the International Journal
on Marine Navigation
and Safety of Sea Transportation

http://www.transnav.eu

Volume 10
Number 3
September 2016

DOI: 10.12716/1001.10.03.09

Functionality of Sea Ice Data Sources on the NSR

T. Pastusiak
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The functionality of available official sources of sea ice data for the Northern Sea Route to date is low. In recent years a large number of new publicly available sources have appeared. Their functionality for purposes of route planning has yet to be evaluated. This study presents results of qualitative and expert analyses of various sources. It is proposed to use new indicators to enable comparison of functionality of data sources. New sources provide the technical progress that is instrumental in reducing the amount of effort and influence of the human factor in the decision-making system. The study also presents solutions to the problem of limited bandwidth available at high latitudes with Iridium satellite system. Presented solutions can be used on any vessel by any company or navigator to implement or design the decision support system related to route planning in ice in accordance with the requirements of the ISM Code and concept of e-Navigation.

1 INTRODUCTION

The need to evaluate the possibility of passage along the Northern Sea Route (NSR) arose when vessels of relatively low ice class appeared on the NSR. Rapid changes in sea ice cover cause periodic blocking of individual sections of the NSR by drifting ice fields. This applies especially to the space constraints at the nodes of the route and especially to the narrow passages. In these places there occur specific phenomenon of ice cover (concentration processes, pressure of ice, hummocking and drift of sea ice) which reduce the safety of vessels, especially those of low ice-class. For this reason, hydro-meteorological data, especially information about ice conditions and specific risks arising in each section of the NSR, are very important to shipping. There exist various types of ice data required to evaluate the passage of vessels through the ice and the ship's safe speed. The above data were initially described and used over 20 years ago in the "Ice Passport" for Russian vessels. The content of the "Ice Passport" is now defined by the IMO and the same document took the official name of the "Ice Certificate" (IMO, 2011). The Ice Certificate describes seaworthiness of vessels in ice, taking into account structure of the hull, dimensions, displacement, propulsion system, characteristics of the propeller, the age and actual condition of the hull. The Ice Certificate contains a vessel’s speed in conjunction with sea ice cover thickness, concentration of ice floe, ice floe size, ice pressure and hummocking. It facilitates the making of well-founded and documented decisions (IMO 2011). Calculations of the above mentioned vessel’s safe speed on ice have been described by Ryvlin and Chejsin (1980).

These sources of limited content or accessibility were used for route planning in ice for many years. In recent years there have appeared a large number of new data sources, mainly in the form of processed satellite images. However, the quality of the information available for use in the procedure of planning and monitoring a voyage from an e-Navigation point of view has not been assessed. Assumed in this study is that the scheme of route planning through ice covered areas of the NSR shall take into account the safety of the decision process, facilitation of downloading more reliable and complete data in the most useful format and functionality, which is to minimise involvement of the user (IMO, 2008; Patraiko, 2008; Jurdzinski and Pastusiak, 2009). The user (navigator) should be able to control a vessel traffic safety according to applicable rules and should not be engaged in activities which are not directly related to the vessel's movement control. It is possible to minimise workload during downloading data sources, digitalisation, processing and evaluation of results. The decision-making process should affect not only content of the data sources but also their accuracy, resolution, availability and information on reliability and overall quality. Determined in this study are criteria for assessing the operational sources of information related to navigation in sea ice covered areas on the NSR and quality assessment procedures of designated data sources. These criteria contain the information content of data sources, accuracy, resolution, reliability, general quality of data sources, workload and weight of the content.

2 RESEARCH METHODS

In order to assess the availability and the quality of information about current hydro-meteorological conditions, information from the services GMDSS (Safety NET forecasting areas of METAREA XX and XXI and also NAVTEX data) was systematically collected for a one year period of time, followed by an evaluation of their content. There was found a high level of generalisation of ice data provided by various means from the official sources. This indicates that they cannot be used as a sole basis for passage planning on the NSR, especially in narrow passages. Therefore, other available data sources on the Web were analysed, which contain more precisely defined parameters of the sea ice cover recognised in the Ice Certificate or classified as hazards that occur on the NSR. In total, 80 groups of data sources were analysed. Data sources were evaluated using qualitonomic analysis (Holodnik-Janczurak, 2007) by newly developed indicators. Values of adopted quality scale are in the range from 0 (worst) to 1 (best). The weights assigned for each data source sets are according to their ascending or descending importance for their intended purpose, which is to evaluate the possibility of passing a part of the NSR. The cumulative level of quality reached by various data sources is defined by the formula for the average value of quality indicators (Holodnik-Janczurak, 2007). Firstly is taken into account the safety and effectiveness of the decision-making process of the route planning, helping to obtain information more reliable and more complete in a more useful format, next functionality and automatic operation with minimal involvement of user (e-Navigation criterion). Secondly it is assumed that the information and commands for direct implementation on a vessel's bridge by navigators "should be given in a clear and simple manner" (ISM criterion).

The author created a mathematical model of assessment based on expert research. This arose from the experience of the author, interviews with practitioners and experts as well as a qualitative analysis of problem and conclusions. Appropriate software was used for type of file or method of data storage during study. In first place was the use of Windows software as the most widespread and the software supported by it or freeware software supported by Windows or a licensed software of low price of purchase and therefore easily accessible to a navigator on the ship or to ship-owner. Data sources are related to the time period 2011-2012.

3 CHARACTERISTICS OF SEA ICE DATA SOURCES

The evaluation of functionality of analysed sea ice data sources for voyage planning purposes takes into account several characteristics. The most important of these are outlined below.

3.1 *Weight of the content*

Weight of the content (Table 1) was determined on the basis of its usefulness for voyage planning. The highest weight was given to the parameters described in the Ice Certificate and parameters considered to be the most serious threat to navigation on the NSR. They directly include strength of the vessel's hull and ability to overcome ice with a safe speed under defined ice conditions. The weight of the ice drift in Table 1 is equal 0.5. This value was adopted for open sea conditions. In case of narrow straits the importance of ice drift data increases due to the existence of local phenomena of closing a lead and the ice jet effect. Increased values of the weight coefficient up to 1.0 should be considered in these regions.

Table 1. Weight coefficient of content

	Weight		Weight
Ice under pressure	1.0	Openings in ice	1.0
Hummocked ice	1.0	Formation of snow-and-ice "cushion" at vessel's hull	1.0
Ice forms	1.0	Stage of ice melting	1.0
Thickness of ice	1.0	Ice drift	0.5
Thickness of snow	1.0	Fog	0.25
Concentration	1.0	Icing of vessel	0.25
Floe sizes	1.0		

3.2 *Resolution - characteristics of position precision on maps*

Data sources have various forms and methods of data recording and data presentation. Most sources do not contain information on the scale of the map. Therefore a new concept for the resolution has been introduced - the minimum identifiable distance. Resolution was adopted as a criterion for comparing the precision of position of various kinds of data sources. Three methods to determine the resolution of data sources were developed for:

- vector files (SIGRID-3, KML, KMZ), raster image graphics and their vector transformations (BMP, JPG PNG, GIF, TIF, EPS, PDF) – the shortest length of a straight line, which approximates to isoline curve of the smallest observed radius,
- gridded files (GRIB, NetCDF, HDF) – the length of the sides of a single grid,
- raster files (BMP, JPG, PNG, GIF, TIF) with an averaged grid of data that does not coincide with the meridians and parallels - the length of the side of a single grid that is specified by the manufacturer.

3.3 *Volume of data storage sources and data transfer indicators*

In order to compare ability to download data sources were developed indicators (measures) of volume of the internet file transfer V_f and the volume of internet file transfer with the necessary elements of the website V_w. File data transfer rate indicator Q_f (Formula 1) is the quantity of files able to be downloaded during visibility of one satellite of the Iridium satellite system above the horizon.

$$Q_f = \frac{B \cdot 3600 \cdot \tau_1}{V_f} \tag{1}$$

where: Q_f – file data transfer rate indicator, V_f – volume of the internet file transfer [kB], B – data transfer rate of Iridium satellite system [kB/s]. Bandwidth adopted for calculations is equal to 7.2 kb/s, equal to 0.95 kB/s, τ_1 – the average time of availability of one Iridium satellite above the horizon [hours]. According to information from the Iridium company τ_1 is approximately equal to 10 minutes. For the purpose of calculations the value τ_1 = 0.1667 hours has been adopted.

Replacing V_f in the formula (1) to V_w allows the obtainment of formula for rate indicator Q_w of the file data transfer with necessary elements of the website. Data transfer rate indicators Q_f and Q_w characterise ability to download a file. In practice it has been observed that visibility of the next Iridium satellite does not guarantee the continuity of a download. Usually a download is aborted. Data transfer rate indicators Q_f and Q_w take into account factors attributable to satellite communication system (download time and time of visibility of single satellite by the receiver of satellite system).

Both indicators Q_f and Q_w express how many times a particular file or a file with the accompanying web site during visibility of a single satellite by the receiver for satellite systems can be downloaded. A comparison of indicators Q_f and Q_w can determine the cause of reduced data transfer and at the same time the opportunities to improve it. Under real conditions the limiting criterion of ability to download a file is value of indicator Q_w equal to 1.

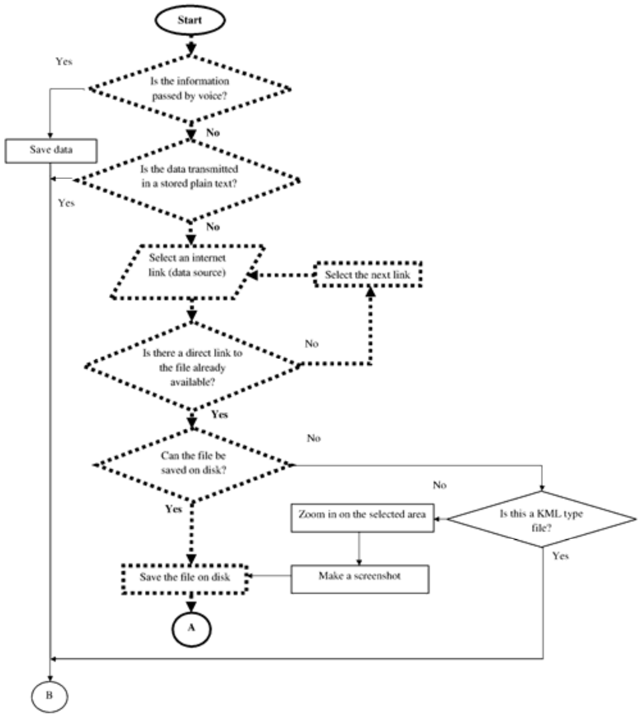

Figure 1. Scheme of downloading procedure

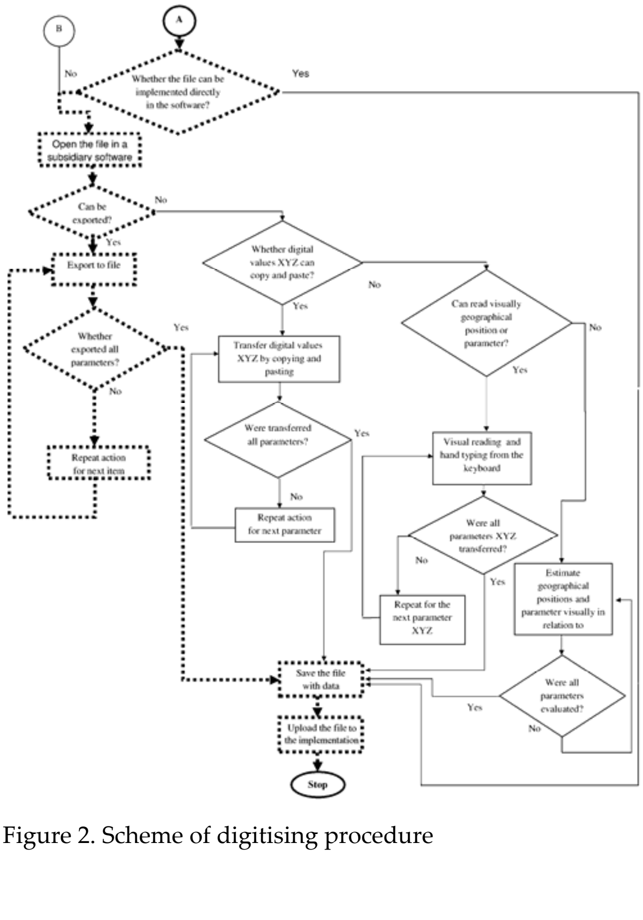

Figure 2. Scheme of digitising procedure

3.4 *Workload*

Various data sources were examined and finally universal procedures for their acquisition and digitising have been developed. They are shown in Figures 1 and 2 with an indication of a sample path for a HDF file and NetCDF file. The sequence of actions in the procedure of downloading and digitising data sources represents the sequence of necessary steps (Figure 1) required to download and save information XYZ (latitude, longitude and parameter of ice navigation) on a computer in a form acceptable for further mathematical calculations (Figure 2).

It has been observed that data sources come together in three groups with similar downloading and digitising patterns. These are: (1) – vector files KMZ, SIGRID-3 and Shapefile, (2) – raster and vector maps with grid coordinates BMP, JPG, TIF, GIF, PDF, EPS and raster georeferenced maps GEOTIFF and (3) – gridded files GRIB-1, GRIB-2, NetCDF and HDF.

Workload is the number of operations performed in diagrams (Figure 1 and Figure 2), which involves an operator downloading a file from the Internet and digitising the data. Workload indicator Q_e is the ratio of workload of downloading and digitalisation of examined file e_i to the highest workload occurring among the examined files e_{max}. It has been described by formula 2.

$$Q_e = \frac{e_i}{e_{\max}} \tag{2}$$

3.5 *Accuracy*

The files are available to the user for a certain period of time after the moment from which they were issued. In the considerations was adopted the indicator Q_a (Formula 3) referring to the number of hours of delay t_a and the number of hours of operational planning cycle t_o, which was assumed equal to 168 hours. Time shift is always negative when considering "analysis". Time shift, as a rule, must be positive when considering "forecasts". This indicator prefers forecast over analysis (the future state more than the historical one).

$$Q_a = \frac{t_o + t_a}{2 \cdot t_o} \tag{3}$$

Based on different scales of the operational planning for the navigation in ice (Khvochtchinski and Batskikh, 1998; Timco et al., 2005), the assumed average duration of the operational planning cycle is equal to 7 days (168 hours).

3.6 *Quality characteristics of a data source*

The ability to export or write the data in a format that is fit for reading and processing software.

Table 2. Export of data indicator Q_1

	Indicator Q_1
Unable to export data	0.00
Cannot export nor save files in simple text formats	0.25
Text files (TXT, ASCII) possible for use by specialised software (such as MATLAB)	0.50
Text files (TXT, PRN, CSV, XLSX) with a complex structure of data storage (stored in separate tabs of MS Excel)	0.75
Text files (TXT, CSV, XLSX) with a simple CSV structure suitable for easy use in MS Excel	1.00

The simplicity of transferring data and their application in reading and processing software was adopted as a quality criterion of the data source (Table 2). Simplicity and clarity received the highest position in evaluation scales due to requirements of the ISM Code and the e-Navigation concept criteria.

3.6.1 *Explanation of the scale of the relevant information (legend)*

It is assumed that the navigator on board the vessel uses what he found on board. A equipment deficiency would cause difficulties for the navigator to carry out his or her tasks and impair the quality of work done. Availability of scale of presented information Q_2 (Table 3) helps determine a proper value in relation to limits and increases precision of the assessment. In the same way it helps to avoid improper reading. Scale clarity indicator Q_3 allows to assign the proper value of this parameter (Table 4) to established standard scales of judgment.

Table 3. Legend availability indicator Q_2

	Indicator Q_2
Legend of information is not available in source file	0.0
Legend of information is not available in source file. It is however available in the digital part of information on a web page or in a publication on source file	0.5
Legend of information is available in source file	1.0

Table 4. Legend clarity indicator Q_3

	Indicator Q_3
The scale is not clearly understood or there is no reference	0.000
Simplified scale in relation to precisely defined established standard	0.333
Scale of parameter is described in commonly known units	0.667
Scale of information is in accordance with established standard	1.000

3.6.2 *Type of file*

File type indicator Q_4 (Table 5) reflects usability and simplicity to direct use in the evaluating possibilities of the NSR passage and also to data processing when using computation. The scale of file type indicator Q_4 measures workload for the application of data sources in the automatic evaluation of possibility to navigate the NSR.

Table 5. File type indicator Q_4

	Indicator Q_4
Raster graphic file or other without grid of coordinates or without georeferenced positions	0.000
Text file of geographical positions or positions related to area described in another document (plain text)	0.143
Raster graphic file with grid of coordinates	0.286
Vector graphic file with grid of coordinates	0.429
Raster georeferenced graphic	0.572
Vector or gridded georeferenced file	0.715
Text alphanumeric file with recorded geographical positions as unordered (complex) data series	0.858
Text alphanumeric tied positions in this or in another file as an ordered (simple) data series	1.000

3.6.3 *Reliability of data described*

To assess the reliability of information on nautical charts the concept of Zones of Confidence has been introduced. On this basis, one can determine quality of data on nautical charts for safe navigation. The concept of confidence level was also developed for the coverage of unsurveyed regions by nautical charts and publications such as those for research vessel equipment support for navigation in poorly surveyed regions (Pastusiak, 2011). Sources of hydro-meteorological and ice data should also be evaluated by the individual reliability indicator. As a measure of reliability of a particular parameter of ice navigation was adopted the concept of the possibility to make a routing decision taking into account the reliability of the parameter values received from providers and not only the value of a single parameter. Information obtained from satellite imagery transformations should be provided with information on quality for each message (file) taking into account spatial distribution. In this case, it is possible to include this information into data processing and evaluation of route calculated. Two indicators were adopted in order to assess the reliability (quality) of the described parameter: indicator on availability of reliability of data described as Q_5 (Table 6) and indicator on availability of quality scale of this parameter Q_6 (Table 7). Assuming that information about the parameter quality allows its evaluation, a value can be placed on a scale of quality "the worst - the best."

Table 6. Indicator on availability of reliability of data described Q_5

	Indicator Q_5
No information about quality of parameter	0.0
No data on quality parameter in the file but it is available in a separate source of information	0.5
Information about the quality of parameter is available in file	1.0

Table 7. Indicator on availability of reliability scale of parameter Q_6

	Indicator Q_6
No data in file on scale of quality	0.0
No quality scale in file containing data but scale is available in a separate source of information	0.5
Information on quality scale is available in file containing data on quality	1.0

3.6.4 *Digitalisation*

The concept of digitalisation sets out how to move data from a source file (usually visualised using software) to data processing software. For each separate file indicators of accessibility were considered (as described in Table 8 for the position coordinates Q_7 and Table 9 for the parameter of navigation in ice Q_8). The same made for complexity of data reading (described in Table 10 for position coordinates Q_9 and Table 11 for a parameter Q_{10}).

Table 8. Indicator on availability of geographical position data Q_7

	Indicator Q_7
No data on position coordinates	0.00
Manual readings of position coordinates on scale on the map by interpolation proportion with calculator and manually typing from keyboard to the computer	0.25
Visual reading of position coordinates from open text (handwriting) or from software on screen and manual entry to computer by keyboard	0.50
Copy and paste position coordinates to computer software (copy & paste)	0.75
Independent data transfer by computer software	1.00

Table 9. Indicator on availability to read parameter Q_8

	Indicator Q_8
Cannot read the parameter	0.000
Visual reading of parameter according to appropriate scale and typing from keyboard to computer	0.333
Copy and paste parameter data to computer software (copy & paste)	0.667
Independent data transfer by computer software	1.000

Table 10. Indicator of complexity of reading geographical coordinates Q_9

	Indicator Q_9
Cannot read geographical coordinates of position	0.000
Reading of geographic coordinates without interpolation (discrete)	0.333
Reading of geographic coordinates manually by interpolation	0.667
Reading of geographical coordinates by the software	1.000

Table 11. Indicator of complexity of reading parameter Q_{10}

	Indicator Q_{10}
Cannot read parameter	0.000
Reading of parameter without interpolation (discrete)	0.333
Reading of parameter manually by interpolation	0.667
Reading of parameter by software	1.000

3.7 *Total quality of a data source*

Based on evaluation of the public data sources indicator Q_T relating to total quality of individual sources of ice navigation on the NSR was developed. It is an average of the 10 indicators describing characteristics of the data source (Formula 4). Thus was obtained the qualitative evaluation indicator, which allows to compare a wide variety of data sources.

$$Q_T = \frac{\sum_{i=1}^{10} Q_i}{10} \quad (4)$$

3.8 *Quality of information access of individual sea on the NSR*

Indicator on available information access quality of a selected sea Q_R (Formula 5) represents the highest values of available sources there. It takes into account the weight of each content of 1.0, 0.5 and 0.25 respectively. Attached indexes are addressed to the following meaning: P – pressure, H – hummocking, T – thickness of ice, S – thickness of snow, O – openings in ice, C – “cushion”, M – melting, U – concentration, F – form of ice floe, D – drift, V – visibility, G – icing, j – index of individual region like Kara Sea, Laptev Sea, East Siberian Sea and Chukchi Sea.

$$Q_R^j = \frac{\frac{(Q_P + Q_H + Q_T + Q_S + Q_O + Q_C + Q_M + Q_U + Q_F)}{1} + \frac{Q_D}{2} + \frac{(Q_V + Q_G)}{4}}{10} \qquad (5)$$

3.9 *Quality of information access on the whole NSR*

Quality of data sources for the appointed route across the entire NSR is given by formula 6. Average value of quality indicators of individual regions reflect the indicator of data sources for the entire NSR. All sources of information are placed on the graph in ascending order values of quality Q_E . The result is a steadily increasing line without spikes. It is assumed, therefore, that this indicator well reflects examined relations.

$$Q_E = \frac{\sum_{j=1}^{4} Q_R^j}{4} \qquad (6)$$

4 ANALYSIS OF RELATIONSHIPS BETWEEN INDICATORS AND WEIGHTS

The above mentioned quality indicators and weights of different sources of data were statistically analysed. Results of this analysis are shown in the graphs of dependencies and correlations. To obtain these graphs MS Excel and CurveExpert software were used. For each of the graphs based on CurveExpert software are given the values of correlation coefficient (r) and standard deviation (S) of dependent variable (y).

The variety of properties of the source files even in the same group resulted in low correlation lines that reflect trends. For example, GRIB files included in the study are related to one or both hemispheres, which is twice the difference in volume of file transfer. Some files contain only one parameter analysis assigned to one moment of time and other files are a compilation of a few or several slides of different parameters or different moments of time. The problem is further complicated by the fact that some files are in GRIB-1 and other files are in a compressed format; GRIB-2. Another difficulty is the diversity of data grid resolution.

The type of file (file type indicator) shows the level of the feasibility of implementation of geographical position coordinates and the parameters included in file when determining the route of the vessel. The graph in Figure 3a shows that with an increase of the file type indicator values, the overall quality of the data source also increases. This relationship is highly statistically significant ($p < 0.000001$). For almost any type of the ice parameter it is possible to select files with a low or high workload of downloading and digitalisation (Figure 3b).

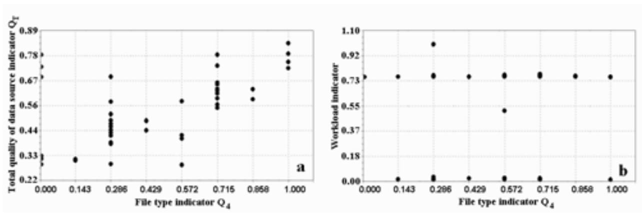

Figure 3. The relationship of quality indicator (a) and workload (b) with file type indicator

The majority of the files are characterised by high workload. These include mainly raster maps with grid coordinates and raster georeferenced maps. During the analysis there was noted some decrease in the workload with increased weight of content (Figure 4).

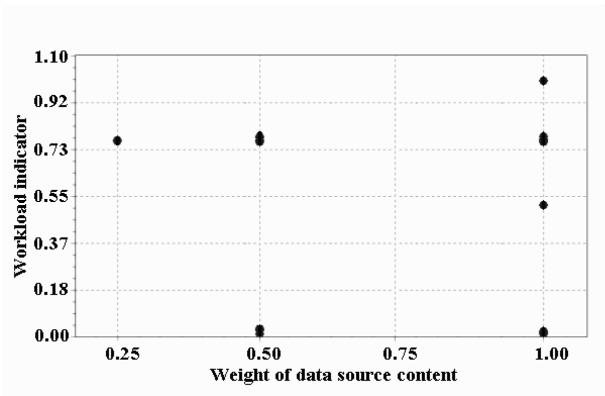

Figure 4. The relationship between workload indicator and weight of information contained in the data sources

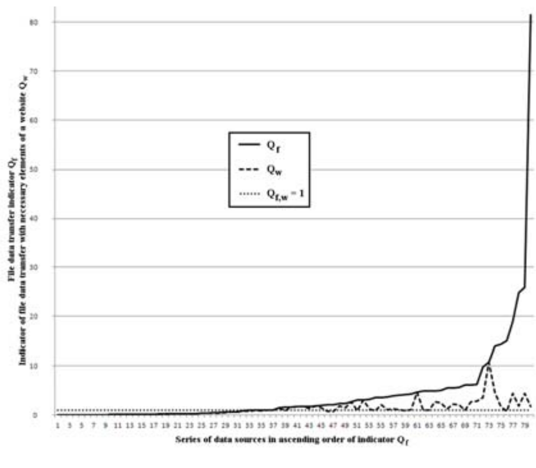

Figure 5. File data transfer indicator Q_f and indicator of file data transfer with necessary elements of a website Q_w in ascending order

The only significant difference in the resulting workload is the need to manually enter the geographical position coordinates and parameters to a computer (Figure 5). This difference did not depend on type of file. It should, however, be noted that the benefits of bypassing the manual entry procedure can be utilised only if there is software that can directly implement files containing these data sets. The internet bandwidth of the IRIDIUM satellite system greatly reduces the possibility of using data sources of higher quality indicator values (Figure 5).

Bandwidth distribution of files without necessary elements of a website adopts linear character for values below 7 on the graph. However, bandwidth distribution for files with necessary elements of the website significantly reduces bandwidth for almost all data sources. Volume of additional transfer of websites seems to be a significant difficulty for acquiring files. Extremely high values were omitted when considering relationships for Q_f and Q_w indicators. In this way was obtained many more details on the graph than on the graph covering all data sources. It was noted that distribution of data has two boundary lines (Figure 6a). Many of the more complex functions displayed a curved line such as on Figure 6b. Such an example of a polynomial curve (Figure 6b) shows that for value of Q_f above value 1 (for files that can be downloaded during one period of visibility of the IRIDIUM satellite above the horizon) indicator Q_w assumes a constant value independent of further increases of Q_f.

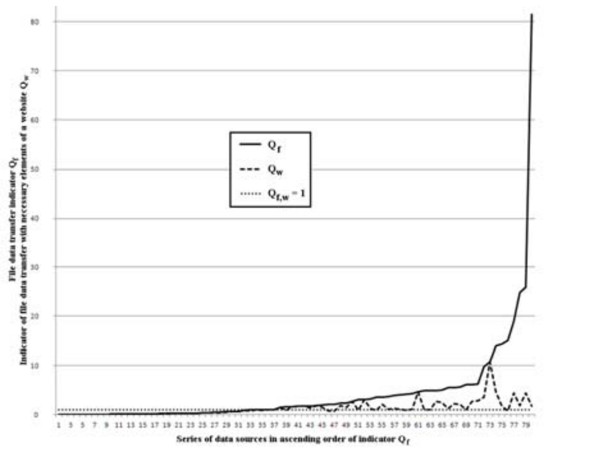

Figure 6. The relationship between indicators Q_f and Q_w: a - approximation by rectilinear function, b - approximation by polynomial function of the third degree

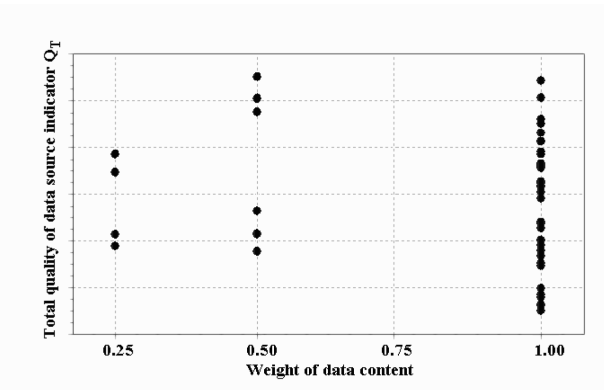

Figure 7. The relationship between the data source quality indicator and the weight of content

There are a large number of data sources of the highest importance to the routing in almost the whole range, from the lowest attainable quality to the highest (Figure 7). There are a lot of data sources available to the user.

The weight of content specifies the importance of data type for the route calculation process and for assessment of the ice and hydro-meteorological conditions. With the increase of weight of content, the delay of delivered "analysis" data also increases. A comparison of maps used commercially by Transas Marine and their free equivalents available on the internet leads to the deduction that some information is provided for commercial purposes on a regular basis, without delay. However, the same information becomes public when it no longer has a commercial value (for voyage planning on NSR).

With increase of data content and resolution comes an increase also in file size. There are two principal tendencies in groups of files. These are very detailed files i.e. of good resolution (seem to be used primarily ashore, where a very large volume transfer is possible for high-speed connections) and files with a relatively low transfer volume (they seem to be predestined to be received by vessels with very low bandwidth connection in the Arctic, when using the Iridium satellite system (Figure 8).

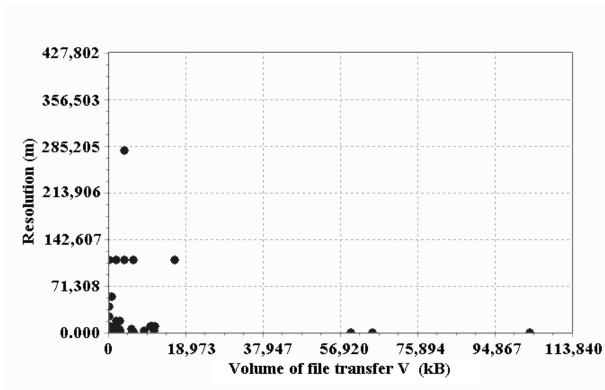

Figure 8. Relationship between the volume of a file transfer V_f and resolution

The widely understood quality of data sources is directly proportional to the volume of internet transfer. Transfer of data in Arctic regions that is fully covered only by the IRIDIUM satellite system is significantly reduced. This reduces quality of the information available to a vessel under way on the NSR. The analysis of about 200 maps indicate that basic access to information about ice conditions (concentration, ice forms, floe size and limit of ice edge) provides just a few of them. Table 12 presents a comparison between the main characteristics of different sea ice data services from various sources (abbreviations: IP - Ice under pressure, HI - Hummocked ice, IF - Ice forms, C – Concentration, FS - Floe sizes, D - Ice drift). It should help navigators to identify the most useful data sources and give more information on agencies providing ice maps and services. The SIGRID-3 format files published by AARI contain information about concentration, ice forms and floe size analysis data for specific regions and all of Arctic. They have a very good resolution, are quite easy to download and have a relatively high total quality indicator. A very low workload value could be acceptable but the accuracy (delay) range of 0.571-1.714 for the operational planning cycle during the navigational season makes them useless. The same situation concerns AARI files for prognosis of ice under pressure (compression), hummocked ice and ice forms for the region of the Barents and Kara Seas. A resolution of 25,000 km could be acceptable for general route planning but a delay range of 1.5-2.0 for the operational planning cycle during the navigational season make them useless. In this situation a much better offer is provided by a screenshot from the website ocean8x.aari.nw.ru representing ice floe concentration. The very low resolution can be partly counterbalanced by using the isoline format of the maps.

Regional maps with ice floe concentration analysis for the Barents and Kara Seas in PDF format available on the website dnmi.no provide good support for voyage planning. They are available with only a very short delay and are easily downloadable. The resolution and total quality indicator are on an acceptable level. An almost similar quality of ice floe concentration analysis maps of the Chukchi Sea is published by NIC on the website bsis-ice.de. The limitation is the availability of these maps on a weekly basis making them useful only for a short time after they are published.

An interesting offer of separate files of concentration and ice format for the whole Arctic is in GRIB format available on the website osisaf.met.no. The resolution is lower at 10,000 km. The total quality and workload indicators are good. The files are easily downloadable with a short delay. Files related to the quality of the data are also available on the site. Everything together make these sources a quite good alternative for files covering only specific regions (DNMI and NIC in PDF format) and a good supplement for all those mentioned earlier including concentration maps from the ocean8x.aari.nw.ru website.

Marginal Ice Zone represents a separate group of files with a limited concentration scale. These are NIC files in GEOTIFF format consisting of regional maps of the whole Arctic with very good resolution, easily downloadable, with a low workload and accuracy (delay) and of acceptable total quality indicator. They were available on polarview.aq website (until the project was closed). Currently they are available on the natice.noaa.gov website. In the same group are maps issued by NIC in shapefile format on the polarview.aq (actually on natice.noaa.gov) website and in KMZ format on the natice.noaa.gov website.

Also worth mentioning are ice floe concentration maps available on the iup.physik.uni-bremen.de website in PNG, GEOTIFF and HDF formats. Their delay is very short. The best indicators offer regional maps in PNG and GEOTIFF format. The user can use also regional maps in HDF format. The files contain information on quality of data but the workload is very high.

There are also various sources of data related to ice drift. The most suitable files for users are in raster image format. All of them have a very low resolution of 31.25-62.50 kilometres. The only important attribute that differentiates them is the accuracy. Ice drift analysis maps can be found on the ifremer.fr website with very long delay. It makes them useless for voyage planning. The maps of analysis available on the osisaf.met.no website have the worst resolution. In this case the most suitable are ice drift prediction maps available on ocean8x.aari.nw.ru. There is possibility to select a map in advance up to seven days at intervals of three hours.

This study did not include the availability of recent raster maps of ice cover analysis developed by the Russian project Planeta. They are available on a daily basis without significant delay. Their resolution is estimated to be very high, at least the same as the above mentioned sources of data. However, reliability and quality indicators of these maps are low and the workload is very high. Also were not included recent KMZ files of ice drift forecast maps developed by U.S. NIC.

Table 12. Main characteristics of selected sea ice data sources

Source	Data	Name of sample file / data source	Weight	Q_f	Q_w	Resolution	Q_e	Q_a	Q_T
aari.ru	C,IF,FS	aari_arc_20100706_pl_a.ZIP (general)	1.00	0.43	0.34	1,008	0.015	-0.571	0.657
aari.ru	C,IF,FS	aari_kar_20110927_pl_a.ZIP (regional)	1.00	2.08	0.74	849	0.021	-1.714	0.657
ocean8x.aari.nw.ru	C	screenshot from ocean8x.aari.nw.ru	1.00	1.62	0.93	55,560	0.768	+0,429	0.434
ocean8x.aari.nw.ru	D	screenshot from ocean8x.aari.nw.ru	0.50	4.16	0.84	55,560	0.768	+0,429	0.421
aari.ru	IP	20090918.BMP (Barents and Kara Seas)	1.00	4.26	1.12	25,000	0.764	-2.000	0.447
aari.ru	HI	20090918.BMP (Barents and Kara Seas)	1.00	4.07	1.14	25,000	0.764	-2.000	0.447
aari.ru	IF	20090117.PNG(Barents and Kara Seas)	1.00	1.47	1.47	25,000	0.761	-1.500	0.392
osisaf.met.no	C	ice_conc_nh_201105211200.grb.gz	1.00	0.30	0.28	10,000	0.764	-0.054	0.733
osisaf.met.no	IF	ice_type_nh_201109301200.grb.gz	1.00	1.00	0.82	10,000	0.764	-0.054	0.683
osisaf.met.no	D	ice_drift_nh_polstere-625_multi-oi_ 201110051200-201110071200_arc.PNG	0.50	3.12	3.12	62,500	0.761	-0.054	0.517
dnmi.no	C	c_map1.PDF (Barents and Kara Seas)	1.00	0.68	0.64	6,945	0.764	-0.009	0.487
NIC (bsis-ice.de)	C,IF,FS	chukcurrentcolor.PDF	1.00	1.99	1.49	3,902	0.764	-1.000	0.445
NIC (polarview.aq)	C	icechart_nic_current_arctic.ZIP (general)	1.00	0.19	0.19	1,070	0.013	-0.051	0.546
NIC (polarview.aq)	C	arctico.tif.tar.gz (regional)	1.00	0.91	0.91	2,000	0.761	-0.051	0.409
natice.noaa.gov	C	arctic_2011286.kmz	1.00	0.30	0.26	2,360	0.015	-0.048	0.546
iup.physik.uni-bremen.de	C	asi-n3125-20111003_nic.png (regional)	1.00	6.27	2.88	3,125	0.772	-0.012	0.490
iup.physik.uni-bremen.de	C	asi-n3125-20111003.tif (regional)	1.00	1.73	1.38	3,125	0.772	-0.012	0.575
iup.physik.uni-bremen.de	C	asi-n3125-20111003.hdf (regional)	1.00	0.45	0.42	3,125	0.024	-0.012	0.826
polarview.aq	FS	WSM_SS_20110925_153307_4417_3.dim	1.00	0.01	0.01	96	0.761	-0.116	0.423
polarview.aq	FS	WSM_SS_20110930_123111_6248_1. dim.final.jpg	1.00	0.01	0.01	104	0.761	-0.116	0.295
ifremer.fr	D	20110101-20110201.PNG	0.50	3.19	1.29	31,250	0.777	-1.143	0.462

For most regions of the Arctic (Laptev Sea, East-Siberian and Chukchi) there was noted a lack of maps for the most difficult parameters of ice navigation, these being pressure of ice and hummocking of ice. At the moment this problem can be solved only by using the maps of ice drift prediction available on the ocean8x.aari.nw.ru website. The shortest regular changes of ice under pressure (compression) depend on semidiurnal tides. The compression reach maximum twice daily in between Low Water and High Water (Mironov et al 2010 following Buinitskii 1951 and Legen'kov 1988). The amplitude of the compression changes due to the effect of the tides does not excide number 0.9 (Mironov et al 2010 following Kagan et al 2007). This is the possible reason why the problem of compression due to tide effect did not attract serious attention (Mironov et al 2010 following Proshutinsky 1993). Based on collected information regarding the speed, direction and duration of ice drift the navigator should use the "Guide on dangerous hydro-meteorological and ice phenomena along the Northern Sea Route" available on the aari.ru website to assess the locations and level of compressed ice as well as for leads opening or closing. However, it requires much experience by an Ice Navigator.

5 DISCUSSION

It is possible to develop a passage plan for a transport vessel of specified ice class and technical properties though the NSR within a specified time period, under specified ice conditions using studied hydrological and meteorological data sources. The quality of the proposed route depends on quality and completeness of the data sources concerning analyses and forecasts of navigation in ice. It is also possible to minimise the workload in the procedures of downloading, digitalising, processing and evaluating data sources using chosen data sources. Reducing the amount of the human factor introduces technical progress into the decision making process and increases safety of maritime transport.

There still exist deficiencies in useful data for the planning of routes on the NSR. They are related with the hydro-meteorological and ice conditions. Only the main and widest straits on the NSR are satisfactorily provided with data sources. Official data sources are of much lower quality in relation to new forms of data storage. There are a large number of diverse sources of information or files on the World Wide Web. New forms of data storage require the use of software that is not commonly known.

It is important to possess data about parameters of navigation in ice and its quality for correct decision making. A few sources of raster-based maps provide very poor information on the quality of ice conditions, or remark on their quality only. They are issued by the Norwegian Meteorological Institute, GMDSS METAREA and OSISAF EUMETSAT. Russian sources ignore issues of parameter quality. U.S. facsimile maps provide unspecified information regarding whole maps. Such files as GRIB (developed by OSISAF), NetCDF (developed by OSISAF), HDF (developed by the University of Bremen) and contain individual information about quality of parameter. This information is contained inside the file or in a separate file. The highest quality of data sources is related to new forms of data storage.

Data quality indicators for particular Russian Arctic seas and the whole NSR achieve very low values. Among 10 parameters of the highest importance, four of them are practically not achievable in current operational practices (snow thickness, "cushion", melting and openings in the ice). For this reason, a quality indicator of data sources for the whole NSR cannot exceed a value of 5.5. with 10 being the maximum (for ice drift weight equal 0.5). Parameters of the ice conditions that present the greatest difficulties and require the avoidance of zones of their occurrence – pressure of ice and hummocking - are available only in a single file, and only for the Kara Sea. In the case of omitting data unavailable in the assessment types of ice parameters, the quality indicator of data sources for the whole NSR, elaborated on basis of quality, achieves only 63% of the maximum value. In the case of taking into account bandwidth limitation, the quality indicator achieves an outcome twice worse - just 33%.

When selecting sources of information according to quality criteria mostly files of format HDF, GRIB, SIGRID-3 and text-type requiring specialised software were accepted. When selecting sources of information according to bandwidth criteria mostly raster maps with grid coordinates and with attributes of paper maps and maps with significantly worse resolution were accepted. The Kara Sea is much better equipped in sources on hydrological, meteorological and ice data than other NSR seas. For this reason, there is considerable disparity between possible quality of the route planning on the NSR and assessment of situations by shore side (for example, the Administration of the NSR) and the vessel. This is due to the low bandwidth of the Iridium satellite system, which affects quality difference. It limits availability of files with higher quality or resolution for vessels. Thus, the main limitation of quality of the available data sources on the internet is the low bandwidth of the Iridium satellite system.

It is possible to solve the problem of limited bandwidth of the Iridium satellite system. Internet data transfer of a single connection through the Iridium system is 2.4 kB/s. It is possible to increase the capacity by using specialised software enabling transfer through several Iridium telephone connections running simultaneously. An improvement can also be achieved through action from the website owner, by reducing the volume of the website. A few data providers allow for this opportunity by making double versions of websites - for connections with high bandwidth and low bandwidth. These include "polarview.aq" (closed) and "noaa.natice/omb." The second possibility is the involvement of the vessel's company by collecting files ashore using fast internet connections, dividing files into smaller portions or selecting small areas needed, compressing them and dividing these files by using for example RAR software and sending them to the vessel using the low bandwidth of the Iridium satellite system. Recently, Microsoft Download Manager software has been made available to users, which permits the automatic download of larger files even following the uncontrolled interruption of connections. This method does not involve other parties in the procedure for downloading files and provide the vessel full independence in this area.

6 CONCLUSIONS

This paper is concerned with the safety of the maritime transport in high-latitude regions of the Russian Arctic seas, where the sea freezes completely during the winter season. There are very difficult, rapidly changing ice conditions and there are risks to shipping that are not found in other parts of the world. A vessel navigating through the NSR has very limited access to information on the hydro-meteorological conditions, including ice conditions.

Innovative approaches to the above problems are the use of new sources of information that are different from commonly known image maps on paper or in electronic form, the development of new indicators and methods to compare usability of the data sources for route planning purposes in ice-covered regions of the NSR, the introduction of technical progress meaning the reduction in workload and the improvement of maritime safety by finding new ways to reduce the impact of the human factor on decision-making and outputs.

The presented algorithm for downloading and digitising is used for the purpose of route planning in ice on the NSR using publicly available sources of data on current and forecast conditions of navigation in ice. The presented algorithm quantifies the workload. In this way, information is available to compare the workload between various sources of information and quality of information used to prescribe the route. A vessel's captain may take a decision independently, selecting a route by choosing appropriate data sources following his or her knowledge, experience and existing circumstances of navigation. This meets the requirements of the concept of e-Navigation.

The most important achievements of this study are the analysis of functionality of various data sources on current and forecast conditions of the navigation in ice on the NSR. This allows developments to support maritime safety through implementation of technical progress. It reduces workload, facilitates the automatisation of data processing and analysis for decision support systems associated with route planning in ice on the NSR, in accordance with requirements of the ISM Code and the e-Navigation concept. Another result is the development of mathematical tools to assess data sources related to navigation in ice conditions and to plan the routes of ships on the NSR. The next achievement is the determination of methods on how to fix the problem of limited bandwidth available at high latitudes using the Iridium satellite system. Methods, procedures and algorithms can be used widely on each ship, by any company or navigator to design the decision support system for navigation in ice, with the occurrence of diverse, incomplete or uncertain information relating to navigation in ice and the ability to overcome ice by vessels of any ice class.

For these reasons, it is expected that the paper will serve navigators on conventional and non-conventional vessels as a guideline on available new, free of charge, modern data sources with a larger range of information than official sources. At the same time information services and agencies providing ice maps in new formats are a source of information providing new opportunities for their use. They include similar data as in the concept of the Zones of Confidence that have been introduced on electronic sea charts. This paper should also be helpful for anyone who appreciates the possibilities of using independent and free sources to assess ice conditions or the possibility to verify or supplement information provided by official sources.

REFERENCES

Buinitskii V. Kh. (1951). Formation and drift of ice cover in the Arctic basin, Proceedings of drifting expedition l / p "G. Sedov" (in Russian), Glasevmorput, Vol. 4: 74-179.

IMO (2011). Development of a mandatory code for ships operating in polar waters, The ice certificate concept. IMO, DE 55/12/11, 14 January 2011: 6 p.

IMO (2008). Draft strategy for the development and implementation of e-navigation. IMO Resolution A. 989(25), NAV 54/25 Annex 12: 14 p.

Hołodnik-Janczura G. (2007). Examining the quality of informatics product using valuation method, Operations Research and Decisions, No 2/2007: 55-69.

Jurdzinski M., Pastusiak T. (2009). E-navigation as a process of modelling of safety of navigation, Economic (in polish), social and legal challenges of maritime state in the European Union, Srodkowopomorska Rada NOT, Koszalin: 85-93.

Kagan B.A., Romanenkov D.A., Sofina E.V. (2007). Simulation of tidal ice drift and ice-generated changes in the tidal dynamics on the Siberian continental shelf (in Russian). Izvestiya of Academy of Sciences, Russia. Atmospheric and Oceanic Physics, Vol. 43, No 6: 831-850.

Khvochtchinski N.I., Batskikh Y.I. (1998). The Northern Sea Route as an element of the ICZM system in the Arctic: problems and perspectives. Ocean & Coastal Management, 41: 161-173.

Legen'kov A.R. (1988). Shifts and tidal deformation of drifting ice, Gidrometeoizdat: 104.

Mironov E.U. (editor), Kljackin S.V., Gudkovič Z.M., May R.I., Frolov S.V. (2010). Dangerous ice phenomena for shipping in the Arctic (in Russian). AANII, St. Petersburg: 320 p.

Pastusiak T. (2011). Ship's Navigational Safety in the Arctic Unsurveyed Regions, Maritime Navigation and Safety at Sea Transportation. Miscellaneous problems in maritime navigation, transport and shipping, CRC Press Taylor & Francis Group, London: 59-64.

Patraiko D.J. (2008). e-Navigation, Digital Ship, Posidonia, July 2008: 26 p.

Proshutinsky A. Yu. (1993). The Arctic Ocean level oscillations (in Russian). Gidrometeoizdat, St. Petersburg: 216 p.

Ryvlin A.Ya., Chejsin D.E. (1980). Tests of vessels in ice (in Russian). Sudostroenie, Leningrad: 208 p.

Timco G.W., Gorman B., Falkingham J., O'Connell B. (2005). Scoping Study: Ice Information Requirements for Marine Transportation of Natural Gas from the High Arctic. Technical Report CHC-TR-029, Canadian Hydraulics Centre, Ottawa: 124 p.