established procedures .2 system and information updating, including the ability to update ECDIS system version in accordance with vendor's product development .3 create and maintain system configuration and backup files .4 create and maintain log files in accordance with established procedures .5 create and maintain route plan files in accordance with established procedures .6 use ECDIS log-book and track history functions for inspection of system functions, alarm settings and user responses Use ECDIS playback functionality for passage review, route planning and review of system functions	Assessment of evidence obtained from one of the following: .1 approved in-service experience .2 approved training ship experience .3 approved ECDIS simulator training	Operational procedures for using ECDIS are established, applied, and monitored Actions taken to minimize risk to safety of navigation

Table 8
Specification of minimum standard of competence for masters and chief mates on ships of 500 gross tonnage or more - Function: Navigation at the management level

IMO has also taken steps to revise and update the existing model courses 1.27 “Operational use of ECDIS” which provide guidance on the implementation of the training and assessment provisions of the amended STCW Convention and Code.

8. Conclusion

ECDIS and GNSS are giving the mariner a powerful tool to increase operational performance and safety of the route monitoring activities. Furthermore it enables the mariner to safely conduct transits in confined and crowded waters that were previously not always possible. To make this integration reliable and successful the user has to know very well the capabilities and all kind of limitations related to the information provided such as ENC and GNSS data first and other sensor data supplied (AIS, ARPA, Radar, etc.). To obtain the maximum advantage and benefit from real-time navigation with ECDIS and GNSS positioning, a different approach by the mariner is required and a specific training program that provides comprehensive instruction on safe equipment operation as well as capabilities and limitations shall be developed. This training program should use available modern, innovative instruction methodologies, including the use of simulators with integrated bridge systems, such as ECDIS, GNSS, ARPA and AIS. The accuracy of GNSS positioning and the advantages of electronic charts will be worthless without this mutual system integration. This integration must occur in order to meet the user needs, in terms of coverage, accuracy and reliability for electronic charts and accuracy, integrity, reliability and system redundancy for position fixing systems. It is for these reasons that IMO has recently amended the STCW related to the ECDIS training. During the implementation of the IMO model course for ECDIS training it is very important to highlight the importance of GNSS integrated with chart data in ECDIS. There are some specific basis for training already available (STCW, Model course, others) where is possible to properly address the correct integrated use of GNSS and ECDIS and where also future improvements can be introduced.

It is important to be aware that in some areas chart accuracy is lower than that available from GNSS. Operationally, this discrepancy in accuracy requires the mariner to be alert to the danger of placing overconfidence in his position in relation to objects critical to navigation, which are likely to be located on charts to an accuracy inconsistent with that of the GNSS. In the future of legally recognized real-time positioning in restricted waters, with enhanced GNSS and ECDIS, there is an urgent need, in some areas of the world, to revise charts to an accuracy consistent with GNSS and to common horizontal and vertical datums. International bodies such as IMO and IHO are therefore giving high priority to this issue.

Biography of the Author

Captain Rosario LA PIRA is the Head of the Survey and Production Department of the Italian HO. He is a Category A FIG/IHO Hydrographer that served for 13 years on board of various Italian Navy Ships, as Navigation Officer, Hydrographic surveyor, Executive Officer and Commanding Officer. He also served for several years on the Italian HO as Head of the Electronic Chart and Paper Chart Offices and has been actively involved in various IMO, IHO, EC and RTCM Committees and Working Groups dealing with electronic chart. He drafted the requirements for the Italian Navy ECDIS and the ECS national requirements and performance standards for the Italian pleasure and fishing boats. Recently he was employed as Professor of navigation at the Italian Naval Academy in Livorno, primarily involved in radionavigation, Electronic Chart and ship manoeuvring and as a member of the full Marine casualty or incident safety investigation board of Direzione Marittima Livorno – Italian Coastguard. He is the author of the Italian Naval Academy book “La Cartografia Elettronica”.

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