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ARTICLE

Practice Study on Operation Evaluation and Limitation for Merchant Ships in Polar Water

Shifeng Ding[1] Li Zhou[1*] Chenkang Zhong[2] Zhengrong Wang[2]

1. School of Naval Architecture and Ocean Engineering, Jiangsu University of Science and Technology, Zhenjiang, 212003, China
2. Shanghai Rules and Research Institute, China Classification Society, Shanghai, 200135, China

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ABSTRACT

All environmental hazards impact the safety of polar ships, especially polar merchant ship with light ice-class. In order to provide a systematic guidance to deal with any situation during polar operation, International Maritime Organization (IMO) raised mandatory requirements of "Polar Water Operation Manual"(PWOM) in Polar Code. This paper focuses on how to determinate operational evaluation and limitation for the PWOM, which is an important measure to avoid polar ships exceeding operational capability. Features of polar navigation are summarized based on the former polar navigation experience, and typical risk model is set up to describe the process of operation evaluation. The operational limitation is analyzed to indicate the actual capability and limitation as the ship encounters unexpected accidents in polar waters. In conclusion, the operation procedure is studied to give a detailed technical proposals for the whole polar operation, which is the main component of PWOM. The outcome may provide help for to arctic shipping of merchant ships.

1. Introduction

As arctic ice coverage decreases with global warming, more and more merchant ships want to use arctic shipping routes in summer [1, 2]. The arctic shipping has great value for reducing shipping cost, increasing shipping safety, saving energy and reducing emission. However, polar navigation is quite different from conventional one since it needs the maritime industry to be more cautious. International Maritime Safety Committee (IMO) ninety-fourth session formally adopted "International Code for Ship Operating in Polar Waters (Polar Code)" [3], and it came into effect on January 1, 2017. "Polar Water Operation Manual (PWOM)" is one of the main parts of Polar Code, which is a compulsive requirement from IMO. The PWOM explains ship operational limitation and operation procedure to captain and crew, and it is an important measure to guarantee the safety of polar shipping.

Polar navigation has additional hazards[4,5] besides conventional situation. In 2013's summer, a Chinese merchant ship named "Yongsheng" successfully sailed through arctic northeast channel[6], and it attracted more merchant ships to attempt the arctic navigation. As the IMO's Polar Code took effect on January 1, 2017, all polar merchant ships must prepare the PWOM[7-8], including ship's ca-

**Corresponding Author:*
Li Zhou,
School of Naval Architecture and Ocean Engineering, Jiangsu University of Science and Technology, Zhenjiang, 212003, China;
Email: zhouli209@hotmail.com

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pability and limitation, procedures for normal operation, special procedures for accident, measures for the use of icebreaker assistance etc. It is a realistic question to prepare the eligible PWOM for all shipping companies that want to attempt polar voyage.

This paper studies on the merchant ship's operational evaluation and limitation in polar water. The existing arctic navigation experience was summarized, including Xuelong ice-breaking research ship and Yongsheng ice-strengthened merchant ship. The operational evaluation method was studied based on the key factors which affected the safety of arctic navigation. A series of risk analysis models were set up to simulate the scenes during polar operation. Then the operational capacity and limitation was analyzed to reduce the risk level of polar operation when the ship encountered accident. As a conclusion, the operation procedure was established to direct the whole polar navigation process, which is the key to form PWOM. Eventually, the outcome was verified by the followed polar shipping voyages, and it was a technical basis for the implementation of the IMO's Polar Code.

2. The Features of Polar Navigation

The polar environmental condition is harsher than conventional waters, geographical location of the former is remote, and ecological environment is fragile [9]. Thus, the polar ships face higher risk level than conventional ships, and the situation also was varied with geographical location, air temperature and ice cover and other factors. The requirements of PWOM in Polar Code only include the targets, functional requirements and risk based operating procedures in Polar Code. However, it is necessary to develop a detailed technical method on how to prepare the qualified PWOM related to ship types, ice conditions and expected operating area.

The existing practical experience for ships was summarized, including Xuelong and Yongsheng (see figure1). The key steps were applied for polar navigation assessment, as shown in figure 2.

Figure 1. Polar navigation of Chinese ship

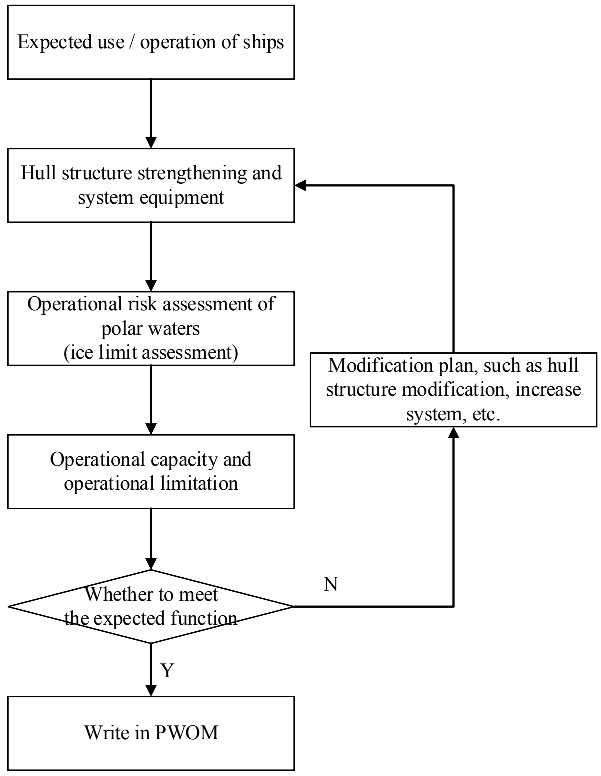

Figure 2. Key steps for polar navigation assessment

From Figure2, polar navigation was function oriented, which was distinguished from conventional navigation. The main features were presented as follow. The relationship was very close among operational measures, expected task and the ship's operational capability. The hull structure and system equipment was specially evaluated to be suit for the ice condition and low air temperature. All the hazards were studied to determinate the risk level during the polar navigation. The possible measures have been planned ahead to improve the safety when the ship encounter the unexpected polar environment.

In order to gain the qualified POWM, all features mentioned above should be fully considered to develop a method on operational evaluation and limitation. The method could be divided into three parts: how to carry out the operation evaluation, how to determinate the operational capacity and limitation, and what should be done when the ship exceeds its limitation. These issues will be studied further.

3. Operation Evaluation Method

The operational evaluation of polar ships and system equipment should be conducted to constitute the contents of the polar ship certificate. The intact operational evaluation is consisted of ice status, temperature, high latitudes and other hazards. There were four steps for the operation-

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al evaluation process: identifying risk, formulating a risk model, assessing and determining risk acceptability, identifying existing or developing risk control alternatives.

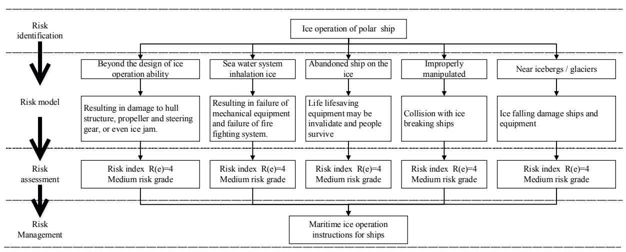

Figure 3. Risk analysis process for polar ship

The ice operation was taken as an example to illustrate the flowchart of risk analysis process as shown in Figure3. From figure 3, the operational evaluation was made up of a series of risk analysis processes. There were about 10 main sources of hazards listed in IMO's Polar Code, including sea ice, experiencing topside icing, low temperature, extended periods of darkness or daylight, high latitude, lack of accurate and complete hydrographic data and information, potential lack of ship crew experience, lack of suitable emergency response equipment, rapidly changing and severe weather conditions, sensitivity environment. All anticipated hazards should be analyzed to reduce their impact on polar ship and polar environment. Considering the expected hazards, several risk models were built respectively separated from the whole ship system. The risk assessment was analyzed to indicate the different risk level, and then some proper measures were studied according to severity of consequences.

4. Determination of the Operational Limitation

The polar operation of the merchant ship was limited by four main factors, including sea ice, low temperature, high latitude and ship's endurance. Sea ice may destroy the hull structure and trap ship, and it is a crucial factor for a merchant ship to choose the arctic route. Low temperature threats to the life-saving and fire-extinguishing systems, and it may also appeared in summer arctic water occasionally. High latitude affects the communication and navigation systems, which take a vital role in the safety of polar navigation. Ship's endurance directly affects the distance and time of whole polar voyage. All these factors should be studied.

4.1 Polar Operation against Sea Ice

The ship's ice operational capability is classified according to the ice class rule related to the nominal thickness of a single ice type [10]. This is idealized for ice conditions, which doesn't exist in reality. The actual ice condition is composed of various types of ice and its corresponding density, such as medium thickness of first year ice, old thick ice. However, the ice information received from weather forecast and ship observation is usually inconsistent with the ice-class. Thus, it is necessary to set up a relationship between ice information and ice class for a merchant ship.

In order to ensure the safety of ice operation, there are four assessment methods: Polar Operational Limit Assessment Risk Indexing System (POLARIS) provided by IACS, Arctic Ice Area Navigation System (AIRSS) provided by Canada, Arctic/Time System (Z/DS) provided by Canada and Ice Passport provided by Russia. All those methods could provide the empirical proposal about "going or not going" referring to the given ice condition.

In this paper, we mainly focus on the latest POLARIS. The ice condition is the decisive factor for choosing the ice class. First, operational time and area are chosen according to target task, and ice information is collected for the whole polar voyage. The operation risk index RIO is calculated referring to the worst ice conditions to determinate the suitable ice-class with formula(1)[7,8]. The ship is capable to operate in the ice water when the RIO is larger than zero, vice versa. Additionally, the RIO value may plus 10 with the escort of icebreaker.

$$RIO = (C_1 \times RIV_1) + (C_2 \times RIV_2) + (C_3 \times RIV_3) + \ldots (C_n \times RIV_n) \quad (1)$$

Where: $C_1 \ldots C_n$ are the concentrations of ice types within the ice regime; $RIV_1 \ldots RIV_n$ are the corresponding Risk Index Values for each ice type.

The calculated RIO could indicate the ice operational proposal based on the encountered ice condition. Then some proactive measures could be adopt in advance to avoid the severe ice condition exceeding the ship's ice operational limitation, such as changing navigation time or route, requesting escort of ice-breaker.

4.2 Effect of Low Temperature

All ships with the lowest daily average temperature (LMDLT) below -10 degree are required to consider the operation capacity and limitation of low temperature according to the requirements of IMO's Polar Code. The low temperature may freeze fire-fighting water and impact function of life-saving system. It is a great threat to the ship in emergency. The limitation of low temperature is related to the ship's service temperature (PST), which is lower than the LMDLT-10 degree at least. The definition of LMDLT is shown in Figure4.

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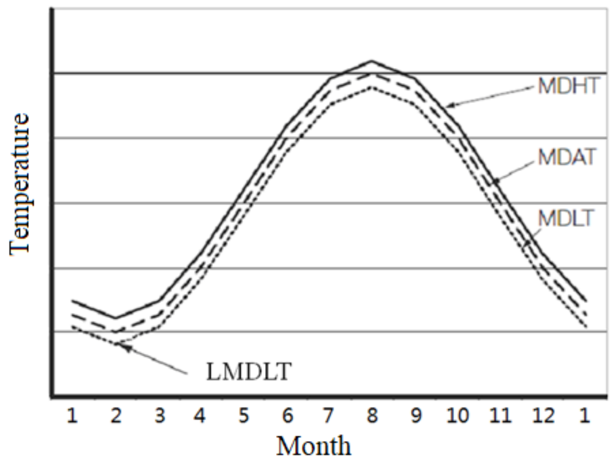

Figure 4. The temperature definition [7]

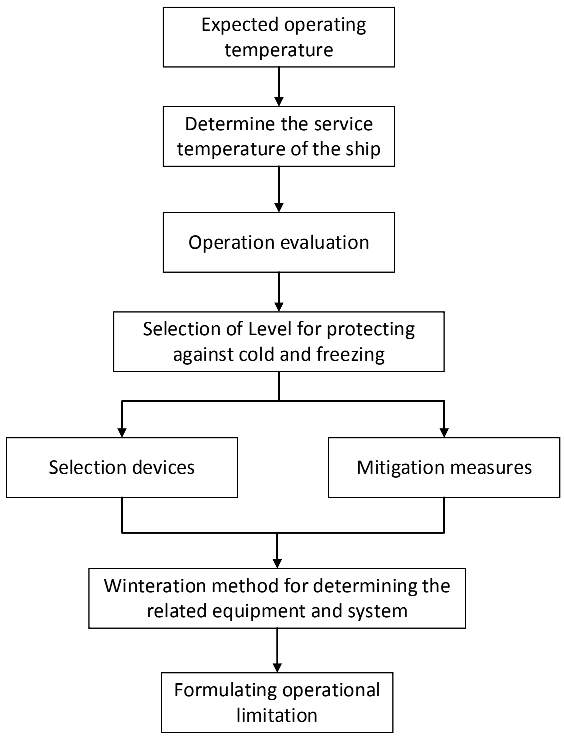

Figure 5. Evaluation process on operational limitation of low temperature

The evaluation process on how to determinate the low temperature limitation is summarized as Figure 5. The lowest temperature in arctic waters is about 0 degree during July to October referring to the existing meteorological data. It is unnecessary to consider the operational limitation of low temperature for a merchant according to the requirement of Polar Code. However, the freezing phenomenon is still possible during the arctic summer voyages. It is wise to adopt some useful de-icing measures, such as hammer, shovel, which could prevent key systems and devices (e.g. life-saving system, escape route) from icing.

4.3 High Latitude

The electromagnetic environment is complex in high latitude area, which impacts the normal use of communication and navigation equipment during polar navigation. According to the existing experience, direction force of the magnetic compass is too weak and unstable at more than 60 degree latitude, and the signal of GMDSS and GPS is unstable at more than 80 degree latitude. That may pose a great risk to polar navigation. It is necessary to equip the reliable communication and navigation equipment for polar voyage at high latitude.

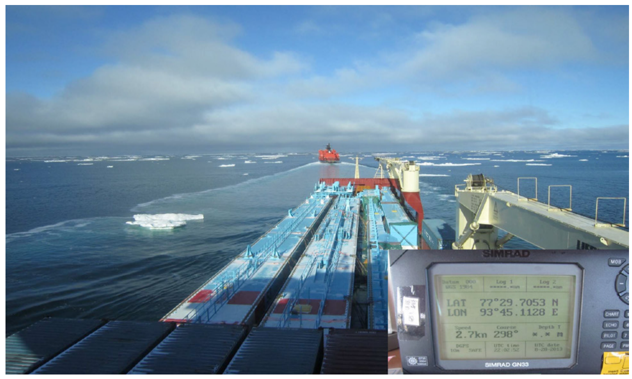

Figure 6. Navigation of merchant ship at high latitude

In general, the highest latitude of a merchant ship's summer arctic route was about 77 degree (see Figure 6). The magnetic compass and gyrocompass are uncertain at that high latitude. Nonetheless, the INMARSAT system and GPS system are available for communication and positioning. The iridium satellite phone would also provide an ideal communication equipment at high latitude. Therefore, all communication and navigation equipment should be examined carefully to ensure applicability at the expected high latitude. It is the guarantee of the safety for polar operation.

4.4 Ship's Endurance

The planned ship velocity [11-15] is influenced by many unexpected factors, such as severe ice condition, unexpected low temperature, dense fog, lack of the escort of icebreakers. It is advisable to plan the ship's voyage carefully to ensure sufficient ship's endurance in polar waters.

The limitation of ship's endurance depends on two factors. One is the storage of fuel, food and fresh water, and the other is the disposal or storage capability of pollutant. Thus, the captain must take management and control of endurance capability into consideration during the voyage plan in polar waters. According to the existing experience, it usually need about 10 days for a conventional merchant ship to cross the northeast passage in summer. The en-

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durance of polar ship should be no less than 1.2×10 days =12days.

5. Operation Procedures

There is no absolute safety in polar navigation, because the unexpected situations may occurr occasionally. Although the ship has been evaluated carefully, the operation procedures must be studied based on risk assessment including conventional operation procedures for normal working scenario and emergency operation procedures for unexpected accident scenario. The process of making the operational procedures is summarized in Figure7.

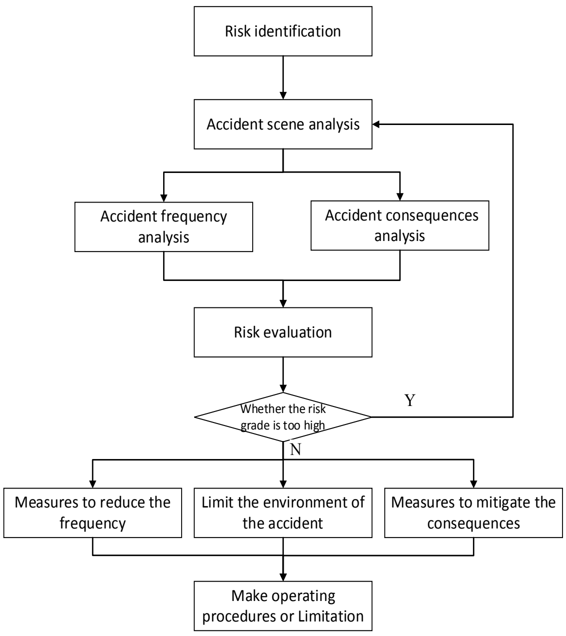

Figure 7. Process of making the operational procedures

The ice operation procedure is taken as an example for a merchant ship with IA ice class. The IA ice class is sufficient for the light first-year ice during summer arctic navigation. But sometimes the thick multiyear ice from the high latitude area may appear at the planed voyage, which is beyond the ice operational limitation of IA ice-class. The risk level could be evaluated according to the dangerous scenario with quantitative risk assessment method (QRA). Some appropriate measures could be adopted in case of the extreme risk level, which includes modifying the voyage plan, strengthening observation of ice condition to reduce the occurrence probability of encountering severe ice condition, optimizing structure to avoid the damage caused by ice impact, requesting the escort of ice-breaker. Eventually, the measures referring to all expected ice conditions should be concluded in the ice operation procedure. The correct operational measures could be chosen from ice operation procedure for the different ice conditions during polar voyage.

6. Practical verification of Arctic navigation

The present method for merchant ship's operational evaluation and limitation was vilified by bi-directional navigation through Northeast Passage of Yongsheng in 2015. Yongsheng ship departed from Dalian port at 8th July 2015, and sailed to north Europe through the arctic Northeast Passage. Then it returned to China at 3rd October after 55 days and nearly 20 thousand nautical miles. That polar voyage plan had a long time period with severe ice condition, which pioneered the first time that China's merchant ships passed through the Arctic Northeast Passage from Europe to China.

At the voyage planning stage, ice condition is the key to choose the ship with ice-class. The worst ice conditions during that polar voyage was collected as Figure8.

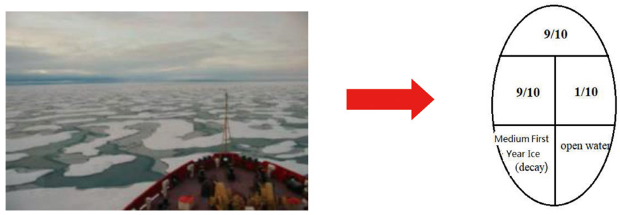

Figure 8. Statistical/expected ice information processing

The calculated RIO values referring to ice-classes were listed in table 1 with POLARIS method.

Table 1. RIO for different ice class ships

Ice Class	RIO Value	Result
PC5	21	P
PC6	21	P
PC7	12	P
B1*/IA Supper	12	P
B1/IA	3	P
B2/IB	-6	N
B3/IC	-6	N

Note: P means the ship is able to ice operate; N means the ship can't ice operate.

The results shows that B1 ice-class is necessary for that specified voyage planning without additional measures. However, ice class of B2 and B3 also could be chosen with especial icebreaker escort. Finally, Yongsheng with ice-class B1 was chosen.

The POLARIS method is also meaningful for ships entering the ice waters. When captain receives the ice information on the route ahead, the RIO value is used to decide the next step of the navigation strategy. During the ice operation in polar waters, the next ice condition in front of Yongsheng was 3/10 medium first-year ice, 6/10 thin first-year ice, 1/10 open water.

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The ice information was analyzed with EGG Code as Figure9.

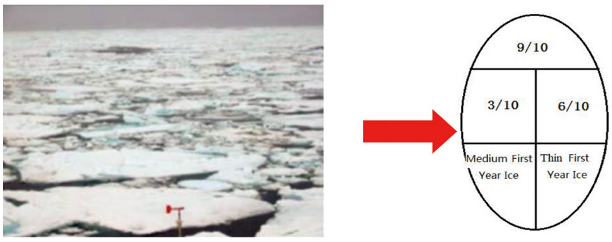

Figure 9. Real-time ice information processing

The calculated RIO value with POLARIS was 6, it illustrated that the ship could sail ahead in the expected ice condition. According to the above method, PWOM of "Yongsheng" ship was formulated based on risk analysis considering all the hazards and corresponding control measures. It played a vital role during the actual arctic shipping and reduced the influence to mariners, ship structure, goods and polar environment.

7. Conclusion

The shipping industry is paying more and more attention to the arctic shipping because of great commercial value and economic benefits. It is very important to study operational evaluation and limitation of merchant ship, because safety is the key for polar navigation. This paper summarizes the previous experience on polar navigation, and presents a method on operational evaluation and limitation. Three practical questions are solved including how to carry out the operation evaluation, how to determinate the operational capacity and limitation, and how to do when the ship exceeds its limitation. The outcome has been used in Chinese arctic shipping since 2015, which has the practical significance of engineering application and shipping guidance.

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