

# MARINE SCIENCE AND TECHNOLOGY BULLETIN

## Route selection approach for vessels in ice covered waters.

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### ABSTRACT

Arctic sea ice melt fast and soon the North Pole will be open water. Besides disadvantages of the global warming to the environment and ecology, it brings some opportunities to the logistics industry. Ice navigation has been conducted intensively in summer seasons of the year, since 2009. Vessels started to move through the Arctic region because ice navigation shortens the route approximately 7.000 nautical miles. This paper focuses on route selection in icy waters. We proposed The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) approach for route selection problem based on the ice-state factors. The indicators of the proposed model involve cost-benefit factors. In this study, the optimal track is selected.

### Introduction

The transport geography of world is on dramatic change with the emergence of new arctic seaways (Wilson et al. 2004). Both greenhouse effect and the seasonal fluctuations of long term average temperatures have brought a historical opportunity to extend maritime transport over the arctic region. Since the most part of continental lands are located on North hemisphere, a possible shipping route on arctic region extremely improves loss of time and energy which are used in case of a long haul over the regular basis (Shen and Shi, 2011). However, available shipping routes are still covered by floating ice (i.e. open ice, closed ice) and the arctic routing is a growing debate with its highly technical circumstances (Buysse, 2007). The optimization of navigational tracks, entry location selection and route selection are some challenges in the field. Among these debates, the selection of optimum route is the concern of this paper and it depends on a number of factors such as the dimensions of route.

International Maritime Organization (IMO) has published an international code titled Polar Code which consists of previous IMO documents based on safe navigation in the polar regions and voluntary guidelines (IMO, 2010; 2014; STCW, 1995). Arctic navigation has a short literature including track optimization among others (Ari et al. 2013). Once a navigational route selected, above mentioned studies improve the navigational quality in terms of time, structural stress, fuel consumption etc. However, the route selection is a prior problem which is not discussed in earlier studies. The route selection problem is twofold: The static route selection and the dynamic one. The static route selection approach is based on instant inputs of indicators while assuming the ice field and weather condition are stationary over the intended navigational sea field. In case of the dynamic problem, the ice field and weather may have variations over the region and the size and direction of vectors may change over the time. As an introduction to the problem, this paper deals with the static route selection problem and it is investigated by using TOPSIS approach.

With measurable and tangible criteria, TOPSIS is one of the most useful methods on analysis of selective or ranking type problems (Kim et al. 1997). An expert consultation process is used for defining the priority level of criteria and further assessments are conducted by using the data. Therefore, it is also very suitable for the static route selection problem.

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**Methodology**

TOPSIS is the acronym of The Technique for Order of Preference by Similarity to Ideal Solution is based on an index of similarity or closeness to the ideal solution and longest distance from the negative-ideal solution. The TOPSIS method compares the alternatives by the weights identified for all criteria, then normalizes the scores and calculates the geometric distance to the ideal and the negative-ideal solution. The alternative solution with the maximum similarity to the ideal solution is chosen. The TOPSIS process is fulfilled as follows:

*Step 0:* Determination of the weight value ( $W_j$ ) of each criterion.

*Step 1:* Construction of a normalization decision matrix: Normalized ratings  $r_{ij}$  are computed by the vector normalization.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}}, i = 1, \dots, m; j = 1, \dots, n$$

This step is a transformation of dimensional units into non-dimensional units to make comparisons

*Step 2:* Construction of weighted normalized decision matrix. Weighted normalized values of each criterion are multiplied by weights.

$v_{ij} = w_j r_{ij}, i = 1, \dots, m; j = 1, \dots, n$  where  $w_j$  is the weight of the  $j^{\text{th}}$  attribute.

*Step 3:* Decision of ideal and negative-ideal solutions.

Since length, minimum width along with the track and ice concentration are of cost, average track width and maximum width along with the track are of benefit, the ideal  $A^*$  and negative-ideal  $A^-$  solutions are defined as:

$$A^* = \left\{ \left( \max_i v_{ij} \mid j \in J \right), \left( \min_i v_{ij} \mid j \in J' \right) \right\}$$

$$A^* = [v_1^*, v_2^*, v_3^*, v_4^*] = [., ., ., .]$$

$$A^- = \left\{ \left( \min_i v_{ij} \mid j \in J \right), \left( \max_i v_{ij} \mid j \in J' \right) \right\}$$

$$A^- = [v_1^-, v_2^-, v_3^-, v_4^-] = [., ., ., .]$$

*Step 4:* Calculation of separation measures. The separation measures of each  $A^*$  and  $A^-$  are calculated by n-dimensional Euclidean distance. For  $A^*$ , separation measure ( $S_i^*$ ) is expressed by

$$(S_i^*) = \sqrt{\sum_{j=1}^4 (v_{ij} - v_j^*)^2}, i = 1, 2, \dots, 5 \quad \text{and} \quad \text{the}$$

separation measure of  $A^-$  is expressed by

$$(S_i^-) = \sqrt{\sum_{j=1}^4 (v_{ij} - v_j^-)^2}, i = 1, 2, \dots, 5$$

*Step 5:* Calculation of the relative closeness to the ideal solution. ( $C_A^*$ ) is calculated from

$$(C_A^*) = S_A^- / (S_A^* + S_A^-)$$

Note that  $0 \leq C_i^* \leq 1$  where  $C_i^* = 0$  when  $A_i = A^-$ , and  $C_i^* = 1$  when  $A_i = A^*$ .

*Step 6:* Ranking each alternatives in a descending preference order of  $C_i^*$ .

**Empirical Results**

*Computing the Optimum Route*

Possible previous tracks are essential for navigation in ice-covered sea regions. Figure 1 shows an empirical image which states an objective vessel and previous tracks opened by ice breakers or another vessels.

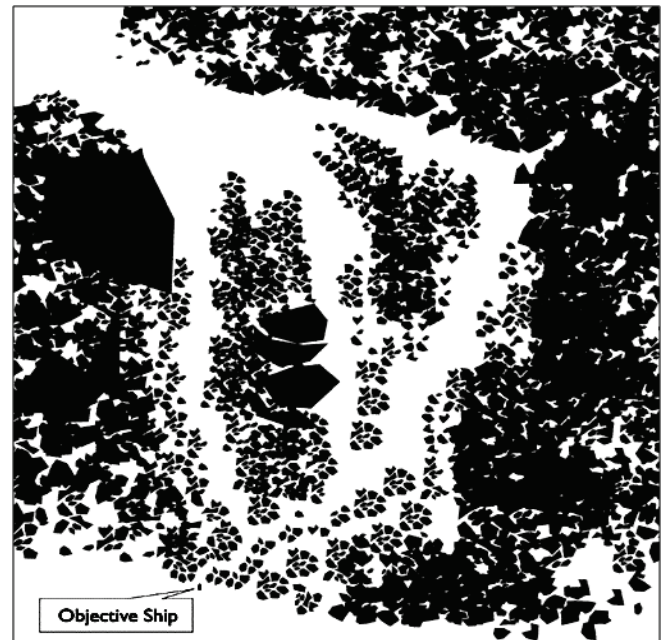


Figure 1. A ship prepares to navigate in ice-covered sea regions.

The vessels traveling from one point to another in ice, it is significant detecting the routes that reduces the travel time, fuel consumptions and as well as getting stuck in ice. For seafarers, the route information is gathered from various sources such as radar, satellite images or charts. Available paths are drawn on Figure 2. There are three different possible routes connect beginning point to the end destination.

The route length (RL), Average Route Width (ARW), minimum width along with the track (Min), maximum distance along with the track (Max) and ice concentration (IC) are the five selective parameters which affect the ice navigation based on time, money and safety. We assume this platform is static and floes are constant. Due to this approach, IC roughly corresponds to an average ice concentration along with the selected tracks.

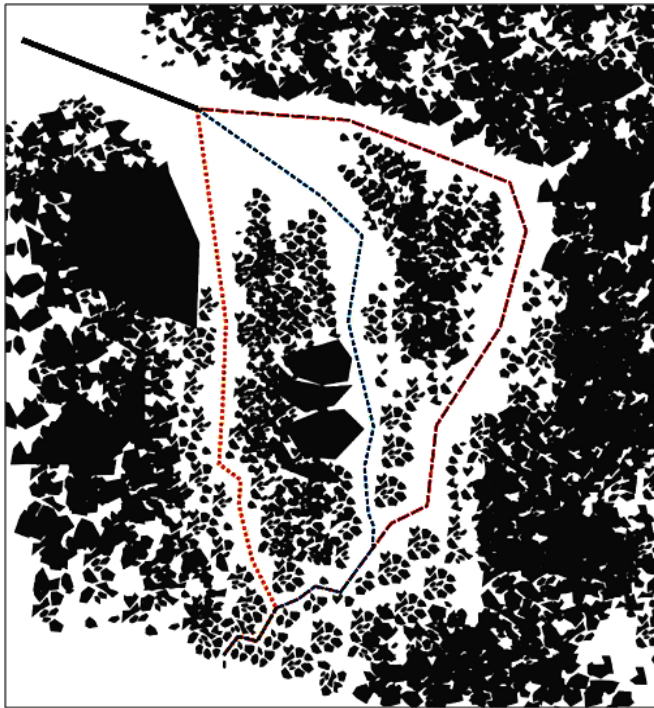


Figure 2. Possible routes for the ship navigating in ice-covered sea regions.

The TOPSIS method is applied to find the optimum track for the ship operating in ice. Table 1 shows the values for each criterion.

Table 1. The values of alternative tracks for vessels shipping in the arctic region.

	RL	ARW	Min	Max	IC
T1	11253	160	93	258	8
T2	12678	290	180	320	6
T3	14321	480	260	862	4

The route length (RL), Average Route Width (ARW), minimum width along with the track (Min), maximum distance along with the track (Max) and ice concentration (IC) are assigned a weight and the sum of all weight is 1. The given values given are assigned according to importance utilized by a survey within 15 experienced captains and academicians (Table 2).

Table 2. Weight percentages derived from a survey of five criteria.

	RL	ARW	Min	Max	IC
Weight	80%	95%	100%	30%	70%

Table 3 shows the normalized values and weighted normalized values are shown on the Table 4. Table 5 indicates the separation measures of three tracks. Table 6 shows the other  $C_i^*$  values. According to preference order is [T3, T2, and T1] the Track 3 is the best alternative for the ship which is given on the Figure 3. As it is seen on the Table 1, T3 has a longest length of 14321. However it has

Table 3. Normalized values of each criterion.

	RL	ARW	Min	Max	IC
T1	0.50	0.27	0.28	0.27	0.74
T2	0.57	0.49	0.54	0.33	0.55
T3	0.64	0.82	0.78	0.90	0.37

480 (ARW), 260 (Min), 862 (Max) and 4 (IC). Comparing to the other tracks, this means that it is the widest route among other. Also its narrowest place is 260 which provide the safest maneuvers.

Table 4. Weighted normalized values of each criterion.

	RL	ARW	Min	Max	IC
T1	0.10	0.06	0.02	0.07	0.13
T2	0.12	0.12	0.04	0.08	0.10
T3	0.13	0.20	0.06	0.24	0.06

Lastly, the ice concentration of Track 3 is 4 which is easy to go through safely.

Table 5. Values of the separation measures for three alternatives.

	T1	T2	T3
$S_i^*$	0.26	0.19	0.17
$S_i^-$	0.11	0.20	0.30

TOPSIS method provides the amount and percentage benefit for Track3 over other tracks. While Track 3 is 100% significant, Track 2 has a value of 79.6 and Track 1 is 48.3.

Table 6. Relative closeness to the ideal solution.

	T1	T2	T3
$C_i^*$	0.31	0.51	0.64

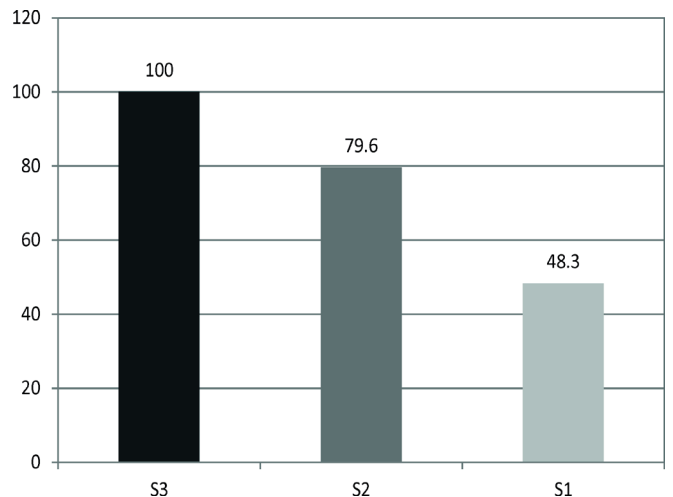


Figure 3. Entry decision results for three alternatives.

## Discussion and Conclusion

In the traditional approach, the shortest sea route is usually preferred since the cost aversion drives decision makers. On the other hand, safety of route is a subjective factor which cannot be directly measured and evaluated. By using the TOPSIS method, the safety risk is indirectly embedded into the decision making process by consulting with experts. Navigational safety in arctic region is mostly related with the dimensional limitations of route. The empirical results exposed an opposite ranking rather than the traditional expectations. The shortest sea route (track 1) is the last optimum while the longest route (track 3) is the best among three alternatives.

It is clear that the shortest navigational route does not ensure the safety of navigation and the group of experts in the field also agreed on the objective of this study by defining a difference between the length of route and other dimensions.

As it is indicated on introduction section, this study is expected to be extended by improving dynamic modeling of unsteady vectors of environment.

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