

극지 운항 선박을 위한 항로 계획 방법 연구

이혜원* · † 노명일 · 이준범** · 김기수*** · 강국진**** · 정성엽*****

*,**,**,***서울대학교 조선해양공학과 대학원, † 서울대학교 조선해양공학과 교수, ****,*****선박해양플랜트연구소

요 약 : 지속되는 지구 온난화 현상으로 인해 해빙 속도가 가속화되면서, 북극 항로 활용의 필요성이 증가하고 있다. 본 연구에서는 북극해의 지형과 해빙 상태를 모두 고려한 최적 북극 항로 계획 방법을 제안하였다. 먼저, 연료 소모량을 최소화하는 항로를 탐색하기 위해 북극 항로 계획을 각종 지표를 전산화한 최적화 문제로 정식화하였다. 또한, 해빙을 고려하기 위해 POLARIS 규정을 고려한 선박의 운항 제약 조건을 추가하였다. 제안된 방법을 이용해 최적 북극 항로를 탐색한 결과, 안전하고 경제적인 항로를 도출할 수 있음을 확인하였다.

핵심용어 : 항로 계획, 북극해, POLARIS

1. Introduction

Research background

Necessity of research

- Ice melts quickly due to global warming
- Arctic route will open.
- Saving time and oil consumption using Arctic route

Demand for finding optimal route for Arctic sea

Current ship-route planning & program

- Limitation of existing algorithm & program
- Absence of consideration for Arctic sea
- Lack of application about ice condition

Ship-route-planning program

- Finding economical, eco-friendly and safe route
- Proposal of ship-route planning considering ice condition and Arctic geography

rydlab ship-route-planning method considering ice condition and Arctic geography 3

2. Ship route-planning method for Arctic sea

Configuration of system

① Optimization model

- Design variables: heading angle, Design RPM
- Objective functions: Power, Distance, RTA
- Constraints: Avoidance of the land, Required time of arrival, Reaction of design variables, ice/sea
- Generation of route: Description of ship operation, Formation of route with series of nodes

② Performance-evaluation model

- Power estimation: Estimation of resistance, Speed correction, Power prediction
- Distance calculation: Speed correction from power calculation, Location from Vincenty's formula
- RIO[®] calculation of ice based on POLARIS rule: Definition of ice regime, Risk index calculation, Risk index outcome calculation

③ Route-finding model

- Seed genetic algorithm: Generating seed using A* algorithm, updating seed, Genetic algorithm
- Port & time-based seed: Initial solution from previous solution, Constructing database, Served by port, departure month

Input data

- Ship model: Profile dimension, Draft specification, Additional info
- Geographical map: Land / sea state, Weather condition, Wave, current, Wind, sea, ice

④ User interface

- Multi-layer architecture: Route finding layer, Weather layer, Geographical layer, World map image, Ice layer

Output data

- Optimal route: Locations, Time, power, Profile of heading, RPM, Profile of distance, speed, Visualized path

rydlab *RIO (Risk Index Outcome): a measure of the likelihood of passage through an area 5

1. Introduction

Related works

Related works	Route optimization	Application for Arctic sea	Considering of ice regime
Kotovirta et al. (2008) ^[2]	Powell's method, polytope method	× (Baltic sea)	AIRSS
Jerome et al. (2009) ^[2]	×	O	×
Laurence et al. (2013) ^[2]	Least-cost path algorithm (minimize time)	O	AIRSS
Nam et al. (2013) ^[4]	Dijkstra algorithm	O	×
Aksenov et al. (2014) ^[2]	Powell's method, polytope method	O	AIRSS
Stephenson et al. (2014) ^[2]	×	O	AIRSS
Grandinetti. (2017) ^[7]	×	O	POLARIS
This study	Genetic algorithm	O	POLARIS

* AIRSS: Arctic Ice Regime Shipping System
 † POLARIS: Polar Operational Limit Assessment Risk Indexing System

Characteristics of this study

- The route planning method considering ice condition
- Proposed optimization algorithm for Arctic sea
- Applied seed genetic algorithm

rydlab 4

2. Ship route-planning method for Arctic sea

① Optimization model; problem definition and formulation

Ship-route-planning problem

Considering path and speed at once!

Formulation ship-route-planning problem into optimization problem

- Design variables**: $\theta = (\theta_0, \theta_1, \dots, \theta_{n-1})$ (Ship direction (heading angle)), $rpm = (rpm_0, rpm_1, \dots, rpm_n)$ (Ship speed (engine RPM))
- Objective function**: Total power consumption, $Power(\theta, rpm)$
- Constraints**:
 - $\|F_1(\theta, rpm) - P_{land}\| \leq \epsilon$ (Avoidance of the land)
 - $RTA(\theta, rpm) - RTA_{max} \leq 0$ (Required time of arrival)
 - $RIO \geq 0$ (Risk Index Outcome criteria)
 - $\theta_{min} \leq \theta_i \leq \theta_{max}$ (Restriction of heading angle)
 - $rpm_{min} \leq rpm_i \leq rpm_{max}$ (Restriction of RPM)

Input values

- Ports and waypoint
- Required time of arrival
- Ship model
- Environmental condition
- Geographical information

Output values

- Profile of path and speed
- Total power consumption
- Avoidance of the land and ice
- Arrival time

rydlab 5

† 교신저자 : miroh@snu.ac.kr
* gpdnjs0215@snu.ac.kr

2. Ship route-planning method 1

① Optimization model; generation of route

Generation of route

- Time duration Δt between nodes is fixed

- Definition of route**
 - The route consist of parts and a set of nodes
 - Route = $\{P_0, P_1, \dots, P_{n-1}, P_n, P_{n+1}\}$
 - Each node has heading angle and engine rpm
 - Route = $\{(\theta_0, rpm_0), (\theta_1, rpm_1), \dots, (\theta_{n-1}, rpm_{n-1}), (\theta_n, rpm_n)\}$
- Evaluation of route**
 - Values of route are obtained by summation of each segment value
 - Value = $\sum_{i=0}^{n-1} \text{value}_{i, \text{segment}}$
 - Values on each segment are constant as values on node
 - Value = $\text{value}_{i, \text{segment}} = \text{value}_i$

Formulation ship-route-planning problem into optimization problem

Design variables

- $\theta = \{\theta_0, \theta_1, \dots, \theta_{n-1}\}$ Ship direction (heading angle)
- $rpm = \{rpm_0, rpm_1, \dots, rpm_{n-1}\}$ Ship speed (engine RPM)

Objective function

- Minimize (if speed)
- Total power consumption

Constraints

- $\{P_j, \theta_j, rpm_j\} = P_{j+1}, \theta_{j+1}, rpm_{j+1} \forall j$ Avoidance of the land
- $0 \leq \theta_j < 360$ Required line of arrival
- $0 \leq rpm_j \leq rpm_{max}$ Risk Index Outcome criteria
- $rpm_{min} \leq rpm_j \leq rpm_{max}$ Avoidance of heading angle
- Heading of ship

- Route is completed by connecting the last node to arrival port for absolutely reaching the arrival port.
- At the arrival port, heading angle and rpm is not needed any more.

Strength of this algorithm

- Simultaneous optimization - heading angle and engine RPM
- Description of ship operation
- User friendly using time-duration setting - fixed time duration

2. Ship route-planning method for Arctic sea

② Performance-evaluation model; avoidance of the land and the ice

POLARIS (Polar Operational Limit Assessment Risk Indexing System) [21]

Risk Values (RV)

- Function of ice class, operation season, and status
- Indicator showing the severity of the ship for ice

Risk Index Outcome (RIO)

- A measure of the likelihood of passage through an area
- If negative, not operational or speed reduction

RV calculation

- Determination of ship type
 - A (PC1-5)
 - B (PC6-7)
 - C (1A super, A, B, C)
- Determination of ice regime
 - Stage of development
 - Stage of decay (season)
 - Ice concentration
- Risk Values (RV) calculation
- Risk Index Outcome (RIO) calculation

$$RIO = \sum C \times RV$$

RIO _{ship}	Category A & B	Category C	Ice Class	Recommended speed limit
RIO > 0	Operation permitted	Operation permitted	PC1	11 kno24
-10 < RIO < 0	Operation not permitted	Operation not permitted	PC2	8 kno24
RIO < -10	Operation not permitted	Operation not permitted	PC3-PC5	5 kno24
			Below PC5	3 kno24

2. Ship route-planning method 1

② Performance-evaluation model; avoidance of the

Avoidance of the land

Distinction of state

Avoidance of the land on the route

Selection of checking points

Formulation ship-route-planning problem into optimization problem

Design variables

- $\theta = \{\theta_0, \theta_1, \dots, \theta_{n-1}\}$ Ship direction (heading angle)
- $rpm = \{rpm_0, rpm_1, \dots, rpm_{n-1}\}$ Ship speed (engine RPM)

Objective function

- Total power consumption

Constraints

- $\{P_j, \theta_j, rpm_j\} = P_{j+1}, \theta_{j+1}, rpm_{j+1} \forall j$ Avoidance of the land
- $0 \leq \theta_j < 360$ Required line of arrival
- $0 \leq rpm_j \leq rpm_{max}$ Risk Index Outcome criteria
- $rpm_{min} \leq rpm_j \leq rpm_{max}$ Avoidance of heading angle
- Heading of ship

Avoidance of the ice

Ice Data

- Ice concentration
- Ice thickness (stage of development)

Ship model

- Ship class

Definition of ice regime

Risk Values (RV) [21] calculation

Risk Index Outcome (RIO) [21] calculation

Determine possibility of passing

Risk Values (RV)

- Function of ice class, operation season, and status
- Indicator showing the severity of the ship for ice

Risk Index Outcome (RIO)

- A measure of the likelihood of passage through an area
- Higher numbers are more likely to pass
- If negative, not operational or speed reduction

2. Ship route-planning method for Arctic sea

③ Route-finding model; seed genetic algorithm

Weakness of genetic algorithm

- Large number of iterations for global optimum
- Low reliability of solution caused by random basis

Features of ship-route planning

- Operation of fixed ports during lifetime
- Similarity between local optimum and global optimum

Seed genetic algorithm

- Application of an initial solution, seed
- Providing fast convergence speed & good solution

Based on the ports and time (departure month), saving path and RPM info.

2. Ship route-planning method for Arctic sea

② Performance-evaluation model; avoidance of the land and the ice

POLARIS (Polar Operational Limit Assessment Risk Indexing System)

Canadian AIRSS (Arctic Ice Regime Shipping System) [21]

- Assuming ice is uniform and persistent
- Define ice state as ice regime
- IN is uniquely defined in each ice regime

Russian Ice Certificate

- The risk to the hull is determined by the ice thickness, strength, and ship speed
- Relationship between safe speed and ice thickness

POLARIS(IMO) [21]

- Integrate experience and best practices of Canadian AIRSS and Russian Ice Certificate
- Evaluate ice condition through RV and RIO

Risk Values (RV)

- Function of ice class, operation season, and status
- Indicator showing the severity of the ship for ice
- The higher the number the lower the severity of ice

Risk Index Outcome (RIO)

- A measure of the likelihood of passage through an area
- Higher numbers are more likely to pass
- If negative, not operational or speed reduction

Ice condition	AIRSS (Threaten Canada)	POLARIS (IMO)
Ice regime	Ice regime	Ice regime
Severity for ice	Ice multiplier (IM)	Risk value (RV)
Possibility to pass the region	Ice number (IN)	Risk index outcome (RIO)

2. Ship route-planning method for Arctic sea

③ User Interface; route optimization program

Multi-layer architecture for containing various information

Route finding layer

Geographical layer

Weather layer

Ice layer

World-map image

Latitude and longitude

Geographical information

Sea state information

Ice information

Graphical pixel information

- Set the geographical grid for checking whether the position is land, sea or ice.
- Set weather grid for containing weather data of each position.
- Visualizing the world map

- A level of details of the information in each grid can differ from grid to grid.