# A NOVEL DYNAMICAL ROUTE OPTIMIZATION METHOD TO IMPROVE SHIP'S VOYAGE TIME: TIME BOUNDARY SEMICIRCLES

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1. **ABSTRACT:** Energy conservation, emission reduction and voyage time savings have garnered considerable attention within the maritime industry. Optimizing a ship's energy efficiency and sailing time holds the potential to effectively reduce both energy consumption and CO2 emissions. However, existing studies predominantly concentrate on either sailing speed or route optimization, with limited exploration of the interaction between speed and route under continuous time-varying weather conditions. These studies often rely on assumptions that introduce drawbacks, compromising the precision and quality of optimized routes. This paper introduces a novel Time Boundary Semicircles (TBS) Algorithm to address and fill the gaps identified in prior research, presenting a more precise and high-quality optimization model centered on involuntary speed reduction. The algorithm utilizes a mathematical model to calculate involuntary speed reduction based on weather conditions acquired from the Copernicus Marine Environment Monitoring Service (CMEMS), constrained by deterministic time boundaries. A hypothetical case study is conducted to compare between SIMROUTE software based on A* Algorithm which is used in weather routing with TBS to show its effectiveness in route optimization. The results confirmed 27.25 % time saving through TBS implementation.

## 2. LIST OF ABBREVIATIONS

TBS: Time Boundary Semicircles
TCV: Time Corrected Values

GCR: Great Circle Route

CSV: Comma Separated Values

CMEMS: Copernicus Marine Environment Monitoring Service

## 3. INTRODUCTION

Maritime transportation stands out as an economically viable and energy-efficient mode of conveyance. It boasts notable advantages, including a substantial transport capacity and a low cost per unit of transported volume [1]. Nonetheless, the industry contributes significantly to fossil fuel depletion and consequential carbon emissions [2] ; [3]. To address this environmental impact, the International Maritime Organization (IMO) continually implements regulations and initiatives such as the Energy Efficiency Design Index (EEDI), Ship Energy Efficiency Management Plan (SEEMP), and Energy Efficiency Operation Index (EEOI) to promote energy conservation and emission reduction within the maritime sector. Achieving enhanced energy efficiency in ships primarily hinges on optimizing fuel consumption for each voyage, with the choice of sailing route and speed exerting a substantial influence on this endeavor [4].

In recent years, substantial research efforts have been dedicated to the modeling and prediction of a ship's energy consumption [5] ; [6], optimization of sailing speed [7] ; [8], and route optimization [9] ; [10]. These endeavors have established robust foundations for enhancing energy efficiency and reducing emissions in the shipping industry. The energy utilization of ships is influenced by environmental parameters during navigation, such as wind, waves, and currents. These parameters exhibit significant spatial and temporal variations and complex variability, resulting in substantial fluctuations in a ship's operational conditions and energy consumption across diverse navigational environments [11]. Consequently, research in energy consumption prediction and optimization must comprehensively consider the impact of these environmental factors, and some notable contributions have been made in this domain. For instance, [12] developed a neural network model utilizing ship-collected data to predict and evaluate a ship's energy efficiency under varying navigational conditions. Additionally, [13] proposed an effective optimization model that assesses parameters like speed, displacement, and environmental conditions through log data, investigating their relationship with energy consumption. [14] advocated a Three-Dimensional dynamic programming method for ship voyage optimization, leveraging weather forecast maps to select an optimal path and speed profile. This method demonstrates potential in enhancing navigational safety and effectively reducing a ship's energy consumption. [15] formulated a multi-objective programming model incorporating fuel consumption, fuel price, freight, and inventory costs to optimize route assignment and speed for multiple ships in transit.

However, these optimization methods have solely concentrated on optimizing energy consumption along a specific route, neglecting the spatial and temporal variations in the navigational environment within a designated area to identify routes that could further minimize ship energy consumption. Additionally, previous research has examined optimization outcomes at fixed, predetermined sailing speeds, failing to comprehensively account for the impact of different sailing speeds on optimization results. Consequently, these optimization algorithms inadequately address the continuously time-varying characteristics and spatial-temporal disparities in environmental and operational information. Over time, real-time information may deviate from predicted values, compromising optimization accuracy and robustness.

In the past three years, researchers have addressed this issue by conducting studies that focus on a joint optimization approach for sailing routes and speeds. This approach takes into account the interaction between route and speed, along with multiple environmental factors. [16] developed a joint optimization model for sailing routes and speeds based on an energy consumption model that incorporates various environmental factors. Building on this, [17] introduced an innovative dynamic collaborative optimization algorithm utilizing the Model Predictive Control (MPC) strategy and swarm intelligence algorithm to enhance ship energy consumption optimization. [18] established a joint optimization model for ocean shipping routes and sailing speed for ocean-going vessels. This model determines the optimal ocean shipping route and corresponding sailing speed to minimize fuel consumption while considering both involuntary and voluntary speed losses due to ocean environments and time window constraints. Despite these advancements, there are two notable drawbacks in the approach employed in the aforementioned papers. Firstly, researchers assumed a constant ship speed during each time step, overlooking involuntary speed reductions caused by added resistance. This oversight impacts the timing of environmental information acquisition for parameter calculations. Secondly, the division of time steps is influenced by velocity changes, leading to reduced distances covered within the preset time frame used in calculations. This alteration affects the precision of the model.

The aim of this paper is to propose new methodology and algorithm to overcome this gap with a more precise perspective and taking into consideration the involuntary speed reduction and time zones through constructing Time Boundary Semicircles (TBS) that ship will not exceed in a preset time frame. The radius of TBS will be the maximum distance the ship can cover based on her maximum speed in preset time frame. So, we have a zone that contain candidate positions as lat. and long. In which ship can choose to optimize the route. Environmental conditions will be obtained in this time frame and involuntary speed reduction based on added resistance from waves will be calculated. Positions with minimum reduction will be chosen to avoid more power and fuel consumption. Distances will be accumulated and summed based on paths followed by the ship and by using initial velocity as it will be assumed to be maintained all over the trip to optimize and save voyage time, we can calculate Time Corrected Value (TCV). When TCV reach preset time frame another TBS will be constructed. This novel algorithm will cover the aforementioned weak points for more precise optimization. Moreover, computational resources used will be minimized due to the calculations will be inside the TBS for each time zone from start to destination without rendering and calculating on all mesh points.

The next sections are concerned about full methodology description and mathematical models used, in results section a hypothetical case study between 2 points will be constructed to fully demonstrate this new approach. A comparison between TBS methodology and A* algorithm implemented in SIMROUTE software proposed by [19] will be conducted and results will be mentioned to minimize voyage time through route optimization. A discussion will be held to show significance of TBS approach and limitations of current implementation of algorithm. Lastly summary of conclusions and future recommendations research will be mentioned.

## 4. METHODOLOGY

The proposed method comprises four integral components: meteorological data acquisition, a mathematical model addressing involuntary speed reduction caused by waves, innovative procedures for solution algorithm, and test case to compare TBS with prior approved methodology to prove its effectiveness in optimizing voyage time. The solution algorithm endeavors to introduce a novel approach for optimizing the utilization of weather forecasting data within deterministic time frames, considering the potential alteration of these time frames due to speed reduction. Meteorological data acquisition is designed to identify sea states relevant to alternative routes. Subsequently, the proposed route undergoes optimization based on precise weather conditions data generated by the algorithm. The mathematical model calculates involuntary speed reduction and dynamically feeds this data into the algorithm, ensuring instantaneous optimization for subsequent time frames. Once the optimized route is determined, emphasizing the least reduction in speed, further optimizations can be initiated to enhance fuel and energy consumptions dynamically with voyage time and speed optimizations. These additional optimizations will be addressed in the future recommendations outlined in the research discussion.

### *4.1 Meteorological data acquisition*

The optimization of ocean shipping routes and sailing speeds is significantly influenced by sea states. Generally, a ship encounters increased resistance when navigating through wind and irregular waves. Meteorological data, often stored in the NetCDF format, plays a crucial role in this context. NetCDF datasets encompass dimensions, variables, and attributes. Variables, such as wind speed, wind direction, wave height, or wave direction, are employed to store meteorological data in grid formats. Independent variables include time stamps, latitude, and longitude of points within the grid. Consequently, meteorological data within the grids can be extracted with given coordinates and time information. Essentially, the NetCDF dataset represents single-value functions with multiple variables. To assess sea states along shipping routes, consideration must be given to the grids traversed by these routes. Wave information files sourced from the European Union's Copernicus Earth observation program are employed. The Copernicus Marine Environment Monitoring Service (CMEMS) offers free access to comprehensive data related to the global ocean's physical state. Various ocean wave products are available in the CMEMS catalog, covering diverse geographical regions. In this study's hypothetical case focusing on the Mediterranean Sea, the Waves Analysis and Forecast Module is utilized, with specific properties outlined in Table 1.

**Table 1**: Mediterranean Sea Forecast Module data and properties

| | |
|---|---|
| Full name | Mediterranean Sea Waves Analysis and Forecast |
| Product ID | MEDSEA_ANALYSISFORECAST_WAV_006_017 |
| Spatial extent | Mediterranean Sea Lat 30.19° to 45.98° , Lon -18.12° to 36.29° |
| Spatial resolution | 0.042° × 0.042° |
| Temporal resolution | Hourly |
| Format | NetCDF-4 |

### *4.2 Involuntary speed reduction mathematical model*

As a sailing ship contends with wind and irregular waves, the ship's resistance amplifies, diminishing its speed under the consistent power output of the main engine. Essentially, a greater power input is necessary to sustain the desired sailing speed. Additionally, encountering an intense sea state may induce pronounced roll motions or even capsize, posing risks to both equipment and cargo and jeopardizing the safety of ship occupants. Furthermore, this reduction in speed results in a modification of the time intervals for data acquisition. Consequently, inaccuracies may arise in the weather conditions data provided to the mathematical model and solution algorithm, resulting in errors in the outputs.

In this study the effect of waves only will be considered through the approach introduced by [20] as employed in the study by [19]. it can be utilized to compute the added resistance resulting from irregular waves, enabling the estimation of involuntary speed loss. we adopt Bowditch's approach to project involuntary speed loss in this study due to its simplicity and to focus on implementing the new algorithm. The new reduced speed (V) in knots is calculated based on the following equation:

$$V\,(Hs,\Theta) = V_o - F\,(\Theta)^*\,Hs^2 \qquad (1)$$

where $V_o$ (kn) is the vessel initial speed without wave effect, $H_s$ (ft) is the significant wave height and Θ is the ship-to-wave relative direction (clockwise).Table 2 shows the value of F (Θ) based on the waves direction in ($kn/ft^2$)

**Table 2:** Values of F coefficients.

| Θ | F ($kn/ft^2$) |
|---|---|
| [0º, 45º] | 0.0083 |
| ]45º, 135º [ | 0.0165 |
| [135º, 225º] | 0.02480 |
| ]225º, 270º [ | 0.0165 |
| [270º, 360º] | 0.0083 |

### *4.3 Solution Algorithm*

The algorithm will be discussed in the light of hypothetical case scenario between 2 points (start: A and destination: B), without any lands between them – this will be discussed later as a corner case- and with one assumption that the ship is already acquired its speed and in open sea not in port or channel and out of any shallow water. **Figure 1** represents the main components of the proposed approach.

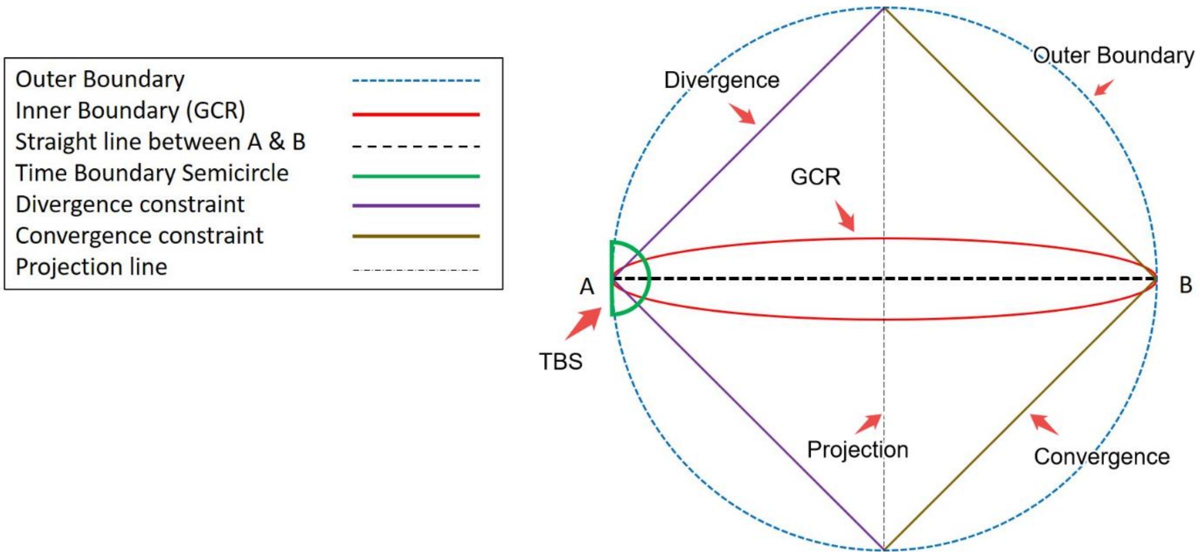


**Figure 1:** Main constructions and components of approach

Outer Boundary: A circle that passes through A&B with radius R1 = $\frac{1}{2}$ AB, in which the ship cannot maneuver outside

Inner Boundary (GCR): great circle route is the shortest distance between 2 points on the sphere, the ship will maneuver around them to be close to the shortest path.

Straight line between A&B and the projection line: they are construction lines to determine spatial properties for instance, divergence and convergence constraints.

Time Boundary Semicircle (TBS): it demonstrates time boundary of a preset value of time, in this paper it will be one hour as data obtained updated every one hour, the ship cannot get out this semicircle in the predetermined time frame even it moves with its maximum speed. The radius of this semicircle R2 = Max velocity of ship * predetermined time frame.

Divergence Constraint: a chord connected between A and the intersection point of the projection line with the outer boundary circle. This projection line is assumed to be at half way between A & B, this projection line could move forward or backward to change the angle of divergence and let the ship maneuver in a wider area away from inner boundary (GCR) If it will yield less resistance based on weather conditions considering achieve time constraint of the voyage.

Convergence Constraint: a chord connected between the intersection point of the projection line with the outer boundary circle and B. This projection line is assumed to be at half way between A & B, this projection line could move forward or backward to change the angle of convergence to ensure the ship will reach destination even it will pass through points with high resistance to achieve time constraint and position of destination.

Divergence and convergence constraints will be optimized in each step specially the initial and final steps due to the necessity of including more area of maneuvering at the beginning of the voyage and at its end. The ship will maneuver inside divergence and convergence constraints area around inner Boundaries of GCR. It is a dynamic Multi phase optimization problem that have many variables that will be determined through the process and fed again to the solution algorithm shown in Table 3 to optimize each step till the destination and this is the key point for precise results.

**Table 3:** Solution Algorithm

| Line | Procedures of solution algorithm |
|---|---|
| 1 | Begin |
| 2 | Construct AB line segment between start point and end point |
| 3 | R1 = 0.5* AB |
| 4 | Construct a Circle with radius R1 passing through A & B (Outer Boundary) |
| 5 | Construct GCRs on both sides of AB line segment as (Inner Boundary) |
| 6 | Construct Projection Line at midpoint of AB perpendicular to it and intersect Outer Boundary |
| 7 | Construct Divergence constraint line segments on both sides, divergence angle = $90^o$ initially |
| 8 | Construct Convergence constraint line segments on both sides, convergence angle = $90^o$ initially |
| 9 | Construct TBS in the direction of End point with radius R2 = Max. Ship Speed * time frame |

| | |
|---|---|
| 10 | Calculate involuntary speed reduction at all positions of intersections between long. And lat. inside the TBS using Mathematical model mentioned |
| 11 | Adjust divergence and convergence angles based on minimum values of reduction regarding their positions, constraints lines will be drawn and pass with farthest points in both direction |
| 12 | Closest node in range of 5 Nautical miles with the min. speed reduction will be chosen as a way point |
| 13 | Plot a line segment between this point and next node. |
| 14 | Take its distance and append it to one dimensional array of distances between nodes |
| 15 | Divide corresponding distances with initial speed (assumed to be maintained constant) |
| 16 | Append it to array of TCV |
| 17 | Do summation for elements of TCV array |
| 18 | If Σ of elements of TCV array ≤ 1 hour (preset time frame) |
| 19 | Loop from line 10 to line 18 |
| 20 | Else, stopping criteria is met, identify the current node position |
| 21 | Loop form line 9 to 20 |
| 22 | This loop will continue till the last TBS |
| 23 | If the node coincides with the End point |
| 24 | STOP |

If there is an obstacle or land between the start and end point of the voyage, the voyage will be divided into more than one initial and end points with the same condition that there is no land or obstacle between the new nodes. The same algorithm will be applied on stages till the final End point.

### *4.4. Test Case comparison between TBS and SIMROUTE software.*

Hypothetical case study between Start point (A) with coordinates of (40.4833, 2.5) and End point B with coordinates of (40.9833, 3.5), first value is latitude and second one is longitude. These positions are located in the mediterranean sea. So, weather conditions data of this region is downloaded from CMEMS with prespecified parameters known as metadata of the simulation. Table 4 Shows metadata of test case. This data is downloaded through MOTU client from CMD.

**Table 4:** Test Case Metadata

| | |
|---|---|
| Data time | 21-01-2020 |
| Time resolution | One hour from 00:00 to 23:00 |
| Initial velocity | 16 knots |
| Data boundaries | Lon. Min =1.500<br>Lon. Max =5.500<br>Lat. Min = 38.450<br>Lat. Max = 42.150 |
| Data included | Wave significant height ($H_s$) in meters<br>Wave Periodic Time (T) in seconds<br>Wave encounter direction in degrees |
| Involuntary Speed reduction model | Bowditch model |
| Start time of sailing | 00:00 |

### *4.4.1 SIMROUTE with A* Algorithm Implementation.*

[19] implemented a comprehensive software for ship weather routing referred to as SIMROUTE. A* pathfinding algorithm is used to optimize sailing route as a function of the wave action. This software is opensource and consists of many python scripts to implement weather routing. To apply this methodology on test case, we Run 3 scripts and import Metadata form separate script named "params" as follows:

1- get_waves_CMEMS.py: to download weather data with prespecified parameters

2- make_waves.py: this script is used to mesh-grid waves data and construct heatmap with waves significant height for each intersection point between latitudes and longitudes.

3- main.py: this is the main script that apply A* algorithm and cost function implementation and get out results needed.

### *4.4.2 TBS implementation.*

The aforementioned algorithm is implemented with little modifications for simplicity using Excel software with number of iterations as follows:

1- The wave data downloaded in (.nc) format has been converted to CSV format to deal with it.
2- CSV file contains data for 24 hours from 00 to 23 for the data 21-01-2020, so we divide each hourly data in a separate file as a chunk of data, every file includes data for each TBS constructed and used.
3- Starting from 00-hour file data as it is the start of the sailing from A, and after setting the closest range of candidate position to be in range of 5 nautical miles, dead reckoning techniques is used to determine the boundaries of searching the candidate positions around the start point by finding 3 values from start point which are: max_lat. at $0^o$, min_lat. at $180^o$, and max_long. At $90^o$, these degrees are measured from north. So, from the start position we add 5 Nm in 3 directions (0, 90, 180). These positions will construct inner semicircle with radius of 5 nautical miles. And within this boundary all candidate positions will be considered.
4- Equations used to determine new latitudes and longitudes are as follows in Excel format (as written in Excel software, these formulas maybe written with another format in another software like: python & matlab) [21]:

$$\varphi_2 = \text{asin}( \sin \varphi_1 \cdot \cos \delta + \cos \varphi_1 \cdot \sin \delta \cdot \cos \theta ) \quad (2)$$

$$\lambda_2 = \lambda_1 + \text{atan2}( \sin \theta \cdot \sin \delta \cdot \cos \varphi_1, \cos \delta - \sin \varphi_1 \cdot \sin \varphi_2 ) \quad (3)$$

where φ is latitude, λ is longitude, θ is the bearing (clockwise from north), δ is angular distance d/R; d being the distance travelled, R the earth's radius in nautical miles, all positions must be converted to radians.

5- Each new ($\varphi_2$, $\lambda_2$) will be calculated to get those boundaries.
6- Based on max_lat. , min_lat., and max_long. filtration of data will take place to determine candidate positions.

7- After determining candidate positions, involuntary speed reduction calculations are conducted based on the data. Units conversions from meter to foot is considered to be compatible with values of F (Θ).

8- Maximum velocity between candidate positions is chosen as the location of minimum reduction. The coordinates of this position are chosen to be the optimized next waypoint.

9- By using spherical law of cosines from the above source, we determine the distance between current position (start point) and following waypoint.

$$\text{Distance} = \text{acos}(\sin(lat1)*\sin(lat2) + \cos(lat1)*\cos(lat2)*\cos(lon2-lon1)) * R \quad (4)$$

10- Through this methodology, velocity is assumed to be maintained around the initial velocity, so TCV will be calculated by dividing distance by initial velocity.

11- TCV will be accumulated and summation will take place after every iteration till Σ TCV will exceed 1 hour. Subsequently, the next data file for next hour is used and another TBS will be constructed.

12- Convergence and Divergence constraints are adjusted and fitted manually for simplicity in this implementation to ensure arrival to end point.

Results are compared between these 2 methodologies based on 3 criteria:

a- Sailing distance

b- Sailing time (main optimization factor)

c- Optimized route

All these results are demonstrated with a Discussion in the next section. Moreover, limitations of proposed implementation will be mentioned.

## 5. Results and Discussion

After running SIMROUTE software, the following outputs are extracted which comprises Figure 2 and 2 (.txt) files that contains data about sailing distance, sailing time and optimized route as waypoints from start point A to end point B. Figure 2 demonstrates two proposed paths from SIMROUTE the first one is the minimum distance route which calculate the minimum distance between 2 points based of great circle path without considering any optimizations to minimize impacts of weather conditions, and the other route is the optimized one that optimize the first route taking into consideration the weather conditions by minimizing cost function that includes many factors for instance, wave effect on navigation, speed reduction and minimum path finding algorithm. The heat map shown in Figure 2 represents Significant wave height in the region under study.

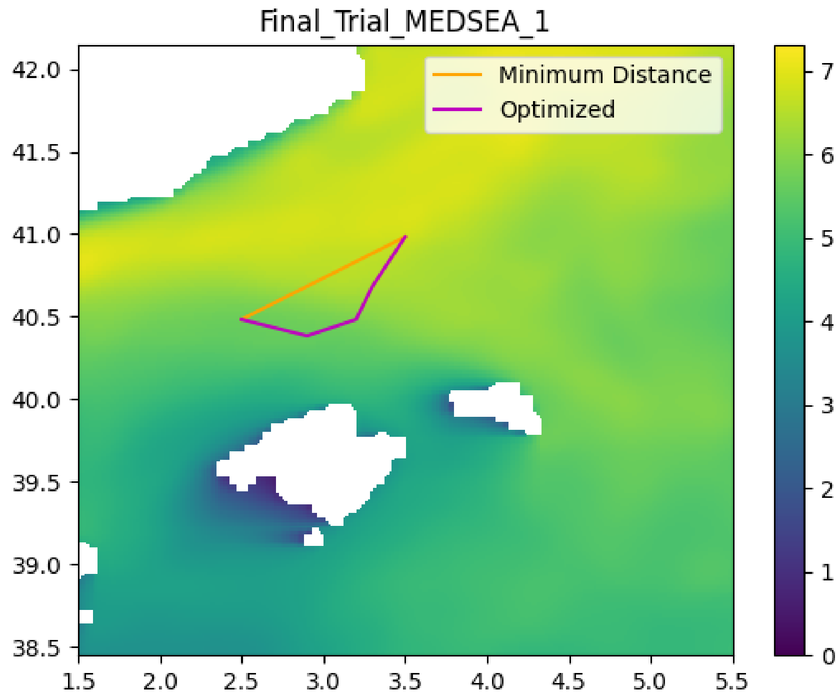


Figure 2: SIMROUTE output simulation of weather routing between A and B

Table 5 summarize the main outputs of simulation that solve the optimization problem for minimum sailing time regarding weather conditions. For the optimized route the voyage between A and B took 7.53 hours, however it moves bigger distance than minimum distance route but the optimized route minimize the impact of weather conditions so the ship will arrive faster. Moreover, SIMROUTE Algorithm divided the route into 24 waypoints from A to B that means 24 iterations are used to reach the end point.

Table 5: Sailing time and travel distance for both proposed routes

| Criteria | Sailed hours | Sailed miles |
|---|---|---|
| Route optimized | 7.53 | 67.18 |
| Route Minimum distance | 11.29 | 54.47 |

On the other hand, after implementing TBS algorithm using Excel software, we found that 6 TBSs are constructed with total of 20 iterations to reach endpoint B. Table 6 summarizes the results of TBS implementation. As we can see below the total sailing time for the trip between A and B is 5.4631 hours with 2.07 hours saving of time by applying TBS algorithm. The total distance travelled is 86.605 nautical miles which is more than SIMROUTE algorithm by 19.425 nautical miles. But it is better to choose longer distance with minimized time of arrival and with minimum impact of weather to ensure less fuel consumption and more safety considerations. Results show significance of TBS over SIMROUTE with A* Algorithm in minimizing sailing time as a main objective for this current problem. Sailing time is minimized by 27.5 % by applying TBS. In addition, more precise model of calculating impacts of weather conditions is presented considering continuous time varying conditions.

Table 6: TBS Algorithm implementation results

| TBS | Iterations | Latitudes | Longitudes | Distance (Nautical miles) | TCV (hours) |
|---|---|---|---|---|---|
| TBS 1 | start | 40.48330000 | 2.500000000 | null | null |
| | 1 | 40.39583206 | 2.500000715 | 5.25161541 | 0.32822596 |
| | 2 | 40.31250000 | 2.541667223 | 5.35419406 | 0.33463712 |
| | 3 | 40.27083206 | 2.666667223 | 6.24736521 | 0.39046032 |
| TBS 2 | 4 | 40.22916794 | 2.791667223 | 6.250506259 | 0.390656641 |
| | 5 | 40.27083206 | 2.916667223 | 6.250506259 | 0.390656641 |
| | 6 | 40.27083206 | 2.958333969 | 1.908783667 | 0.119298979 |
| | 7 | 40.3125 | 3.000000715 | 3.146430415 | 0.196651901 |
| TBS 3 | 8 | 40.35416794 | 3.041667223 | 3.145710124 | 0.196606883 |
| | 9 | 40.39583206 | 3.041667223 | 2.501532961 | 0.15634581 |
| | 10 | 40.4375 | 3.083333969 | 3.144288423 | 0.196518026 |
| | 11 | 40.4375 | 3.125000715 | 1.90407162 | 0.119004476 |
| | 12 | 40.52083206 | 3.125000715 | 5.003295276 | 0.312705955 |
| TBS 4 | 13 | 40.5625 | 3.166667223 | 3.142136889 | 0.196383556 |
| | 14 | 40.64583206 | 3.291667223 | 7.582899766 | 0.473931235 |
| | 15 | 40.6875 | 3.416667223 | 6.218159162 | 0.388634948 |
| TBS 5 | 16 | 40.72916794 | 3.500000715 | 4.543549697 | 0.283971856 |
| | 17 | 40.8125 | 3.500000715 | 5.003295276 | 0.312705955 |
| | 18 | 40.89583206 | 3.500000715 | 5.003295276 | 0.312705955 |
| | 19 | 40.9375 | 3.500000715 | 2.501762315 | 0.156360145 |
| TBS 6 | 20 | 40.97916794 | 3.500000715 | 2.501762315 | 0.206635664 |
| | | | **Summation** | 86.6051604 | 5.463098044 |

Although, speed is reduced due to weather conditions but while implementing TBS solution, the operator is assumed to maintain the velocity of the ship around the initial velocity even if this will increase fuel oil and energy consumption. this will need another optimization work which is out of scope of this study and will be considered for future work.

This study has some limitations, Excel software usage for implementing the algorithm which has less precision than python programming language, but we choose to use it for its simplicity. Number of iterations also considered as limitation. By increasing number of iterations and decreasing range of closest distance more precise outputs will be gained. This will be considered for future work

## 6. CONCLUSIONS AND FUTURE WORK

In this study, TBS novel approach is proposed to cover the gap in the previous academic advancements regarding continuous time varying weather conditions and its impact on prediction of optimized routes. Route is optimized by finding positions (lat., long.) where the weather conditions have the least impact in range of divergence – convergence constraints. Involuntary speed reduction model is chosen (Bowditch) to predict these positions and propose an optimum path consisting of points of least speed reduction which reflect least waves impacts on navigation. Test case between 2 hypothetical positions in Mediterranean Sea has conducted to compare between TBS methodology and previous approved methodology which is SIMROUTE software with A* Algorithm developed by [19]. The results confirm the significance of TBS algorithm by reducing sailing time by 27.25 % from the SIMROUTE methodology for the same initial conditions. For future work recommendations, mathematical model used must be developed to comprise wind effect also not only waves effect. Python scripts will be developed to maximize efficiency of TBS algorithm and consider all corner cases. Fuel and Energy consumption will be studied and optimizations tradeoffs between velocity, time and energy consumption will be modeled to fulfil the needs of the operators based on different situations.

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