ASSESSMENT AND MANAGEMENT OF RISKS IN THE INDUSTRIAL FISHERY

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Abstract. One of tasks of maritime education and training (MET) is preparing maritime specialists for risks assessment and management in navigation. A special approach in MET has to be realized in the field of the industrial fishery because specific types of accidents with fishing vessels may be happened there. The effectiveness of the fishing fleet work depends on the quality of management decisions related to the safety of navigation and fishing. The feature of the work of the fishing fleet is that all operations are performed under the influence of many internal and external factors. Risks assessment and management in the industrial fishery can be made at several stages: preparing a fishing vessel for a trip and elaboration its scenario; calculating the acceptable values of the risk and comparing with risk assessments; developing a plan of organizational and technical measures and calculating its implementation cost. An analysis of possible scenarios of the emergency situations development allows to suggest the structure of practice-oriented tasks for the risk management. Risk assessment based on the theory of statistical decisions allows to find the best ways for actions in conditions of uncertainty. The paper demonstrates an example to assessment and management of risks in the industrial fishery.

1 INTRODUCTION

The risk theory both in the financial/economic and technogenic spheres has developed significantly recent years [1]. Since the 70s of the last century much attention has been paid to the development of scientific tools and technological support of the theory of risks. In particular, the International Maritime Organization (IMO) has adopted a manual on Formal Risk Assessment (FSA) in navigation [2]. Risk management has become objectively necessary in many key areas of activity including human activities at sea. The activity in the area of shipping and the industrial fishery has a risk-bearing character. On estimation of the Food and Agriculture Organization of the United Nations (FAO) [3]: “Fishing at sea is probably the most dangerous occupation in the world. Over 24,000 fishermen die every year. The degree of danger is in part a function of the options of fishers’ choices about the risks they take, such as the weather they fish in, the boats they use, the rest they obtain, and the safety gear they carry. How fisheries are managed may affect the options of fishers and trade-offs as they make these choices – thus affecting the safety of the fishery”. There are a number of economic, environmental, regulatory, and cultural conditions that can influence fishermen’s safety. One way to identify the major hazards and safety patterns present within a fishery is to conduct a risk assessment of that fishery. The results of this assessment can then be used to inform the development of tools and programs designed to reduce fishermen’s level of risk exposure in that fishery [4].

Thus, forecasting, assessing and managing risks become a vital necessity. The fulfilment of these functions requires special training maritime specialists. In this regard the organization of training in the field of risk management is an urgent task that will increase the level of professionalism of maritime professionals and the shore personnel involved in the process of organizing shipping and fishing.

2 IDENTIFICATION OF RISK TYPES IN THE INDUSTRIAL FISHERY

The specifics of fishing incidents are determined by the specifics, the state of the environment and often extreme working conditions (hurricanes, storms, fogs, etc.) of the fishing fleet. According to the review [5] fishing vessels have the second place after cargo ships with total losses over the past decade (Table 1).

Table 1: Annual fishing vessels losses

2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total
34	36	29	21	14	12	13	15	15	9	198

The scope of the analysis [6] was the detection of potential safety issues concerning marine casualties and incidents that involved fishing vessels with the length over all greater than or equal to 15 meters that occurred between June 2011 and August 2017. More than 2,400 occurrences were investigated for “Casualty with a ship” and “Occupational accident”. Results of studying these safety areas are shown in Table 2.

Table 2: Casualties with vessels and occupational accidents

Casualty type	Lives lost	Vessel sunk	Accident type	Lives lost	Injured people
Collision	46	21	Fall of persons	20	227
Listing/Capsizing	45	14	Shock, fright, violence	0	6
Vessel foundered	39	44	Other	2	64
Grounding/Contact	16	17	Loss of control	10	209
Flooding	9	31	Gas or liquid effects	5	34
Loss of control	6	10	Electrical problem, fire	0	5
Damage to vessel	3	3	Breakage, bursting	4	99
Fire/Explosion	3	15	Body movement	8	250

The number of accidents in the first half 2018 with Russian fishing vessels [7] was already 22 cases while in 2017 and 2016 for 35 cases, 23 in 2015, 9 in 2014 and 16 in 2013. Total losses of vessels were as follows: in 2010 - 6; in 2011 - 6; in 2012 - 7; in 2013 - 2; in 2014 -

1; in 2015 - 4; in 2016 – 2; in 2017 – 3; in the first half 2018 - 1.

A fishing vessel operates usually at limited water areas with a large number of other vessels. As it is seen in Table 2 the main types of accidents with fishing vessels are the same as for other vessels. But there may be also specific types of accidents such as: snagging of fishing gear and their loss; failure of a hydroacoustic equipment; loss of fishing gear with the hook on reefs or underwater rocks; winding nets or ropes on the screw; pile when mooring the board of a transport ship, etc. It should be noted that the probability of emergencies and accidents with fishing vessels is higher than with transport/merchant vessels. This is evident from the fact that the work of the fishing vessel includes such stages as a trip to a fishing ground, catching, loading, unloading and bunkering operations, etc. directly at sea. Risks that may arise for the fishing vessel during these operations are recommended to assess and identify when preparing the vessel at a port to the fishery, as well as to define cause-effect relationships.

Risks assessment and management in industrial fishery can be realized at several stages.

At the first stage, it is necessary to determine the composition and to analyze the information needed to know conditions of the forthcoming trip and to study previous accidents at the areas of navigation and fishing. The following differentiation of sources of causes of emergencies is suggested:

– the human factor as a source of accident causes is characterized by the skill level of operators (navigators, pilots, dispatchers, etc.) and the level of their psychophysiological stability;

– technogenic factors which are characterized by technical condition of the vessel, machinery and mechanisms, navigation and fishing equipment, etc.;

– hydrometeorological and oceanological conditions [8].

At the second stage, a scenario for the trip of the fishing vessel is developed. The stages of the trip are considered in the context of "sources of accidents - causes - risks - possible consequences". A set of processes and conditions with logical links between them represents a generalized model (scenario) of arising and developing emergencies and accidents with the fishing vessel. This scenario includes the following main stages: preparation the vessel at the port for work when fishing; the trip of the vessel to the fishing ground; searching fish schools, fishing (catching); loading /unloading and bunkering at sea; transportation the catch to the transport/refrigerating ship or to the port. An example of such scenario (not full) with some stages is presented in Table 3. Then an analysis of the scenario is carried out. It allows to identify possible risks during the forthcoming trip. Risk priorities (ranking) are defined. Qualitative and quantitative risk assessments are determined. An integral risk assessment is calculated. An example of calculating risk assessments is given below.

Table 3: Example of a fishing vessel trip scenario, sources and consequences of emergencies/accidents

Stage	Accidents source	Causes	Type and character of risks	Possible consequences
1. Port, roadstead	1.1. Improper technical condition of the vessel	1.1.1 Appearance of a hull leak; ballast-drainage system failure; misclosure of holds hatch covers;	Outside/rainwater inflows in compartments	Flooding compartments/ sinking a vessel; damage of the cargo

Table 3 continuation

		1.1.2 Damage of electrical wiring, cables, low insulation of electric motors, oil leaks, etc.	Burning oil products or other materials	Fire. Burnout of compartments or completely the vessel
2. Trip to a fishing ground	2.1 Technical conditions of the vessel (hidden defects).	2.1.1 The same as 1.1.1, 1.1.2		
		2.1.2 Main engine, steering, radio navigation equipment, radar failures	Loss of maneuverability, reducing the level of information support of a vessel navigation	Collision, grounding, flooding. shipwreck
	2.2 Hydro-meteorological conditions	2.2.1 The same as 2.1.2		
		2.2.2 Damage of hatch covers. Destruction of vessel structures (bulwarks, illuminators, etc.), deck machinery and mechanisms, life-saving appliances (boats, rafts)	Breakdown of tightness and strength of the vessel; Loss of stability of the vessel	Flooding holds, destruction of the hull. Shift, damage/loss of cargo. Critical state of the vessel and crew. Loss of the vessell
3. Fishing	3.1 The same as 1.1; 2.1	The same as 1.1.1; 1.1.2; 2.1.2		
	3.2 Technical condition of the radio facilities.	3.2.1 Failure of radionavigation equipment and radiolocation station of echo sounders, hydroacoustic stations.	Difficulties in determining the location of the vessel. Loss of information about the fishing object, the ground condition.	Damage or loss of fishing gear
	3.3 Organization and management of fish school searching and catching	3.3.1 Errors of the choice of fishing grounds and vessel maneuvering with fishing gear	Hook of gears on reefs or underwater rocks; winding nets or ropes on the screw; pile when mooring the board of a transport ship	Possible running aground. Snagging fishing gear and their loss
		3.3.2 Maneuvering errors in the group of fishing vessels	Winding nets or ropes on the screw	Damage of the screw-steering group, loss of speed and control, collision to other vessels, groundings

At the third stage, the acceptable values of the risk are calculated and compared with risk assessments. A decision on the realization of the trip (or other operations) is made. Proposals to realize organizational and technical measures in order to reduce the level of risk are elaborated in a case of the high risk.

At the fourth stage, a plan of organizational and technical measures is developed and its implementation cost is calculated. Also the effectiveness of the measures is assessed.

3 RISK ASSESSMENT BASED ON THE THEORY OF STATISTICAL SOLUTIONS

The use of this method allows to find the best ways for actions in conditions of uncertainty and the associated risk. The uncertainty is often associated with the state of the nature, i.e. the system “man – technics – nature” in the practice of the industrial fishery. The “nature” is the element of the uncertainty in this chain. Only assumptions about possible states of the nature can be made. Whether the decision is profitable in a particular situation can be determined on the value of the risk. The value of the risk can be defined as the difference between the expected outcome of an activity in the presence of accurate data about the concrete situation and the result that can be achieved if these data are unknown exactly.

Let us consider an example [8]. The trip of the fishing vessel to a fishing ground is planned. The expected situation at sea is uncertain. In particular, there are three variants of weather conditions: W_1 – a variable wind of 2-3 points, W_2 – the North-East wind of 3-5 points, W_3 – the West wind of 4-7 points. Three options for choosing the route: A_1, A_2, A_3 are stipulated. The shortest route is A_3. Each of these variants will lead to certain results depending on the weather conditions. Data on probabilities of the weather conditions on the routes are given in Table 4. Speeds of the vessel for the given wind strength for each variant of routes are calculated using these probabilities. Also reducing speeds under the action of wind is taken into account.

Table 4: Probability of weather conditions

Routes	Wind		
	W_1	W_2	W_3
A_1	0.75	0.25	0.00
A_2	0.25	0.50	0.25
A_3	0.00	0.30	0.70

Let us suppose that the speed of the vessel is 15 knots when the “good” weather condition. The route A_1 is 3,300 nautical miles long, the route A_2 is 3,000 miles, and the route A_3 is 2,900 miles. An estimation of the efficiency of the trip routes by the time criterion is given in Table 5. It provides an opportunity to evaluate each variant according to the time criterion under the conditions of the risk caused by weather conditions. The shortest (on the time criterion) route A_2 with the given operating speed of 13 knots is taken as a “standard” variant for the trip. In this case, time required for the trip is equal to 222 hours. The shortest (on the distance criterion) route A_3 takes 284 hours. Therefore, the price of the risk will be in a case of choosing the shortest route: 222 hours - 284 hours = - 64 hours. The choice without any risk is represented by routes A_1 and A_2.

Table 5: Estimation of the efficiency of routes

Routes/ miles	Speed of the vessel, knots			Average weighted estimation of the ship speed	Time of the trip
	W_1	W_2	W_3		
A_1/3,300	15	13	9	14.5	228
A_2/3,000	15	13	9	13.5	222
A_3/2,900	15	13	9	10.2	284

The choice of the best solution in conditions of uncertainty about the situation is carried out under the following variants.

1) The probabilities of possible conditions of the situation are known. In this case a way of actions when the average value of the expected result is calculated, i.e. the sum of the products of the probabilities of the weather types to the corresponding results of the solution of the task is maximal has to be chosen.

2) The probabilities of possible conditions of the situation are unknown but there are considerations about their relative values. It is assumed that any of the conditions of the situation are no more probable than others. Then the probabilities of the various conditions of the situation can be taken equal.

3) The probabilities of possible conditions of the situation are unknown but there are principles and methods of approach to the evaluation of the result of actions that can be represented by the Wald, Savage, and Hurwitz criteria [9].

4 MATHEMATICAL MODEL FOR CALCULATING PROGNOSTIC ESTIMATES OF THE FAILURE OF TECHNICAL MEANS OF A FISHING VESSEL

Hydrometeorological conditions at sea are constantly changed when the fishing vessel operates at a fishing ground, i.e. the nature can be in the states S_1, S_2, S_3, ..., S_i. Long-term statistics [8] shows that the probability of failure of the main engine or the steering device increases under conditions of the unfavorable weather. Since the probabilities of changing weather states do not depend on the time but depends only on the states of S_i, a uniform Markov' chain [9] can be considered here. The probability of the nature transition from the state of S_i to S_j is denoted by P_{ij}. Then the total transition probability can be given by the transition matrix:

$$P = \begin{vmatrix} P_{11} & P_{12} \dots & P_{1n} \\ P_{21} & P_{22} \dots & P_{2n} \\ P_{31} & P_{32} \dots & P_{3n} \end{vmatrix} \quad (1)$$

Elements of the matrix satisfy to conditions:

$$0 \le P_{ij} \le 1; \;\; \sum P_{ij} = 1 \quad (2)$$

where: $i, j = 1,2\ldots$

The unconditional probability that the vessel will be in the state S_i at time T_m is denotes by $P_i(\tau)$. The conditions for the trip may be as follows: S_1, S_2, S_3 .... S_i. This case the set of probabilities $P_i(\tau)$ forms a stochastic vector of the system state:

$$U_\tau = P_1(\tau), P_2(\tau), \ldots, P_i(\tau);\ 0 \leq P_i \leq 1;\ \sum P_i(\tau) = 1 \quad (3)$$

The unconditional probabilities $P_i(\tau)$ for any value of m characterizing the state of the system S can be determined if the vector of initial states is known:

$$U(0) = P_1(0), P_2(0), \ldots, P_i(0) \quad (4)$$

Using the formula of total probability it can be written:

$$U_j(1) = \sum P_i\,(0) \quad (5)$$

In the matrix form this expression can be represented as:

$$U(1) = U(0)P \quad (6)$$

For any τ:

$$U(\tau) = U(\tau - 1)P \quad (7)$$

The total probability of failure of the main engine during the state $U(\tau)$ of the system is calculated by the formula [9]:

$$V_i = \chi_i U(\tau) \quad (8)$$

where: χ_i = probability (frequency) of failure of the main engine, $i = 1,2\ldots$, $\tau = 1,2\ldots$

Let us consider the following conditions during the trip of the vessel as an example for its state assessment [4]: “good” weather conditions (wind of 1-5 points); weather conditions of medium "severity" (wind up to 7-8 points); “difficult” weather conditions (wind of 9-11 points). The probability (the vector) of the failure under the first weather conditions is 0.001, at the second - 0.002, at the third - 0.01. The transitional probabilities can be given as:

$$P = \begin{vmatrix} P_{11} = 0.5 & P_{12} = 0.3 & P_{13} = 0.2 \\ P_{21} = 0.3 & P_{22} = 0.3 & P_{23} = 0.4 \\ P_{31} = 0.2 & P_{32} = 0.2 & P_{33} = 0.3 \end{vmatrix} \quad (9)$$

using statistical data, past experience and expert estimates. It is required to obtain predictive estimates of the probabilistic state of the system in two, three, four, five periods (decades). Initially, the limiting probabilities of the state of the system are established for a sufficiently long period $\tau = 1,2,3, \ldots$ n. Then, the probabilities of failures of the main engine for different states are calculated. Calculations will be made using the formula for the total probability. The theory of Markov’ processes is used to solve the problem. An ergodic Markov’ chain is considered when any state S_i can be reached from any state S_j in a finite number of steps [9]. Using the transition matrix P (9) the vector of initial states is found as: $U(0)$ = 0.5; 0.3; 0.2. The state of the system when $\tau = 1$ is described by the vector:

$$U(1) = U(0)P = [0.5\ 0.3\ 0.2] \begin{vmatrix} 0.5 & 0.3 & 0.2 \\ 0.3 & 0.3 & 0.4 \\ 0.2 & 0.5 & 0.3 \end{vmatrix} = [0.38\ 0.34\ 0.28] \quad (10)$$

The above probabilities define conditions of the trip. After two decades:

$$U(2) = U(1)P = [0.38\ 0.34\ 0.28] \begin{vmatrix} 0.5 & 0.3 & 0.2 \\ 0.3 & 0.3 & 0.4 \\ 0.2 & 0.5 & 0.3 \end{vmatrix} = [0.348\ 0.356\ 0.296] \quad (11)$$

The results of similar calculations after four decades are shown in Table 6.

Table 6: The state of the system when $\tau = 4$

τ	0	1	2	3	4
$U_1(\tau)$	0.50	0.38	0.348	0.340	0.338
$U_2(\tau)$	0.30	0.34	0.356	0.359	0.360
$U_3(\tau)$	0.20	0.28	0.296	0.301	0.302

Let us assume that the vector of initial states has a value that differs from the vector in the previous calculations: $U(0)$ = 0.6; 0.2; 0.2. The results of similar calculations for $\tau = 5$ are shown in Table 7.

Table 7: The state of the system when $\tau = 5$

τ	0	1	2	3	4	5
$U_1(\tau)$	0.6	0.40	0.354	0.341	0.338	0.337
$U_2(\tau)$	0.2	0.34	0.352	0.359	0.360	0.360
$U_3(\tau)$	0.2	0.26	0.294	0.300	0.302	0.302

An analysis of the data in Tables 6 and 7 shows that real probabilities tend to $U_1(\tau)$ = 0.337, $U_2(\tau)$ = 0.360, $U_3(\tau)$ = 0.302 when τ tend to ∞. It can be concluded that for the given matrix of transition probabilities the limiting probabilities of the system states do not depend on the initial states. The total probability of the main engine failure for each period and the weather conditions V_i is calculated by the formula (8): V_1 =0.004; V_2 =0.0031; V_3 =0.0030; V_4 =0.0031. The most important is the probability of engine failures under a severe storm, which offers a real threat of emergencies and accidents.

5 CONCLUSIONS

- The increase of the intensity of navigation and the volume of sea freight traffic is associated with an increase in the likelihood of the accidents occurrence. The development of the industrial fishery activates the necessity of providing the fishing fleet safety during the trip to/at the fishing grounds.
- The scenario method is suggested to define "bottlenecks" when planning the trip of the fishing vessel to a fishing ground, to predict developing emergency situations, to identify tasks which necessary to solve for preacting them or reducing possible negative consequences.
- Mathematical model for calculating predictive assessments of the state of the "vessel-

nature” system and probabilities of technical means failures, in particular the main engine, can be used as an imitation model. It can give a possibility to study the dynamics of changes in the state of the system under different input variables, to choose rational management decisions, including solutions for the risk management.

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