III INTERNATIONAL CONFERENCE
TRANSPORT SYSTEMS TELEMATICS TST'03

ZESZYTY NAUKOWE
POLITECHNIKI ŚLĄSKIEJ 2003
TRANSPORT z.51, nr kol. 1608

*sea transport ,computation algorithms, route optimization*

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# EVOLUTIONARY ALGORITHMS AND METHODS OF DIGRAPHS IN THE DETERMINATION OF SHIP TIME-OPTIMAL ROUTE

The article attempts at the verification of time-optimal ocean routes computations made with the use of evolutionary algorithms. The verification was based on the results obtained from verified and reliable method of optimization based on the graph theory. Simulations were performed covering the North Atlantic area. Authors made an attempt to select program parameters (methods of crossover and mutations) so that a computer program could be used for working out ship ocean route recommendations.

# WYKORZYSTANIE ALGORYTMÓW EWOLUCYJNYCH I METODY DIGRAFÓW DLA USTALENIA OPTYMALNO-CZASOWEJ TRASY STATKU NA OCEANACH

Artykuł podejmuje temat weryfikacji obliczeń tras oceanicznych, zoptymalizowanych pod względem czasu, wykonanych z wykorzystaniem algorytmów ewolucyjnych. Weryfikacja oparta została na wynikach uzyskanych ze sprawdzonej i niezawodnej metody optymalizacji opartej na teorii grafów. Wykonano symulacje obejmujące obszar Północnego Atlantyku. Autorzy dokonali próby wyboru parametrów programu (metody krzyżowania i mutacji) tak, aby program komputerowy mógł być użyteczny do opracowywania zaleceń dla tras oceanicznych statków.

## 1. INTRODUCTION

Weather navigation is basically concerned with the programming of ship ocean routes. Before a voyage commences the planned ship route should be dynamically programmed when the ship is underway. Such programming should account for assumed goals, constraints, criteria, specific characteristics of the control object and the influence of changing environmental conditions (weather). The safety of the ship, personnel, and cargo is the basic criterion in the programming and route selection. However, other criteria, such as economical aspects, i.e. minimizing voyage time and optimization of fuel consumption are also considered.

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Ship route programming most often utilizes optimization algorithm for the determination of time-optimal routes. The kind of algorithms used and how detailed the computations are depends on the availability of weather data and software used.

Presented below are concepts of two methods for computations and examples of determined optimal-time routes in the Atlantic Ocean for a selected ship. The results were obtained through a method based on the theory of digraphs and computed with the use of evolutionary algorithms.

## 2. COMPUTATION METHODS

### 2.1. THE USE OF DIGRAPH PROPERTIES

In order to solve the problem of ship ocean routing, it is purposeful to utilise the properties of a digraph, where edges are oriented and the arrows indicate the direction of movement or the order of choice. The edges are called arcs, branches, a path or sections of a network of routes. This kind of graph is called a digraph.

Conditions are added to the digraph, resulting from the fact that it is a way of representing various possible tracks from point A (port of departure) to point B (port of arrival) in a preset area. The digraph is developed with the purpose of choosing the shortest time route.

One of the most effective algorithms proposed for the determination of the shortest path between a given pair of vertexes is Dijkstra's algorithm [1]. In a given digraph G with n vertexes, labels are attributed to each vertex. The starting vertex is attributed with a fixed label with the value of 0, whereas the remaining vertexes obtain a temporary label denoted as $\infty$ (a very large number, e.g. larger than the sum of all weights attributed to graph edges).

In subsequent iterations the following operations will be repeated:

- for each vertex $v_j$ that has a temporary label, a new one is calculated whose value is:

  min [previous label j, /label i+$d_{ij}$/]

  where "i" is the last vertex with a fixed label determined in the previous iteration, whilst $d_{ij}$ / $d_{ij} \geq 0$/ is a distance attributed to the edge $e_{ij}$ between vertexes $v_i$ and $v_j$. It is assumed that when no edge $e_{ij}$ exists, then $d_{ij} = \infty$.

- from the set of all temporary labels the smallest one is chosen (or one of them, if they are equal. It becomes a fixed label of an appropriate vertex. Steps 1 and 2 are repeated alternately.

The algorithm terminates its operation the moment the final vertex receives a fixed label.

Dijkstra's algorithm is of the $O(n^2)$ complexity class, where "n" is a number of graph vertexes. While using a given algorithm for the optimisation of voyage time, one cannot specify in advance the weights $d_{ij}$ referring to the times of passages between particular nodes. The weights depend on hydrological and meteorological conditions which vary in time and can only be calculated in the process of algorithm implementation after the labels of particular nodes have been taken into account. More details on the algorithm are presented in publications [1, 2].

### 2.2. ADAPTATION OF GENETIC ALGORITHMS AND EVOLUTIONARY PROGRAMS

Genetic algorithms can be another class of algorithms for solving the problem of time-optimal ship voyages. Genetic algorithms represent a method of solving problems, mainly optimization tasks, based on natural evolution [4]. These are searching procedures utilizing the mechanisms of natural selection and inheritance. They use the evolutionary principle of survival of best-fit individuals.

Evolutionary programs are a form of genetic algorithms generalization. An evolutionary program is a probabilistic algorithm operating within a population of individuals. These authors have attempted at adjusting an evolutionary program to the specific needs of determining a ship time-optimal route [4]. Every individual in the evolutionary program represents a potential solution of the problem, in this case co-ordinates of a ship ocean route.

The initial population is selected from possible climatic routes and a number of routes generated at random. The fitness function is the time of covering a given route in preset navigational and meteorological conditions. The time can be determined with the use of standard navigational procedures (position coordinates, speed, course, ...). The function defines the fitness of each route and differentiates better and worse individuals. Designed crossover operators (C) recombine randomly chosen routes and take into account constraints due to navigational requirements that have to be satisfied. Besides, the mutation operation (M) was used for transformations of single route coordinates. The evolutionary program is particularly suitable for solving optimization problems with large space parameters and unknown analytical solution. Thanks to mutation the program is resistant to local extremes and finds approximate solutions.

Research so far has shown that the selection of initial population of routes is essential for the optimal-time route determination [3,4]. The size of initial population so far chosen at random can be supplemented with routes set by the operator. From the practical point of view it is important that the recommended ship routes on the seas and oceans take into account operator's requirements at the stage of input parameters and operating data of the computation process. Navigational routes recommended by professional publications the great circle (GC – shortest distance) and rhumb line (RL – route or its section on the same course) are particularly useful.

The herein considered voyage started from the Baltic (L/v Skagen) to the Caribbean Sea (Providence Channel). Fig.1 shows declared great circles and rhumb lines running from the English Channel and Pentland Strait across the Atlantic to the examined point of destination.

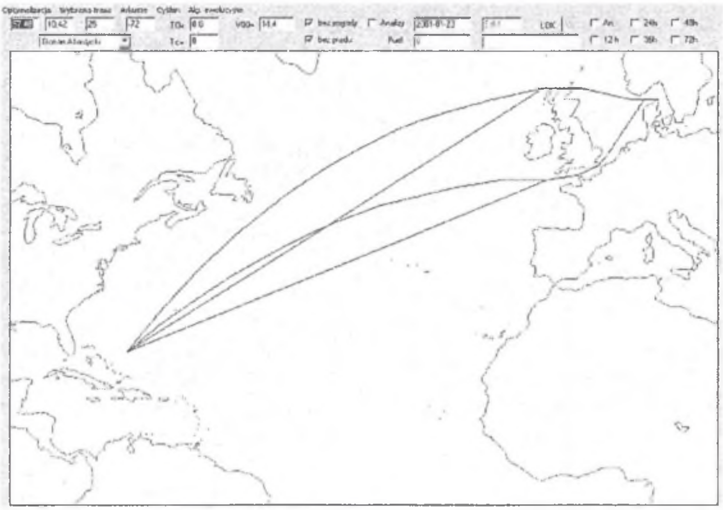

Fig. 1. Great circles and rhumb lines for various routes of a ship running through the English Channel and Pentland Strait

## 3. RESEARCH RESULTS

The research consisted in testing the route from Europe (L/v Skagen) to Central America (Providence Channel) through the North Sea and the Atlantic Ocean. Computations were made by two different methods for the determination of time-optimal routes for a particular ship (m/s Daszyński $v_0$=14.4 kt) and actual weather conditions prevailing in the ocean on 23 January 2001 (Fig. 2.) One method, using the theory of graphs [1], gave the result of 289.16 hours of the voyage. Its graphical illustration is shown in Fig.3. That choice of the route was due to rough weather conditions in the ocean. Seas west of Great Britain exceeded 8 metres; besides, seas over 10 metres high were observed along the entire ocean length in latitudes between parallels 40 and 50 degrees. Therefore, the computed route runs through Pentland Strait, not through the English Channel. It avoids the mentioned areas of high waves to the north. Besides the results of computation by the graph method, tests were made with the use of a computer program based on evolutionary algorithms. The tests were executed for the same weather conditions, ship speed characteristics, starting and destination points etc., but for two computing variants – accounting for starting routes in the population and with routes chosen only at random. Detailed results of computations are shown in tables 1 and 2.

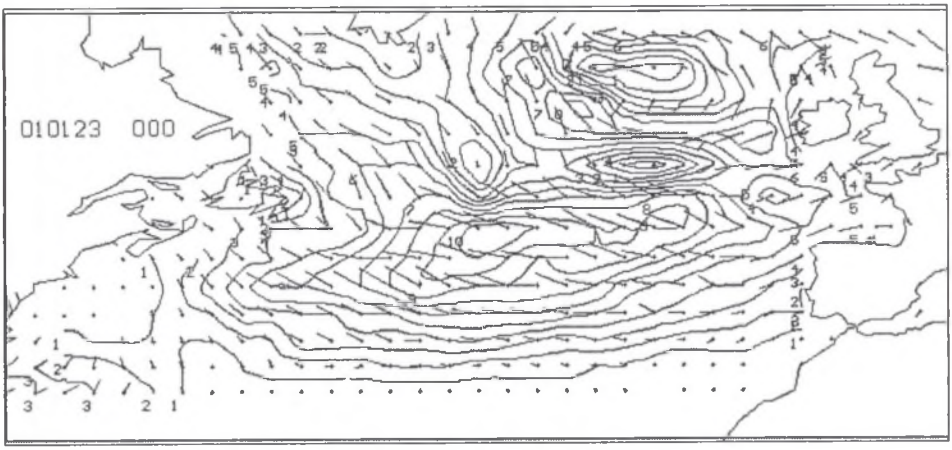


Fig. 2. Wave heights and directions in the North Atlantic on 23 January 2003

Table 1 based on the computations for the population of initial routes randomly chosen shows the figures close to 300 hours of voyage duration time only if there were 1000 computing cycles.

The example in Fig.4 presents a graphic image of the initial population of 10 randomly chosen routes for which the computations were made. Fig.5 shows a route computed after combined operations of crossover and mutation. The result is close to the time-optimal route computed with the graph method.

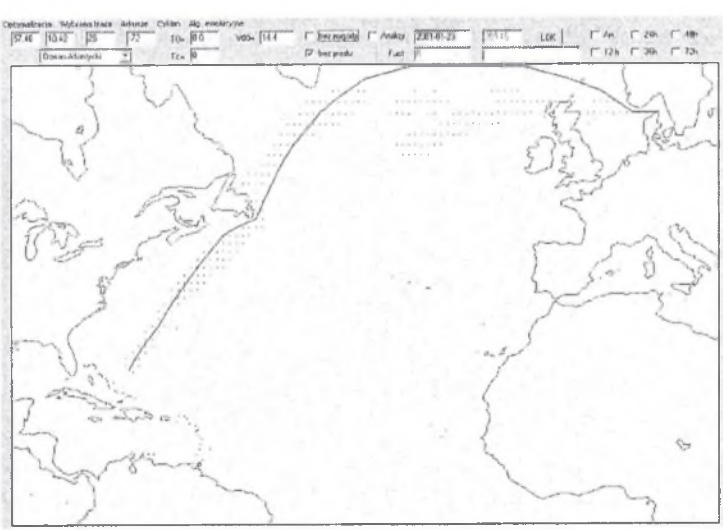

Fig. 3. Graphical illustration of the time-optimal route computed by the graph method (voyage time 289.16 hours) for the weather conditions on 23 January 2001

Table 1

Voyage times on the route L/v Skagen-Providence Channel
for a given number of route initial population chosen at random

| Operations C – crossover M - mutation | Operating data for the initial population | | Voyage time (hours) for a number of generations (100, 500, 1000) | | |
|---|---|---|---|---|---|
| | Distance between points relative to λ/φ | Number of routes of initial population chosen at random | $P_{100}$ | $P_{500}$ | $P_{1000}$ |
| C+M | 3°/5° | 10 | 330.60 | 305.84 | 305.41 |
| | | 50 | 306.25 | 303.74 | 303.34 |
| M | 3°/5° | 10 | 368.15 | 325.04 | 304.76 |
| | | 50 | 322.37 | 305.59 | 301.17 |
| C | 3°/5° | 10 | 350.32 | 320.36 | 308.39 |
| | | 50 | 310.38 | 302.18 | 300.83 |

Table 2

Voyage times on the route L/v Skagen-Providence Channel
for a given number of initial populations with preset navigational routes

| Operations C – crossover M – mutation | Operating data for the initial population | | Voyage time (hours) for a number of generations (100, 500, 1000) | | |
|---|---|---|---|---|---|
| | Distance between points relative to λ/φ | Number of routes of initial population with preset navigational routes | $P_{100}$ | $P_{500}$ | $P_{1000}$ |
| C+M | 3°/5° | 10 | 297.88 | 297.63 | 297.57 |
| | | 50 | 297.51 | 297.51 | 297.51 |
| M | 3°/5° | 10 | 299.67 | 299.04 | 297.98 |
| | | 50 | 299.51 | 299.24 | 298.41 |
| C | 3°/5° | 10 | 298.39 | 298.23 | 297.85 |
| | | 50 | 298.75 | 298.19 | 297.95 |

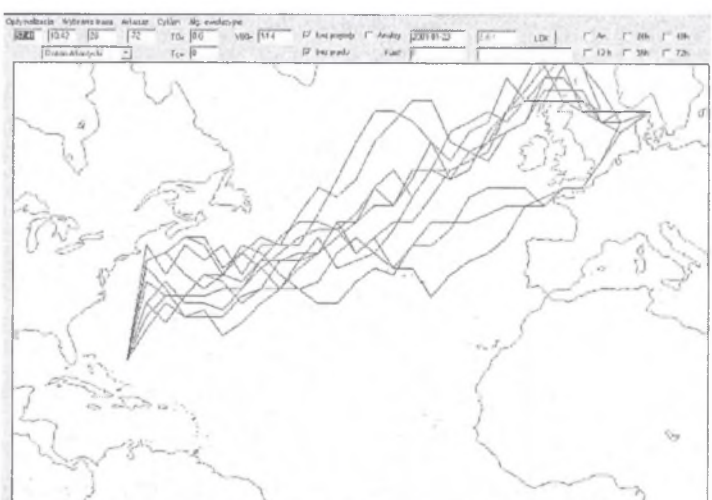

Fig. 4. An example of an initial population of 10 randomly chosen routes

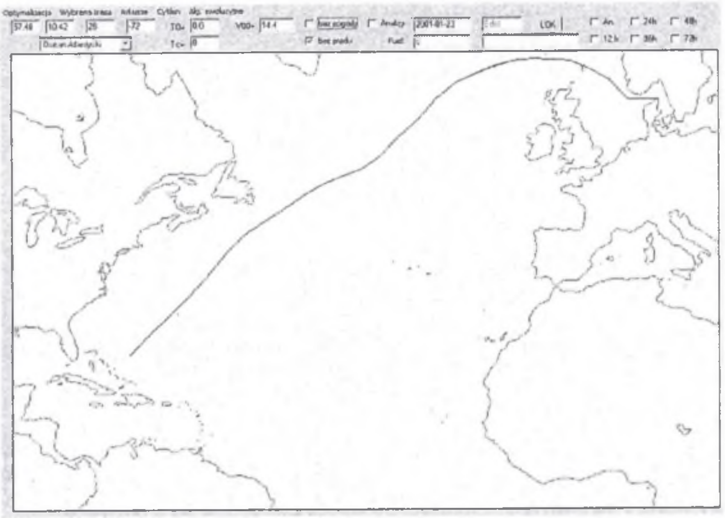

Fig. 5. Time-optimal route computed after 1000 generations using the crossover and mutation operator (voyage time - 305.41 hours) according to Table 1

Even more interesting results were obtained when pre-determined possible navigational routes had been used for creating the initial population as shown in Table 2. For only 100 computation cycles (generations) the result was 297 hours of voyage duration regardless of the methods of using crossovers and mutations.

Fig.6 illustrates an example of 50 routes of the initial population together with navigational routes. The graphical image of the time-optimal route obtained from computations and route selections can be seen in Fig.7.

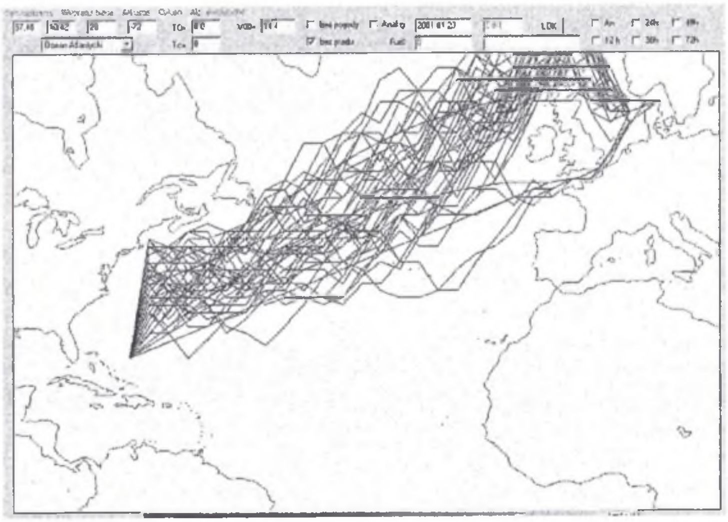

Fig. 6. An initial population of 50 routes with preset navigational routes

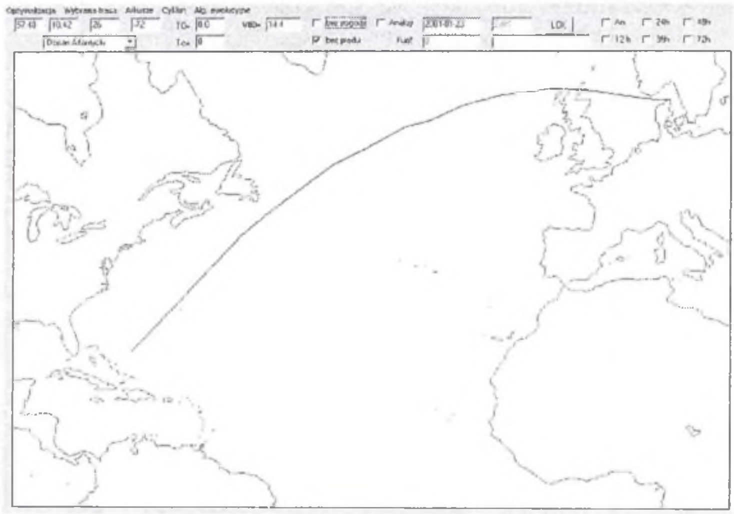

Fig. 7. Time-optimal route determined after 1000 generations with the use of crossover and mutation operator (voyage time 297.51 hours) according to Table 2

## 4. SUMMARY AND CONCLUSIONS

The research aimed at the testing of the evolutionary program for computations of the time-optimal route. The program makes use of evolutionary algorithms. The results are compared with the computations of the time-optimal route obtained by the method based on the theory of digraphs. The latter method is practically used on ships. The results encourage further use of the method.

Advantages of the evolutionary program are its capability of showing many variants of routes, computing speed or the flexibility in introducing navigational assumptions as input parameters; these might include standard routes running along great circles or rhumb lines.

The result obtained for the time-optimal route through the digraph method (289.16 hours) compared to the results of computations made by evolutionary algorithms method (297.51 hours) shows the difference of 3.15% to the advantage of the former. The difference is due to operating data taken for computations such as area gridding, randomly chosen population of initial routes, number of computing cycles, designing of procedures in the operation of crossover and mutation. The following conclusions can be drawn from the research:

- it will be possible to use, through the correct choice of operating parameters, the program using evolutionary algorithms for the optimization of ship's ocean route. If the results obtained make a difference less than 1% in relation to those yielded by other methods, the program will be used for operational control of ocean-going ships.
- the computing method using evolutionary algorithms has some practical advantages, such as indicating directly to the user a number of possible routes and a possibility of introducing the routes chosen by the user into input parameters (e.g. computations for the great circle and rhumb line).

- a disadvantage of the method based on evolutionary algorithms is difficulty in selecting such input and operating parameters that would give better results. This refers to route crossovers and their mutations, distances between computing points ($\Delta\varphi$, $\Delta\lambda$), and the selection of the initial population.

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Reviewer: Prof. Ryszard Wawruch