Research Report No 80

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ICETRAFPREP — A FEASIBILITY STUDY OF A TRAFFICABILITY ICE CHART SERVICE

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FOREWORD

In its report no 80, the Winter Navigation Research Board presents the outcome of the project: A feasibility study of a trafficability ice chart service.

Information about the dynamically changing ice cover and its effects on ship traffic is an important topic for transport logistics in wintertime. The shipping and logistics operators need this information for planning purposes. Presently the ice charts, compiled by the Ice Services, even though updated once a day based on satellite images, only gives a rough overview of the ice situation with little information about how the ice situation affects the ship speed and thus the transit times of the ships. The objective of this pre-study is to estimate the feasibility of a new information product/service that would show the ice conditions in a simplified way on the routes used by ships as perceived by the ships themselves. If successful, this would improve the real-time estimation of travel times in ice thus serving the needs for improved logistics planning involving ship transports in ice covered waters.

The Winter Navigation Research Board warmly thanks Mr. Robin Berglund and Mr. Mathieu Molinier for this report.

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IceTrafPrep — A feasibility study of a Trafficability Ice Chart Service

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Confidentiality: Restricted
IceTrafPrep — A feasibility study of a Trafficability Ice Chart

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Preface

This study has been performed during 2011 to investigate the feasibility of a new service for stakeholders and users that need up-to-date information about how the ice situation affects the travel times for the merchant ships in wintertime. Presently this information is compiled manually in daily ice charts, but the ice charts – however detailed they may be – do not show how the ice cover affects the speed of different ships that has to go through the ice covered areas.

The study has been done by Robin Berglund and Matthieu Molinier in the centre for Knowledge Intensive Services at the VTT Technical Research Centre of Finland and is a continuation of a series of services developed to help winter navigation in the Baltic Sea.

The project has been supervised by a steering group with the following members: Ilmari Aro, Finnish Transport Agency, Jorma Kämäräinen, Finnish Transport Safety Agency, Ulf Gullne, Swedish Maritime Administration, Ari Seinä, Finnish Meteorological Institute and Ville Kotovirta, VTT

The work has been funded by the Winter Navigation Research Board.

We also want to thank the end user representatives that have taken time to comment on the service plans.

Espoo, 28.3.2012

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1 Introduction

Information about the dynamically changing ice cover and its effects on ship traffic is an important topic for transport logistics in wintertime. The shipping and logistics operators need this information for planning purposes. Presently the ice chart, even though updated once a day based on satellite images, only gives a very rough overview of the ice situation with little information about how the ice situation affects the transit times of the ships. To overcome this lack of information, this pre-study is performed to go more deeply into the possibilities of developing a service that would serve the needs of shipping operators and authorities.

The idea is to use Automatic Identification System (AIS) data to obtain information about the practical effect of the ice situation on ship speed and transit times. This idea has been proposed in the ShipSensornet-project [R1] where VTT, together with other project partners, among other things, studied the dependence of ice thickness and ship speed. Similar studies are performed in the ongoing IceWin –project [R2].

2 Goal

The objective is to study the feasibility of a new information product/service that would show the ice conditions in a simplified way on the routes used by ships as perceived by the ships themselves. If successful, this would improve the real-time estimation of travel times in ice.

3 Description

Originally the purpose was to use tools and data collected in earlier and parallel projects, to develop a statistical model that would describe the dependence of ship speed based on ship parameters and ice thickness.

The hypothesis is that knowing the ice going characteristics of a ship, the monitored speed can be used to infer how difficult the ice conditions are – thus the effect on another ship can be estimated.
Figure 1 Relative ship speed ($v_{OW}/v_{ice}$) as a function of ice thickness (from Riska et. al 1997 [R5]). The graphs show a fairly linear dependence of relative speed as a function of ice thickness.

A previous study was done based on data in the Bay of Bothnia. The idea would then be to gather an average value of ship speed from several ships and then invert this to equivalent ice thickness in grid cells of about 10 x 10 km.

The resulting map would (optionally) be overlaid with the actual ship tracks to improve visual appearance.

The study was then expanded to include ideas on what kind of presentations that would benefit the users the most.

4 Limitations

This study was limited to archived data – no real-time implementation or pilot was planned for. The period studied was winter 2010 and the area Gulf of Finland (GoF).

5 Methods

The primary data is collected from the AIS network. To be able to combine speed information from several ships, the observed speed is scaled relative to the open water speed of the individual ship.

The first idea is to calculate the average speed values in grid cells. The selection of cell size is a compromise between resolution and statistical significance. The larger the cell, the larger the sample – thus the statistics is improved. On the other hand, the spatial resolution is degraded in a larger cell. Also the homogeneity of the ice conditions is worse for larger areas.
The second idea is to cluster the speed of the ships around the “corridors” that are formed by the ship tracks themselves. As the ships are obliged to follow the waypoints given by the icebreakers, the ships do follow rather narrow “corridors” that can be clustered and visualised. This idea has not, however, been implemented nor validated in this study.

### 5.1 Collecting the AIS data

For the study the AIS data is collected from the Finnish national AIS server and basically contains data from ships moving in Finnish territorial and international waters.

According to the AIS standard [R5], the time interval between observations transmitted from the ships depend on their speed (Table 1) but the national AIS network server may filter these messages according to server user account-specific parameters.

<table>
<thead>
<tr>
<th>Ship’s dynamic conditions</th>
<th>Nominal reporting interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship at anchor or moored and not moving faster</td>
<td>3 min(^{(1)})</td>
</tr>
</tbody>
</table>

*Figure 2 Elements in the trial system. The AIS data is archived in a database containing the time, position, speed, course over ground, etc. of the ships that have been in the Gulf of Finland area in 2010. The database also contains ship parameters like length, breadth and machine power. The aggregation of data (calculating average values etc.) is performed using SQL database queries. Visualisation is here implemented by producing files with the spatio-temporal data in KML mark-up language. The user can then study the data using a map visualising application like Google Earth.*
than 3 knots
Ship at anchor or moored and moving faster than 3 knots 10 s(1)
Ship 0-14 knots 10 s(1)
Ship 0-14 knots and changing course 3 1/3 s(1)
Ship 14-23 knots 6 s(1)
Ship 14-23 knots and changing course 2 s
Ship >23 knots 2 s
Ship >23 knots and changing course 2 s

(1) When a mobile station determines that it is the semaphore , the reporting interval should decrease to 2 s

The envisaged application is not so sensitive to sampling interval length, therefore temporal filtering of the data does not degrade the results significantly. However, short term variations in speed could be used as one feature for determining ice conditions if calibrated per individual ship.

5.2 Obtaining information about Open Water Speed

To obtain the relative speed of a ship when going in ice, the open water speed of the ship has to be obtained. This can be taken from the design speed of the ship (often found in the set of ship register parameters), but this is not the same as the normal open water speed of the ship, i.e. the speed that the ship normally uses when going in open water. In this study the open water speed of the ship has been taken as the average speed when the ship has proceeded with over 5 knots and in an area where the ice concentration is below 5% according to the ice chart. The goal is to gather information about as many ships as possible. Thus – for ships that have not been in the area before in the open water season – the open water speed has to be obtained when there are ice conditions, otherwise the easiest approach would be to obtain the data from a period when there is no ice.

5.3 Aggregating speed information

To obtain average values of ship speed, the observations from a specific area and a specific time window, have to be obtained. This can be easily derived for a rectangular latitude-longitude grid. The challenge here is to filter out ships that adjust their speed because of other reasons than ice. To some extent, the ship state information in the AIS message can be used, but there will always be cases when the ship slows down because of reasons not related to ice. Assuming that the variations due to deliberate slowing down are the same in summertime as in wintertime, summer conditions can be taken as the “background” noise baseline in the observations.

Another issue is how to handle ships in ports. Berthed ships should be excluded, but average time to get the ship into port is something to account for when calculating ETA-values. A simple filter would exclude speed observations below a threshold like 1 knot. This approach has been used in the example maps presented here. A more accurate filter would estimate when a ship is berthed and use that time as time of arrival info.
5.4 Producing visual information:

The first experiments in this pre-study were performed in EXCEL using conditional formatting and colouring. More elaborate visual examples have then been produced by generating KML files and displayed in Google Earth. No numerical comparison (statistics) of ice chart information versus observed speed, has been done.

6 Results

The primary result is that a cell based approach can be used for rough monitoring and estimating of ship speed through the ice field.

For visualisation there are many options: to display the values as such (or color the cell according to this value) or to spatially filter the value to create a more homogenous map. Example of spatially filtering of the map is shown in Figure 3 and Figure 4. In these examples the values in the cells are obtained using spatial filtering with a 3 x 3 kernel where the centremost pixel has a weighing factor of 4 compared to 1 for the other cells.

![Figure 3](image_url) This shows a speed chart of January 1st, 2010, based on AIS data. The situation describes the open water case with almost no ice. The numbers in the cells refer to average relative values. If the value is near 1 (0.95 – 1.0) the cell is coloured green, then the colouring is changed to via yellow to red (0.5 or less). In this example a rather even chart has been obtained using spatial filtering with a 3 x 3 kernel. The weight of the centre cell is 4 times the weight of the other cells. This filtering explains the spread out of values on shore around the Tallinn harbour.
Figure 4 A speedchart of February 14th, 2010, based on AIS data. Here the speed distribution shows more variations due to ice conditions.

Figure 5 A speedchart of February 18th, 2010, based on AIS data showing the relative speed (ObservedSpeed/OpenWaterSpeed) of the ships. This chart is generated as an KML file where the grid cells are coded as polygons. This enables more information to be included in the cells. The grid cells are not filtered.
Validation of results

Validation of the results can be separated into technical validation and user validation. Technical (or statistical validation) could be done by calculating the variances of the data, i.e. how much do the speed observations vary from ship to ship in similar conditions measured as relative speed (or expressing it the other way around: what is the cross-correlation between relative ship speed in similar conditions). Another approach is to perform a comparison of ship speed chart with the traditional ice chart. There should be a correlation between decrease of ship speed and ice thickness, where the residuals are of interest.

User validation would require a demonstration system with systematic follow-up. The user validation that has been done until now is to gather comments about the presented maps from users that have several years of experience in winter navigation.

In Figure 7 the symbols and colours used in a traditional ice chart, is shown.
Below (Figure 8 to Figure 12) is a sequence of 5 days where the trafficability map is compared with the traditional ice chart (the ice charts are from the Swedish Hydrological and Meteorological Institute, SMHI). The 18th February the Gulf of Finland (GoF) was covered with ice. There was consolidated or compact pack ice in the middle of GoF. Some ridges have been indicated on the ice chart. The effect of this ice is clearly shown in the trafficability map, but the western part seems still to be quite easy to pass compared to the mid parts of the GoF.

![Figure 7 Ice chart legend (from SMHI ice chart)](image)

Figure 7  Ice chart legend (from SMHI ice chart)

The situation changes somewhat the day after (19th, Figure 9). Now there seems to be ships slowing down also westwards, but the effect is not so clearly seen yet.

![Figure 8 18th February. This is the first day of the period of detailed study](image)

Figure 8  18th February. This is the first day of the period of detailed study
The 20th of February we can see significant slowing down of ships in the western part of GoF. This is probably due to the close pack ice being pushed northwards by the winds causing the ice field to converge and probably also some ice pressure.

The situation then is relieved the day after (21st, Figure 11). The ice edge is retracting northwards and this can be seen as an increased average speed in the trafficability chart.
The retracting of the ice edge is very clear in Figure 12. Now ships are proceeding with almost open water speed.

Figure 12  22nd February. Open water areas appear in the Southern part of GoF

The comparison of the ice chart and the trafficability maps shows visually the correlation of the ship speed with ice conditions. It also indicates a time lag in the information – the ice chart seems to be somewhat “behind” the situation as indicated by the trafficability map. This may be due to the fact that the ice chart is drawn in the morning, thus effectively showing the situation from the previous evening or up to the most recent satellite image in the morning, whereas the
trafficability map is based on the observations during the whole day up to midnight.

What is also clearly indicated is that the effects of the ice cover on ship speed is difficult to estimate from the ice chart alone, therefore the trafficability map gives valuable additional information about this aspect.

8 Conclusions

The results are promising. The main uses of the product would be for the following purposes:

1. Improved estimation of travel times in current ice conditions
2. Improved route selection: showing other ships’ tracks with indicated speed would help other ships to utilise easier ways through the ice. NOTE: the ships should always follow the instructions given by the icebreakers though.

The next sections elaborate on how this idea could be developed into an operational service.

8.1 Architecture alternatives

When considering different architecture alternatives for implementing the service, the following requirements are the most important:

- ease of use for the end user
- intelligibility, i.e. the user should be able to comprehend what is shown on the map without a lot of training
- scalability regarding number of users
- reliability – both from a technical point-of-view and from the users point of view
- real time requirement
- automatic operation

**Ease of use** is required to enable a large number of users to be able to utilise and understand the information. A web based presentation requiring no installation is then the preferred way to go.

**Intelligibility** is part of the ease-of-use. No dedicated training should be required, although this may be the case in the long run to prevent misunderstandings. Training could then be implemented in the form of self-study course or short training video.

**Scalability** means that the system should be able to cope with many simultaneous users and easily expanded to handle more users if the number of users would rise.

**Reliability**: means technically that the information is available on-line with a low enough downtime. The other aspect is more validity: the information shall be reasonably accurate, but this does not affect the technical architecture.
**Real-time** requirement: the information should be updated using real-time AIS information.

**Automatic operation**: the algorithms and system should work without manual intervention.

The preferred architecture model that takes the above mentioned aspects into account is shown in Figure 13.

![Preferred architecture model for operational service.](image)

8.2 SWOT analysis of the service

To further analyse the Trafficability map service, a SWOT –analysis (Strengths, Weaknesses, Opportunities, Threats) is presented in Table 2 below.

<table>
<thead>
<tr>
<th>Trafficability Map SWOT Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strengths</strong></td>
</tr>
<tr>
<td>• Automatic production – low cost production when correctly parameterised</td>
</tr>
<tr>
<td>• Provides information that Baltic end-users have asked for</td>
</tr>
<tr>
<td>• Possibility to present information even on-board in a clear &amp; compact way</td>
</tr>
<tr>
<td>• The concept is a modification of what has been proven to be successful in road traffic monitoring</td>
</tr>
</tbody>
</table>
### Opportunities
- This kind of information is new, not currently available, nor in the past
- Large number of potential end-users/customers (& increasing)
- The system should lead to savings for end-users in improved logistics planning
- Additional benefits expected when combined with ice forecasts
- Combination with machine power and ship characteristics may improve quality of information
- System & services can be easily tailored to individual users if necessary

### Threats
- Variance/uncertainty in information may make users disappointed (thorough testing required)
- Additional benefits expected when combined with ice forecasts – but no trials yet on how to fuse this information in the trafficability map
- If uncertainties are too great the information may only be “nice to know”
- Getting information to the users may be an obstacle – facilities are improving but use of web services on board is still a problem and often expensive
- Liability issues

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>• This kind of information is new, not currently available, nor in the past</td>
<td>• Variance/uncertainty in information may make users disappointed</td>
</tr>
<tr>
<td>• Large number of potential end-users/customers (&amp; increasing)</td>
<td>(thorough testing required)</td>
</tr>
<tr>
<td>• The system should lead to savings for end-users in improved logistics</td>
<td>• Additional benefits expected when combined with ice forecasts</td>
</tr>
<tr>
<td>planning</td>
<td>– but no trials yet on how to fuse this information in the</td>
</tr>
<tr>
<td>• Additional benefits expected when combined with ice forecasts</td>
<td>trafficability map</td>
</tr>
<tr>
<td>• Combination with machine power and ship characteristics may improve</td>
<td>• If uncertainties are too great the information may only be “nice to</td>
</tr>
<tr>
<td>quality of information</td>
<td>know”</td>
</tr>
<tr>
<td>• System &amp; services can be easily tailored to individual users if necessary</td>
<td>• Getting information to the users may be an obstacle – facilities are</td>
</tr>
<tr>
<td></td>
<td>improving but use of web services on board is still a problem and</td>
</tr>
<tr>
<td></td>
<td>often expensive</td>
</tr>
<tr>
<td></td>
<td>• Liability issues</td>
</tr>
</tbody>
</table>

Table 2. SWOT Analysis for the Trafficability map service.

### 8.3 Sustainability aspects

For a service to be sustainable there should be a model of how the costs are covered. In the PolarView project [R4] the financing models of services like the proposed one, have been identified as follows:

*Figure 14 Financing models (from the PolarView project)*

Usually services are not purely in the Model A or B category, but rather a mix of these. In the Model A the users pay for the services, in model B, the benefits are considered to justify the costs to be paid from public funds (ultimately by political decision makers).
8.3.1 Cost and benefits

*Costs*

The costs can roughly be divided into set-up costs and running costs.

<table>
<thead>
<tr>
<th>Item</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algorithm development and validation</td>
<td>2 person-months</td>
</tr>
<tr>
<td>Computer server infra</td>
<td>Could use shared server capacity to lower the set-up cost.</td>
</tr>
</tbody>
</table>

*Running costs:*

<table>
<thead>
<tr>
<th>Item</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Server maintenance (HW and SW)</td>
<td>If shared capacity is used, this is not a significant cost.</td>
</tr>
<tr>
<td>Algorithm tuning</td>
<td>Amount depends on results. The division between algorithm development and tuning is somewhat diffuse.</td>
</tr>
<tr>
<td>Application SW maintenance</td>
<td>Roughly 20 % per year of development costs</td>
</tr>
<tr>
<td>Input data cost</td>
<td>If satellite data is used, this may be a significant cost. On the other hand, plans exist that would make Sentinel radar satellite data freely available – only processing cost would then have to be accounted for.</td>
</tr>
</tbody>
</table>

*Benefits*

<table>
<thead>
<tr>
<th>Stakeholder/Users</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authorities – winter navigation</td>
<td>Improves estimate of ice conditions to be able to issue proper ice restrictions at the right time -&gt; savings to all parties</td>
</tr>
<tr>
<td>Icebreaker operator(s)</td>
<td>Helps in determining the optimal waypoints through the ice.</td>
</tr>
<tr>
<td>Shipping operators</td>
<td>Helps in logistics planning – better estimates of transit times and effect of ice conditions.</td>
</tr>
<tr>
<td>Individual ships</td>
<td>Helps in communicating with ports etc. Also helps in determining the optimal route.</td>
</tr>
</tbody>
</table>
Stevedores | More efficient logistics.
---|---
Port authorities | More efficient logistics.
Search and rescue | Improved information on ice conditions for better planning of rescue operations.

A quantification of the benefits can be done, but would require more background data like costs for delays etc.

### 8.4 Further ideas for products

During the discussions with the users (persons from the Finnish Traffic Administration and the Swedish Maritime Administration), the primary idea that was endorsed was the Trafficability ice chart as shown in Figure 15. The advantages of such a chart are ease of interpretation and thus utilisation. In addition to this static chart that would be common to all users, an interactive chart could be developed where the user (a ship) would indicate the ships current position and destination, whereby the system would display the estimated travel time. This functionality could be improved by making a tailored prediction for the ship where the current position and destination are taken from the AIS network, and the ship characteristics from a ship database. This kind of service could be considered as a user tailored service available only to premium customers that have paid for a subscription of the service.

*Figure 15 Trafficability ice chart. The ship tracks are clustered into corridors representing reasonable homogenous ice conditions from a trafficability point of view. The average speed of the ships within this corridor is indicated by the colour. In addition, the average transit time from end to end of the corridor is shown numerically.*
Another idea presented by the users was a simple, rather coarse gridded map with average speed indicated in the grid cells. (See Figure 16)

![Average speed](image)

**Figure 16**  Average speed is calculated per grid cell where the grid is rotated to better fit the geography of the Gulf of Finland

There were also user comments that the *real* speed is easier to understand for a user than the *relative* speed.

In the discussions with the users regarding how to make different ships more comparable when monitoring the impact of ice on their speed, a suggestion was to concentrate on ships that have an open water speed of max 15 knots. The strong containerships, passenger - and other ships with high machine power usually manage well on their own, but even if the impact of ice is not so much on timetables for these ships, the effects of ice on the ships are more on fuel consumption, thus an issue of travel costs that have to be compared to the cost for delays in arrival schedules.

### 8.5 Proposed next steps

For the service to be developed further the following critical elements should be addressed.


<table>
<thead>
<tr>
<th>Issue</th>
<th>Action</th>
<th>In what context</th>
<th>Estimated effort (person - months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design and tuning of Clustering algorithm</td>
<td>Plan algorithm in detail, set up test environment (Matlab or similar), run test cases using archived material.</td>
<td>Preferably research project</td>
<td>2, may require more effort.</td>
</tr>
<tr>
<td>Design and implementation of KML generator</td>
<td>Using algorithm developed in the previous task, implement the visualisation elements.</td>
<td>Can be done in more application oriented project</td>
<td>1</td>
</tr>
<tr>
<td>Provide service to user</td>
<td>Design and implementation of simple map based user interface</td>
<td>Can be done in more application oriented project</td>
<td>1</td>
</tr>
<tr>
<td>Develop <em>ship specific</em> trafficability chart</td>
<td>A ship resistance model based on ship design parameters should be obtained.</td>
<td>Preferably research project</td>
<td>2</td>
</tr>
<tr>
<td>Provide <em>tailored service</em> to user</td>
<td>Design and implementation of <em>user tailored interactive</em> user interface. First step could be that only the position of a ship is used, then the next step is to utilise ship parameters to calculate ship specific values.</td>
<td>Can be done in more application oriented project</td>
<td>3</td>
</tr>
<tr>
<td>Marketing, roll-out etc.</td>
<td></td>
<td>As part of service provider’s service</td>
<td>1</td>
</tr>
</tbody>
</table>
As seen in Table 3, the development of the idea into an operational service needs resources and funding. Suitable funding mechanisms may be found from the EU research programmes unless the funding could be arranged in a more direct way as contract work. The uncertainties – thus risks – in the algorithm would, however, be handled in a more controlled way if some of the critical elements could be developed and validated within a research project framework.

If the very first step is to generate and present a coarse gridded view of average ship speed with the strongest ships and ships in port filtered out, this should be possible to achieve with much less effort (order of 1 person month).

9 Summary

A Trafficability ice chart service seems to offer valuable and timely information to the winter navigation users and stakeholders. In the idea proposed and investigated in this project the dense traffic in the Baltic Sea can be utilised to provide almost real-time information about the ice cover and its effects on the winter traffic. Some additional work has to be done, however, to bring the idea to an operational level. This work has to be implemented as a cooperation between the users, authorities, satellite data providers and technology providers. Therefore a suitable framework for this cooperation should be looked for and the opportunity seized as soon as such an opportunity seems to emerge.

References

[R2] IceWin - Innovative Icebreaking Concepts for Winter Navigation, Eu FP7 project, grant number 234104.
[R5] Recommendation ITU-R M.1371-4, Technical characteristics for an automatic identification system using time-division multiple access in the VHF maritime mobile band. 04/2010