CRITERION FOR COMPARISON OF RISKS AT PLANNING OF NAVIGATION IN ICE CONDITIONS

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ABSTRACT

Navigation in the water areas covered with ice in many cases become complicated in connection with ice conditions decline. It can be connected with compression of ices, visibility decline, wind strengthening, fall of temperature and other reasons. In this case, the person (the navigator, the ship-owner), which makes the decision on a departure of vessel from port or the further movement of a cargo vessel is required to choose one of two variants of the decision. The first variant is the termination of traffic before improvement of ice conditions to comprehensible level. The second variant is departure from port (or continuation of traffic) and movement on a route by self-navigation or with use of icebreaking assistance (ice pilotage). Each of variants differs with expenses (besides cost of ice pilotage) as it is connected with certain risks of the emergency incidents which realization is interfaced to economic losses, which in each of considered variants will be various.
The methodology of comparison of risks is necessary for acceptance of the decision for the purpose of a choice of an optimum variant.
In the report, one of approaches to the decision of the given problem is considered: use of criterion of comparison of risks. That allows considering probabilities of realization of various scenarios of ice conditions, probability of emergency incidents, economic losses because of idle demurrage or repairing work after failure, and readiness of the operator to run risks for acceleration of delivery being onboard cargo.

1. INTRODUCTION

Risk of emergency exists always under the navigation in ice conditions. Consequences with various heaviness are effect of accident: from damages of the ship hull or equipment, spill of transported crude oil or fuel, down to sinking of the ship. On the other hand, connected with demurrage and delay of transported cargo the economic losses accompany the vessel delays in port for waiting of favorable ice conditions. Therefore, adequate planning of ice navigation requires the account of correlation of emergency risk with accompanying economic damages and economic losses because of the forced outage of vessel.

2. STATEMENT OF PROBLEM

Ice navigation is curried out by following variants depending on the complexity of ice conditions:
- independent navigation of the ship among ice fields;

- traffic of the ship within the ice channel created and supported by icebreaker;
- ice pilotage of the ship by an icebreaker;
- navigation as part of caravan that one or several icebreakers hold.

The vessels intended for ice navigation (possessing the ice classification) should have a reinforced of the hull corresponding to own ice class. For each ice class the Ship Classification Societies have established the characteristics of the ice conditions that are admissible for independent navigation or for traffic with pilotage by icebreaker.

At the same time, the risk of emergency incident exists always. Accident can happen even in favorable conditions owing to event of latent defects of the vessel equipment and because of “human factor”, that is because of the navigator’s mistake. At ice navigation, accidents (on base of available statistics) happen owing to unexpected deterioration of hydrometeorological and ice conditions, which concern following:
- caused by wind strengthening drift of ice fields that results in increase the ice concentration and liquidation of fractures between ice floes on which the traffic occurs mainly;
- caused by the same reason the compression of ice floes conducting to the jamming of the ship in ice cover and resulting in increase of ice pressure on the ship hull;
- caused by compression of ice floes the hummocking of ice floes resulting in occurs of hummocks ridges that become an absolute obstacle for independent traffic of usual transport vessel;
- caused by compression of ices the fast filling with ice floes of the navigable ice channel created by the icebreaker that result in sinkage of these ice floes under the vessel hull and their impacts on the propeller-rudder device of vessel;
- deterioration of visibility that complicates an adequate estimation of the surrounding conditions and the distance between the ship and the icebreaker and between vessels in a caravan;
- temperature of air fall resulting in decrease of strength of the hull and deck plating, deck equipments and devices, and towing cables.

In such situations, even good skills of ice navigation cannot prevent the emergency incidents completely. In practice of ice navigation the following damages caused by the specified above reasons occur:
- catastrophic destruction of the ship hull (the heavy hole in plating),
- light holes in the plating of ship hull,
- dents with cracks and goffering of the hull plating with deformation of the ship framing,
- light dents of the hull plating with cracks,
- destruction of the ship superstructures,
- breakages or losses of the propeller blades,
- loss of propelling screw,
- breakage of the propeller shaft and damage of the deadwood,
- deformation of the blade and twisting of the rudder stock.

Ideal weather conditions (the gentle wind, the transparent atmosphere, the open pack ice, etc) are observed very seldom in the Arctic Seas. On the other hand, the time of heavy ice conditions, when only powerful line icebreakers have possibilities for movement and maneuvering, is restricted also. In this range of ice conditions persons (heads), who make decisions, impose some traffic of vessels restrictions: windspeed, ice concentration and other circumstances, or resolve traffic by one of specified above variants of navigation: independent, ice pilotage or other. These persons can be the captain of ship, the captain of port, the captain of caravan or ship-owner.

The estimation of the availability of weather conditions for navigation on the concrete segment of the water area has subjective character always. In many cases, the ice conditions are not represented as favorable for traffic though they cannot be fall to ones, when traffic is not possible absolutely with support by available icebreakers. The route of forthcoming traffic of vessels is long enough in many cases, the rate of sailing among ice fields is not great, therefore weather and ice conditions during navigation of vessels can change towards deterioration or improvement. In this situation, the dilemma appears for the head: to wait desirable more favorable ice and weather conditions or to risk, that is to carry out the traffic at existing conditions with some variant of the icebreaker pilotage.

Waiting of desirable weather is accompanied by financial losses because of the demurrage time of vessels and icebreakers, outage of cargo terminal, and because of the missed incomes of ship-owners and cargo owners as result of untimely delivering cargo to the customers. On the other hand, the navigation in heavy ice conditions is accompanied by the higher risk of accident that defined by financial losses for liquidation of effects of accident, including the possible emergency spill of transported crude oil or fuel.

Therefore, some objective formalized criterion is necessary for planning the navigation in ice conditions that will allow making the proved decision about:
– an independent navigation of ship under existing weather and ice conditions,
– usage of ice pilotage by icebreaker,
– some delay and then the trip as part of a caravan of vessels under support of icebreakers,
– waiting of favorable (admissible for the given ice class of ship) ice conditions and about admissible term of the ship idleness.

3. THE COMPLEX RISK FACTOR OF ICE NAVIGATION

As such objective formalized criterion it is offered to apply ***the complex risk factor of ice navigation*** (CRFIN). This parameter allows taking into account the probability of the reasonable ice and weather conditions variants realization, connected with these conditions and other circumstances probability of an emergency incident, the probable expenses for liquidation of accidental effects and financial losses at idle time in expectation of the ice conditions improvement. The similar approach was offered earlier for an estimation of risk of the accidental oil spill when the tanker bunkerage at located on a sea shelf terminal (see Goncharov, 2004).

The construction and use CFRIN scheme is considered on a following example: the decision-making on a departure of the ship in trip with icebreaker pilotage, or about waiting of favorable conditions for the subsequent independent navigation in ices.
Mathematical expression for calculation of the complex risk factor of ice navigation value has following form:

$$F_{rin}^{c} = n\,S\,P_m^d - E_{ib} - K_{pr} \cdot \left[P_{ac}\,E_{ac} - P_{op}\,E_{op} \right] \cdot C_p . \qquad (1)$$

The first item in the right part of expression characterizes the probable financial losses when the ship stands idle in a port. The second item E_{ib} is the economic expenses in case of a departure in trip with usage of the icebreaker pilotage. In the third item E_{ac} - expenses for liquidation of consequences of probable emergency incident on a route of forthcoming navigation and E_{op} - expenses in case of accident at navigation in favorable ice conditions are considered.

In the first item: *n* – planned term of demurrage (amount of days) until the ship departure in trip when favorable ice conditions; *S* – financial losses as result of every day of demurrage in a port. Pointed financial losses include, for example: the cost of 1 days of the vessel operation - s_f, the cost of 1 days of the vessel stay in a port – s_p, the missed profit because the delayed delivering of transported cargo - s_c, etc., that is

$$S = s_f + s_p + s_e + \ldots \qquad (2)$$

Further, $P^d{}_m$ is the probability of that on $(n+1)^{th}$ days after decision-making on delay of ship in a port the ice conditions on the traffic route will appear really suitable for independent navigation of ship. That means, the ice conditions will correspond to some desirable combination of parameters that characterize the ice and weather conditions - *w* at the level – *m*. Into amount – *d* of these parameters following items enter an ice concentration and hummocking, a wind direction and its speed, an air temperature, visibility and others. Probability $P^d{}_m$ is defined, obviously, by the join probability of realization *w* parameters of the weather and ice and weather conditions at level *m* at $(n+1)^{th}$ day following after planned demurrage.

$$P_{mn}^{d} = q\left(w_1^m \cap w_2^m \cap \ldots \cap w_d^m \right) \tag{3}$$

In the presence of the hydrometeorological service's forecast about the improvement of ice and weather conditions up to level *m* through *n* days, this value is the statistically established item in the previous period. It can be the accuracy of the n-days weather forecast, produced by the hydrometeorological station that services a port and route of vessels traffic.

The second item in the right part of formula (1) represents the expenses connected with the trip of ship with use of ice pilotage by icebreaker - E_{ib}. If do not consider a consequences of probable emergency, then decision about the departure in trip is defined by comparison of losses from demurrage with cost of icebreaker pilotage.

The third item in the right part of formula (1) estimates the risk of emergency incidents with vessel, where the probability of an accident and expenses for liquidation of its consequences are considered. The probability of an emergency incident exits always, therefore expenses for liquidation of probable accident in the heavy ice conditions at icebreaker pilotage E_{ac} should be reduced by the value of economic losses E_{op} , that can appear in case of accident with the ship in favorable ice conditions when independent navigation, that is impossible to exclude.

Emergency incident when the ship navigate in the favorable ice conditions, which probability is P_{op}, can happen owing to probable latent defects of ship equipment or to the navigation mistakes that can lead to collision with other vessel, to grounding, etc. Each of these accidents (total amount *A*) has probability p_i^{op} and is characterized by possible expenses for liquidation of accident effects - e_i^{op}. The following formula gives possibility to calculate the size of the most probable economic damage in case of accident in the favorable ice conditions

$$E_{op} = \sum_{i=1}^{A} e_i^{op} \; p_i^{op} \cdot \left[\sum_{i=1}^{A} p_i^{op} \right]^{-1} . \tag{4}$$

E_{ac} is the probable economic damage of accident under the ice pilotage in unfavorable - heavy ice conditions. It develops of two components: from the same components as that E_{op} and with specific to heavy ice conditions and ice pilotage emergencies. Thus it is necessary to consider that probability of each emergency incidents p_i^{ac} in heavy ice conditions, naturally, is more than in the favorable ice conditions, that is $p_i^{ac} > p_i^{op}$, and effect of accidents is heavier. Therefore the economic damage from each probable emergency incident e_i^{ac} becomes also more. Specific for ice conditions accidents: damages of the hull plating, propeller screw, rudder, etc., (total amount *B*) have probability p_j^{ac} each. Liquidation of effect of these accidents demands expenses p_j^{ac}.

Considering stated, the most probable economic damage in case of emergency incident at ice pilotage by icebreaker in the heavy ice conditions is defined as follows

$$E_{ac} = \left[\sum_{i=1}^{A} e_i^{ac} \; p_i^{ac} + \sum_{j=1}^{B} e_j^{ac} \; p_j^{ac} \right] \cdot \left[\sum_{i=1}^{A} p_i^{ac} + \sum_{j=1}^{B} p_j^{ac} \right]^{-1} . \tag{5}$$

it is necessary to carry out analyze of the accessible statistical data about the breakdown susceptibility of vessels at the ice navigation in order to evaluate the probability of each probable emergency incident: p_i^{op}, p_i^{ac} and p_j^{ac},. It is possible obviously to estimate the probable expenses for liquidation of their effects: e_i^{op}, e_i^{ac} and e_j^{ac}, applying the method of expert system.

Coefficient K_{pr} in formula (1) characterizes the "assumed" risk, that is readiness of the ship-owner or the cargo carrier to run risk of emergency incident with vessel under navigation in the heavy ice conditions in order to avoid the financial losses because the demurrage of vessel in port. This coefficient lies in a range: $0 \leq K_{pr} \leq 10$. Case $K_{pr} = 1$ corresponds to complete aversion of additional risk (in relation to E_o, existing always) connected with navigation in heavy ice conditions. Case $K_{pr} = 0$ corresponds to complete neglect of risk of accident at realization of trip. C_p is normalizing coefficient defined by the ice class of vessel, specificity of the water area and ice conditions, the crew skills of the ice navigation, etc. At the initial stage it is possible to accept this coefficient $C_p = 1$ and then to specify on the basis of available experience or by modeling.

4. APPLICATION OF THE COMPLEX RISK FACTOR OF ICE NAVIGATION

It is supposed that application of the complex risk factor of ice navigation (CRFIN) will be carried out as follows. To make decision about the ship departure in the trip, obviously, it is desirable to have some spectrum (or set) variants: duration of idle time – risk of emergency incident. This set of variants can be develop, if to mean that in four-dimensional space { P^d_m, n, m, K_{pr}} CRFIN - F^c_{rin} forms hypersurface Ψ_F. Sections of this hypersurface on separate values of P^d_m, n, m or K_{pr}, allow finding the series of three-dimensional surfaces, on which it is possible to select the optimum decision of problem.

For example, for each chosen value $K_{pr} = k_i$ there is some three-dimensional surface $\mathbf{\Omega}_K$

$$\Omega_K\left(K_{pr} = k_f\right) \in \Psi_K\left[P_m^d, m, n, K_{pr} = k_f\right]. \qquad (6)$$

Surface $\mathbf{\Omega}_K(k_f)$ section with a plane $\{P^d_m=p, n, m, K_{pr}=k_f\}$ forms the line bordering an area of some interrelated values n and m, that is function $n = f(m)$ for known accuracy of the forecast of the ice and weather conditions $P^d_m = p$. The nearest to definable by this function the integer value n (from exceedance) is decision of the given problem.

The second possible variant of problem consists in a choice of term of expectation n some situation of the ice and weather conditions m_i that will be favorable for the independent navigation of the ship. In this case, it is necessary to construct the surface

$$\Omega_M\left(m = m_f\right) \in \Psi_M\left[P_m^d, m = m_f, n, K_{pr}\right]. \qquad (7)$$

Surface Ω_M (m_f) section with a plane $\{P^d_m=p, n, m=m_f, K_{pr}\}$ forms the line corresponding to function that connects the term of prospective demurrage n with supposed risk K_{pr}, that is $n = f(K_{pr})$. It allows choosing the term of idle time for the acceptable for the ship-owner risk.
In the considered variant it is possible to choose some differing situations of ice and weather conditions and to obtain the series of curves $n_i = f_i(K_{pr}, m=m_i)$, forming a three-dimensional surface Θ_M intersecting surface Ψ_M. Values of parameters m, n and K_{pr}, on a surface Θ_M located most close to value $F^c_{rin} = 0$ will define an optimum combination of term of the demurrage n, eligible situation with the ice and weather conditions and necessary risk of the ship-owner.

The problem of choice of the eligible ice and weather conditions for the accepted term of idle time and admissible risk can be solved in the same way. For this purpose it is necessary to construct the following surface

$$\Omega_{\mathrm{N}}\left(n=n_f\right)\in\Psi_{\mathrm{N}}\left[P_m^d,m,n=n_f,K_{pr}\right]. \tag{8}$$

Surface $\Omega_{\mathrm{N}}(n_f)$ section with a plane $\{P^d_m=p,\ m,\ n\ n_f,\ K_{pr}\}$ allows to obtain a set of values $m = f(K_{pr})$, that will be the basis for the making decision on choice of the admissible for the ship departure in trip ice conditions under the chosen by ship-owner term of idle time and admissible risk of emergency incident.

In some simplified statement, it is possible to illustrate the application of CRFIN as follows. First of all, it is necessary to pay attention when the decision on the ship departure in trip under ice conditions favorable for the independent navigation it is appear that

$$P_{ac}=P_{op},E_{ac}=E_{op},E_{ib}=0,S=0,n=0,\quad u\quad F_{rin}^c=0. \tag{9}$$

That means CFRIN is equal to zero though the risk of accident remains. If the ice conditions mismatches to a desirable conditions, according to the forecast of the ice and weather conditions improvement to some level m will come in $(n+1)^{th}$ days the value CFRIN is calculated. If the following result takes place

$$F_{rin}^c\geq 0, \tag{10}$$

the expected financial losses because of the ship demurrage in a port during n days exceed the probable expenses for the ice pilotage and liquidation of the probable accident effects.

Therefore, it is possible to consider that risk of the ship departure in trip without icebreaker pilotage in under review m_f ice conditions is admissible and defensible. Otherwise, if following result tales place

$$F_{rin}^c<0, \tag{11}$$

it means that cost of the icebreaker pilotage and probable expenses for liquidation of probable accident effects at $(n+1)^{th}$ day under m_f ice and weather conditions exceed the probable financial losses of the ship demurrage in a port. The departure of the ship in trip should be delayed for days or more.

If not to create the hypersurfaces Ω_K, Ω_N or Ω_M and to be limited to such simplified analysis, it is necessary to carry out the corresponding estimations of F^c_{rin} for the next days: $n_1 = n + 1$, $n_2 = n + 2$, …, that will allow to find an acceptable term of demurrage n_f for waiting of ice conditions mf. Calculations for others acceptable mi variants of the ice conditions will allow obtaining admissible terms of waiting. Obtained set of values $[m_i, n_i]$ will create the basis for proved choice of the idle days in waiting of the weather improvement which is admissible for safety of navigation reasons and economic efficiency of cargo transportation.

5. CONCLUSION

At present the computerized methods of the routes of navigation planning, calling in port, cargo operation, etc, based on application of the formalized criteria of the economic efficiency and safety of navigation are more and more widely used in the practice of the transportation of cargo by vessels management. Presented complex risk factor of ice navigation (CRFIN) is the similar formalized parameter. It has as goal the increase in common of the safety of navigation and economic efficiency of cargoes transportation on routes in the Arctic and freezing seas (including the Gulf of Finland). Computer modeling and comparison with real situations in this field should precede the practical application of CRFIN.

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REFERENCES

Goncharov V.K., (2004). “The Complex Factor of Ecological Risk and its Application for Planning the Marine Transport of Crude Oil”. Proceeding of the Twenty-seventh Arctic and Marine Oil Spill Program (AMOP). Technical Seminar. Edmonton, Alberta, Canada. June 2004. Vol. 1. pp. 287 – 293.

Goncharov Vadim K., Klementieva Natalia Yu., Sazonov Kirill E. (2011). “Russian brings experience to winter navigation safety”. The Naval Architect, July/August, 2011, pp. 56 - 58.

Арикайнен А.И., Чубаков К.Н. (1987). “Азбука ледового плавания (Alphabet of ice navigation)”. М.: Транспорт, 1987, 224 с.

Смирнов А.П., Майногашев Б.С., Голохвастов В.А., Соколов Б.М. (1993). “Безопасность плавания во льдах (Safety of ice navigation)”. М.: Транспорт, 1993, 335 с.