Progress Report on Debriefing Section 2020-2021

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22nd March, 2021

Arctic Challenge for Sustainability II

AGENDA

- Progress: Part 1
- Progress: Part 2
- Related Publications
- Future Works
- References

Progress: Part 1

Economic Feasibility of Arctic Shipping from Multiple Perspectives

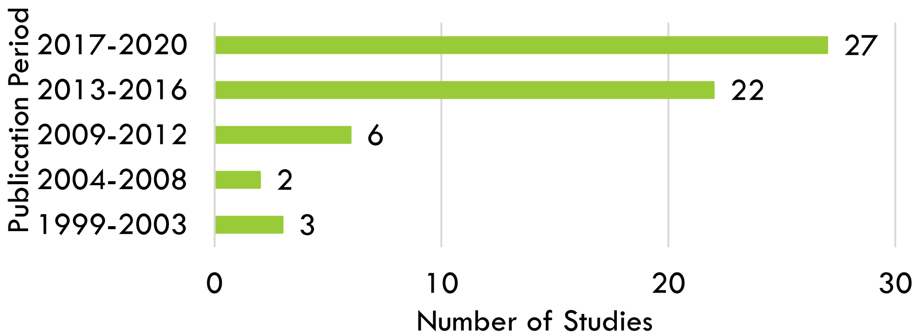
Research Objectives:

Provide a better understanding of the economic feasibility of Arctic shipping by summarizing previous studies that focused multiple perspectives

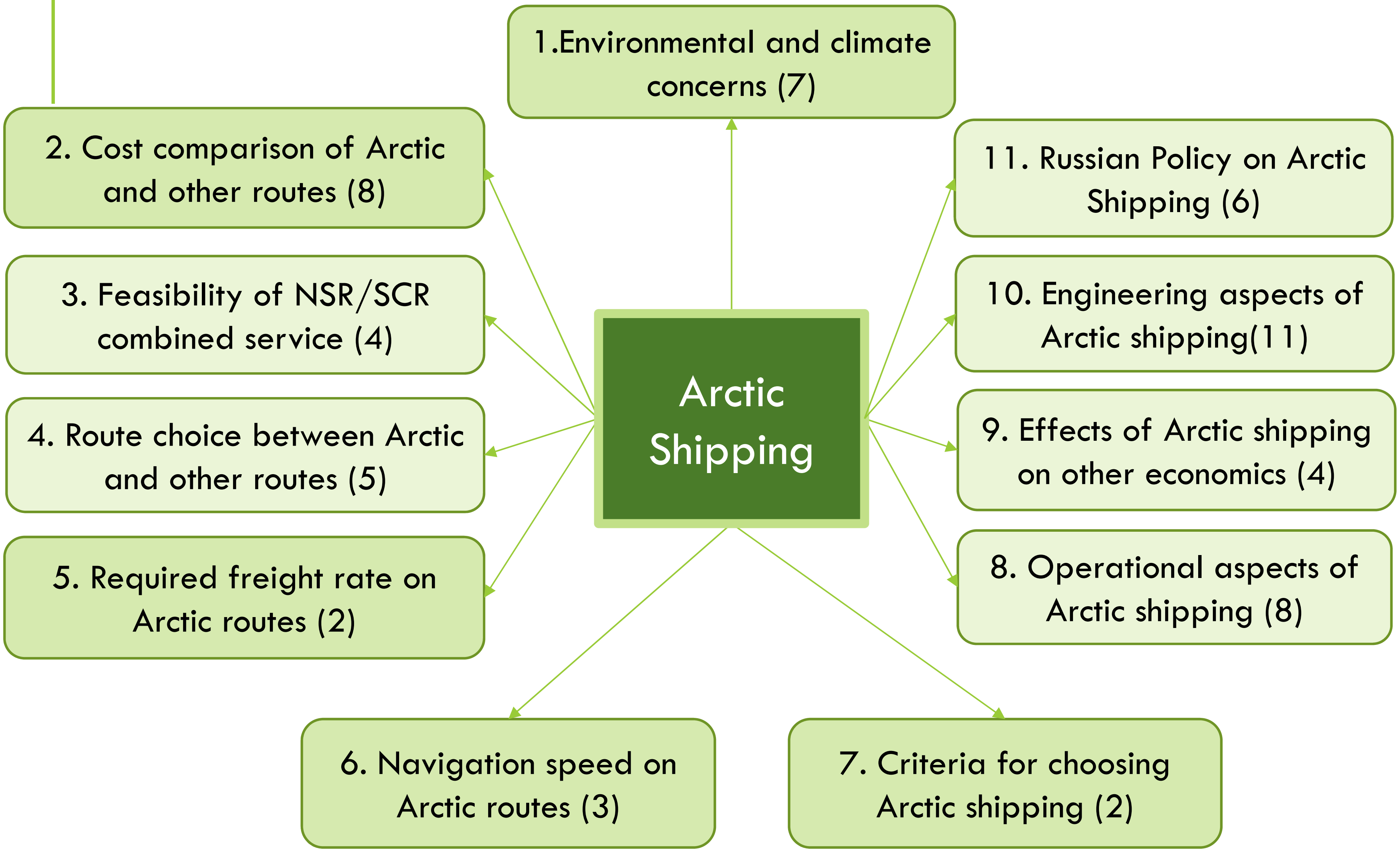
Research Method: Systematic Review

60 studies

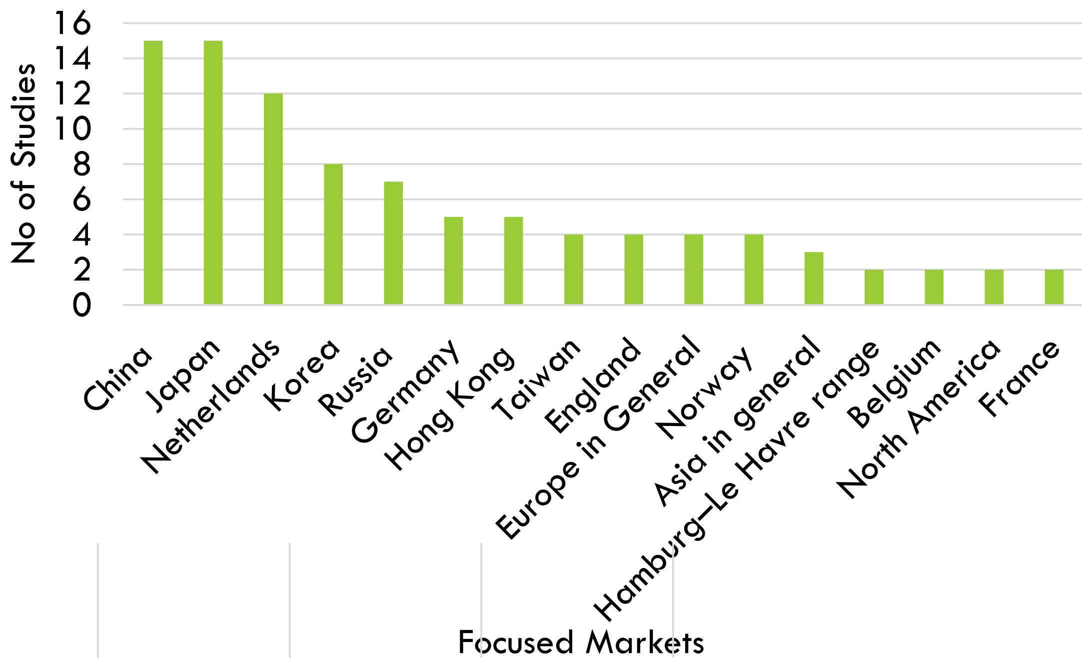
- 57 from international journals
- 2 from refereed international conferences
- 1 from research organization

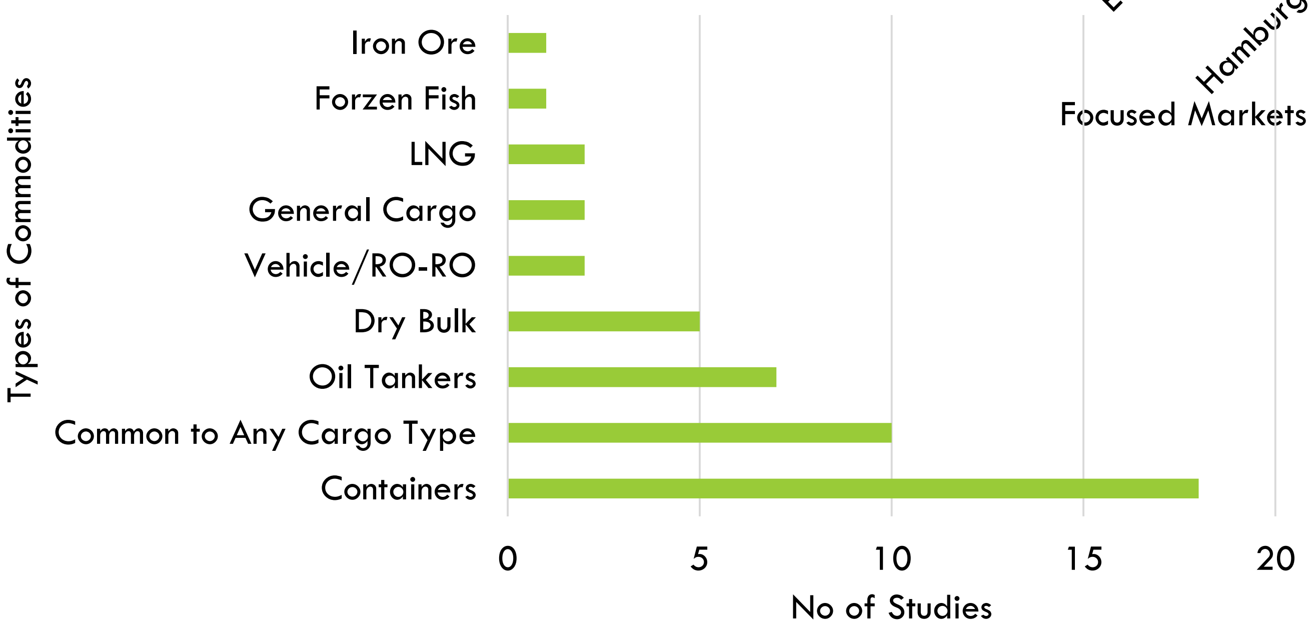


Classification of Studies

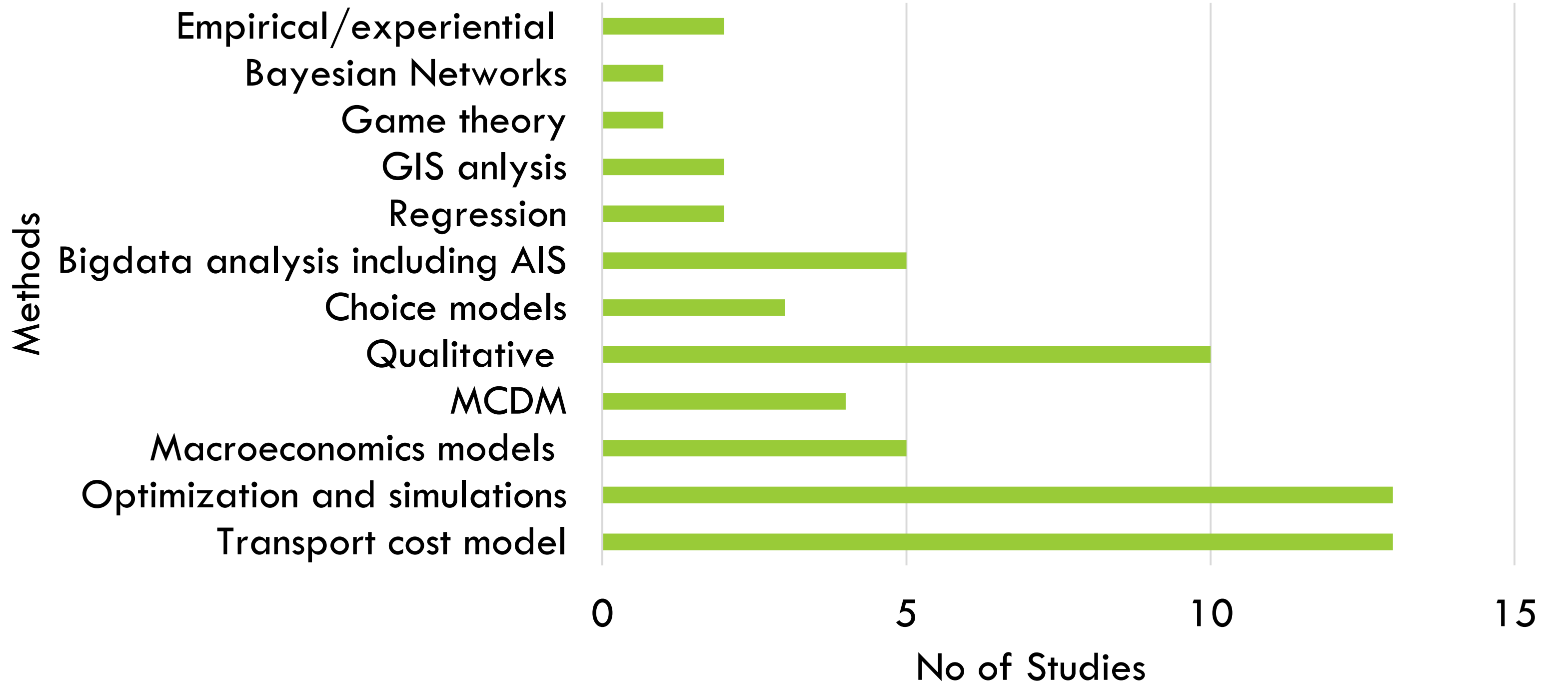


Focused Geographical Markets and Types of Commodities





Methodological Aspects



Factors Considered in Model Developments

Factors Considered	No of Studies
Voyage cost, fuel cost, fuel consumption rates	19
Capital cost, depreciation cost	17
Transit fee, ice-breaking fee, canal toll	16
Insurance	12
Crew cost	12
Maintenance cost	11
Operating cost in general	10

Factors Considered	No of Studies
Port charges	8
Ice condition, ice thickness	5
Carbon tax, emission	4
Load factor	3
Delays and waiting time	2
Port time	2
Exchange rates	1

Vessel Size and Types Used by Studies

Study	Size	Type
Cariou and Faury (2015)	40,000 DWT Handymax	1A (IAS)
Theocharis et al. (2019)	Suezmax, Aframax, Panamax, Handymax	1A (Arc4) ice class
Ding et al. (2020)	9 ship sizes between 5089 - 21237 TEUs	ice-class
Erikstad and Ehlers (2012)	N.A.	Non-ice-class to 1AS ice class
Faury and Cariou (2016)	Panamax oil tanker	1A
Furuichi and Otsuka (2014)	6,500 CEU car carrier, 4,000 TEUs	Ice class
Ha and Seo (2014)	650, 4300, 5000, 8000 TEUs	DAS
Konygin et al. (2015)	70 000 t DWT tanker	Arc 6
Lasserre (2014)	4500 TEU	1AS
Lindstad et al. (2016)	Dry bulk (Panamax and Capesize)	N.A.
Liu and Kronbak (2010) Wang et al. (2018)	4300 TEU	Ice class 1B
Otsuka et al. (2013)	75,000 dwt (bulk), 147,500 m3 (LNG), 12,383GT (reefer)	Ice-class IA
Pruyn (2016)	11 ship sizes between 17,800- 289,400 DWT	ice-class 0, 1, 2, with given specifications, regular vessel with ice breaker
Shibasaki et al. (2018)	147,500 m3, 172,000 m3, LNG carrier	Arc 4, Arc 7
Somanathan et al. (2009)	N.A.	CAC3
Solakivi et al. (2019)	7 ship sizes between 500–700 TEU, 10,000–12,000 TEU	IA and IAS Ice Class (FSCIR)
Stephenson et al. (2013)	N.A.	PC3, PC6, open-water vessels with high, medium, and no ice-breaking capability
Xu et al. (2011)	10,000 TEU	non-ice class
Xu et al. (2018)	8000, 10 000, 12 000, 14 000 and 16 000 TEUs	ice-class 1A (Finnish-Swedish) or ARC4 (Russian)
Yumashev et al. (2017)	> or < 2500 TEU, > or < 50,000 DWT (bulk)	ice-strengthened vessels in the future
Zhang et al. (2016)	Panamax, Aframax	Arc 4
Zhao et al. (2016)	4800 TEU	ice-strengthened ship

Navigation Speed at Arctic Vs Other Routes

Study	**Arctic Routes**	**Other Routes**
Lasserre (2014)	14 knots for NSR and 13 knots in NWP for the whole summer	20 knots SCR
Ding et al (2020)	17.73 knots in blue water and 12.00 knots in ice	16.47 knots
Wang et al (2018)	>25 knots in open water and <10 knots in ice water	25 knots
Xu et al (2018)	Spatiotemporal mapping of speed with sea ice extent	8 knots (inside Suez canal), 25 knots
Liu and Kronbak (2010)	12–13 knots during summer and 6–7 knots during winter	
Pruyn (2016)	11 knots (without ice-breaker) and 9 knots (with an ice-breaker)	14.3 knots
Shibasaki et al (2018)	6 -15 knots	18 knots
Cariou et al (2019), Olivier and Pierre (2016)	Speed from ice thickness–speed relationship	19 knots, 14.5 knots
Somanathan et al (2009)	Speed-ice numeral relationship	20 knots
Furuichi and Otsuka (2014)	14.1 knot for Summer, 12.8 knot for spring/winter	20 knots
Erikstad and Ehlers (2012)	12 knots	20 knots
Zhang et al (2016)	12 knots	16.47 (WB)/14.42 (EB)

Navigable Period and Types of Fuels

Study	Navigable Period
Chang et al. (2015)	July - September
Furuichi and Otsuka (2014)	105, 135, 165, 195, 225 days
Ha and Seo (2014)	3 and 6 months, all year
Lasserre (2014)	May - November (180 days)
Liu and Kronbak (2010), Wang et al. (2018)	91, 182, 274 days
Otsuka et al. (2013)	15th June - 30th November
Shibasaki et al. (2018)	4, 6, 9 months, all year
Xu et al. (2011)	September
Xu et al. (2018)	Dynamic navigable window considering changes in sea ice extent
Yumashev et al. (2017)	Outer navigability window (August, October), inner window (September)
Zhang et al. (2016)	6 months (summer-autumn)
Zhao et al. (2016)	4, 6, 8 months

Fuel Types	No of Studies
Intermediate Fuel Oil (IFO 380/IFO 180)	10
Marine Gas Oil (MGO)	5
Heavy Fuel Oil (HFO)	4
Liquified Natural Gas (LNG)	3
Light Fuel Oil (LFO)	2
Do not specify the fuel type	8

Feasibility of Arctic Shipping

Feasibility of Arctic Shipping		No of Studies
Feasible in general		8
Feasible only at	**High fuel prices**	5
	Long navigable period	4
	Certain vessel sizes	4
	Specific origins/destinations	4
	Sea-ice diminishes	4
	Low transit fees	3
	Certain fuel types	2
	With emission tax	2
	Certain sailing speed	1
	High load factor/ cargo volume	1
	Independent sailing without ice-breaker	1
	High global emission	1
	Short-haul	1
Not feasible due to	**Risk with difficult weather conditions and a short navigable period**	5
	Limited navigation speed	5
	High cost of ice-class vessels	5
	Ice-breaking and transit fees	5
	Vessel size's restrictions on navigation paths	4
	High emission per unit cargo	3
	Low load factor/ cargo volume	2
	Under-developed infrastructure	2
	Supply chain risk and uncertainty	2
	Political and legal aspects	2
	Impacts of cold temperature on cargo	1
	Differences in navigational practices	1

Common Limitations Highlighted From Studies

- ✓ Profitability sensitive to the cost parameters
- ✓ Excluded important stakeholders, trade volume changes and load factors
- ✓ Lack of attention towards engineering aspects in economic feasibility analysis
- ✓ Simplified assumptions on fuel consumption, speed, etc
- ✓ Exclude extra administrative and planning challengers for NSR/SCR combined service
- ✓ Barely consider reliability, just-in-time operations in liner shipping
- ✓ Ignore the loss of excluding significant markets (ex: Singapore, India)

Conclusions and Insights

Cost Factors	Market Factors	Risk Factors	Benefit Factors
✓ Additional cost for ice class vessels ✓ Fuel cost at vessel speed ✓ Emission tax ✓ Administrative cost on seasonal service ✓ Transit and ice-breaking fees ✓ Trade-off between fuel, operation, and capital costs	✓ Economic growth from Arctic routes ✓ Through traffic/OD traffic/OD pairs ✓ Ports equipped to handle containers at rotations ✓ Expansion of Suez and Panama canals ✓ Limitations on economies of scale due to small vessels	✓ Accurately predicting of ice freeze-up and breakup events ✓ Risk from icebergs and growlers ✓ Length of NSR varies with distribution of sea ice ✓ Impacts from vessel-based emission to the fragile Arctic sea environment	✓ Increase no of round trips and reduce capital cost ✓ Slow-steaming and fuel savings ✓ Emission reduction ✓ Decrease of piracy risks ✓ New market and trade potential

Progress: Part 2

Environmental Sustainability of Arctic Shipping through Vessel Speed Optimization and HFO-banned Areas

Research Objectives:

1. Analyze the effectiveness of imposing HFO-banned areas along NSR, and the locations of HFO-banned areas

2. Analyze the effectiveness of speed optimization when navigating via NSR

Focused Measurers on Vessel-based Emission Reduction

Measurers	**Description**	**Implementation**
Slow steaming	Reducing the navigation speed, which is a promising alternative due to the non-linear relationship between ship speed and fuel consumption	Voluntary/market-based measure
Speed optimization	Optimize speed to ensure service integrity and access to markets while minimizing operation cost, may not be the minimum speed	Voluntary/market-based measure
HFO-banned Areas	Enforcing HFO-banned areas so that vessels cannot use HFO inside these areas	Mandatory/regulatory option
Emission Tax	Enforcing tax for the emissions generated from vessels	Mandatory/regulatory option

Increase in NSR traffic can have various impacts to the fragile Arctic sea environment from vessel-based emissions

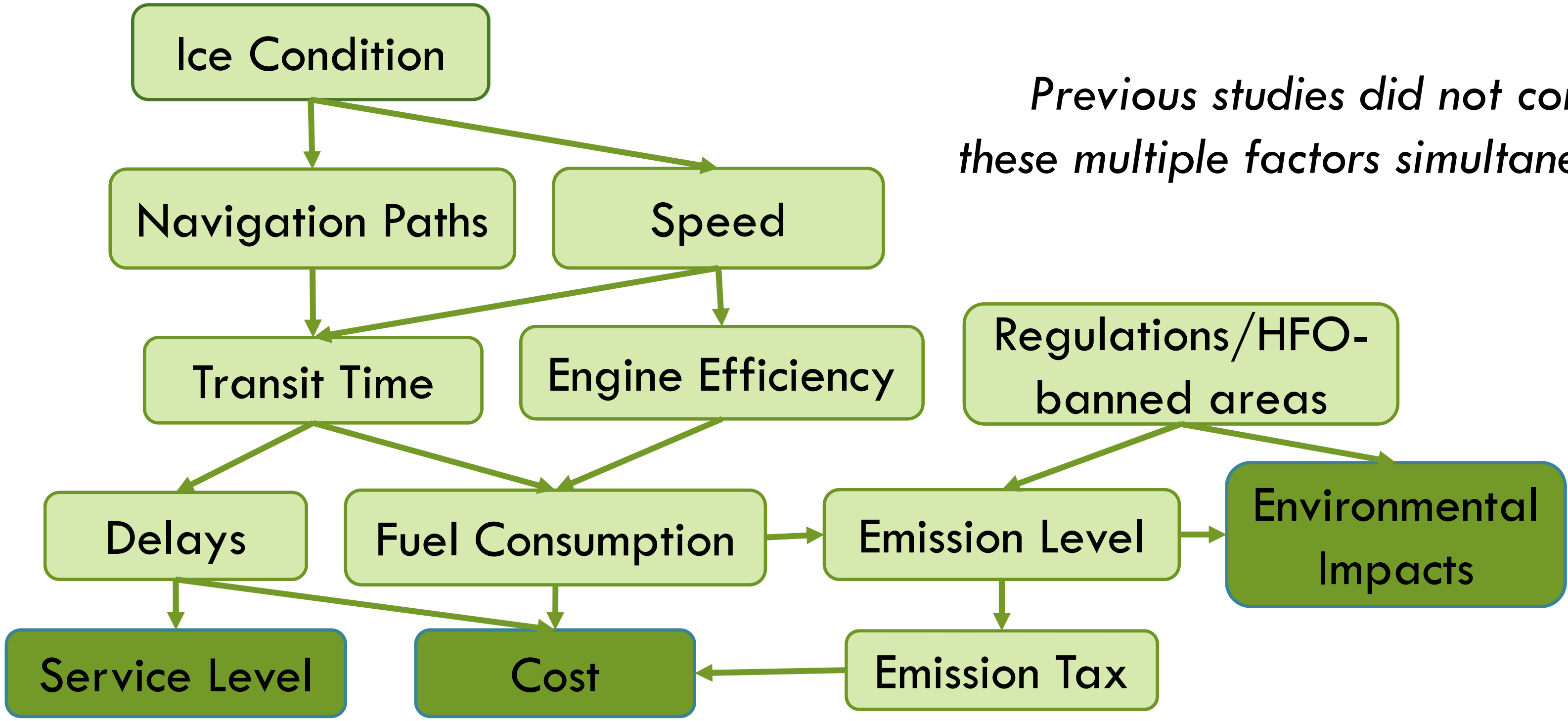
Analysis Framework

Optimum speed can have different interpretations;

- To minimize total voyage cost
- To ensures service integrity and access to markets

In Arctic routes, speed also depends on ice condition, weather, among others

However, in a majority of studies, ship speed is considered as an input not as a decision variable

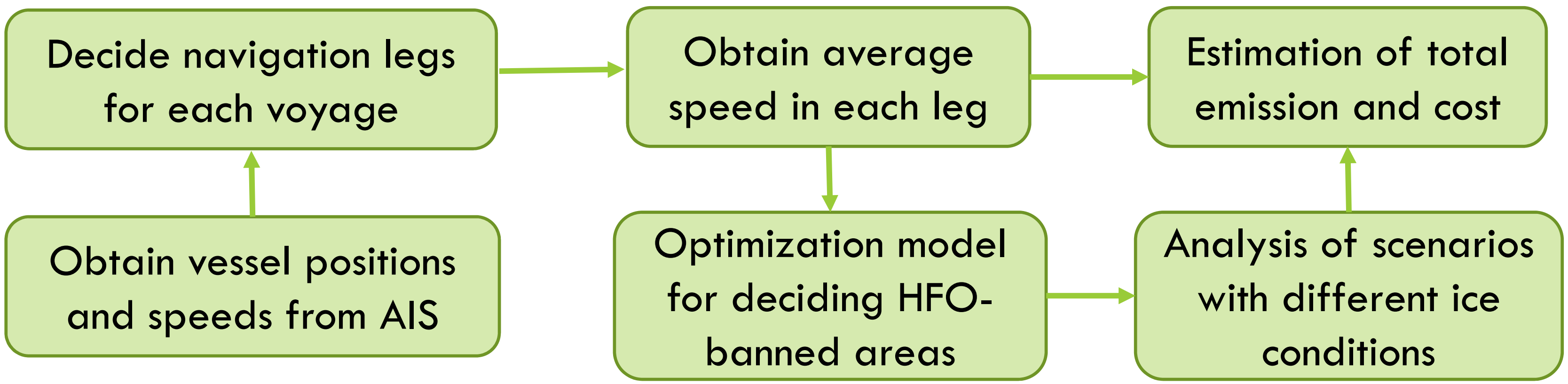


Previous studies did not consider these multiple factors simultaneously

1. Analyze the effectiveness of imposing HFO-banned areas along NSR, and the locations of HFO-banned areas

Assumptions and Work Flow

- Vessels navigates with its actual speeds given by AIS in the status quo
- Fuel switching occurs when navigating through HFO-banned areas from HFO to MGO
- Calculation of vessel-based emissions based on IMO GHGs study 2020
- Consider trip-specific HFO-banned areas due to the variation of speeds along the NSR with different vessel- and trip-specific characteristics



2. Analyze the effectiveness of speed optimization when navigating via NSR

Assumptions and Work Flow

- Cost functions and parameters of HFO-banned area selection are similarly applicable for speed optimization
- Maximum speed can be changed based on the vessel's position (leg l_n) at time t due to the ice thickness ($I_t^{l_n}$) of leg l_n at that time
- Speed can be varied in between min and max speeds considering vessel's position (leg l_n) and the time of the year

1. Estimate the emissions and cost without speed optimization when navigating via NSR (with actual vessel transit data)

2. Estimate the emissions and cost with speed optimization when navigating via NSR and with enforced HFO-banned areas
   - 2.1 With the objective of minimizing total emission
   - 2.2 With the objective of minimizing cost

3. Optimum speed at different fuel prices and emission tax levels

Vessel-, Model- and Market-specific Parameters

Vessel-specific parameters	Model-specific Parameters	Market-specific Parameters
GT of vessel	Premium on vessel new building price	Ice-Breaking cost per Zone/GT (As a function of no of zones which required ice-breaking service)
Life time of vessel	Premium on operating cost	Fuel Price HFO
Ice class	Emission Tax per CO_2e (USD/T CO_2e)	Fuel Price MGO
New building price	Fouling correction factor	Exchange rate (USD/RUB)
Specific fuel oil consumption	Speed-Power relationship	Emission types (CO_2, CH_4, N_2O, BC, SOx)
Design speed	Weather correction factor	Fuel-based emission factors
Instantaneous speed	Correction factor on speed-power relationship	Global warming potentials
Min/Max speeds	Draft-Power relationship	Emission tax
Ref Power of the Main Engine	Auc Engine usage as a % of total navigation time	
Reference and Instantaneous draft	Boilers usage as a % of total navigation time	
Engine load		
Aux Engine power output KW		
Boilers Power KW		
Draft at a time		

Analysis Cases and Scenarios

- 3 representative routes with different vessels
- 3 different ice condition scenarios

Vessels	Ice condition scenarios
1. Venta Maersk 2. Tasmanic Winter 3. Lomonosov Prospect	1. Free-ice 2. Medium-ice 3. Heavy-ice

Related Publications

Refereed Journal Publications

- Kavirathna, C.A. and Shibasaki, R. (2021) Economic feasibility of Arctic shipping from multiple perspectives: a systematic review. Okhotsk Sea and Polar Oceans Research, 5: 15-22

Currently Accepted as Full Papers for Forthcoming International Conferences

- Kavirathna, C.A., Shibasaki, R., Wenyi D. and Otsuka, N. (2021) Environmental Sustainability of Arctic Shipping through Potential HFO-banned Areas along the NSR. 26th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), Moscow, Russia

- Kavirathna, C.A., Shibasaki, R., Wenyi D. and Otsuka, N. (2021) Vessel speed optimization considering the environment and economic perspectives of Arctic Shipping, International Association of Maritime Economics (IAME), Rotterdam, Netherlands

Conference Presentations by Abstracts

- Kavirathna, C.A. and Shibasaki, R. (2021) Trends and Perspectives on Arctic Shipping Potential from Scientific Research, Arctic Science Summit Week (ASSW), Portugal

Immediate Future Works

- Collect remaining data and improve the model incorporating both ice thickness and ice concentration
- Possibly analysis of HFO-banned areas considering all transit vessels simultaneous (model for policy-making) with their actual speeds
- Analyze all scenarios of speed optimization model with different ice-conditions and vessel specifications after making possible improvements to the model

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