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 $\left(W_j\right)$ of each criterion.

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

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

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.

$v_{ij} = w_j r_{ij}, i = 1,...m; j = 1,...,n$ where w_j is the weight of the j^{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:

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

$$A^* = \left[v_1^*, v_2^*, v_3^*, v_4^*,\right] = [,,,,]$$

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

$$A^- = \left[v_1^-, v_2^-, v_3^-, v_4^-,\right] = [,,,,]$$

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 $\left(S_i^*\right)$ is expressed by

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

separation measure of A^- is expressed by

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

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

$$\left(C_A^*\right) = S_A^- / (S_A^* + S_A^-)$$

Note that $0 \le C_i^* \le 1$ 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.

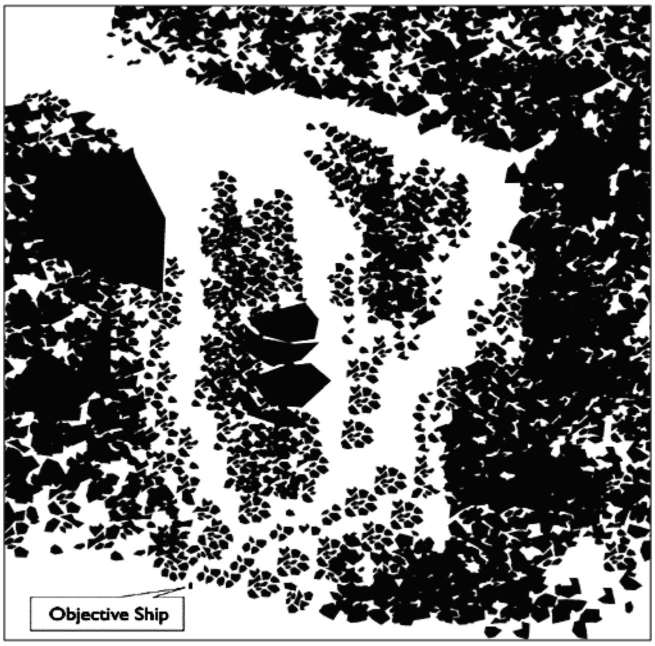

Figure 1. A ship prepares to navigate in ice-covered sea regions.

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

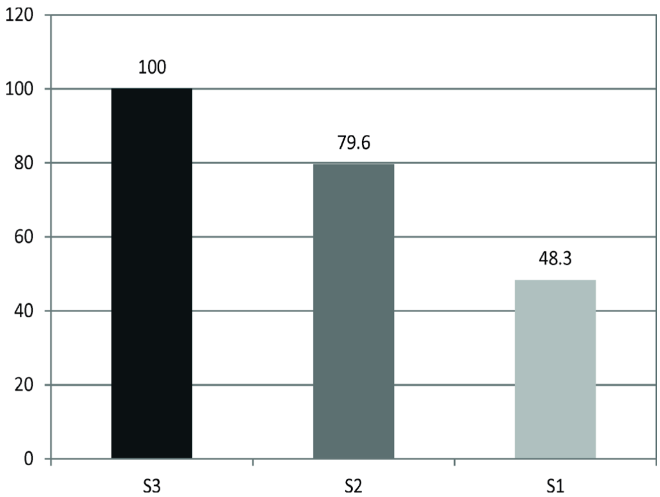

Figure 3. Entry decision results for three alternatives.

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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