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Application of the 1-2-3 Rule for Calculations of a Vessel's Route Using Evolutionary Algorithms

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ABSTRACT: An example is shown of the 1-2-3 rule application for calculations to determine a route avoiding tropical cyclones. The dynamic programming used is based on regularly received weather reports containing present and forecast data on tropical cyclones. The results were compared with the *post factum* calculated route which utilized only weather analyses concerning the relevant moments of the voyage and with routes calculated using the cyclone fuzzy domain as an area dangerous to navigation. The calculations were made in the evolutionary algorithms environment.

1 INTRODUCTION

1.1 *The 1-2-3 Rule*

The 1-2-3 rule consists in extending the forecast storm field of the cyclone with an approximated value of the forecast error based on 10 years of the relevant forecast time interval. The rule is recommended for the North Atlantic waters, but it can be easily adopted for other sea areas. The mean error of a given forecast is added to the largest forecast radius of the stormy area. Consistently, 100 Nm distance is added as the forecast error to the longest radius of the stormy area for 24 hour forecast for all quadrants. Similarly, 200 Nm is added for 48 hour forecast and 300 Nm for 72 hour forecast. The method does not take into consideration effects of sudden change in the intensification of the cyclone system, which consequently extends the stormy zone of winds ≥34 knots. Besides, it does not account for the cyclone changes into extra-tropical stages, which also result in sudden changes of storm force winds. Additionally, it is recommended in the method description to further extend the dangerous area without specifying any values, particularly when forecasts are highly unreliable, captain and crews' experience is limited, the vessel's seaworthiness is restricted or there are other limiting factors defined by the captain. Therefore, the method does not precisely determine the area to avoid. If we combine the principle of avoiding the storm area where wind W≥34 knots with the extended zone where risk is high, we obtain a danger area to avoid by applying the 1-2-3 rule (Fig.1) [1].

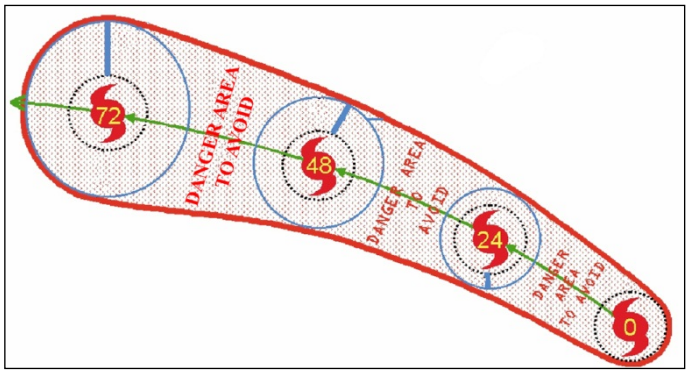

Figure 1. The 1-2-3 Rule [1].

1.2 *Calculations*

Evolutionary algorithms were used in calculations of the time-minimum route which passes by the are affected tropical cyclones [4].

The randomly chosen initial population of routes consisted of 50 individuals. The routes were processes by two operators: crossover and mutation. The number of generations amounted to 700.

As time passed by, the area threatened by tropical cyclone determined by the 1-2-3 rule increased and was treated as prohibited to navigation, which means no computing route point could appear within this field.

2 ROUTE CALCULATIONS

There were two tropical cyclones in the examined period over the North Atlantic, Gordon and Helene. The vessel began a voyage from Gibraltar to New

York. Starting at 0300UTC on 15 September 2006 from position 36N/007W, the vessel headed for position 40N/073W.

Figure 2 presents the situation of the voyage beginning where the 1-2-3 rule was applied. The route is almost loxodromic one. It can be seen that only waves, having nothing to do with tropical cyclones, affect the way it runs (long distance to the cyclones, forecasts up to 72 hours are considered as prescribed by the 1-2-3 rule).

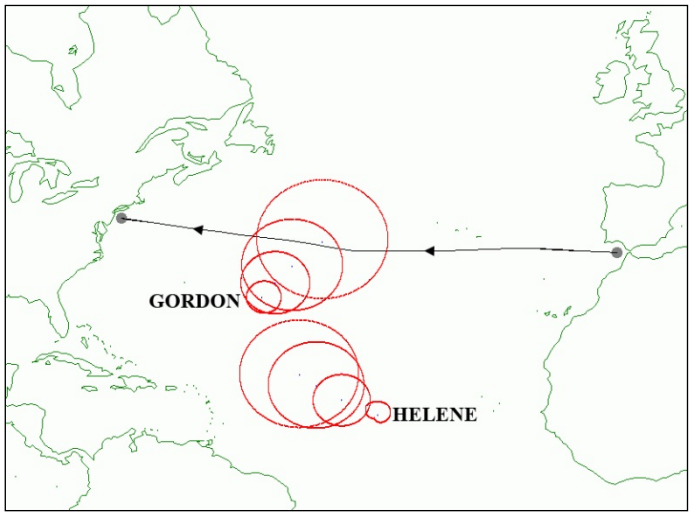

Figure 2. Vessel's position and calculated route on 15 September, 0300UTC – start of the voyage.

On 17 September at 0300UTC the vessel approached the danger area affected by tropical cyclone Gordon and avoided the storm field going south of it. Cyclone Helene then was not dangerous for the vessel (Fig. 3.).

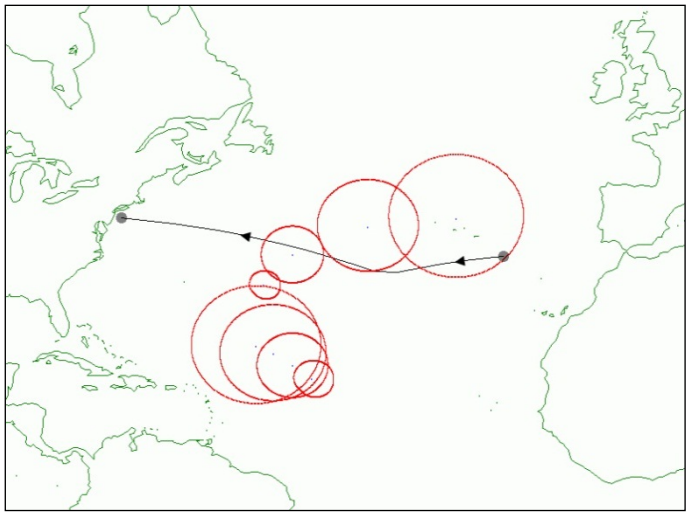

Figure 3. Vessel's position, calculated route and cyclone-threatened areas to avoid – 17 September, 0300UTC.

From 1500UTC 19 September the proximity of the cyclone significantly affected the calculation results and the danger area to avoid determined with the 1-2-3 method (Fig.4.).

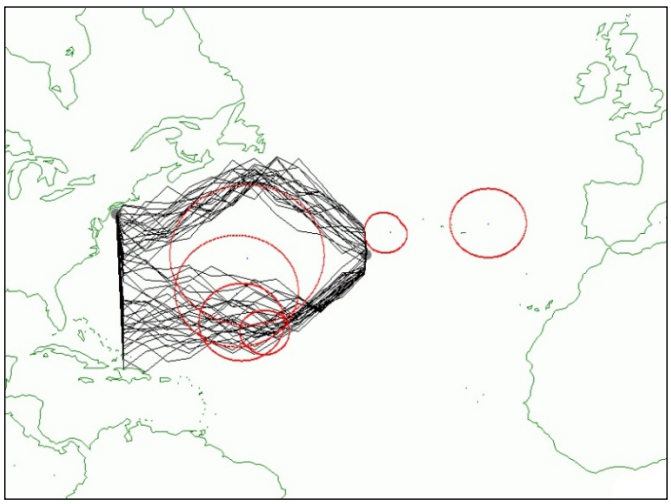

Figure 4. 19 September, 1500UTC – initial population

Cyclone Gordon was out of the vessel's way at that time. The initial population of routes avoiding Helen, as shown in Figure 4, indicates there are two possible groups of routes to avoid the cyclone: northern and southern ones.

Calculations of the best track (time-minimum route) recommend avoiding the cyclone to the north (Fig.5.). The calculated route has only one point adjacent to the forecast circle of danger area ($T+72^h$) defined by the 1-2-3 method. This, however, was not in compliance with other navigational principles; one of them says: never cross the track.

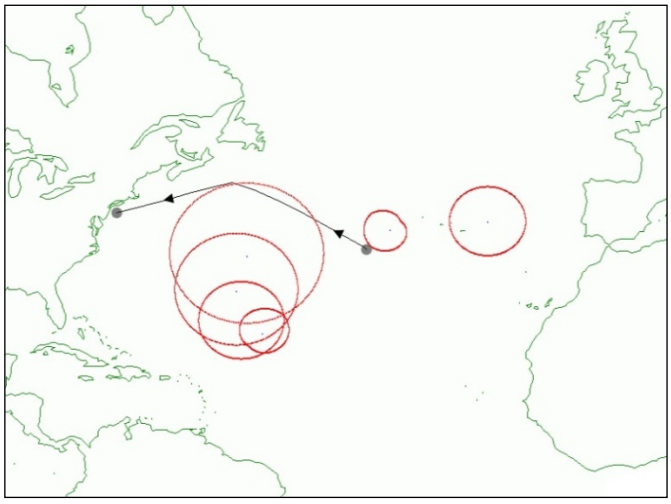

Figure 5. Vessel's position, calculated route and cyclone-threatened areas to avoid – 19 September, 1500UTC

Six hours later (19 Sept at 1200UTC) calculations dramatically changed the previous decision concerning which route to choose to avoid the cyclone. Now the vessel's track went to the south of the cyclone (Fig.6.).

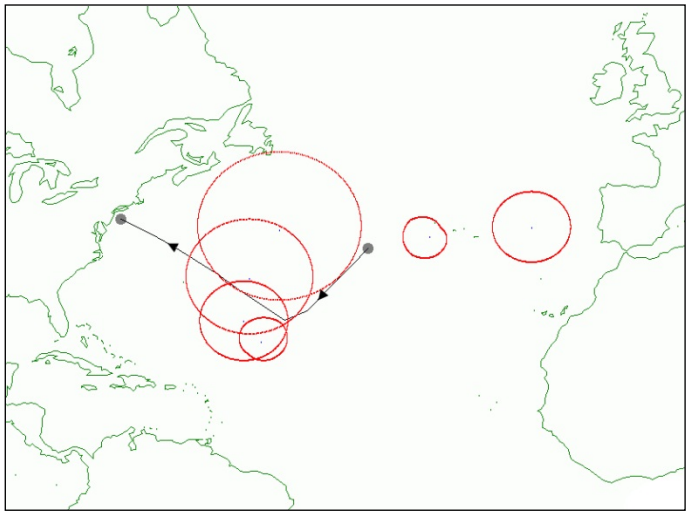

Figure 6. Vessel's position, calculated route and cyclone-threatened areas to avoid – 19 September, 2100UTC.

This results from such factors as noticeable acceleration of cyclone Helene's speed of movement according to the latest short-term forecasts and from the range of forecasts considered in the 1-2-3 method.

Further in the course of the voyage, in tests performed every six hours, the vessel consistently avoided cyclone Helene sailing south of it, and from 1500UTC 22 September the vessel headed directly for her destination (Fig.7.).

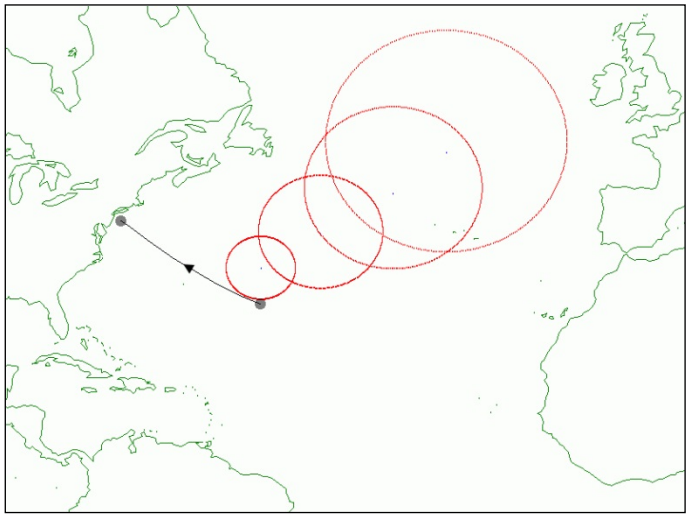

Figure 7. Vessel's position, calculated route and cyclone-threatened areas to avoid, 22 September 1500UTC.

Finally, the tested route took 254^{h} 12' to cover. Figure 8 shows the route together with the locations of Helene and Gordon at the start of the voyage and their further routes, worked out from real analyses.

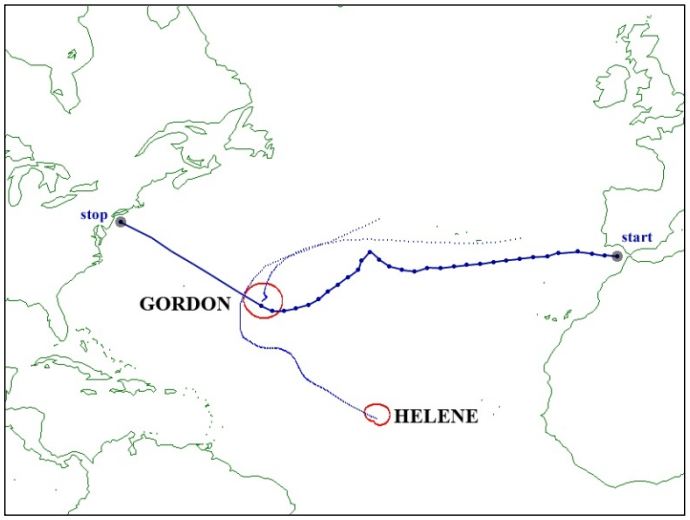

Figure 8. Final route based on 6-hour tests and the positions of cyclones Gordon and Helene at voyage start and their further movements.

3 THE RESULTS DISCUSSION

The test results concerning a vessel route from Gibraltar to New York, using the 1-2-3 method and actual analysis and forecast data real received onboard the vessel every six hours from 15 to 25 September 2006 will be compared to earlier results published in [5, 6]. Those studies took into account analyses that appeared after the cyclone had occurred as well as operational T+48h forecasts and available forecasts for periods up to 120 hours. The calculations using 48h and 120h forecasts regarded cyclone's danger area as a fuzzy domain according to the methodology found in [2, 3]. The overall results are given in Table 1 and Figures 9 and 10.

Table 1. Duration times and distances of a vessel's route for various methods of calculation.

route calculation type	**1-2-3 rule**	120h forecast fuzzy domain	48h forecast, fuzzy domain	analysis (post fatum)
time	254h 12'	260h 12'	231h 48'	214h
distance	3128.4Nm	3616.6Nm	3260.8Nm	3071.8Nm

Figure 9 compares two resultant routes, calculated using:

– the 1-2-3 method (route D),
– forecasts up to 120h received in uptodate reports and description of the danger area with a fuzzy domain, as presented in authors' previous publication [5].

Both routes differ to some extent. The route obtained from the 1-2-3 method is shorter in terms of time by six hours and considerably shorter in terms of distance.

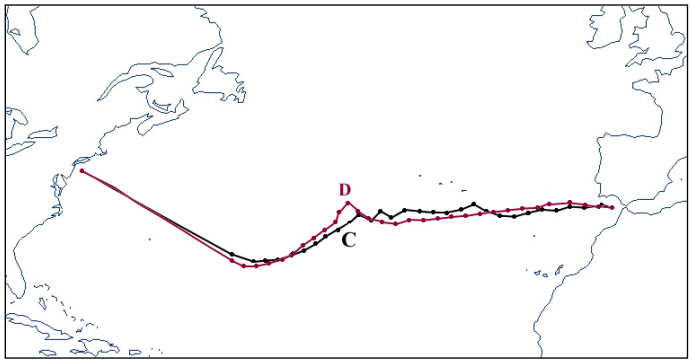

Figure 9. Route calculated using T+120h (C) forecasts and 1-2-3 rule (D).

Knowing the results of other tests, considering only up to 48h forecasts and using analyses made after the cyclone operation, we notice significant differences in the character of routes. The considered voyage assumed the same vessel speed and accounted for the actual weather conditions and the same departure and arrival points, etc.

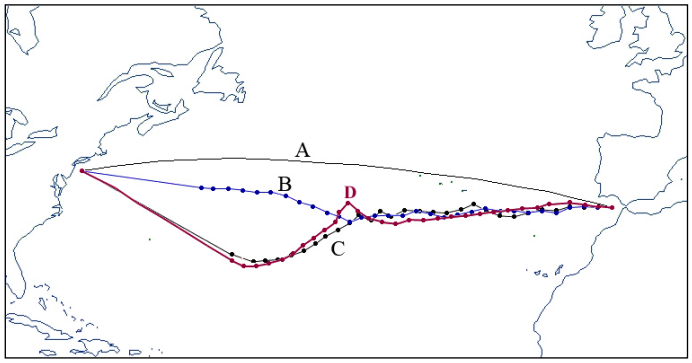

Figure 10. A – post factum route, B – 48h forecasts and cyclone's fuzzy domain, C –120h forecasts and cyclone's fuzzy domain, D –1-2-3 method.

The application of the 1-2-3 method yields results comparable to those obtained from the method using long-term T+120h forecasts.

The danger area generated by this method, a circle increasing in time up to 72 hours until the moment the vessel comes relatively close to the cyclone, does not show substantial differences as compared to other methods.

4 CONCLUSIONS

The conclusion reached in previous publications has been confirmed. As the time horizon of forecast increases, its reliability decreases and regardless of the method used, the area of potential danger due to tropical cyclone dramatically extends in time. For the 1-2-3 method, after 72 hours this area is a circle with a 600 Nm diameter plus the forecast cyclone diameter. This hinders effective determination of routes that would not abruptly change the actual courses of vessels underway.

It seems reasonable to grade the value of unreliability of tropical cyclone area of storm depending on the time to reach it (distance, vessel's speed characteristics, weather conditions outside the cyclone area).

The 1-2-3 method should not add the values of 100, 200 and 300Nm to the longest radius of the four quadrants of cyclone storm field. At least, it should make a difference between its two semi-circles.

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