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OCEAN SHIP'S ROUTEING USING DYNAMIC PROGRAMMING

A voyage plan prepared beforehand and a plotted seasonal route are subject to change during the voyage because of changing weather conditions and optimization criteria alterations. Calculations are made with the use of wave analysis and forecasts valid from 0 to 120 hours. This paper presents most important results and the description of a voyage as an example of dynamic route programming. Different kinds of optimization algorithms are used (isochrone method, directional graph, evolutionary algorithms).

DYNAMICZNE PROGRAMOWANIE TRAS STATKÓW NA OCEANACH

Przygotowany przed podróżą plan jej realizacji oraz wyznaczona trasa sezonowa ulegają zmianom w trakcie jej realizacji z uwagi na zmieniające się warunki pogodowe, oraz ewentualne zmiany kryteriów optymalizacji. Trasę oblicza się na podstawie analiz i prognoz falowania w przedziale od 0 do 120 godzin. W artykule zaprezentowano ważniejsze wyniki i opis podróży będące przykładem dynamicznego programowania trasy. W obliczeniach wykorzystano różne typy algorytmów optymalizacyjnych (metoda izochron, metoda grafu skierowanego, algorytmy ewolucyjne).

1. INTRODUCTION

A ship is setting off to proceed from point A with the coordinates xo,yo to a point of destination with the coordinates xu,yu choosing the courses u(t) optimal in relation to external conditions changing in time and space.

The assumed quality indicator is the time of the passage. For the optimal time the indicator assumes the minimum value, i.e.

$$T = \min_{u \varepsilon \omega} \{T\} \qquad (1)$$

where: ω - set of admissible settings determined by setting constraints, and, indirectly, by state variable constraints.

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Therefore, it can be said that the optimal choice of a sea route a ship is to follow is the one that, when calculated by the kinematic equation of ship movement in the geographical coordinates system, satisfies the condition (1).

$$\frac{d\varphi}{dt}=\frac{180^{c}}{\pi R}V_{\varphi}^{d}(N,\varphi,\lambda,u,t)$$
$$\frac{d\lambda}{dt}=\frac{180^{c}}{\pi R}V_{\lambda}^{d}(N,\varphi,\lambda,u,t) \qquad (2)$$

where:

$V_{\varphi}^{d}, V_{\lambda}^{d}$ - components of the speed over ground directed towards the North Pole and towards the east;

R – mean Earth radius;

N – propeller revolutions per minute (rpm), with $N_{min} \le N \le N_{max}$;

u – ship's course

φ, λ – geographical coordinates

t – time

The chosen route should satisfy the boundary conditions in the starting point A and the destination point B of the ship's passage and the state constraints Oi (φ, λ ,t) ≤ 0 for i=1,2...,m and the settings Oj (φ, λ ,t ,u) ≤ 0 for j=1,2...,n such as land, prohibited areas, high seas, intensive wave action areas etc. [1]

Considering the application of any method for the choice of a ship's route, we have to ensure that navigational constraints and those related with the safety of navigation are satisfied. In this way the problem becomes non-classical one. Consequently, neither Lagrange's method nor Pontryagin's maximum principle can be accepted, although they are usually applied in the theory of optimal processes. For this reason, we have to assume the variation problem in its discrete form. In this case the whole process of the ship's route choice should be divided into separate steps, where the ship's course within one step is constant and covers, e.g., one geographical degree. Thus we embark on a multi-step control process, which will allow to determine the time of passing one step taken for calculations if we know the effect of wind and wave conditions, and currents on the ship's speed. In this way the determination of the time-minimum route of an ocean-going ship comes down to n-fold decision making process and the dynamic programming process [2,3].

Dynamic programming is usually used for solving multi-criteria optimization problems which often results in a few close solutions.

2. TESTING A CHOSEN SHIP AND ITS ROUTE

A voyage plan prepared in advance to be followed and the determined seasonal route change during the voyage due to changing weather conditions, and possible changes in optimization criteria. Route calculations are repeated at such intervals as present weather reports are made available. As a rule, at each stage of the voyage the calculations are made for the entire distance from the actual ship's position to its final destination. The ship follows the recommended route (REK) only to the next point of calculations, usually for 24 hours. If we sum up such 24-hour route sections, we receive the so called aggregated route. The route is calculated using wave analysis and forecasts at 0-120 hour intervals.

The 'Powstaniec' type of vessel was taken for the testing and presentation of dynamic programming of ocean-going ships. The ship proceeded from the Baltic Sea (L.V. Skagen) to the Gulf of Mexico.

Tests were made for the actual ship (using its speed characteristics) and actual weather forecasts available from weather centers throughout the world.

The ship starts the voyage from the Danish Straits (L.V.Skagen), the position φ=57°25.5'N λ=010°43.0'W on 18 March 2004 and heads for the Gulf of Mexico, point φ=26°N λ=072°W(before the entrance into Mona Strait). On the first day of the voyage the captain has to decide which route to choose: through the English Channel passing Bishop Rock or through Pentland Strait passing Cape Wrath. Of these two, the route through Pentland Strait is shorter by about 294 Nm, but runs at higher latitudes where climatic conditions are generally worse, therefore the navigation through Pentland Strait is more difficult, e.g. due to tidal streams reaching 8 knots. Tests made by various methods (isochrones, directed graphs, genetic algorithms) on the first day – on 18 March 2004 at 1200UTC have shown that the optimal route (REK) runs through Pentland Strait by Cape Wrath and over the distance of 3902 Nm the estimated voyage time amounts to 277 hours. The route is not usual as it goes along a great circle (ORT) calculated from Cape Wrath, then it approaches Newfoundland and along the great circler reaches the point of destination (B). Essential results of the first stage of calculations are presented in Figures 1 to 4.

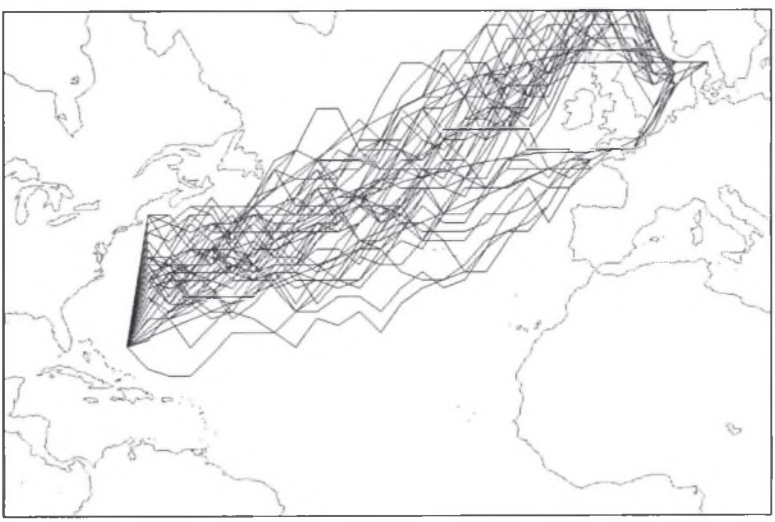

Fig.1. Random choice of routes for the initial population used by the program computing with the use of evolutionary algorithms on the LV Skagen - Mona passage

Fig.2. Graphical image of a recommended route (REK) obtained from the testing at the first calculations stage. The result - 277 hours, as shown in Table 1

Fig.3. Graphical image of the preset route (ZAD) through the English Channel. Duration 318 hours in real conditions as shown in Table 1

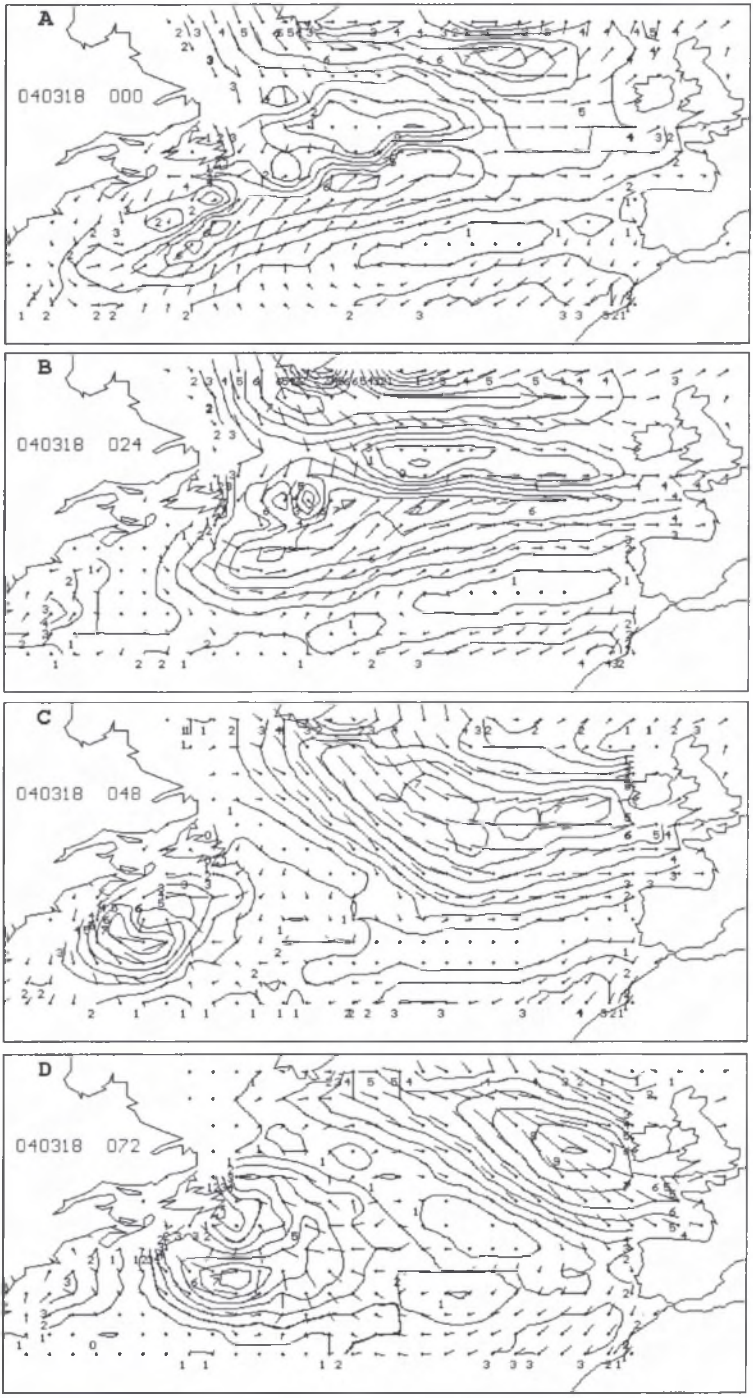

Fig.4. Weather conditions received on 18 March 2004 covering the North Atlantic a – wave analysis, b – 24-hour wave forecast, c – 48-hour wave forecast, d – 72-hour wave forecast

Table 1
Calculated results for the routes: recommended (REK), great circle (ORT), rhumb line (LOK) and preset (ZAD)

				48h	96h	144h	192h	
		Stage 1 18 March 12:00 57°48'N 010°42'E		Stage 2 20 March 04 59°48'N 009°27W	Stage 3 22 March 04 56°06'N 28°15'W	Stage 4 24 March 04 50°13'N 44°51'W	Stage 5 26 March 04 42°41'N 57°15'W	Voyage completed at Λ=26°N Φ=072°W
		A (C.Wrath)	B (B.Rock)	A	A	A	A	
Time [h]	REK	277	306	232	184	134	86	30 Mar 2^h
	ORT	292	336				(3d i 14 h)	
	LOK	305	316					
	ZAD	-	318	266	219	181	132 (5d i 12h)	1 Apr 00^h
Route [Nm]	REK	3902	4237	3261	2611	1918	1238	-
	ORT	3850	4200					
	LOK	3980	4300					
	ZAD	-	4548	3839	3148	2506	1890	-

No other route of the other variant of navigation through the English Channel is not close to the recommended route (Table 1 – Stage 1). At this stage the traditional preset route (ZAD) that from the English Channel would run through the Azores (45°N/010°W, 35°N/025°W, 30°N/ 050°W, 26°N/072°W and take 318 hours – Fig.3.).

In these conditions, considering the waves developing in the central region of the Atlantic (Fig.4), the ship chooses the northern route through Pentland Strait (Fig.2.).

After two days of the voyage on 20 March 2004 the second stage of calculations was performed for the recommended route (from position φ=59°48'N λ=009°27'W) and the preset route (ZAD). The calculations indicated the time 232 hours to the voyage completion on the recommended (REK) route and 266 hours on the preset (ZAD) route of navigation. Tests based on real weather analyses and forecasts available for the next five days for the two routes confirmed that the choice of the route was correct. The ship on the recommended route would sail at seas 2 to 3 metres high, while the ship on the preset (ZAD) route from the English Channel would sail through 5 to 6 metre seas (Fig.5).

The results of subsequent tests done on the following days are presented in Table 1. The route calculated on the following days as the optimal one from the particular stages of calculations (REK) can be referred to as the route calculated on recommendations. The ship following that route would reach its destination on 30 March 2004 at 0200 UTC, which means the voyage duration would be 278 hours. Along the preset route the voyage would take 324 hours and would finish on 1 April 2004 at 00 UTC, that is 46 hours later.

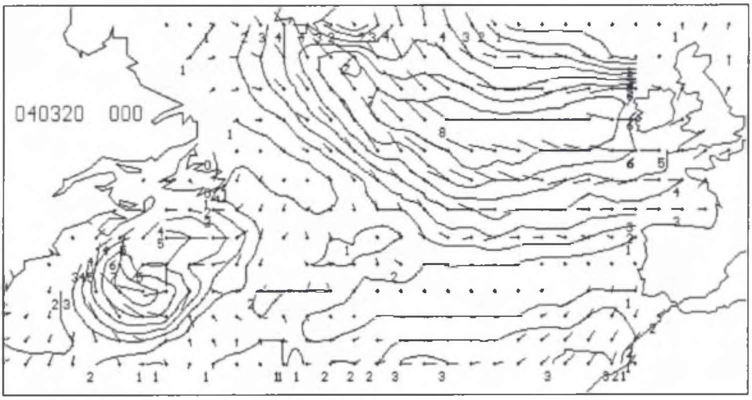

Fig.5. Wave analysis on 20 March 2004 on the Northern Atlantic

Fig.6. Graphical image of the time-minimum (REK) route from the Stage 2 of the tests

3. SUMMARY

As available weather forecasts from land-based centres cover up to five days, it seems purposeful to make calculations of several route variants, compare them and develop recommended routes. These can be obtained by the use of dynamic programming of ship's routes, in which the route followed is practically corrected every 24 hours due to the fact that weather conditions change dynamically [2,3]. The idea of using dynamic programming of ship routes is shown in Figure 7.

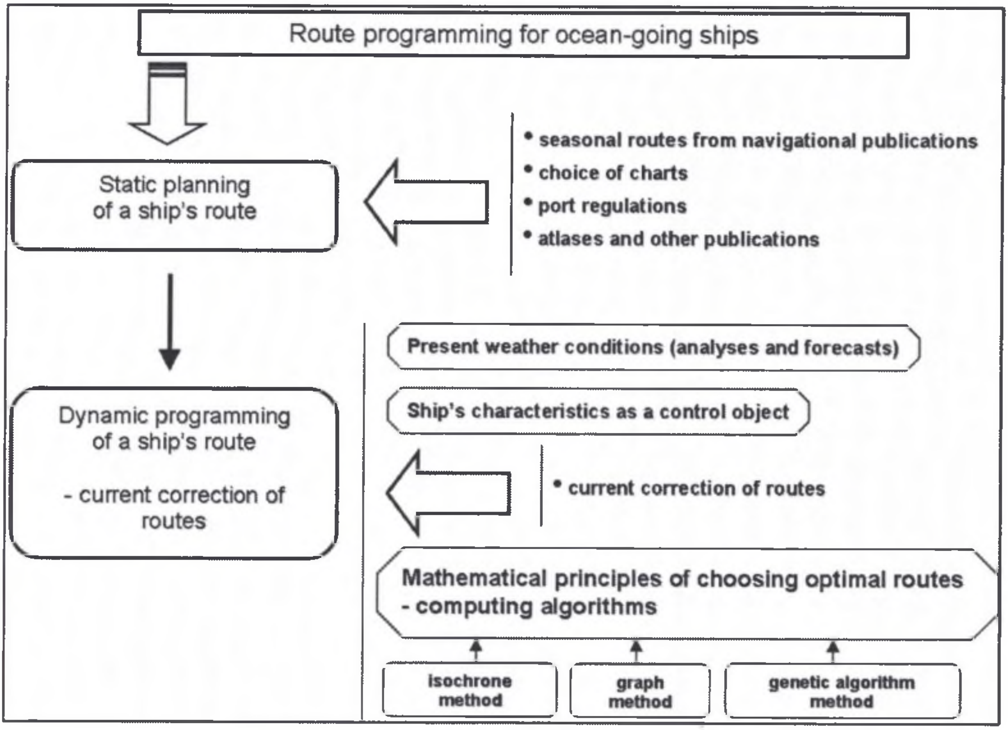

Fig.7. Programming of ocean-going ship routes

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Reviewer: Prof. Ryszard Wawruch