The Influence of Operational Risks for Ice Transit Simulations

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ABSTRACT

Navigation in ice poses a number of hazards, which may have significant consequences if not addressed. Significant efforts are frequently made to ensure the ship is designed and constructed for the anticipated ice conditions; however, operational aspects play a crucial role in mitigating risks and avoiding hazards in ice transits. This paper outlines some of the operational situations that may occur during ice navigation and illustrates the potential risks, and explores some of the elements for the risk management necessary for safe navigation in ice. Further, the paper discusses the influence of the operations with a particular emphasis on how these can be applied to ice transit simulations, with an application case study used as an illustrative example to highlight these elements.

KEY WORDS

Sea Ice, Transit Simulations, Baltic Navigation, Operations, Risk

INTRODUCTION

The inhomogeneous nature of sea ice creates an uneven level that may extend many meters below the water level, such as ice ridges and edges of old channels, and consequently ice may alter the transit profile of the ship. Navigation in ice may also create unexpected restrictions of movements that may lead to unavoidable delays. This can lead to deviations from routes. Should conditions deteriorate, the ice channel may close in due to the moving ice field. In this situation the ship may get stuck. Thus, it is important to understand and account for these variables in voyage simulations.

The focus of ice transit simulations has often been based on the mechanisms and performance of ice-hull/propulsion interactions, as this often being easier to quantify, such as Riska et al. (2001) and Kotovirta et al. (2009), and many others. However, some studies on details of transit voyages have provided an insight into some of the specific aspects of ice navigation. For example, Tsoy et al. (1999) investigated transits along the Northern Sea Route. Of interest the following reasons are often highlighted:

Traditionally, vessels often became trapped in ice and damaged, in part due to the lower power and strength, however, stronger and more powerful ships have since been constructed for ice navigation, and consequently there has been an increase in the number of commercial ships operating in these waters. The operations of these ships consequently differ, in ship types, sizes and capabilities. One such example is the compromise in open water and ice going performance to provide an economical ship. This leads to a risk profile change, which may not be fully understood, or extrapolated from limited historical data, in applicability and sufficient numbers, which can lead to uncertainties in transit simulations. This paper provides an insight into the operational characteristics that can influence ship navigation transits and provides an example simulation to highlight some of these aspects.

OPERATIONS RISK IN ICE NAVIGATION

Operational risks can have a significant influence on ice navigation. An adage of this is whereby a Master experienced in ice navigation may avoid dangerous ice features, whilst a Master with less ice experience may impact hard ice resulting in much speed loss. These effects are typically not captured during statistical analysis and very few studies exist on this aspect. However, they play a crucial role in the management of risks in ice. The following discusses some of these risks associated with operational aspects for navigation transits in ice.

One of the main factors in ship operations is the ship speed, here the ship may contact ice with too high speed, as outlined by Maksutov and Popov (1981), or conversely become beset if proceeding too slow. The experience of the Master to assess the ice conditions as well as the ship installed power are the key elements. Handling of the vessel and the manoeuvrability characteristics of the ship also play a pivotal role in the operational risk. Here, the ability to sail around dangerous ice features or use leads in ice can reduce the likelihood of speed loss/change. Knowledge of the local ice conditions, provision of ice charts, as well as detection of ice and ridges all help minimise uncertainties in transit times.

Passage planning forms a prerequisite for ice operations. The provisions include those contained in IMO regulations and for ice navigation it is important to consider conditions when it is not safe to enter areas containing ice or icebergs, or because of darkness, swell, fog and pressure ice. However strict weather routing in ice operation is typically not enforced as cracks and pressure zones might change since the latest weather update, and the Master might face a completely different scenario than predicted. Equally voyage planning may differ...
due to icebreaker assistance, or following a pre-made ice channel. Deviations from the intended passage planning should however be made considering the subsequent potential navigation hazards, such as change of depth.

Whilst the above highlights some of the inherent risks, it may also be noted that navigation in ice may also reduce certain risks compared to open water operations, due in part to the operating environmental conditions and enhanced mitigation measures. For example, in ice navigation, the ships generally proceed at slower speeds, in the Polar regions there is higher preparedness of the crew, and higher reliability and redundancy of systems on the ships and of the crew procedures. Crew tend to be skilled through dedicated ice training courses and simulations, which are often complimented with knowledge and experience. They may also be from Arctic or Sub-Arctic regions, thus having a working understanding of the risks having experience in a cold environment.

Finally, many damages due to ice navigation are often repaired during the periodic dry-docking required and thus typically considered as part of a normal ship maintenance process and simulations often do not include this. However, icebreakers tend to have a higher frequency of dry-docking (annual), as in the Russian Maritime Register of Shipping (RMRS) Rules (2014), and thus may need consideration. Equally, maintenance of the ship hull painting is required which can lead to an increased rate of abrasive effects of ice if not properly maintained. Thus, a thorough planned maintenance system should be in place and included in transit simulations to ensure that substantial tasks are carried out before entering cold climate regions, or embarking on long voyages within them.

**RISK MANAGEMENT FOR ICE TRANSITS**

A risk assessment is a rational and systematic process for assessing the risks relating to safety and the protection of the marine environment. Where the risk is defined by the combination of the frequency of occurrence (the number of occurrences per unit time) and the severity of the consequence (outcome of an incident). Due to the variability of environmental conditions, and in particular the ice conditions, as well as potential for sudden changes in weather, a risk assessment can be a useful tool to address all the elements that could affect transit simulations.

A key component of a risk assessment is the identification of hazards that may lead up to an event, adopting such questions as what could go wrong, or how likely is it to go wrong? A particular attribute that endears this approach to ice navigation is that it provides a means of enabling potential hazards to be considered. Ice conditions may increase the probability of an incident as it may affect the hull structure, stability characteristics, machinery systems, navigation maintenance and emergency preparedness tasks, and of safety equipment and systems. It may also be noted that the risk level may differ depending on the geographical location, time of the year with respect to daylight and ice-coverage etc. Here, Jalonen et al. (2005) provides a useful insight into many of the risk aspects for Baltic winter navigation. Thus the mitigating measures required to address the above specific hazards may vary and be different for different regions and seasons. Further, the potential rapid rate of change in addition to the severe multiple hazards may, when acting together, present a synergistic risk level that is greater than the sum of the specific individual risks normally considered when evaluating risk mitigation measures. For example crew fatigue, combined with loss of visibility due to snowstorm, darkness and being in rapidly changing conditions such as ice drift.

Thus, a good understanding of the hazards and interrelationships will provide a solid foundation for the approach taken in the assessment.

Wherever possible, risk should be eliminated through the selection and design of facilities and equipment. If risks cannot be eliminated, they may be minimised by physical controls or, as a last resort, through systems of work and personal protection equipment. The measures resulting from the risk assessment and any additional mitigating actions are then included in subsequent versions of operating procedures and manuals. Typical mitigation measures for ice navigation are generally limited to change of speed and heading, and thus preventive control measures are often preferred for ice operations, and with respect to the higher consequences of failure in the operating environment and potential for rapidly changing environmental conditions.

**EXAMPLE ICE TRANSIT SIMULATION**

As noted above, there are a number of situations that may cause changes to ship speed when navigating in ice. The following does not discuss all the possible scenarios in a risk assessment, but provides an outline of some specific technical aspects, to highlight the influence, and with the intent of providing focus on some, of the inherent operational risks that can be included in transit simulations.

The goal of the study was to determine the time for a ship to travel along a section of the Northern Baltic, from the South to the North (or vice versa). The study was based on equivalent ice thickness for each month, and applying the ship’s ice performance from full scale ice data, to calculate the speed in each ice thickness, and then estimate the duration of the voyage, knowing its distance.

It may be noted that the risks in Baltic navigation will differ from other ice covered regions. For example, transits will be dependent on ice conditions, and in worse conditions more ice avoidance may be required than would be for the Baltic. The following simulations have been made to allow an insight into the sensitivity of the transit times due to these risks and to illustrate the effect they may have, but the specific regional application and vessel characteristics should be borne in mind.

**Ice Conditions Data**

Apart from vessels’ characteristics, the information on ice conditions along the routes is required in order to perform the simulations. This can include the ice concentration, average level ice thickness, ridge density and average ridge thickness along the routes. The method of obtaining this data is discussed in the following.

In this example, the equivalent ice thickness was used as introduced by Kujala (1994), which relates the equivalent ice thickness to the maximum level ice thickness with the occurrence probability of ridging, and calculated based on the geometric definition based on ice cross sectional area along the track and in a modified form. The equivalent ice thickness used was as follows:

\[ h_{eq} = C h + k \mu l \]  

(1)

Where the ice coverage is \( C \), level ice thickness is \( h \), average ridge thickness \( H_r \), ridge density is \( \mu \) (ridges per linear horizontal distance, unit 1/km), and \( k \) ridge shape constant.

For the example simulation, a route to the ice covered Northern Baltic from the Southern ice edge was used and specifically a voyage to the
port of Kemi, Finland. The ice parameters were determined based on the data and distributions presented in Leppärinta et al. (1988). Here the mild value of $h_{eq}$ may be noted to approximately correspond to 10% of the data recorded over the years and the value of severe to 90% of cases. The ice data are given in Figure 1.

![Figure 1](image1.png)

**Figure 1 – Equivalent ice thicknesses for winter conditions to Kemi (Northern Baltic)**

**Analysis of the Transit Speed**

A multi-purpose icebreaker was used in the ice transit simulation with the following main dimensions:

- Length, between perpendiculars: 75.20 m
- Breath, moulded: 18.00 m
- Draught, max icebreaking: 6.50 m
- Power output: 13 440 kW

The specification value of the vessel performance in ice is with an ahead speed of 3.0 knots in 1.0 m level ice. The ship speeds were calculated using the ship-ice speed relationship, so called ‘h-v curves’, from full scale data during ice trials, as reported by Riska (2001), and using the equivalent ice thickness to get the ships speed in knots. Results are shown in Figure 2.

![Figure 2](image2.png)

**Figure 2 – Average speeds for mild, average and severe winter conditions**

It may be noted that the possibility of the ship getting stuck is not considered in this method of ship’s speed estimation, as the use of the equivalent ice thickness ignores the ridges, and the related variability of the consolidated layer thickness. Typically, the inclusion of ice ridges in the ice cover can make the ship stop and then continue with the very low speed whereas using the equivalent ice thickness the ship speeds never dropped below about 2 knots.

**Influence of Operating Variations**

To provide an insight into the operational performance on the transit route, the ‘active’ navigation, which is defined here as the navigation act of avoiding the worst ice conditions, was taken into account and the transit speeds adjusted for this aspect.

The simulation, in Figure 2, was carried out assuming the ship to proceed along a straight route i.e. without avoiding the worst ice conditions. It is clear that both shipborne observations and the use of satellite images and other ice information products enable the ship to avoid the worst ice conditions. The drawback of these deviations from the direct route is that the distance travelled becomes longer.

There is not much quantitative knowledge about how much easier the ice conditions get by navigating actively nor about how much longer the distance travelled becomes. In Tunik (1994) it is stated that the encountered ice thickness becomes about 50 to 65% of the region specific ice thickness. Further, some trafficability studies, such as Lensu (1998), have indicated an elongation of some 30%. This elongation is probably dependent on ice conditions, in worse conditions more ice avoidance is required.

Here the assumption is made that the encountered ice thickness is reduced based on active navigation, by the introduction of $C_{in}$, and that in worst ice conditions the route becomes longer, which is taken into account by $C_{di}$. $C_{in}$ is derived as a multiplication increase in ship speed in relation to the open water speed, whilst $C_{di}$ is taken into account as a reduction by calculating a geometric distance increase circumferentially in turning the ship with a set angle. Thus if the speed in direct navigation i.e. original result is $v_{ow}$, and $v_{in}$ is the open water speed, then the new speed based on active navigation may be expressed as follows:

$$v_{active} = \frac{(1-C_{in})+C_{di}v_{in}}{C_{di}-C_{in}}v_{ow}$$  \hspace{1cm} (2)

The effect of the active navigation is shown in Figure 3 for the example transit simulation to Kemi. The ‘direct’ route is shown as a baseline for comparison, being the same as in Figure 2 for the severe winter. The influence of increased route, $C_{di}$, was introduced based on a maximum arc length with 35 degree radian, and is seen as ‘route+$v$’ which assumes the same ice conditions, but a greater distance travelled, and thus a slower speed is observed. The application of the ice thickness reduction, $C_{in}$, is seen as the plot ‘active’ and a corresponding increase in navigation speed. This is further highlighted by ‘heq-10%’, which has a reduced equivalent ice thickness, $h_{eq}$, by a further ten percent.

![Figure 3](image3.png)

**Figure 3 – Speed increase from active navigation in a severe winter**
SUMMARY

Performing work effectively and efficiently on a ship in conditions of extreme ice, while ensuring personal and vessel safety, presents many and varied hazards and challenges. This paper has presented an overview of the types of hazards, their potential effects, and some of the methods which can be applied to transit simulations.

A simulations study for a ship transit along a section of the Baltic Sea included the calculation in ice conditions and a relationship between equivalent ice thickness was developed. Further the transit simulation was modified to investigate the adjustment of the operational parameter of active navigation.

This paper principally discusses the hazards and risks associated with navigation in ice, and the affects of sea ice on the ship and systems. However, it should also be noted that operations in ice covered waters also may create additional risks. For example, the additional weight from ice accretion can also affect the draught and trim of the ship, leading to a reduction in propeller immersion and possibly the loss of manoeuvrability. Equally, cyclonic weather in high latitude regions often experience extreme wind and wave conditions. Rough sea states make controlling and manoeuvring the ship more demanding and less predictable.

It is vital to take proper account of the role of people in this system, including the varied physical and psychological factors which can influence performance. A risk assessment and performance management approach to the operation in cold climates should thus incorporate both the ship systems and human performance aspects.

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THE INFLUENCE OF OPERATIONAL RISKS FOR ICE TRANSIT SIMULATIONS

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**INTRODUCTION**

- Significant efforts are frequently made to ensure ships are designed and constructed for the anticipated ice conditions...
  
  ...however, operational aspects play a crucial role in mitigating risks and avoiding hazards in ice transits

- This paper presents outline of some of the operational situations that may occur during ice navigation and included in risk management approaches

- Focuses on the influence on how the operations can be applied to ice transit simulations, with application case study used as an illustrative example to highlight these elements
ICE TRANSIT SIMULATIONS

- The inhomogeneous nature of sea ice creates an uneven level that may extend many meters below the water level, such as ice ridges and edges of old channels, and consequently, ice may alter the transit profile of the ship.

- Navigation in ice may also create unexpected restrictions of movements that may lead to unavoidable delays. This can lead to deviations from routes.

- Should conditions deteriorate, the ice channel may close in due to the moving ice field. In this situation, the ship may get stuck.

- Thus, it is important to understand and account for these variables in voyage simulations.
The focus of ice transit simulations has often been based on the mechanisms and performance of ice-hull/propulsion interactions, such as Riska et al. (2001) and Kotovirta et al. (2009), and many others.

However, some studies on details of transit voyages have provided an insight into some of the operational aspects of ice navigation.

Tsoy et al. (1999) investigated transits along the Northern Sea Route. The following reason for damage was cited:

‘...poorly selected tactics of the icebreaker escorting, and errors of operators in the choice of the speed of movement of ships through ice.’
Traditionally, vessels were constructed with lower power and strength, however, bigger, stronger and more powerful ships have since been constructed for ice navigation.

Additionally, there has been an increase in the number of commercial ships operating in ice covered waters.

The operations of these ships differ, in ship types, sizes and capabilities.

This leads to a risk profile change, which may not be fully understood, or extrapolated from limited historical data, in applicability and sufficient numbers, which can lead to uncertainties in transit simulations.
Operational risks can have a significant influence on ice navigation

- Ship speed
  - The experience of the Master to assess the ice conditions may contact ice with too high speed, as outlined by Maksutov and Popov (1981), or conversely become beset if proceeding too slow

- Handling of the vessel
  - The ability to sail around dangerous ice features or use leads in ice can reduce the likelihood of speed loss/change

- Knowledge of the local ice conditions
- Provision of ice charts
- Detection of ice and ridges

Risk level may differ depending on the geographical location, time of the year with respect to daylight and ice-coverage etc. Here, Jalonen et al. (2005) provides a useful insight into many of the risk aspects for Baltic winter navigation

Potential rapid rate of change in addition to the severe multiple hazards may, when acting together, present a synergistic risk level that is greater than the sum of the specific individual risks normally considered when evaluating risk mitigation measures

- For example crew fatigue, combined with loss of visibility due to snow storm, darkness and being in rapidly changing conditions such as ice drift
A good understanding of the hazards and interrelationships will provide a solid foundation for the approach taken in the assessment.

Navigation in ice may reduce certain risks compared to open water operations due in part to the operating environmental conditions and enhanced mitigation measures.
- The ships generally proceed at slower speeds.
- Preparedness of the crew.
- Reliability and redundancy of systems on the ships and of the crew procedures.
- Crew tend to be skilled through dedicated ice training courses and simulations, which are often complimented with knowledge and experience.

Inclusion of planned maintenance systems in transit simulations, such that substantial tasks are carried out before entering cold climate regions, or embarking on long voyages within them.

Damages due to ice navigation are often repaired during the periodic dry-docking and considered as part of a normal ship maintenance process ...
... however, ships systematically navigating in ice, as well as icebreakers, tend to have a higher frequency of dry-docking (annual - RMRS Rules 2014).
The goal of the study was to determine the time for a ship to travel along a section of the Northern Baltic, from the South to the North (or vice versa).

The study was based on equivalent ice thickness for each month, and applying the ship’s ice performance from full scale ice data, to calculate the speed in each ice thickness, and then estimate the duration of the voyage, knowing its distance.

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...risks in Baltic navigation will differ from other ice covered regions. For example, transits will be dependent on ice conditions, and in worse conditions more ice avoidance may be required than would be for the Baltic. The following simulations have been made to allow an insight into the sensitivity of the transit times due to these risks and to illustrate the effect they may have, but the specific regional application and vessel characteristics should be borne in mind.
ICE CONDITIONS DATA

- This can include various parameters, such as the ice concentration, average level ice thickness, ridge density and average ridge thickness along the routes.

- Equivalent ice thickness was used, which relates the equivalent ice thickness to the maximum level ice thickness with the occurrence probability of ridging, and calculated based on the geometric definition based on ice cross sectional area along the track and in a modified form.

\[ h_{eq} = C h_i + k \mu H_R^2 \]

Where the ice coverage is $C$, level ice thickness is $h_i$, average ridge thickness $H_R$, ridge density is $\mu$ (ridges per linear horizontal distance, unit 1/km), and $k$ ridge shape constant.
A multi-purpose icebreaker was used in the ice transit simulation.

The ship speeds were calculated using the ship-ice speed relationship, so called ‘h-v curves’, from full scale data during ice trials, as reported by Riska (2001), and using the equivalent ice thickness to get the ships speed in knots.

Note - the possibility of the ship getting stuck is not considered in this method of ship’s speed estimation, as the use of the equivalent ice thickness ignores the ridges, and the related variability of the consolidated layer thickness. Typically, the inclusion of ice ridges in the ice cover can make the ship stop and then continue with the very low speed whereas using the equivalent ice thickness the ship speeds never dropped below about 2 knots.
INFLUENCE OF OPERATING VARIATIONS

- The simulation was carried out assuming the ship to proceed along a straight route i.e. without avoiding the worst ice conditions
- It is clear that both shipborne observations and the use of satellite images and other ice information products enable the ship to avoid the worst ice conditions. The drawback of these deviations from the direct route is that the distance travelled becomes longer
- Introduction of ‘active’ navigation which is defined here as the navigation act of avoiding the worst ice conditions, was taken into account and the transit speeds adjusted for this aspect
- There is not much quantitative knowledge about how much easier the ice conditions get by navigating actively nor about how much longer the distance travelled becomes
- In Tunik (1994) it is stated that the encountered ice thickness becomes about 50 to 65% of the region specific ice thickness
- Further, some trafficability studies, such as Lensu (1998), have indicated an elongation of some 30%. This elongation is probably dependent on ice conditions, in worse conditions more ice avoidance is required
ACTIVE NAVIGATION

- Here the assumption is made that the encountered ice thickness is reduced based on active navigation, by the introduction of $C_{vi}$, and that in worst ice conditions the route becomes longer, which is taken into account by $C_{di}$.

- $C_{vi}$ is derived as a multiplication increase in ship speed in relation to the open water speed.

- $C_{di}$ is taken into account as a reduction by calculating a geometric distance increase circumferentially in turning the ship with a set angle.

- If the speed in direct navigation i.e. original result is $v_{0}$, and $v_{ow}$ is the open water speed, then the new speed based on active navigation may be expressed as follows:

$$v_{active} = \frac{(1 - C_{vi}) + C_{vi} \frac{v_{0}}{v_{ow}}}{C_{di1} - C_{di2} \frac{v_{0}}{v_{ow}}} v_{ow}$$
The ‘direct’ route is shown as a baseline for comparison, being the same for the severe winter.

The influence of increased route, $C_{di}$, was introduced and is seen as ‘route+’ which assumes the same ice conditions, but a greater distance travelled, and thus a slower speed is observed.

The application of the ice thickness reduction, $C_{vi}$, is seen as the plot ‘active’ and a corresponding increase in navigation speed.

This is further highlighted by ‘heq-10%’, which has a reduced equivalent ice thickness, $h_{eq}$, by a further ten percent.
Performing work effectively and efficiently on a ship in conditions of extreme ice, while ensuring personal and vessel safety, presents many and varied hazards and challenges.

A risk assessment and performance management approach to the operation in cold climates should thus incorporate both the ship systems and human performance aspects.

A simulations study for a ship transit along a section of the Baltic Sea included the calculation in ice conditions and a relationship between equivalent ice thickness was developed. Further the transit simulation was modified to investigate the adjustment of the operational parameter of active navigation.

Further development in ice navigation and cold climate aspects to be considered:
- Additional weight from ice accretion can affect the draught and trim of the ship, leading to a reduction in propeller immersion and possibly the loss of manoeuvrability.
- Cyclonic weather in high latitude regions often experience extreme wind and wave conditions.

It is vital to take proper account of the role of people in this system, including the varied physical and psychological factors which can influence performance.
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