

Optimal Management of Fleet Relocation at Deepsea Fishing Grounds

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Abstract: Methods of the fishing ground efficiency criteria definition, connected with the basic parameters of a vessel's production program, such as a catch volume, producing of food/commercial fish products, profit, etc. are presented in the paper. The structure of criteria reflects the basic conditions of producing and limits of fishery system subsystems: "catch", "catch processing", "material and technical supply of a vessel". These criteria reflect the purposes of the fishing system and means of their achievement. The practical example of calculation of efficiency (usefulness) criteria of a fishing ground for concrete type of a vessel is resulted in the paper.

Keywords: fishing fleet, fishing ground, relocation, efficiency criteria, theory of operations research

1. INTRODUCTION

The problem of fishing fleet or a single vessel relocation arises in connection with a change of fishing conditions at a certain fishing ground. Simultaneously there is a forecast of good fishing conditions at other grounds or subregions and it is required to make a decision, what of them to choose for fishing. As well vessels of various types with different production capacities can catch fish at the certain fishing ground. In this connection fishing operations of some vessels can be effective at one or another fishing ground but less effective for operations at others. Thus, there is a problem of fleet optimal regional allocation at fishing grounds.

This problem have been solved earlier [1, 2, 3] by methods of linear programming taking into account different limitations on using of fishing vessels at certain fishing grounds; on catching by certain vessels' types, on seasonality of fishing, etc. Mathematical models presented there can be realized if there are the planned catch at the fishing grounds and the production plan for each period. These approaches were based on parameters of fishing operation which had a proper to the planned state economics character.

At present, in conditions of the market economics, decision makers have to solve this problem taking into account some basic arbitrarily given parameters of a fishing vessel or a group of vessels production program. It should be noted [4], that the role of expert estimation is not reduced even if there is the mathematical models for catch forecasting and fishing fleet allocation. This is due to the large number of unstable factors, changing fishing conditions, a low reliability of the biological predictions, etc, and, finally, a whole group of such subjective factors as the organizational problems of fishing, personnel problems and some others. One of the latest papers [5] says that a large number of complex cybernetic systems with multi-level structure can be allocated in processes of catching, fishing and in the management of fish stocks. Methods of optimal management theory, systems analysis, theory of operations, mathematical modeling, information theory, etc. are used in the analysis or synthesis of such systems. For example, considering the process of catching fish, management systems of fishing objects, fishing gear, other technical means of fishing in general are allocated. Optimality criteria for solving general and specific optimization problems are usually a combination of several indicators. The problem of decision-making in the management of complex processes and systems is related to the choice of options to achieve management objectives. In general, several variants of many possible are chosen but in the special case a concrete variant of actions is chosen. Selection is made by the decision maker, who has certain rights and powers. This same person is responsible for the consequences of the decisions. Concerning to the problem described in this paper, the decision maker has to optimally allocate fishing vessels at certain fishing grounds.

It is necessary to define efficiency (usefulness) criteria of a fishing ground to resolve the above mentioned problem. Management decisions on the fleet allocation have to be made taking into account these criteria. Generally, a fishing system is represented consisting of several subsystems, such as “a fishing vessel”, “fishing gear”, “fishing objects”, “catch”, “catch processing”, “delivery of production to the port or to a fish factory”, “technical supply of a fishing vessel”, etc. All these sub-systems define fulfillment of the production program and a fishing production quota of the voyage by each fishing vessel. It is suggested [6] that the basic parameters of a vessel’s production program are:

- catch volume,
- producing of food,
- commercial fish products,
- profit.

Also an effectiveness of a chosen fishing ground is connected to these parameters.

2. EFFICIENCY (USEFULNESS) CRITERIA OF A FISHING GROUND

2.1 A fishing ground subregion usefulness on a catch volume criterion

This criterion is defined as a ratio of the expected catch value by a vessel or a group of vessels in time t to the value of the planned catch for this time taking into account time for the vessel (a group of vessels) passage to the fishing ground subregion:

$$F_{1k}^l = \frac{\sum_{i,j,k} W_{im}^l g_{km}^l N_{km}^l k_{km} t^l}{\sum_{k,m} g_{km}^{pl} N_{km}^l (t^l + t_n^l)} \quad (1)$$

where W_{im}^l - a weighted estimate of i fish species in a catch in m way to catch fish at l fishing ground subregion; g_{km}^l - an expected catch value per a fishing day by k vessel type, t/day; N_{km}^l - a number of vessels directed to the fishing ground subregion, units; t^l - fishing operation time of a vessel (a group of vessels) at l fishing ground subregion, days; g_{km}^{pl} - daily (planned) rate of catch by k vessel type with m way to catch fish, t/day; k_{km} - coefficient of actual fishing time usage; t_n^l - time for a vessel (a group of vessels) passage to the fishing ground subregion, days.

Values of W_{im}^l and g_{km}^l - are defined from short-term forecasts of operative fish searching.

It should be noted that this criterion also depends on such factors as the adaptation of catch objects to the type of fishing gear. That is, if fishing vessels have been operated for a long time at the certain fishing ground, for example, with the specific trawl type, some kinds of fish are getting used to the hydrodynamic fields (velocities and pressures) inside the trawl. This case the catch will be probably not effective. This factor is under investigation till now [7, 8].

2.2 A fishing ground subregion usefulness on a food raw material output criterion

This criterion is defined by the formula:

$$F_{2k}^l = \frac{\sum_{k,m} W_{mn}^l g_{km}^l N_{km}^l k_{km} t^l}{\sum_{k,m} g_{km}^n N_{km}^l (t^l + t_n^l)} \quad (2)$$

where W_{mn}^l - a weighted estimate of a food raw in the total mass of the catch; g_{km}^n - a planned value of a raw use for food, t.

2.3 A fishing ground subregion usefulness on a commercial fish products output criterion

This criterion is defined as a ratio of an expected commercial fish output in value terms to the planned value of this parameter. This criterion can be designed in the following way. A vessel or a group of vessels are directed conditionally to the fishing ground subregion.

$$N_{km}^l \leq N_{km_{acc}}^l \quad (3)$$

where $N_{km_{acc}}^l$ - acceptable number of vessels for simultaneous fishing at the fishing ground subregion.

Then an expected catch value for duration of vessels stay at fishing ground l is calculated. Also a value of a criteria function on the maximum cost of a commercial output for a vessel or a group of vessels is calculated using a linear optimization model. In general, the model has the form:

$$\sum_{i,j,k,m} c_{ij} x_{ijkm} \rightarrow \max \quad (4)$$

$$\sum_{i,j,k,m} a_{ij} x_{ijkm} \leq \sum_{i,k,m} W_{im}^l g_{km}^l N_{km}^l k_{km} t^l \quad (5)$$

$$\sum_{i,j} x_{ijk} \leq \sum_{i,j} C_{ijk} \quad (6)$$

$$\sum_{i,j} x_{ijk} \leq \sum_{i,j} P_{ijk} \quad (7)$$

where $x_{ijkm} \geq 0$ – a value of fish products of j assortment made of i kind of a fish raw, caught by k type of a vessel in m way to catch fish, t ; c_{ij} – a cost of fish products; a_{ij} – a rate of raw consumption; C_{ijk} – capacity of the technological equipment of k vessel type, t /day; P_{ijk} – resources required for fish production, t .

The planned daily volume of commercial fish products is calculated according to the fishing production quota of the voyage:

$$T_{pl} = \sum_{i,j,m} c_{ijkm} x_{ijkm} \quad (8)$$

The criterion is defined by the formula:

$$F_{3k}^l = \frac{\max \sum_{i,j,k,m} c_{ijkm} x_{ijkm} t^l}{T_{pl} (t^l + t_n^l)} \quad (9)$$

2.4 A fishing ground subregion usefulness on a profit criterion

This criterion is designed similar to the criterion F_{3k}^l and calculated by the formula:

$$F_{4k}^l = \frac{\sum_{i,j,k,m} b_{ijkm} x_{ijkm}}{\sum_{i,j,k,m} b_{ijkm} x_{ijkm} (t^l + t_n^l)} \quad (10)$$

where b_{ijkm} – profit from realization of one ton of fish products by k type of a vessel in m way to catch fish.

The structure of criteria F_{3k}^l and F_{4k}^l reflects main conditions of production and limits of subsystems “catch”, “catch processing”, “material and technical supply of a vessel”. Criteria themselves reflect purposes of the fishing system and means to achieve them. Effectiveness of k - type vessel or group of vessels operation at l fishing ground subregion can be presented as the composite vector criterion:

$$\bar{F}_k^l = [F_{1k}^l; F_{2k}^l; F_{3k}^l; F_{4k}^l] \quad (11)$$

Criteria of the fishing ground subregion usefulness can be calculated by simplified formulae. For example, criteria for trawler or seiner types of fishing vessels are calculated as:

$$F_{1k}^l = \frac{P_k g_k^l k_k t^l}{g_k^{pl} (t + t_n)} \quad (12)$$

where P_k - probability of effective fishing by k type of a vessel.

$$F_{2k}^l = \frac{W_{ik}}{W_k^{pl}} F_{1k}^l \quad (13)$$

where W_{ik} - a weighted estimate of a food raw in the total mass of i fish species in a catch by k type of a vessel; W_k^{pl} – rate of a planned raw for food fish products.

$$F_{3k}^l = \frac{\max_{ij} \sum c_{ij} x_{ij} t}{T_{pl} (t + t_n)} \quad (14)$$

$$F_{4k}^l = \frac{\max_{ij} \sum b_{ij} x_{ij}}{b_{pl} (t + t_n)} t \quad (15)$$

where b_{pl} - a planned daily profit.

Probability of effective fishing for each vessel is different and depends on a set of factors. It is defined on a base of statistical trials as a particular of the event. Also P_k can be

given a priori using a method of expert evaluations. A coefficient of a fishing time usage is defined with as a ratio of actual fishing time to common duration of a vessel stay at the fishing ground. By short-term forecasting this coefficient can be given also taking into account an analysis of internal and external factors, evaluating on the fishing system, like weather and sea conditions, a vessel and fishing gear status, conditions of fishing and commercial fish concentration, etc. The value of an expected daily catch for a vessel is given in the short-term forecast, but can be defined on results of other vessels fishing by the formula:

$$g_k^l = \frac{3g_{k \min}^l + 2g_{k \max}^l}{5} \quad (16)$$

where $g_{k \max}^l$ and $g_{k \min}^l$ - maximal and minimal catch values by k vessel type operated at l fishing ground subregion.

3. SELECTION OF AN OPTIMAL SOLUTION FOR VESSELS RELOCATION IN FISHERIES

A search for an optimal actions variant in multi-criteria problems is associated with big difficulties, because of contradictions arising between certain local criteria. An effort to improve any one local criterion is usually a deterioration of another. For example, the desire to increase a catch value and simultaneously to increase a profit is often contradictory. Because fishing fleet can have a big catch, but a small profit at one fishing subregion, while at the other – the smaller catch, but the great profit. A search of an optimal solution is connected to the choice of a compromise scheme, that is, with vectors comparison. Let the usefulness of two fishing ground subregions is presented by the vector effectiveness criteria:

$$\bar{F}_k^{1l} = [F_{1k}^{1l}; F_{2k}^{1l}; F_{3k}^{1l}; F_{4k}^{1l}] - \text{the 1-st subregion};$$

$$\bar{F}_k^{2l} = [F_{1k}^{2l}; F_{2k}^{2l}; F_{3k}^{2l}; F_{4k}^{2l}] - \text{the 2-nd subregion}.$$

Methods of decision-making [9, 10] give following rules of vectors comparison that can be used to assess the preferences of the selection of a fishing ground subregion.

3.1 The principle of absolute equitable compromise

This principle is that a compromise is considered as “an equitable” when the total absolute level of reduction of one or more criteria does not exceed the total of the absolute level of other criteria increasing. This principle corresponds to the principle of optimality, which consists in maximizing the sum of local criteria:

$$\underset{\bar{F} \in \Omega_{\bar{F}}^c}{opt} \bar{F} = \underset{\bar{F} \in \Omega_{\bar{F}}^c}{max} \sum_{i=1}^n F_i \quad (17)$$

where F – an optimal solution of the integrated criterion; opt – an operator of optimization, that defines the chosen principle of optimization; Ω – a region of acceptable solutions that can be divided on two non-intersecting parts: Ω_F^a – an accord region, where the quality of the solution can be improved simultaneously in all the local criteria and without decreasing any of the criteria level; Ω_F^c – a region of compromises, where improving the quality of a solution under one local criteria leads to deterioration of the quality of solutions under others.

It is obviously, that the optimal solution can belong only to the region of compromises, as the decision in the accord region can be improved by appropriate criteria. For example, the value of total absolute compromise Δ_{abs} is calculated by comparing two vector criteria as follows:

$$\Delta_{abs.} = [F_{1k}^{2l} + F_{2k}^{2l} + F_{3k}^{2l} + F_{4k}^{2l}] - [F_{1k}^{1l} + F_{2k}^{1l} + F_{3k}^{1l} + F_{4k}^{1l}] \quad (18)$$

Preference will be given for the operation, the sum of the criteria according to which is more. Consequently, the 1-st subregion gets priority.

3.2 The principle of relative equitable compromise

This principle is that a compromise is considered as “an equitable” Δ_{rel} when the total relative level of reduction of one or more criteria does not exceed the total relative level of increasing the efficiency under other criteria. In this case the principle of optimality is written as a multiplication of local criteria, on which a maximum is found as:

$$opt \bar{F} = \max_{\substack{\bar{F} \\ \in \Omega_F^c}} \prod_{i=1}^n F_i \quad (19)$$

$$\Delta_{rel.}^1 = \sum_{i=1}^n \frac{F_i^{2l} - F_i^{1l}}{F_i^{1l}}; \Delta_{rel.}^2 = \sum_{i=1}^n \frac{F_i^{3l} - F_i^{2l}}{F_i^{2l}}; \Delta_{rel.}^3 = \sum_{i=1}^n \frac{F_i^{3l} - F_i^{1l}}{F_i^{1l}}$$

where n – a number of criteria.

3.3 The principle of priority

Local criteria of usefulness may be ranked by priority. Then the problem of finding the optimal solution (the choice of a fishing ground subregion) reduces to the following models: the order of priorities is given in the sequence: $F_{4k}^l, F_{3k}^l, F_{2k}^l, F_{1k}^l$, that is:

$$F_{4k}^l = \max; F_{3k}^l \geq F_{3acc}^l; F_{2k}^l \geq F_{2acc}^l; F_{1k}^l \geq F_{1acc}^l \quad (20)$$

where F_{iacc}^l – acceptable values of local criteria.

An order of priorities is given by the decision maker, responsible for the decision, and based on the analysis of the vessels status and environmental factors.

3.4 The problem of criteria convolution

The problem of criteria convolution, considered in the theory of operations research, consists in the transition from a vector criterion to some generalized scalar criterion. Thus, if local criteria are measured in the same scale, the generalized criterion is calculated as a weighted average of local criteria:

$$F_{gen}^l = \sum_i \alpha_i F_{ik}^l \quad (21)$$

where $\sum_i \alpha_i = 1$ – a sum of weighted estimates of each criteria.

Using the principle of criteria convolution is related to the difficulty of α_i values choosing. It is possible to use an empirical method of calculation to determine the weighted estimates of local criteria F_{ik}^l . The method is based in the following. Implementation of the planned indicators of a fishing vessel is calculated as the ratio of actual output to the planned one for the same period of time. Obtained nondimensional values characterize the quantitative assessment of implementation of the voyage plan in fixed time and can be written as a vector:

$$\bar{\Phi} = [\Phi_{1k}, \Phi_{2k}, \Phi_{3k}, \Phi_{4k}] \quad (22)$$

where $\Phi_{1k}, \Phi_{2k}, \Phi_{3k}, \Phi_{4k}$ - nondimensional estimations characterizing implementation by k type of a vessel of planned indicators on catch, food, commercial fishing product and profit.

If the decision maker aims to provide an increase first and second indicator, the corresponding weighted estimates are assigned large compared with the estimates of the remaining criteria. In that case estimations can be guided by a common sense. If the aim is a steady smoothing estimation, the weights α_i can be determined from the system of equations:

$$\frac{\Phi_1}{\Phi_2} = \frac{\alpha_2}{\alpha_1}, \frac{\Phi_2}{\Phi_3} = \frac{\alpha_3}{\alpha_2}, \frac{\Phi_2}{\Phi_4} = \frac{\alpha_4}{\alpha_2} \quad (23)$$

4. FISHING VESSELS REGIONAL ALLOCATION AT FISHING GROUND SUBREGIONS

4.1 Procedure for the problem resolving

Let suppose that twenty fishing vessels of type A and five vessels of the type B have fishing procedures at the certain fishing ground. There is a forecast of fishing conditions for the three subregions. Production characteristics and resources of vessels are known. Procedure for the problem resolving reduces to implementation the following main operations:

- to calculate criteria F_{1k}^l and F_{2k}^l for each of subregions and a type of vessels;

- having made a mathematical model of the form (4-7) for each type of vessels, simulating their fishing in each of subregions, to solve the linear programming task by simplex method;
- to calculate values of the F_{3k}^l criterion for each of subregions and a type of vessels (or the concrete vessel);
- to solve the linear programming task of the form (4-7) for maximum of profit and to calculate the criterion F_{4k}^l ;
- to choose a scheme of compromise and to compare the vector functions of usefulness, to determine the priority of subregions, taking into account the type of a vessel;
- to distribute vessels at fishing ground subregions taking into account restrictions on the number of vessels N_{kmacc}^l at a subregion, if such restrictions exist.

Let us assume that values of the effectiveness criteria are calculated and the results shown in Table 1.

Table 1

Type of a vessel	Fishing ground subregion	Criteria values				N_{kmacc}^l
		F_{1k}	F_{2k}	F_{3k}	F_{4k}	
A	1	1.2	0.4	0.5	0.6	20
	2	0.6	0.9	1.0	1.2	15
	3	1.0	0.7	0.8	0.9	10
B	1	1.4	0.4	0.9	0.8	25
	2	0.6	0.9	0.8	0.9	20
	3	1.1	0.7	0.9	1.0	15

Then, using the absolute equitable compromise principle, vector effectiveness criteria are compared sequentially in accordance with formulae (17, 18). For the 1-st and 2-nd fishing ground subregions and for the B-type of vessels:

$$\Delta_{abs.} = [F_{1k}^{2l} + F_{2k}^{2l} + F_{3k}^{2l} + F_{4k}^{2l}] - [F_{1k}^{1l} + F_{2k}^{1l} + F_{3k}^{1l} + F_{4k}^{1l}] = 3.7 - 2.7 = 1.0$$

Thus, the 2-nd subregion has a preference for the A-type of vessels. It is possible to see that comparing the 1-st and 3-rd subregions $\Delta_{abs.} = -0.7$, therefore the 3-rd subregion is preferable than the 1-st one. When the 2-nd subregion is compared to the 3-rd subregion $\Delta_{abs.} = 0.3$, therefore the 2-nd subregion is preferable than the 3-rd one. Thus, the usefulness priority of subregions for the A-type of vessels is: the 2-nd, the 3-rd, the 1-st. The priority of subregions for the B-type of vessels is defined similarly. In this case it is: the 3-rd, the 1-st, the 2-nd. Vessels' allocation is made taking into account restrictions on the number of vessels N_{kmacc}^l given in the Table 1. Definition of the vessels number directed to one or another subregion is found by the method of variants search limitation. Thus, in this example, 15 vessels of the A-type expediently to direct to the 2-nd subregion,

5 vessels of the A-type to the 3-rd subregion and 5 vessels of the B-type to the 1-st subregion.

4.2 Alternative solutions (the principle of strict priority)

Alternative solutions of multicriteria problems can be considered on different schemes of compromise. Let us consider such solutions.

A mathematical model of the form (20) realizes the principle of strict priority. A model of vessels' allocation problem is presented in Table 2.

The criterion F_{3k}^l for vessels of the A-type reaches the maximum value at the 2-nd subregion and the second largest value of this criterion is at 3-rd subregion. The maximum value of the criterion for vessels of the B-type is achieved at the 3-rd subregion also.

A rational distribution of vessels at subregions is: 15 vessels of the A-type direct to the 2-nd subregion; 5 vessels of the B-type and 5 vessels of the A-type direct to the 3-rd subregion.

Table 2

Type of a vessel	Criteria	Subregions			F_{acc}
		1	2	3	
A	$max F_{3k}^l$	0.5	1.0	0.8	—
	F_{4k}^l	0.6	1.2	0.9	0.9
	F_{1k}^l	1.2	0.6	1.0	0.5
	F_{2k}^l	0.4	0.9	0.7	0.7
	N_{kmacc}^l	20	15	10	—
B	$max F_{3k}^l$	1.4	0.6	1.1	—
	F_{4k}^l	0.8	0.9	1.0	0.9
	F_{3k}^l	0.9	0.8	0.9	0.8
	F_{2k}^l	0.4	0.9	0.7	0.7
	N_{kmacc}^l	25	20	15	—

4.3 Alternative solutions (the principle of criteria convolution)

The principle of criteria convolution gives another alternative solution for vessels allocation. Let operating indicators for vessels of the type A are characterized by the vector $\bar{\Phi}_1 = [0.8; 0.3; 1.0; 1.0]$, for vessels of the type B by the vector $\bar{\Phi}_2 = [1.2; 0.8; 0.9; 0.6]$. Values of generalized effectiveness criteria of fishing subregions calculated by the formula (21) are shown in Table 3. Data analysis in Table 3 shows that for vessels of the type A is most effective the 2-nd and the 3-rd subregions, and for vessels of the type B is preferable to work at the 3-rd subregions. A rational variant of vessels allocation is: to direct 15 vessels of the type A to the 2-nd subregion, 5 vessels of the type A and 5 vessels of the type B to the 3-rd subregion. This example shows that the solution result of fleet allocation coincided for various schemes of the compromise. But it should be considered as a special case only, that is, in general, solutions can be different. Therefore, the decision maker chooses any variant from alternative ones.

Table 3

Type of a vessel	Weights				Subregion	Generalized criterion F_{gen}^l
	α_1	α_2	α_3	α_4		
A	0.34	0.25	0.2	0.2	1	0,73
					2	0,86
					3	0,86
B	0.17	0.26	0.23	0.35	1	0,83
					2	0,87
					3	0,93

5. CONCLUSION

The paper presents definition of efficiency (usefulness) criteria of fishing grounds for optimal fishing vessels allocation. According to suggested four basic parameters of a vessel's production program the paper describes mathematical models and the order of the procedure for the problem resolving. The given example shows practical results of calculation and the base for decision making which can be used in practice.

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