Marine Corridors: a Methodology for Planning and Prioritizing Hydrographic Surveys, Products and Services

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Abstract

The balance between capacity and demand is an ever-increasing challenge for hydrographic offices of which the Canadian Hydrographic Service (CHS) is no exception. In this regard, the balance between changing conditions on the ground and the suitability of existing hydrographic data and products to meet the user needs, becomes complex. The mechanisms for assessing priorities and the necessity to keep these priorities up-to-date, relevant and comprehensible amongst a diverse collection of decision-makers and technical operations levels requires the integration of data with appropriate access and visualization tools.

The CHS is taking steps to use Geographic Information System (GIS) and interactive web-map technology to achieve this coordinated approach to planning, prioritization and organizational communication. This paper will talk about the concepts, the practical challenges in the building of this infrastructure tool including assembly of validated data and explore the lessons learned during a transition to a GIS decision-support environment for the prioritization of hydrographic operational planning.

Forward

The scope of this research was based within Arctic 'frontier' waters however CHS foresees an application could to all Canadian navigable waters. The core concept for this work, the Marine Corridor, is rooted in knowing where navigation occurs, identifying trends in navigation and gathering information to project where navigation may occur in future. In the context of this research, a marine corridor is an area where there exists a measureable amount of diverse marine transportation with commercial purpose. It is a methodology for planning and prioritization through spatially referencing and comparing specific transportation needs with marine navigational services. In practice, the concept isn't new as hydrographic survey planning in Canada has long used a "corridor" approach to defining where to focus effort in frontier areas in order to maximize the effective use of platform and equipment assets within limited operational windows. In most cases, cold war era reconnaissance surveys have provided a basis for subsequent routing choices. Furthermore, client consultation has served to substantiate an understanding of the location and extent of modern survey coverage necessary to adequately support specific navigational needs. Modern (post 1970's) charting delineates the resulting surveyed corridor area with the use of pecked magenta or pecked grey line work and with notes to identify the area enclosed by the corridor as 'surveyed more completely and accurately than the area outside of the corridor' (See Figure 1)

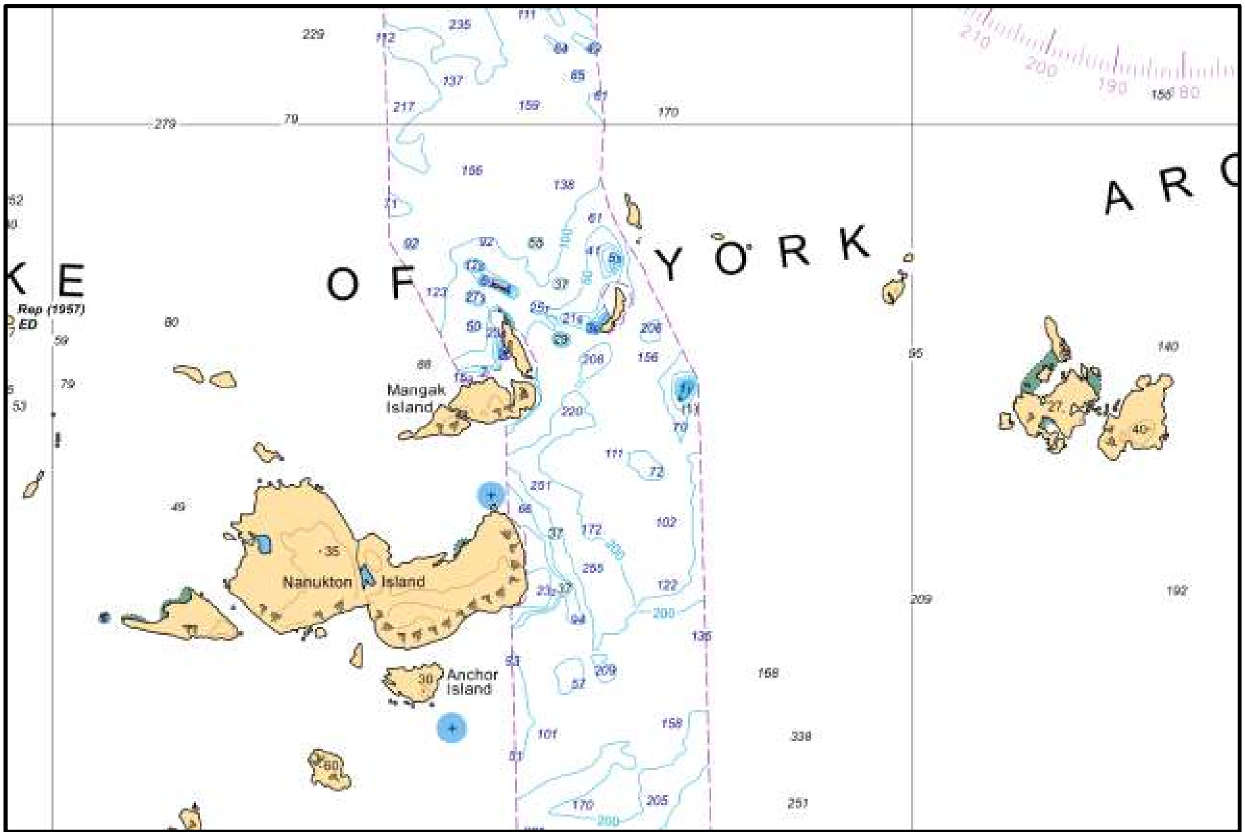

Figure 1, Surveyed corridor, Coronation Gulf, New Edition, Chart 7777

Automatic Identification System (AIS) data, has provided more complete and current information of where vessel traffic is actually occurring and in particular, has validated whether vessels are following existing surveyed corridors or not. However, to fully analyse and compare vessel traffic data with existing survey data, nautical publications, marine navigational services (MNS) plus a variety of other spatial information and its metadata required the use of GIS technology. Once spatially referenced within the GIS environment the user has the tools to further quantify and forecast how trends in navigation might be influenced. Given the complexity, it was recognized early on that the use of GIS tools alone might pose a challenge for lay-users to access the information openly and easily and hence emphasized the need for a web-based data portal.

GIS Application

The CHS has a large inventory of geospatial data. Several years ago we recognised that the integration of all our geospatial data within one Geographic Information System (GIS) could help us better manage our existing data and plan for new data acquisition and nautical publications. The compilation of large, complex spatial layers within a single GIS database would make it possible to analyse large quantities of data to support decision making, produce maps and create reports.

In 2009, CHS implemented a GIS database[1] to manage chart product limits and associated metadata in order to create products like chart catalogues and to improve efficiencies in our service to clients requesting chart information or value added products. The management of our geospatial data within a GIS environment also gave CHS the ability to build a web application for our clients to search and query information on our products. The Arctic Voyage Planning Guide (AVPG)[2] is a good example of a web tool derived from the CHS GIS database. The AVPG was created as a logistic planning tool for both domestic and international vessels traveling in the Canadian Arctic. It draws together regulatory information pursuant to the *Canada Shipping Act, 2001* and the *Charts and Nautical Publications Regulations, 1995* as well as complementary data and information from Canadian federal departments with mandates to support safe navigation.

CHS has also developed additional GIS-based tools, to aid in planning its chart production and surveys. These are the Chart Prioritization Tool and the Survey Planning Tool respectively. The Chart Prioritization Tool was developed to support decision making for planning and prioritization of a national chart production strategy. The Chart Prioritization tool also calculates the quality of CHS charts (paper, vector and raster) by considering several factors like chart datum, units, level of risk, quality of survey, vessel traffic, etc. The Survey Planning tool was designed to identify deficiencies in hydrographic surveys across the country and to rank the deficiencies from most to least critical. Additionally, the tool includes an analysis capability to determine the level of effort to collect hydrography within defined areas.

In 2013 CHS committed to develop and maintain a GIS-based tool which included elements of the aforementioned applications but with a view towards identifying marine transportation corridors and enabling data exchange and interoperability with other government departments and stakeholders in the marine environment. Vessel type and vessel tracking information from AIS data supplied by Transport Canada was introduced and analysed within the GIS towards accurately referencing types of vessels and traffic patterns along with existing information on hydrography, seabed morphology, marine navigational services environmental sensitivities, sealift-cargo supply, cultural and resource interests. A significant output of this tool was the delineation of vessel traffic (marine) corridors and analytical zones within which policy and strategies for the delivery navigational products and services can be developed, planned and prioritized.

Like the Survey Planning Tool, further analysis within the marine corridor construct has provided for preliminary estimates on the level of effort required to survey specific areas based on the order of survey to satisfy a specific S-57[3], Category Zone of Confidence (CATZOC) considered necessary to support navigation within a given marine corridor area. The metadata to support this form of analysis was derived from bathymetric surface objects integrated within the CHS Bathymetric Data Base (BDB)[4]. Metadata from CHS Tides Currents and Water Levels (TCWL) section was also input such that the level of effort required to provide TCWL information sufficient to support navigation was also considered. While clearly a benefit to CHS operational planning, access to the data management and information analysis capactity of this

[1] ESRI ARC GIS
[2] http://geoportal.gc.ca/eng/Gallery/MapProfile/5
[3] http://www.iho.int/iho_pubs/standard/S-57Ed3.1/31Main.pdf
[4] CARIS BDB

GIS can serve to support other departmental stakeholders in developing their respective service level and transportation policy and management requirements within a marine corridor construct. There is a strong synergy between this work and other applications, since the source for all the geospatial data are all managed from a common GIS database.

Data, Governance and Interoperability

Recognizing a potential need to enable stakeholders both internal and external to the Department of Fisheries and Oceans, guidelines for data governance were developed. The preferred format for data exchange is via web services, direct SDE[5] Connection or connection via spatial query to a view in an Oracle database. Internally, CHS connected with its CHSDIR metadata database to capture chart product limits. All other data was supplied as stand-alone files in ESRI Shape (SHP) format or parsed from ascii CSV format or entered from technical reports. Metadata was to be compliant with ISO 19115: Geographic Information Metadata. Bathymetric surface (surfac) objects exported from the CHS Bathymetric database were stripped of most attribution once converted to Shape format.

The objective is to update the GIS with live data as it comes available. CHS is further developing an approach to synchronizing metadata between CHSDIR and its Bathymetric Data Base such that as new data becomes integrated within BDB, the geographic limits of CATZOC layers within the GIS will be updated. While it is understood that CATZOC is not the most appropriate attribute for classifying hydrographic surveys, the current architecture of both CHSDIR and BDB utilizes this attribution to identify the suitability of use of bathymetric source data for ENC production purposes. With a view towards initially developing a test GIS application around Arctic frontier waters, CHS, Central and Arctic Region loaded its BDB with all available digital bathymetric source data up to and including 2012. In doing so, it was apparent that interpretation of CATZOC and the methodology for delineation of surface objects were not being applied consistently within the region.

The following is an inventory of information included within the GIS:

- Populated Places (Statistics Canada, NRCAN-GeoGratis)
- Port Tonnage, 2006-2011 (Community prioritization analysis, Port tonnage 2006-2011)
- Marine Navigational Services (Fixed, floating and electronic Aids to Navigation- CCG)
- Places of Refuge (North Warning System, Transport Canada Reports)
- SAR Incidents (Search and Rescue Incidents- CCG)
- Tides and Currents (CHS Sailing Directions, raster, vector and paper charts)
- Environmental Data:
    - Protected Areas (NRCAN-GeoGratis, charted Marine Protected Areas)
    - EBSA (Ecologically and biologically significant areas)
    - Traditional Knowledge (Seal, Whale, Fish and Walrus Habitats, DFO Ecosystems and Habitat Management)
- Safety Control Zones (CCG)
- Analytical Zones (Based on CCG Safety Control Zones, Canada's Bioregions[6] and CCG Ice Breaker Requirements)

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[5] ESRI Geodatabase ARCSDE

[6] http://www.dfo-mpo.gc.ca/oceans/publications/dmpaf-eczpm/framework-cadre2011-eng.asp

- NORDREG vessel traffic analysis
- Arctic Circle
- Arctic Marine Traffic (2010-2013 AIS- TC)
- Median Ice Concentrations, 1981-2010 (CIS, EC, CCG)
- Ice Break up and Freeze up Week (CIS, EC, CCG)
- Arctic Ice Breaker Requirements[7] (CIS, EC, CCG)

Resource Development and Projections:

- Mines, Minerals, and Metals (NRCAN-GeoGratis)
- Projected Mines (NRCAN)
- Oil and Gas Developments (NRCAN-GeoGratis)
- Oil and Gas Licenses (AANDC)

CHS Charts and Publications

- Sailing Directions
- Tides and Currents
- ENC
- Paper Charts

Hydrography

- Bathymetric Surface ('surfac') Object limits (CATZOC A, B, C layers)
- CHS Surveyed Corridors (Charted limits of Adequately Surveyed Areas)
- Anchorages (CHS)
- Seafloor Complexity (CHS analysis of depth variation and morphological data)
- General Bathymetric Chart of the Ocean (GEBCO) Depth Contours (0-5, 50-100, 100-200, GT200)

BaseMaps

- Administrative Boundaries
- Land (Canada and international boundaries)

Data on culturally sensitive archaeological areas from (Parks Canada and Nunavut), coastal classification data (Environment Canada, eSpace) and Comprehensive Land Claims and Treaties (NRCan Legal Surveys Division) were considered but not included in the present version of the database. The latter albeit useful in referencing the extent of specific treaty rights and jurisdiction within the analytical zones defined within the GIS were not completely validated for use within the timeline of data integration.

Marine Corridors

As previously noted, the unique characteristic of this planning tool is the marine corridor construct which in and of itself is a significant contributor to the planning and prioritization model as is creates justification for the need for nautical publications and other marine navigational services within a specific area. The process for research and development of our corridor construct has been well documented by the CHS National Capital Region (NCR) research team for which the following summary is offered:

[7] http://www.ccg-gcc.gc.ca/Icebreaking/Icebreaker-Requirements/index

Analytical Zones were established for GIS analysis with consideration for commonality in vessel traffic patterns, ice regimes and existing CCG Safety Control Zones. Automated Identification System (AIS) vessel traffic data from Transport Canada was introduced as line data and reviewed against existing surveyed/charted corridors and bathymetric database meta objects for CATZOC A, B and C source data whereby all would serve as a reference for the existence of a corridor. A selective line density analysis was performed within the GIS using algorithms to identify a generalized traffic "corridor" areas based on a selection of cargo, tanker and passenger traffic. A 3-class (High, Medium and Low) quantile classification was then performed with tail trimmings to the histogram of values assigned to the traffic densities.

The histogram of values assigned to the traffic densities were as follows:

i. 0.062497491 - 0.124994981
ii. 0.124994981 - 0.437482434
iii. 0.437482434 - 15.93686008

Corridors were then characterized with a view towards prioritization with consideration for traffic density and purpose:

Primary- Corridors where navigation is for the purpose of transit and/or innocent Passage. These corridors are the main highways characterized by the graphic extents of all three buffered traffic density levels. The primary corridor provides a means to enable secondary access to ports.

Secondary- Corridors characterized by the geographic extents of medium and low traffic density levels which provide navigational access to ports to fulfil supply links and the movement of passengers. Secondary corridors are validated by the presence of cargo, tanker and passenger traffic.

Tertiary- Corridors characterized by the geographic extents of the medium and low density traffic levels which provide navigational access to Places of Refuge[8] including charted anchorages located nearest to a primary or secondary corridor AND farthest away from ports. Tertiary corridors may also serve to support supply links to unpopulated or not-permanently-populated sites with strategic importance to Canada, e.g. Military, Navigational or Meteorological stations[9].

Quaternary (4th Class)- Corridors characterized by the geographical extents of low buffered density levels. Quaternary corridors provide navigational access to resource development/extraction sites or other Private interests.

Quinary (5th Class) Corridors characterized by the graphical extents of low buffered density levels or, in the absence of any density analysis or vessel traffic data, characterized by any existing or proposed bathymetric survey data. Quinary corridors provide navigational access to proposed or potential infrastructure for resource development.

[8] http://www.imo.org/OurWork/Safety/Navigation/Pages/PlacesOfRefuge.aspx
[9] Vessel traffic in some cases may be exclusive to government assets.

A quality analysis workflow was then applied to validate the results whereby:

a- it was observed that vessel traffic crossings created a "cluster" error on the density results, AIS traffic data was superimposed to identify crossing areas and where necessary corridors were amended in these areas;
b- the influence of ice was considered as a factor for diverting traffic within specific passages and thus widening the resulting graphical extents of buffered density levels;
c- CATZOC A, B, C meta object layers and charted surveyed areas was used to adjust traffic; and
d- all other types of transportation were introduced using the above-mentioned density analysis then 'risked' out of the solution. Research vessel traffic was identified, qualified using CATZOC layers (where its purpose was for hydrography) and removed. Coast Guard traffic was qualified for inclusion only where its purpose was for 'Sealift' re-supply work.

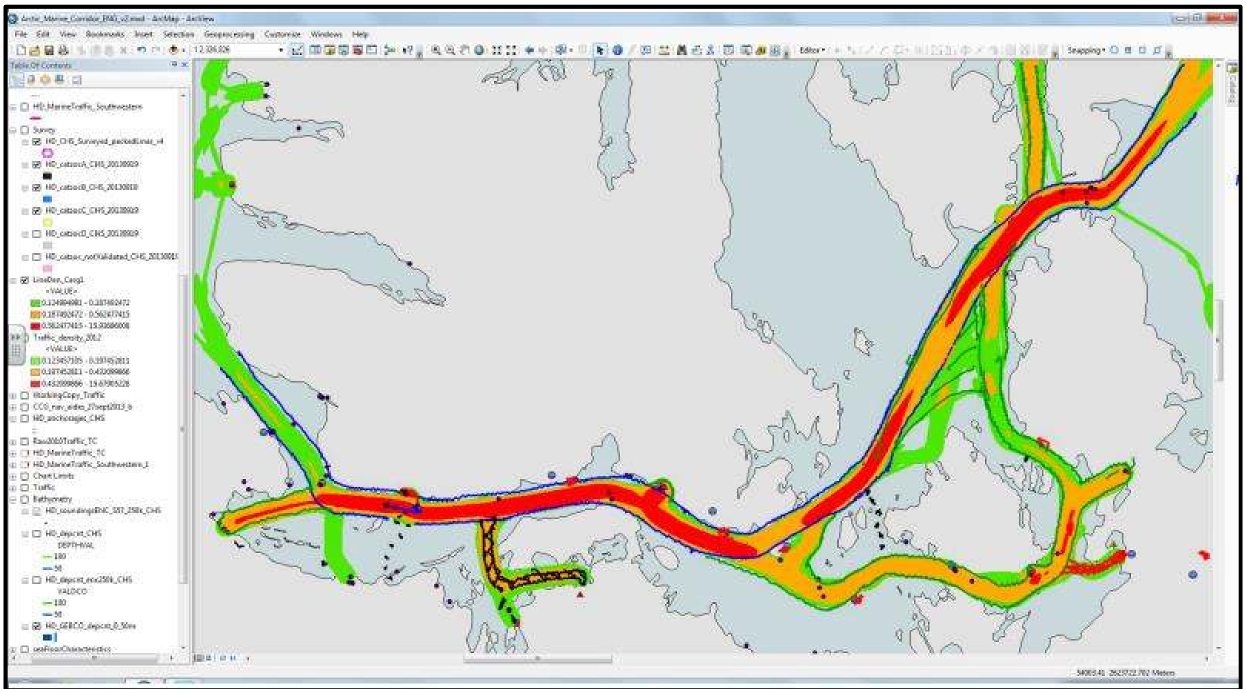

Figure 2- Line Density analysis of 2012 AIS (Tanker, Cargo and Pax) traffic data.

Figure 2 was captured from one a lab exercise performed by the NCR team. It illustrates the preliminary results of density analysis whereby: a high traffic density was indicated by red; medium density by yellow and low density by green. During the lab work, preliminary results were projected, corridors were interpreted and hand-drawn using a large touch screen monitor. Primary (Blue outline), Secondary (Green outline), Tertiary (Red), 4th Class (Hatched Black) and 5th Class (Dotted Black)

Prioritization Criteria

With corridors in place, the next phase of research turned to calculating and prioritizing Level of Effort (**LoE)** for risk managing costs based on various hydrographic options while ensuring an adequate level of service. Of primary concern were surveys and products to maintain access to ports to support supply links for populated centres. Here, focus was drawn to corridor areas where water depths were less than 50m, with complex seabed characteristics and where under keel clearance concerns would naturally drive the need for products supported by high resolution bathymetric source data. By doing so, primary corridors, if within deep water or non-complex seabed areas would not necessarily trigger a high priority. Instead, secondary corridors, particularly within the approaches to port areas would garner a higher priority.

A template for modern bathymetric source data coverage requirements was proposed as follows:

- 0-50m water depth to be covered by CATZOC-A (High resolution multi-beam sonar or systematic single beam sonar swept with side-scan sonar) surveys.
- 50-100m water depth to be coverage by CATZOC-A surveys where seabed is complex or CATZOC-B (eg. systematic single beam sonar) surveys where seedbed is non-complex.
- 100-200m water depth to be covered by CATZOC-B where seabed is complex or systematic CATZOC-C (spot bathymetry or wide spaced single beam sonar) where seabed is non-complex.

For the purpose of these estimates, a complex seafloor is one where present mapping indicates the potential for an unexpected and potentially hazardous change between soundings.

The sea floor complexity was derived from the General Bathymetric Chart of the Oceans (GEBCO). The GEBCO gridded bathymetry data has grid spacing of 30 arc-second. A slope base algorithm[10] was used to calculate the sea floor complexity, for each pixel, a 3 x 3 window was used around the processing pixel to calculate the slope. The slope model was classified in two classes (Complex and non-complex); the classes were created by grouping the slope values based on training sites where we have a good understanding of the sea floor complexity.
A methodology for further prioritization included the grandfathering of CATZOC B coverage, whereby it could be determined that existing CATZOC B, if large scale and complete could suffice to provide adequate coverage within an approach area in 0-50m water depth.

Within our analysis strategy it was agreed that surveys and products necessary to ensure a ‘soft landing’ when mariners approach critical depth areas at the end of their journey and/or in navigational choke points enroute. The corridor construct provides a clearer understanding of the anticipated highway and secondary roadways travelled to reach the desired roadsteads. So in consideration of ports and approaches as high priority areas, a second-phase prioritization was performed on a port by port basis. Ports were thus prioritized by population traffic frequency, tonnage, the extent of approach area where water depths were less than 50m and seabed complexity. Additionally, the physical approach distance along the corridor from the 50m contour to the port itself was measured and attributed against each port. Lastly as a measure of

[10] Burrough, P. A. and McDonell, R.A., 1998. *Principles of Geographical Information Systems* (Oxford University Press, New York), p. 190.

navigational risk a summary of current survey coverage, the quality of water level predictions and chart product health were further attributed.

Conclusion

The application of GIS tools for planning and prioritizing has been adopted by the CHS National Planning Committee as the way forward towards implementing a nationally coordinated approach to maintaining a level of service sufficient to support navigation on all three coasts and inland waters. Getting there has not been without its challenges particularly where we are endeavouring to balance information technology security policy with operational needs for more open and automated access to data. The quality of information out depends directly on the quality of data going in. This is true to our collective ability as an organization to fully populate each regional bathymetric data base and to consistently apply an interpretation of CATZOC when attributing the bathymetric meta-objects queried by the GIS.

An improved bathymetric model, particularly in frontier areas, will obviously improve delineation of the 50m contour and thus our ability to estimate risk and accuracy when planning within coastal areas. Good quality coastline data is essential to accurately closing the land area topology for estimating LoE. However, finding accurate coastline data of sufficient resolution continues to pose a challenge in frontier areas whereas very high resolution data serves to create a burden on GIS processing resources.

Corridor accuracy is dependent on the accuracy and currentness of the AIS vessel traffic data used to compile and update the corridor construct. A comprehensive understanding of vessel traffic trends will further develop over time as multiple years of data are introduced to the system. Conversely the prioritization surveys and products for a given port or area may decrease if we notice a decline in traffic within a specific analytical zone. AIS traffic records aside; we are yet to test the influence of cultural or environmental data, on how this information may force a shift in corridor positions and extents. While CHS is not in the business of prescribing where vessels can and cannot navigate in future, how we define and prioritize our products and services may affect future vessel traffic routing.

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