

# Ship's Navigational Safety in the Arctic Unsurveyed Regions

**T. Pastusiak**

*Gdynia Maritime University, Gdynia, Poland*

**ABSTRACT:** High traffic of the vessels in many regions of the world pressed maritime nations to issue good quality nautical charts. Vessels could proceed safely on planned voyage using nautical chart and GPS position receiver. Above popular assumptions were right in well recognized and charted regions. But some regions were not sufficiently surveyed or not surveyed at all. In this case position fixing system was useless. The only way was to follow the vessel's hydroacoustic equipment to find out safe route in between dangers. The goal of the author was to settle matters of the unsurveyed regions. First question was quality of the information on charts and role of the vessel's autonomous hydroacoustic equipment in safety of the navigation. Second question were safety parameters kept by the research vessel.

## 1 INTRODUCTION

The popular assumption is that a safety of the vessel is fulfilled by having in vessel's disposal a navigational chart in proper scale and a device or a method fixing position on this chart. By this way is possible to establish the main criterion of the navigational safety in regions well recognized - distance to the dangerous objects. In this case the object is univocally defined and charted.

The goal of the author is to establish methods for assessment of the vessel's safety during planning and monitoring of voyage in unsurveyed or poorly surveyed regions in clear and simple manner that fulfill requirements of governing regulations (IMO 1993). It includes the navigational information in world resources of charts and the autonomous equipment possible to be on board the vessel. One identifies relations corresponding to the navigational safety based on field data.

## 2 MEANS TO SUPPORT THE NAVIGATION

The navigational support of the voyage was divided into internal and external navigational information. Internal one was related to the ship's own technical devices. External one was related to the charts, pilot books or other information.

### 2.1 *External methods to support the navigation*

The main sources of the information for the safe navigation were sea charts contents. Rest of the information came from the various nautical publications. Usefulness of the charts was assessed at first approach by theirs scale and reliability of the content (Pastusiak 2010).

#### 2.1.1 *Scale of charts*

The application of the charts for navigational purposes was closely correlated with theirs scale. The electronic chart catalogues (Jeppesen Norway A/S 2010; Primar Stavanger 2010; Transas Marine Ltd 2010; UKHO 2010) and the internet chart catalogues (IC-ENC, <http://www.ic-enc.org>, 23-Mar-2011; NOAA, <http://charts.noaa.gov>, 16-Jan-10; NOAA, <http://www.nauticalcharts.noaa.gov>, 16-Jan-

10; IC-ENC, <http://ic-enc.org>; Garmin Ltd, <http://www8.garmin.com>, 08-Jan-10; Jeppesen Norway A/S, <http://www.c-map.no>, 25-Jan-10; ChartWorld GmbH, <http://www.chartworld.com>, 29-Jan-10) introduced division mostly in 6 groups of charts. It was related to kind of voyage, details of the information included and the scale of chart (Weintrit 2009). The scale of chart was correlated with position error of features placed on chart. It was 0.3 millimetres in lineal measure. In Table 1 there are presented the position errors of the placed information (features) related to the worst scales of charts in the group.

Table 1. Groups of charts and position error of charted features.

Group (band)	Scale	Position error of charted feature (m)
Overview	1:700,000 or smaller	700 or more
General	1;180,000 to 1:350,000	105
Coastal	1:75,000 to 1:180,000	54
Approach	1:12,500 to 1:45,000	13.5
Harbour	1:8,000 to 1:22,000	6.6
Berthing	1:4,000 or greater	1.2

### 2.1.2 Reliability of chart content

Reliability of charts content was described by date of a survey when source data came from. Actually used descriptions like “unsurveyed” region, “poorly examined”, “inaccurately examined”, “fully examined” should be correlated with presently being introduced meaning like Zones of Confidence ZOC (Gale 2009; UKHO 2004). Zones of Confidence referred to detection and quality of the measurement of the features on a seabed. Important matter was probability of missing (not placing) a navigational danger on a chart. Zones of Confidence were not implemented on all charts till now. On many electronic charts of not well surveyed regions placed ZOC category “U” that means “unclassified”. The vessels should use best scale charts for the intended voyage. The world charts resources were searched in relation to Murchisonfjorden region at Nordaustlandet.



Figure 1. (a) Surveyed region in Isvika (contour line indicates edge of surveyed lane). (b) Isvika survey region on Svalbard

Table 2. Coverage of Isvika region by charts.

Source	Scale / Bands	SOLAS	Kind of chart
UKHO	general 1:600,000	Official	paper, ARCS
Norwegian HO	1:100,000	Official	Paper
Russia GUNiO	1:200,000	Official	Paper
AVCS	Transit	Official	Electronic
ECDIS Service	Full =1:600.000	Official	Electronic
Primar	no coverage	-----	-----
Transas Marine	1:200,000	Unofficial	Electronic TX-97
Garmin	1:100,000	Unofficial	Electronic products Garmin
Bluecharts			
Jeppesen	1:100,000	Unofficial	Electronic products NT, MAX, MAX PRO
Marine C-MAP			
Jeppesen	1:1,500,000	Official	Electronic CM-93/3
Marine C-MAP			
SevenCs GmbH Harbour		Unofficial	Electronic Navionics ENC

### 2.1.3 Sources of origin of the chart

For purpose of this work reviewed, taken into consideration and subsequently divided charts as follows: official, unofficial, „other – bathymetric“ and „other - non bathymetric. Official charts fulfilled requirements of SOLAS, Chapter V, Regulation 2.2 (IMO 2004) that states “Nautical chart or Nautical publication is a special purpose map or book, or a specially compiled database from which such a map or book is derived that is issued officially by or on the authority of a Government, authorised Hydrographic Office or other relevant government institution and is designed to meet the requirements of marine navigation”. Official charts published by Hydrographic Offices guaranteed systematic updates of the informational content according to IMO requirements. Zones of Confidence scale should be available on the chart.

Unofficial charts were of commercial destination. Theirs informational content had same source of origin like charts issued by Hydrographic Offices. Unofficial charts not fulfilled SOLAS requirements and not guaranteed systematic updates of the informational content. These charts frequently contain additional commercial information. Vessels operating on unofficial charts are to have and use also up-to-dated official charts - at least paper ones.

„Other – bathymetric“ unofficial charts were of scientific value. The goal of the authors was the most reliable presentation of depths and sea bottom relief. Source materials were made frequently without taking into consideration standards of related to hydrographic surveys described in IHO publication (IHO 2008) by the persons not being qualified in the hydrography discipline nor production of official sea charts. Such charts not included in most cases corrections for sea level in relation to Chart Datum nor corrections for vertical location of sounder or echo-

sounder transducer. Accuracy of sounding was not estimated nor included in depth reduction. However „other – bathymetric“ charts were related to hydro-graphic niches and sometimes were valuable source of information about sea bottom relief in the region of interest. Due to lack of better sources of hydro-graphic information these charts could be useful for the initial voyage planning of hydro-graphic surveys. Informational content allowed to grant them class from „Coastal” till „Approach”. Appointment of ZOC class for each „other - bathymetric“ unofficial chart required individual assessment.

„Other – non bathymetric“ charts were of scientific value. Their authors not planned reliable presentation of depths nor sea bottom relief. Sources of information related to the sea bottom were in most cases unknown. However these charts contained informations that allowed to give them ZOC class „Overview”. For the voyage planning purposes ZOC scale on „other – non bathymetric“ charts was not so important.

Reliability of the information content was attributed to the new scale ZOC that replaced informations about date of last hydrographic survey in the mentio-ned region. Assumed, that implementation of new scale of reliability of informational content on the charts requires prolonged period of time. It was due to necessity to re-assess date of hydro-graphic survey and corellated informations on actual charts that not corresponded with new precise scale of ZOC.

During process of voyage planning in the unsurveyed or poorly surveyed regions should be taken into consideration the coverage of the region of interest by charts for navigational purposes take into account all three informative elements: the scale of a chart, the scale of reliability ZOC and the reliability of the sources of origin of the chart information.

Table 3. Assessment of external support.

Kind of charts	Scale same with norm	One level lower then norm	Two levels lower then norm	Three levels lower then norm	Four levels lower then norm	Five levels lower then norm	Lack of chart
Official charts	6	5	4	3	2	1	0
Unofficial charts	6	5	4	3	2	1	0
"Other charts – bathymetric"	6	5	4	3	2	1	0
"Other charts – non-bathymetric"	6	5	4	3	2	1	0
Sum of scores	Maximum possible 24 scores						

External methods to support the navigation can be estimated by reviewing available world charts resources and the charts possessed by the vessel. Introduced quality scale of support (Table 3) to evaluate external support to the navigation on board the vessel. The norm was the scale of chart comparable to the planned kind of the navigation (UKHO 2009; UKHO 2010; Jeppesen Norway A/S 2010; IC-ENC 2010; ChartWorld GmbH 2010; Primar Stavanger 2009; Weintrit 2009).

For easy assessment of the external support to the navigation available on board a vessel introduced relative coefficient of the external support  $C_e$  expressed by Equation 1:

$$C_e = \frac{(O + U + B + N) \cdot 100}{24} \quad (1)$$

where  $C_e$  - the coefficient of the external protection (%); O - quality rating support by the official charts in scores from 0 to 6; U - quality rating support by the unofficial charts in scores from 0 to 6; B - quality rating support by the "other charts - bathymetric, in scores from 0 to 6; N - quality rating support by the "other non-bathymetric charts" in scores from 0 to 6.

The comparison in between potential and actual support on board the vessel can indicate possibility and/or necessity of improvement of the external support quality.

The survey region of Isvika was situated in the South Eastern part of Murchisonfjorden located on Nordaustlandet (79°58'N, 18°33'E). The bottom of Isvika region was rocky, partly coated by a layer of sediments of glacial origin. From the external sources of the information (UKHO 2007; The Norwegian Hydrographic Service and Norwegian Polar Research Institute 1990) found that the surrounding region not passed any systematical survey. The ships should navigate with considerable caution because the sea bottom is very irregular. To be taken into consideration the existence of not detected dangerous banks. Ascertained existence of almost vertical changes of depth. Even at depths 50 -100 meters can appear small depths in vicinity. It requires special caution. The distances to the visible apparent danger (coast line) on the radar screen during surveys were about 0.05 nautical miles (Fig. 2a). However, the coast line was not the closest dangerous feature. The closest dangers were unknown small depths in close vicinity of the vessel (Fig. 2b). Reviewing the above mentioned external information ascertained the proper scale of a chart required for survey works in Isvika region as 1:10,000. It corresponded to the group "Harbour".

The official paper chart (Statens Kartverk 2001) shown reliable isobaths, features and coast line. The scale of the chart and the informational content not

assured 100% of navigational safety. The official electronic chart of Transas Marine in scale 1:12,500,000 was not qualified to support navigation. The unofficial electronic chart Garmin Bluechart shown isobaths, features and coast line properly, but the scale of the chart and the informational content not assured 100% of navigational safety.

Insufficient external information on the charts required to support the navigation in poorly surveyed region (an partly not surveyed at all) of Murchisonfjorden including Kinnvika and Isvika (The Norwegian Hydrographic Service and Norwegian Polar Research Institute 1990) with the autonomous ship's internal methods detecting dangers to the navigation.

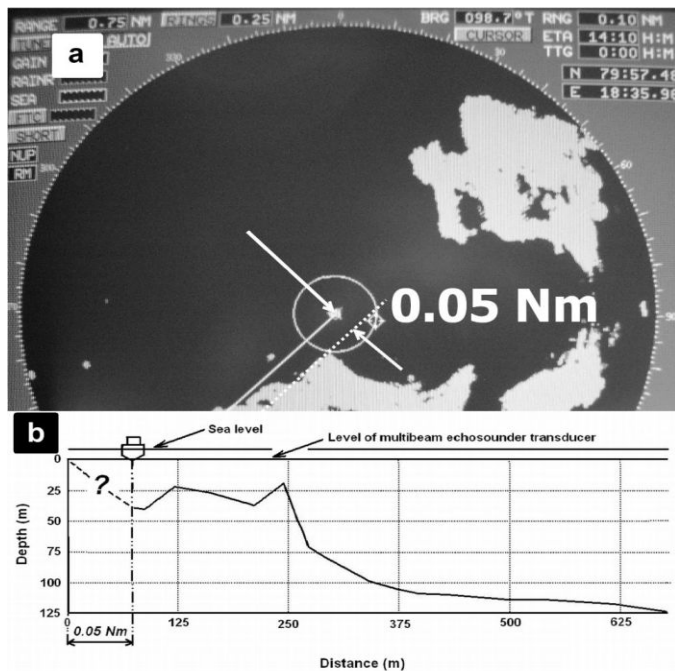


Figure 2. (a) Distance to danger on radar image. (b) Transverse depths profile at radar position

## 2.2 Internal methods to support navigation

Internal methods to support the navigation of the vessel were based on possessed by the vessel technical resources. They allowed autonomous detection of underwater dangers. Advantages and disadvantages of each method not clarified superiority any of below mentioned methods.

### 2.2.1 Sonar looking forward

The sonar looking forward allowed detection of underwater objects (features) in front of the vessel. The image of the situation was presented on heading in vertical and horizontal sections. In case sonar looking forward was only one electro acoustic device being on board vessel, one could continue a safe voyage in any direction.

### 2.2.2 Multibeam echosounder

The multibeam echosounder detected underwater objects (features) in transverse plane of the vessel. It not informed about the situation in front of the vessel. In case the multibeam echosounder was only one electro acoustic device being on board the vessel in unsurveyed regions, one could continue safe voyage across planned direction of the voyage. It required proceed along the lanes of previous measurements of the multibeam echosounder.

### 2.2.3 Single-beam echosounder

The single-beam echosounder detected underwater objects along perpendicular line under the vessel. It not informed about the situation in front of the vessel. In case the single-beam echosounder was only one electro acoustic device being on board the vessel in unsurveyed regions, one could extrapolate a distance to the potential underwater danger from tendency of depth changes. The single-beam echosounder was not a fully autonomous device nor assured 100% safety of the navigation.

### 2.2.4 Echosounder on boat proceeding in front of the vessel

The boat proceeding in front of the vessel was equipped with single-beam echosounder. Results of this method were very similar to sonar looking forward. Safety output depended on qualifications of the boat crew and cooperation in between the boat and the vessel. It required good radio information exchange.

Quality of internal methods to support the navigation ascertained by reviewing equipment possessed by the vessel. Proposed scale was presented in Table 4.

Table 4 . Assessment of internal support.

Device being aboard	Efficient and reliable	Efficient and not reliable	Inefficient or lack device
Sonar looking forward	2	1	0
Multibeam echosounder	2	1	0
Single-beam echosounder	2	1	0
Echosounder on boat proceeding forward	2	1	0
Sum of scores	Maximum possible 8 scores		

For easy assessment of internal support to the navigation available on board the vessel was introduced relative coefficient of internal support  $C_i$  expressed by Equation 2:

$$C_i = \frac{(F + M + S + R) \cdot 100}{8} \quad (2)$$

where  $C_i$  – the coefficient of the internal support (%);  $F$  - quality rating support by the sonar looking forward in scores from 0 to 2;  $M$  - estimation of support by the multibeam echosounder in scores from 0 to 2;  $S$  - estimation of support by the single-beam echosounder in scores from 0 to 2;  $R$  – estimation of support by the boat with the echosounder in scores from 0 to 2.

### 3 ESTIMATION OF THE DISTANCE TO THE DANGERS WITH THE MULTIBEAM ECHOSOUNDER

The assessment of navigational safety in the regions well recognized and charted was made in relation to the superficial and underwater dangers plotted on the sea charts. The information about the dangers on Svalbard not existed or was not sufficient or was not reliable. The assumed “danger” was unknown region („blank place”) out of the edge of not processed information from the multibeam echosounder (Fig.3a). The criterion of danger was the distance to this edge (Fig.3b). The navigator made continuous interpretation of multibeam echosounder image. Curvature of sea bottom was presented by serial of dots. The contiguous line to the most external dots allowed extrapolation of the sea bottom curvature up to sea surface. It gave additional reserve to the expected danger. In some cases was not easy to identify fallacious dots from whole sea bottom line. In dependence from the navigator decision various contiguous lines could be taken into consideration. This led to receive various reserve of expected distance to the “danger”.

The sea charts of Murchisonfjorden region not assured safe navigation. These charts based on the information from the paper chart in scale 1:100.000 (Statens Kartverk 2001). Theirs information content not shown all features discovered by the multibeam echosounder. In some cases the sea charts shown inadequate locations of the coast line and the bottom features. The British and Norwegian pilot publications contained very limited information. Same time these publications advised mariners about almost vertical high changes of depths in the western part of Murchisonfjorden (The Norwegian Hydrographic Service and Norwegian Polar Research Institute 1990). Taking into considerations the International Hydrographic Organization (IHO) regulations, soundings and changes of depths described above, the regions of Isvika and Murchisonfjorden should be treated as insufficiently surveyed and partly as unsurveyed regions (IHO 1994; IHO 2009; The Norwegian Hydrographic Service and Norwegian Polar Research Institute 1990).

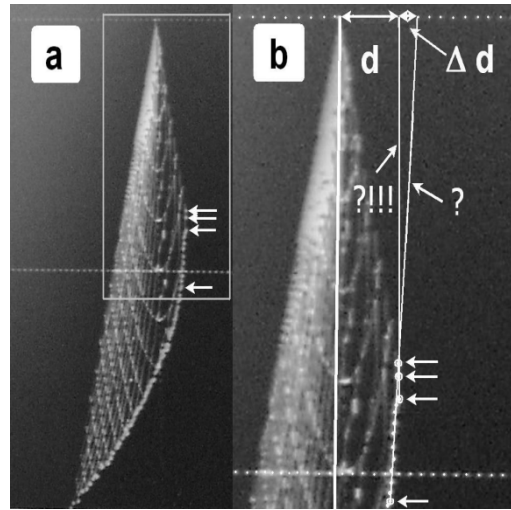


Figure 3. (a) Multibeam echosounder image, (b) The “unknown” area on multibeam echosounder image and probable distance to danger“

#### 3.1 Method of analysis of field data

Survey data collected by multibeam echosounder Sea Beam 1180 of ELAC Nautik GmbH on r/v “Horizont II” under IPY- Kinnvika expedition 2009. During work with the multibeam echosounder made continuous pinging and record of depths. The vessel followed route according to the voyage plan. In some cases the vessel deviated from planned route to avoid uncharted dangers or to collect more data of unknown area. The movement along the edge of the previously surveyed lane was also included into consideration.

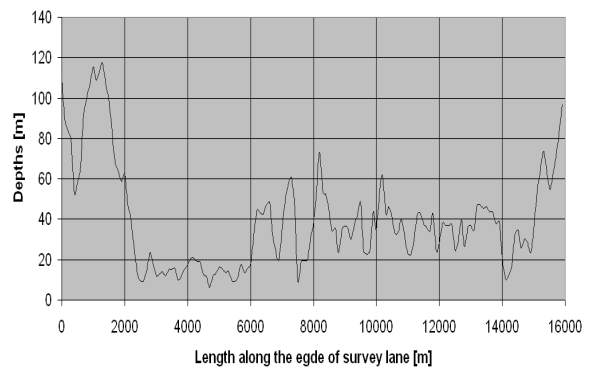


Figure 4. Depths along the edge of survey lane

The main aim of analysis was to find out correlations in between distance to the danger (the criterion of International Maritime Organization), depths and longitudinal and transverse changes of depths at the edge of surveyed lane. The analysed distances and bottom profiles (Fig.4) were not related to the coastline. Also they were not related to any isobaths. They were related to the non-linear movement and position of the vessel. This movement was the result of subjective assessment of the safety by the navigator. Position of the transducer of the multibeam echosounder was point of reference for depths and

distances. The correlation represented by equations in between navigational safety parameters were received by PAST (Paleontological Statistics) software of Natural History Museum in Oslo.

### 3.2 Results

Analyzing series of data received during survey identified formula (Eqn 3) showing correlations in between distance to danger and longitudinal changes of depths.

$$D = 19.1484 - 0.2741 \Delta h_L \quad (3)$$

where  $D$  – distance to the edge of the surveyed lane interpreted as distance to the danger (m);  $\Delta h_L$  – change of depths along the edge of the surveyed lane on the longitudinal section of 100 meters (m).

Same way identified formula (Eqn 4) showing correlations in between distance to the danger and transverse changes of depths.

$$d = 19.5455 - 0.8512 \Delta h_P \quad (4)$$

where  $d$  – distance to the edge of the surveyed lane interpreted as distance to the danger (m);  $\Delta h_P$  – change of depths along the edge of the surveyed lane on transverse section of 100 meters (m).

## 4 CONCLUSIONS

The electronic charts made by various makers may be made in the different standard then accepted by the ship's ECDIS system being on board the vessel. In such case the ship-owner must solve dilemma of undertaking high buying costs of second ECDIS system that will serve for other electronic charts fulfilling necessities of the planned voyage. Purchase of next ECDIS system for a single or occasional voyage seems loose the financial competition with the paper or raster charts as far as such alternative exists.

The makers of the electronic charts being under pressure of strict requirements of ZOC are forced to downgrade quality of presented information on paper charts even for few groups. Issuing gratuitous unofficial charts (NOAA, <http://charts.noaa.gov>; <http://www.nauticalcharts.noaa.gov>, 16-Jan-10) or with considerably lower price than theirs official equivalents (Garmin Ltd, <http://www8.garmin.com>, 08-Jan-10; Jeppesen Norway A/S, <http://www.c-map.no>, 25-Jan-10) is favourable signal for sea charts users. Planning of navigational voyage support of the vessel seems to be simple and clear in case exist the official nautical charts of suitable parameters for the intended kind of the voyage.

The goal of author is to elaborate simple appraisal method for planning navigational voyage support in-

cluding unsurveyed or inaccurately surveyed regions. The external and internal methods to support the navigation were described. Proper assessment scales and coefficients were proposed. Above method gave tool for appraisal of the navigational voyage plan in clear and simple manner so convenient for organizers and performers of a voyage. By this way is possible to detect the weaknesses of vessel's preparedness and improve it.

The unknown regions ("blank places") on screen of the multibeam echosounder are treated with distrust by the navigators. The distance to the edge of unsurveyed region that navigator try to hold is approximately 20 meters. This distance is inversely proportional to the tendency of changes. The angular dimensions of the image on screen (visual estimation of not processed image of the sea bottom relief), the range of beams of the echosounder and the distance to the edge of the surveyed lane are essential for estimation of safety. Identification of more detailed correlations requires however further research.

## REFERENCES

- Gale, H., 2009: From paper charts to ECDIS, A practical voyage plan: Part 3, Seaways November 2009, p. 5 - 9.
- IHO, 1994: Hydrographic Dictionary, Part I, Volume I, English, Special Publication No. 32, Fifth Edition, Monaco 1994, 280 pp.
- IHO, 2008: IHO Standards for Hydrographic Surveys, Special Publication No 44, Fifth Edition, Monaco February 2008, pp.28
- IHO, 2009: Regulations of the IHO for international (INT) charts and charts specifications of the IHO, Edition 3.006, April 2009, 392 pp.
- IMO, 1993: Resolution A.741(18), International Safety Management Code, 4 November 1993.
- IMO, 2004: SOLAS consolidated edition 2004, London, pp.628. Jeppesen Norway A/S, 2010: C-MAP Chart Catalog v.2.4.0.8.
- Pastusiak, T., 2010: Problems of coverage of unsurveyed regions by electronic charts [in Polish], Logistyka 2/1010, ISSN 1231-5478, p 2069-2086.
- Primar Stavanger, 2009: Primar Chart Catalogue 4.3.
- Statens Kartverk 2001: NO537, Paper chart, Svalbard, Hinlopenstretet N, scale 1:100,000.
- The Norwegian Hydrographic Service and Norwegian Polar Research Institute, 1990: Den Norske Los, Arctic Pilot, Vol. 7, 2nd Edition, 433 pp.
- Transas Marine Ltd, 2010: Transas Chart World Folio v.3.2.332, WF 28.
- UKHO, 2004: NP100, The Mariners Handbook, 8th Edition, 260 pp.
- UKHO, 2007: NP11 Arctic Pilot, Edition 2004, Correction 2007.
- UKHO, 2010: Admiralty Digital Catalogue v.1.6.0.
- UKHO, 2009: Catalogue of Admiralty Charts and Publications NP131, 2009 Edition.
- Weintrit, A., 2009: The electronic chart display and information system (ECDIS) - An operational handbook, Boca Raton - London - New York - Leiden, CRS Press, Taylor & Francis Group, ISBN-13: 978-0-41548246-2, 1101pp.