Integrating GIS, ECDIS and web-based marine information systems for maritime navigation and coastal protection

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OVER 70% of the Earth's surface is covered with water upon which world trade, fisheries, marine transportation and costal populations are relying and require safe navigation and environmental protection. This paper summarises the principal components of a web-based marine information system (MIS), the data formats of electronic nautical charts (ENC), digital nautical charts (DNC®) and raster nautical charts (RNC) for electronic chart display information systems (ECDIS) and safe navigation, the critical infrastructures under protection by coastal management regimes, the recent advances of acquiring hydrographic data by light detection and ranging (LiDAR) for use in geographic information system (GIS) applications, the reliable sources of ENC, DNC and RNC, and the techniques of converting GIS data to ENC or vice versa to expedite the implementation of a MIS.

Principal components of MIS, GIS and ECDIS

A web-based MIS is a computerised information system which facilitates; (1) data storage and maintenance, (2) retrieval of data based on their spatial, temporal, and/or thematic properties, (3) integration of diverse data, for example remote sensing data and field survey measurements and other records, (4) data analysis and visualisation and (5) simulation models for prediction of marine parameters (Jacob et al 2003). It obtains data via survey instrumentation, GIS and ENC distributors in order to perform its functions efficiently and effectively under the worldwide electronic navigational chart database (WEND) model of the International Hydrographic Organisation (IHO). Principal components of a web-based MIS and its communication networks are shown schematically in Figure 1.

GIS has been long recognised as an integral component of the MIS for coastal protection and homeland defence operations. It is essentially a computer-based data management system which can handle vast amounts of georeferenced data to assist decision-making by having the system components of data inputs, metadata management (data storage and retrieval), data manipulation and analysis and data outputs. Typical components of a complete GIS are illustrated in Figure 2. Its input data are addressed as geospatial data of vector or raster objects and attribute data of an object's description (e.g. texts).

According to the code of practice established by the Safety of Life at Sea (SOLAS) Convention and the International Maritime Organisation (IMO), all ships must have an approved ECDIS on board with ENCs to be maintained and displayed on the ECDIS. The ENCs must comply with IHO S-52, IHO S-57 and other standards. The hardware of ECDIS must comply with all the calibration tests established by the International Electrotechnical Commission (IEC). Many ECDISs are also capable of displaying the DNCs produced by US National Geospatial Intelligence Agency (NGA). The DNCs cover the whole world and are intended for GIS and military/security applications. In the absence of ENC and DNC, RNC in bitmap format will be allowed to be used in navigation, which is displayed on raster chart display systems (RCDS).

As shown in Figure 1, a true ECDIS is essentially a vector system which displays position, imagery and navigational information received from ship-board sensors on a vector ENC. It has the advantage of interfacing with an automatic identification system (AIS), automatic radar plotting aid (ARPA), global navigation satellite system (GNSS) and other sensor data to provide 24-hour real-time positioning, anti-collision and anti-grounding alarms, and autopilot guidance for navigation. It also has application functions for updating and displaying the ENC data, route planning, route monitoring and recording the ship's past ENC and track logs including date, time, position, direction and speed of the ship. The main advantage of an ECDIS over GIS, in general, is that it can dynamically display cartographic objects, including coastlines, bathymetry and real-time positions and track of other vessels (including host vessels) within range of an AIS telemetry interface. This computerised system is capable of computing the tracked object's course, speed and

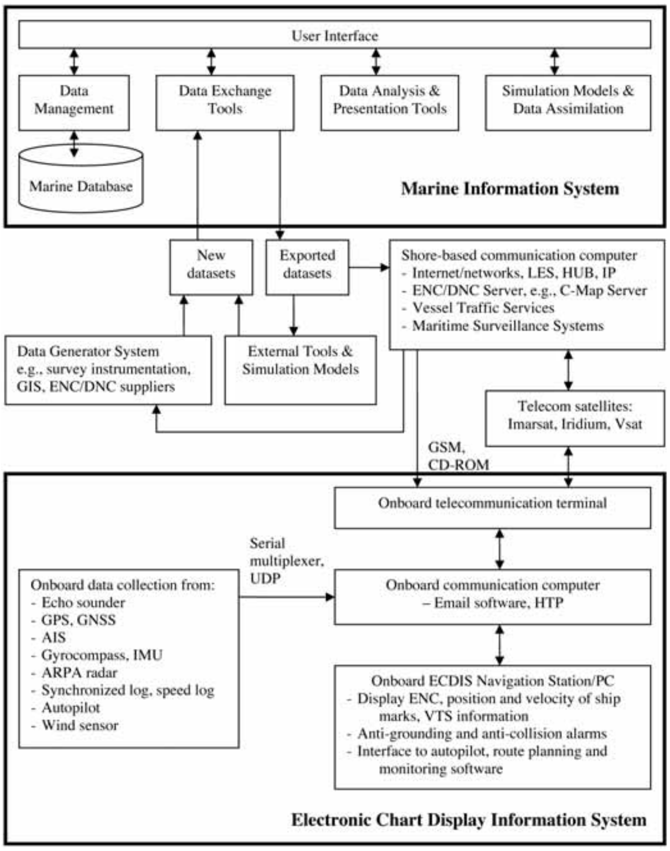

Figure 1: Components of a web-based MIS
(Jacob et al 2003, Pillich et al 2003, Ince 2000, IHO WEND model 2007, IHO S-63).

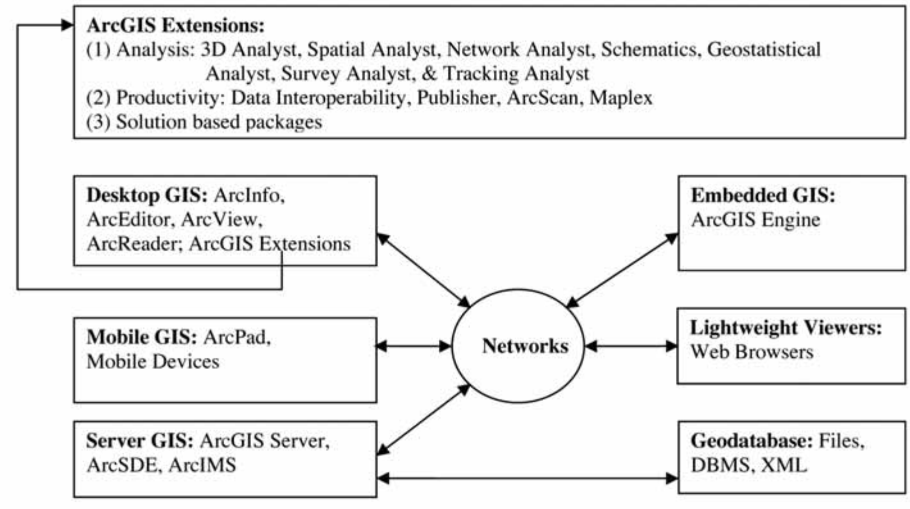

Figure 2: A complete GIS by ESRI
(www.esri.com 2007)

closest point of approach (CPA), thereby warning the operator if there is a danger of collision with another ship or land mass. The ECDIS is a tool for safe navigation and the prevention of collisions, the dividends of usage being the safety of life at sea, the protection of property and the marine environment. Its primary purpose is as an aid to navigation whereas GIS is not. However, since a true ECDIS is a vector-based charting system, it offers limited interoperability with other GIS formats.

GIS, ECDIS and MIS data for coastal protection

The objective of integrating GIS and ECDIS with a MIS is to protect onshore and offshore assets and infrastructure, which if disrupted or destroyed could cause serious damage to health, safety, security and commerce. The applications of which could impact a coastal state's infrastructure, its economic wellbeing and the effective functioning of government services. Within the scope of a GIS, critical infrastructures can be classified into energy and utilities (e.g. electricity supply), information and communication systems (e.g. broadcasting stations), finance (e.g. banking and investment), healthcare (e.g. hospitals), food supply (e.g. agriculture and food safety), water supply and sewage disposal, transportation (e.g. air, rail, road and marine traffic), safety and security (e.g. nuclear safety), government services and assets, and manufacturing (e.g. chemical industry) (PSEPC 2004). To aid in the detection of threats to coastal infrastructure posed by pollution and shoreline stability, while establishing the MIS for sustainable development of maritime trade, transportation and property rights, the following intelligence mapping programme is recommended (Barter et al 2000):

- Mapping of all onshore geology, beach profiles, land use and flora by applying high resolution LiDAR surveying methods (e.g. Optech's ALTM airborne laser scanning system and LIRIS-3D ground-based laser scanner).

- Mapping of all offshore geophysical objects, marine habitats and other marine objects within marine boundaries using, for example, Optech's SHOAL airborne laser bathymeter.
- Mapping and assessment of all engineering structures with the assistance of digital solid models created by LIDAR surveys and reverse engineering software.
- Mapping and analysis of oceanographical and meteorographical data including sampling and analysis of marine and terrestrial water and sediments by acoustic bottom classification (ABC) survey.
- Socio-economic surveys and public consultation to establish the characteristics of coastal communities.

In areas where LiDAR applications are limited by water depth and/or water clarity, the combined use of multibeam and sidescan sonar systems can provide complimentary high resolution data for mapping bathmetry and seabed classification. In addition to remote sensing and hydrographic techniques, LiDAR techniques based on satellite platform sensors such as elastic-backscatter, differential-absorption, Raman, fluorescence and direct-detection Doppler techniques are recommended to map or monitor atmospheric and meteorographical objects, for example aerosol particles, water/ice clouds, precipitation, radiation, temperature profiles, windstorms, visibility and industrial emissions (Weitkamp 2005, Barter et al 2000).

In addition to national hydrographic offices, recognised suppliers of ENCs (in S-57 format) and ECDIS software and hardware include the Primar Stavanger ENC service (a distributor of ENCs produced by government HOs and the International Centre for ENCs), C-Map Inc of Norway and British Transas Marine Limited. At the time of reporting, 181 object classes are defined in the IHO S-57 object catalogue, similar to those classes of DNC. DNCs in vector product format (VPF) are supplied by dealers of NGA, which cover the following categories or layers of information for GIS applications, ECDIS and MIS:

- Cultural landmarks (manmade and land features).
- Earth cover (shoreline, islands and other boundaries).
- Environment (current, tides and magnetic anomalies).
- Hydrography (soundings, bottom characteristics and depth curves).
- Inland waterways (canals, rivers, locks, lakes etc).
- Land cover (glaciers, trees, marches etc).
- Limits (restricted areas, traffic separation schemes etc).
- Aids to navigation (buoys, lights, beacons etc).
- Obstructions (rocks, wrecks, obstructions etc).
- Port facilities (breakwaters, piers, seawalls etc).
- Relief (contours and spot elevations).
- Data quality (source boundaries and information).
- Tile reference (tile boundary delimiters and information).
- Library reference (library boundaries and coastal shoreline) (Fishburn and Kimos 1995).

The last three layers provide source, background and location information. Since 2001, the US National Oceanic and Atmospheric Administration (NOAA) has been offering their ENCs in S-57 and GIS data formats free of charge to users over the Internet. But most of the data is converted from raster imagery and may not be valid for navigation operations. In the near future, more oceanographic objects known as marine information objects (MIO), e.g. meteorological objects, and additional military layer (AML) objects will be developed and added into the new IHO object catalogue to expedite MIS applications (Alexander 2003, Alexander et al 2007).

Integration of GIS data and ENC

The main challenges associated with the integration of GIS and ENC relate to the collection of data (in S-57 format) and the conversion from GIS spatial data formats into S-57 object format or vice versa so that these two categories of data can be assimilated together and applied in spatial analysis, dissemination of findings and decision making in coastal management. Regarding data conversion, GIS vendors (e.g. CARIS and ESRI) offer conversion services, software and training to users. For example, the transformation of data from ENC/DNC to GIS or vice versa via ESRI's ArcGIS platform has been both efficient and effective. Another example (Wan et al 2005) describes the method of applying a three-dimensional quad-tree data structure for developing ECDIS software that integrates with CARIS HOM/DOM for ENC/S-57 and DNC/VPF production. In this case, despite the disadvantage that a quad-tree data structure is shift sensitive (in the sense that its space requirements are dependent on the stability of origin or higher hierarchical levels), it is easy to program and implement fast updates and queries of large spatial databases.

Conclusions and further development

In integrating GIS and ECDIS with MIS, both land and hydrographic data are best collected in ENC (IHO S-57 object format), DNC (VPF format) and a combination of other vector, raster and attribute data can be used to enhance the MIS. LiDAR technology is highly recommended for cost effective, high resolution data acquisition in near shore areas.

The main challenges associated with the integration of GIS and electronic nautical charts relate to the collection of data in S-57 format and the conversion from GIS spatial data formats into S-57 object format.

However, it may be necessary to integrate high resolution sonar technology to supplement LiDAR coverage. Software to facilitate the interoperability between ENC and various GIS and database formats is key to presenting information in a MIS to support decisions made by navigators and persons involved with coastal management. Under the leadership of IHO, IMO, Fisheries and Oceans Canada, NOAA and other international and national maritime organisations, more oceanographical and meteorographical layers of data (which are classified as MIOs and AML objects) can be added to expand the capabilities of a MIS to clients concerned with navigational and environmental issues. It is worth considering the potential for the integration of cadastral layers within a MIS to relate mapping and environmental data to a property rights framework.

Presently, the main obstacles are the quality of available source data as well as the cost of acquiring data to be used in the production of ENCs and the availability of training courses on ENC data production and validation. Some government hydrographic offices are still having difficulties in producing ENC data in compliance with IHO S-57 due to the lack of funding and technical expertise.

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