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Integrated problem of ship route planning

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ABSTRACT

Planning and realization of ship route is a complex problem, which consists of elements from different disciplines. It is necessary to take into account: the formal requirements, the organization of traffic in restricted areas, exploitation limitations of the ship; economic issues relating to the costs of fuel and the costs associated with the possible unscheduled reaching the ship at the port of destination and waiting for unloading. It is important to maintain safety conditions related to extreme weather conditions. As the sailing is done on the changing weather conditions, considerable issue is the problem associated with the acquisition, processing and integration of weather data.

Issues connected directly with the procedures of route computation are also important - the choice of optimization algorithm, matching the speed characteristics, the state of load.

Increasingly being taken into account as restriction of navigation has to be the threat of piracy and terrorism. In the planning and realization of a ship voyage important issue is so called human factor and thus the experience of the master, which will include a decision as to the extent of detail of route planning, taking into account the restrictions importance and eventual adoption or not the proposed route

KEYWORDS: ship route planning, limitations, procedures

1. Introduction

Ships route planning is still an actual problem of maritime navigation. Ship as the object is still under the influence of changing environmental conditions and environment (weather) and the effect of travel depends on the changing economic aspects.

Route selection is based on criteria describing the safety of the ship and cargo, the minimum travel time, lowest fuel consumption for a given travel time, a certain degree of travel comfort (e.g., for passenger ships or specific cargo), the criterion of profit.

These criteria are often contradictory, so the aim is to set the level of compromise and Pareto-optimal solutions. The route is Pareto-optimal when there is no worse route in every respect, and is better in one respect. Each route better due to some criterion, must be worse because of the other. This is a problem of multi-criteria optimization, which should contains all the appropriate constraints.

The whole process of ocean route programming can be divided into two stages: finding a set of routes for a given optimization problem, and the second stage, arrangement of a set of designated routes taking into account their ranking and compromise between the accepted criteria. In the first stage can be used calculations based on the isochrones method, defined by a grid of roads and directed graphs, or most convenient route for the most effective method of evolutionary algorithms [8, 9].

Taking into account the constraints of the environment (weather, prohibited areas) and control (dangerous slamming, flooding the deck, dangerous resonant states) usually

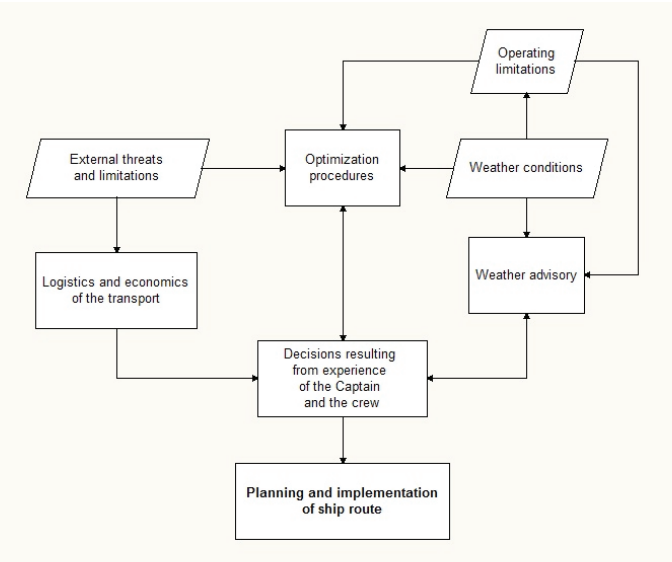

Fig.1. The process of planning and implementation of ship route

the greatest importance is attributed to the criterion of minimum travel time. This minimum time substantially affect the final selection and approval of the route.

In a second stage the decision maker's preferences on the criteria for optimization are complied, which can be described by linguistic values with weights assigned to them, for example, in certain conditions, the captain acknowledges that he has a reserve of time for the service ordered by the agent at the port of destination and decides to designate route with minimum fuel consumption for a given predicted travel time. Statistical methods and tools of artificial intelligence, such as multi-criteria ranking method [3] can be applied here.

2. Criterions and relationships

Among the many criteria for optimizing the most important role is attributed to the criterion of minimizing travel time. It is the most important indicator and its role is accented in many research works.

So the goal functions are defined here as follows [3]:

$$f_{passage\_time}(t_n) = t_n \to min \quad (1)$$

$$f_{fuel\_consumption}(\gamma_n) = \gamma_n \to min \quad (2)$$

$$f_{voyage\_risk}(i_n) = i_n \to min \quad (3)$$

Undoubtedly, from the economic point of view the time criterion is not sufficient. The owners are interested in multi-criteria optimization and searching for the ultimate economic effect of profit maximization, so the equation can be written as [7]:

$$Z = F - Kz - Ko(t) - Kp(t, Vs) \quad (4)$$

where:

Z - profit, F - Freight, Kz - the cost of loading, Ko - prime cost, t - time travel, Kp - fuel costs, Vs - velocity of the ship.

Given that the most favorable time of arrival of the vessel to the point of destination may not always be a minimum time (pier reservation time for unloading/loading), function of time will take the form:

$$f_{passage\_time}(t_n) = t_n \to t_{expected\_time} \quad (5)$$

Equation 4 can be considered only if the process is deterministic. On the other hand it is known that the ship speed (Vs) is a function of many variables, even if the weather conditions and characteristics of the ship power. Similarly, travel time (t) is a function of weather conditions and control parameters.

It follows that, weather conditions always affect in the variable way on the changeable costs (Ko + Kp) and the various factors that impact on it (the main engine speed, fuel consumption, course, speed). For this reason, minimizing travel time, which takes into account the weather conditions is a fundamental task in optimizing the entire project.

In some cases, it is reasonable to seek such a route that would include the minimization of fuel consumption, which ultimately boil down the problem to finding the optimum of these two criteria [7]. This problem will be important for ships, which are imposed deadline for entry to a port when it precedes a specific trip planned times or is likely to complete an earlier voyage. This applies to both linear and tramp shipping.

In each situation should be considered the criterion of safety of navigation [11, 13]. It is of course dependent on the the condition that the ship safely reaches the destination. It is important so that ship or cargo is not to undergo the negative effects of excessive slamming, flooding and generally understood storm damage, and the crew was not subjected to a critical stress. A particular example which so directly translates to the level of safety and economic effects is the threat of piracy and terrorism.

External factors affecting the planning and implementation of the journey are the weather conditions, exploitation constraints, and external threats and constraints.

2.1 Weather data

In the case of weather data the most important issues are:

- The time interval of available forecasts,
- Reliability of forecasts,
- The extent of the data received,
- The frequency and regularity of the data received.

The scope and frequency of the hydro-meteorological data depends on the method and sources of their acquisition. The most comfortable situation we have in case of a regular, usually every 12 or 24 hours, obtaining information from land weather routeing centers. In the case of acquiring information in a traditional format such as Facsimile charts, NAVTEX, it requires a greater investment of time and the interpretation of information is more difficult. Either way, we get the problem of decreasing forecasts reliability with increasing time interval.

One possibility to reduce the negative impact of expected inappropriateness of data, especially concerning the height and wave direction and wind speed is to apply fuzzy sets to describe the meteorological situation [10].

An example of fuzzy set can be set of high waves FW. Waves with a height of 6 - 9 meters, we can clearly classify as high, which is entirely belonging to the set of tall waves, 1-meter waves as certainly not high (not belonging to the set of high waves), while intermediate values: 2, 3, 4 and 5 meters belong to a set of high waves only to a certain extent.

The operation to assign individual wave heights given degree of belonging in this case is subjective and dependent on situational context. Wave height can be defined here as a linguistic variable, which we can assign linguistic values - such as high waves (6 meters and higher), rather high (4.5 meters), average (3 meters), rather mild (2 meters).

Let's suppose that we are dealing with information that at a given point of the ocean, after 48 hours (48-hour forecast), there is a wave height of 4 meters. According to the assumptions forecast of given hydro-meteorological parameter for a given time interval (the range of forecasts) will be treated as a fuzzy number that is "about 4 feet." To determine the function of belonging of fuzzy number "about 4 feet," we use the method of determining the degree of belonging based on measurement data.

In other works [10, 12] the waves in the North Atlantic were analyzed, including 48-hour forecasts of wind wave height issued by the U.S. NCEP (National Centers for Environmental Prediction) and compared with the analysis (from the same source), which was taken as completely verifiable.

For the selected period of years 2000-2003 for the North Atlantic, for example, 49 289 forecasts wave height of 4 meters (as a wave height of 4-meter adopted range between 3.51 - 4.50, similarly other ranges in height were digitized) were issued On this basis the degree of belonging ($m4(h_f)$) for each wave height to the set "wave height of about 4 meters" attributed in the following way: the largest number of events (23 224 cases) the actual wave heights of 4 meters is assigned degree of belonging m4(4) = 1, the remaining wave heights belonging degree were assigned proportionally, such as the 3-meter wave m4(3) = 14 899/23 224 » 0,64 (normalization of fuzzy set). Course of membership function $m4(h_f)$ were approximated by asymmetrical Gaussian function [4], where the degree of belonging m4(hf) is determined by the relation:

$$\mu_4(h_f) = w \cdot e^{-\left(\frac{h_f - m}{a_1}\right)^2} + (1-w) \cdot e^{-\left(\frac{h_f - m}{a_1}\right)^2} \qquad (5)$$

where:

m - modal value (center of function);

w - logical variable informing about the level of variable: w = 1, when $0 < h_f < m$; w = 0, when $h_f > m$;

a1, a2 - width of the left (a1) and right (a2) side of the fuzzy set for the level $m4(h_f) = e^{-1}$.

2.2 Operating limitations

Operating limitations are partly derived from the

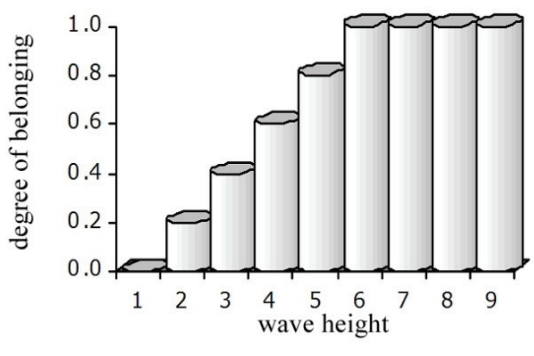

Fig.2. Degree of belonging of individual wave heights for the fuzzy set FW „high wave"

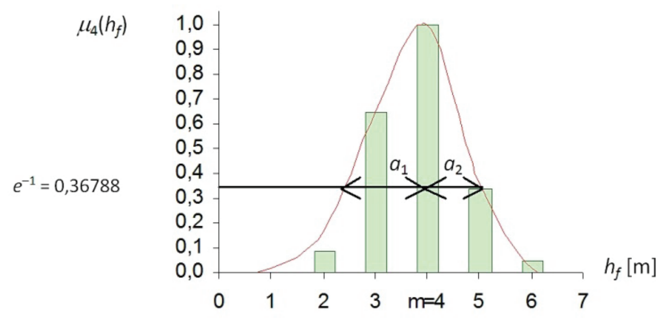

Fig.3. Function of belonging of fuzzy number „wave height of about 4 meters for a 48-hour forecasts"
Source: [10]

weather conditions encountered. Ability to achieve preset waypoints in appropriate time results mainly due to the ship speed characteristic and in part may be conditioned by the nature of the cargo and the need to provide adequate levels of comfort and convenience of carriage of passengers and the crew. Maintained engine rotations and the ship speed obtained in the given meteorological conditions affect the size of the fuel consumption, so in some situations, the ability to lower rotations and reduce the speed of the vessel brings the effect of economic benefits.

The accuracy of ship speed characteristic, its adaptation to the type of vessel, loading condition, the actual seaworthiness, is a key element in the process of computing the route of the vessel [2, 6].

Speed characteristic in addition to losses resulting from natural motion resistance also includes reductions in speed performed by masters in order to eliminate the adverse effects resulting from the impact of waves [10].

The difficulty of accurate determining the ship speed characteristic, therefore, results from the fact that the assessment of safety of navigation is a subjective assessment of the ship's captain. So, to record changes in vessel speed as a function of the impact of wind and waves, notation in a fuzzy form can be offered.

Imprecision (fuzziness) of environment in which there is a decision-making process is represented by introducing so-called. fuzzy environment, which consists of the fuzzy objectives, fuzzy constraints and fuzzy decisions [2, 12].

In order to formally define the fuzzy environment elements a set of so-called options (variants) is introduced, denoted as:

$$X = \{x\} \qquad (6)$$

- set X contains all possible values (procedures, variants) in the concerned situation.

It is assumed that the optimal route choice is a problem of choosing among a finite, predetermined number of variants. Let's confine the number of variants to 9 roads,

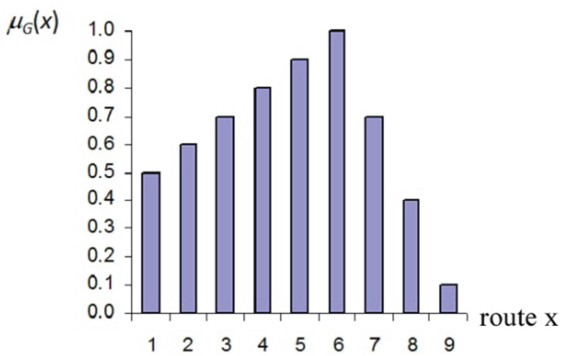

Fig.4. Example of determining the degree of belonging the various routes to the fuzzy goal G (route optimal in terms of time).

which the ship can realize (Fig. 4.).

Fuzzy goal is defined as a fuzzy set G specified on the set of options X, described by the belonging function:

$$\mu G : X \rightarrow [0, 1] \qquad (7)$$

such that G(x) [0,1] determines the degree of belonging for each option x to fuzzy goal G.

Another possibility to improve the ship speed characteristic could be its constant current correction based on the comparison of planned and achieved positions in the ith time interval against the weather conditions encountered. This issue can be achieved through using self-learning neural networks.

2.3 External threats and limitations

For several years for the safety of navigation next to the weather and navigational conditions the pirates began to threaten . They became the main navigation hazard early twenty-first century. Just because of them, the existing routes of ships depart from the seasonal, and the threat they bring is taking into account in the decision making process to choose the sea route of the vessel [1].

The amount of pirate attacks and their regional assignment vary in different years and weather seasons. It is important to continuously analyze these changes to consider the "best" alternative routes for the safe planning of the ship route.

Pirates attack on the ship in monsoon season is doubtful. Such a weather determines the number of pirate attacks, therefore, it may be reasonable to dispense with additional protection or additional insurance of the ship.

Passage through the areas at risk of piracy limits the ship route choices. For example, in planning the ship's voyage through the Gulf of Aden it is recommended that masters go through established International Transit Corridor, which is indicated route by this waters with length of 492Nm. It consists of two separate tracks 5Nm wide, dissociated by the separation zone with a width of 2Nm (Fig. 5.).

An example shows the calculation of two routes - a shorter and more dangerous by the Gulf of Aden and a longer around Africa.

Both routes have been calculated based on the programs Navi Sailor 3000 and SPOS 7.0 with consideration of navigational criteria with the current and forecasted weather conditions.

On the basis of the adopted data an average exploitation costs for the route from Kuwait to Rotterdam around Africa with the calculated 33 days of travel are about 480

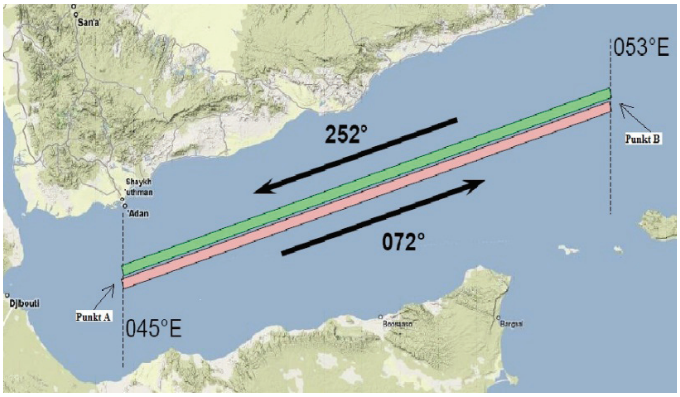

Fig.5. International Transit Corridor
Source: [14]

000. USD. For a route through the Suez Canal at 18 days of travel it's estimated to be around 510 000 USD, so the cost of both voyages can be comparable. For such calculated route through the Suez Canal channel costs are nearly 33% and the cost of protecting the ship about 18% of the total travel expenses without an extra insurance and additional equipment.

In the process of optimizing the route of ships the ship owner should consider the criterion of safety, because events related with the loss of cargo, the ship, and especially the people in the Indian Ocean are very significant. In this case saving 15 days of voyage through the Suez Canal does not compensate for losses.

According to different criteria ships routes should be optimized paying attention to the impact of exploitation parameters. For each vessel route optimization must be made separately by the ship owner, which has much greater access to confidential information, the amount of insurance premiums, fuel costs, etc. For the ships with high broadside and reaching higher speeds, it may be appropriate to dispense with the protection of the vessel, or dispense with taking out additional insurance.

2.4 Optimization procedures

To select the optimal route for a ship on the ocean, we can use different algorithms and different methods such as isochrones method, directed graphs, or genetic algorithms and plotting for evaluation of hazardous sectors of ship courses.

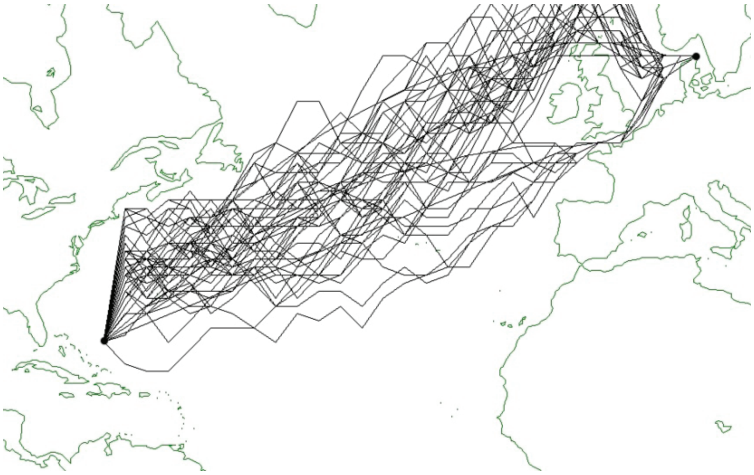

Fig.6. Random selection of routes for the initial population used by the calculation program of evolutionary algorithms on the way from LV Skagen to Mexican Bay

An example of an initial population of routes for the oceanic voyage shows Fig.6.

Regardless of the type of calculation algorithm of the minimum-time route, they all work correctly when computing routes in the open ocean. In case of the limits resulting from the land configuration (pass through the channels, the cabotage shipping, etc.) there are difficulties which could result in the inability to lead the road to the port of destination. While in the navigation on the open ocean searching for the optimum route can be carried out on a route departing from great circle, loxodromic or randomly generated route between points, then in a situation such as sailing round the continent, these methods begin to fail. Therefore seems reasonable to call the methods used to determine routes on restricted areas to the methods used in the open ocean. Adding to the population of the initial route, or starting finding alternatives from the route, which possibly leads to the goal, eliminating the problems going through restricted waters such as channels and straits.

2.5 Logistics and economics of the transport

All the above mentioned conditions and restrictions will affect the economic aspect of a journey. In addition

Table 1. Calculation of the ship route: Kuwait-Rotterdam

Route	Distance [Nm]	Distance difference [Nm]	Fuel consumption [t]	Time	ETD	ETA
Kuwait - Rotterdam through the Suez Canal	6688	5768	454,1	18d04h	03.03.2010 12:00 UTC	21.03.2010 15:56 UTC
Kuwait - Rotterdam around Africa	12456		831,6	33d06h	03.03.2010 12:00 UTC	05.04.2010 18:22 UTC

Source: [13]

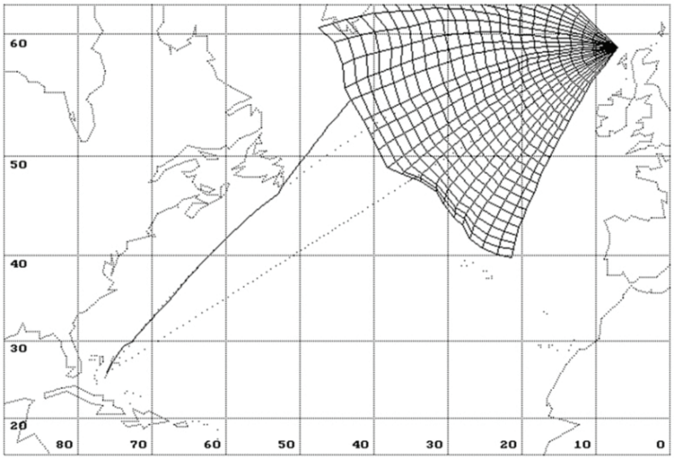

Fig.7. Example of route calculations taking into account the fuel consumption

to the timely arrival of the vessel to the port of destination while maintaining the safety of the crew, ship and cargo, fuel economy is an important factor. Minimum-time route may also be often minimum-fuel route, but may also significantly differ.

Sample calculation of ship Powstaniec Śląski routes due to the fuel consumption for weather from 24.04.2001 present Fig.7. and Table 2 [9].

2.6 Weather advisory

Weather routeing center meets consultative role for vessels and relieves the captain from some considerations related to the weather conditions in the process of route optimization. The final result of cooperation depends largely on the quality of communication between the ship and the center, as well as the procedures implemented by the same center.

Route optimization results obtained using different tools used by the centers shows Fig.7. and as you can see they are not identical.

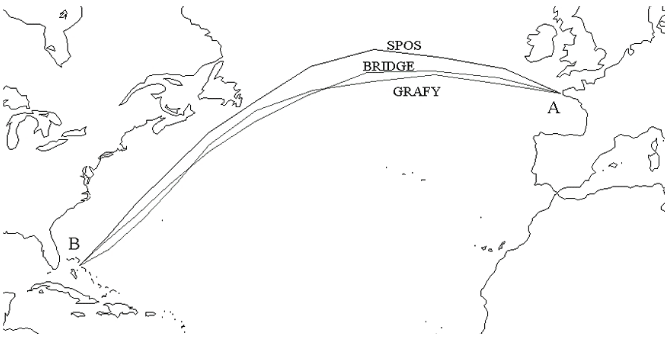

Fig.8. Graphic image of the route Brest (A) - Providence Channel (B), 13-23.VI.2005, tested by 3 programs: SPOS (journey time 237.0 h), Bridge (journey time 233.5 h), Graphs (travel time 235, 2h) Source: [11]

Table 2. Fuel consumption on the concerned routes.

Route type	Fuel consuption	Time
Great circle	199.1tons	280.60h
Loxodromic	252.2tons	355.29h
Optimal	197.1tons	277.75h

2.7 Decisions resulting from experience of the captain

The final implementation or rejection of the assumptions about the planned and realized route belongs to the ship's captain. His decision will be conditioned by the guidelines of the ship owner or charterer, weather information available, possible indications of land weather routeing center and knowledge about the behavior of ship in the present weather conditions.

An important role of the master is the current verification of previously planned route of the vessel at the time of a journey and an eventual correction.

3. Conclusion

Running route optimization taking into account the many factors we obtain the resulting set of routes consisting of routes with assigned the appropriate balance of individual wages of preferences resulting from optimization criteria (time of passage, risk factor, fuel consumption, ...).

The final sorting of a set of routes can be achieved by statistical methods or the application of fuzzy set theory.

The effectiveness of the practical use of the integrated calculation program depends on the proper selection of weights assigned to certain limits.

Seems to be a deliberate departure from the pure minimum-time optimization of ocean routes towards the optimization of other factors, while maintaining the assumed time to reach the destination point.

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