Optimization of Maritime Transportation

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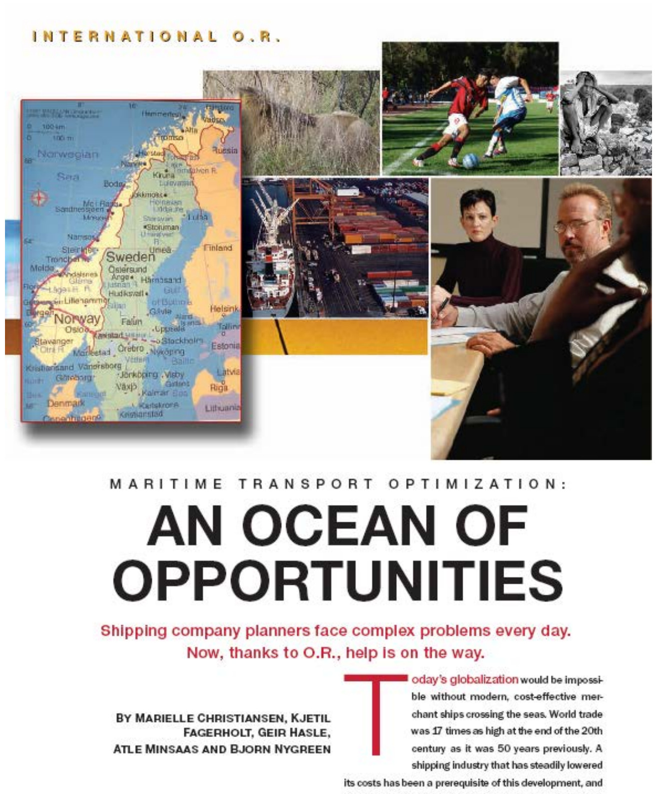
Main references used:



INTERNATIONAL O.R.

MARITIME TRANSPORT OPTIMIZATION:

AN OCEAN OF OPPORTUNITIES

Shipping company planners face complex problems every day. Now, thanks to O.R., help is on the way.

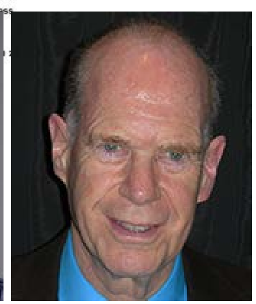
BY MARIELLE CHRISTIANSEN, KJETIL FAGERHOLT, GEIR HASLE, ATLE MINSAAS AND BJORN NYGREEN

Today's globalization would be impossible without modern, cost-effective merchant ships crossing the seas. World trade was 17 times as high at the end of the 20th century as it was 50 years previously. A shipping industry that has steadily lowered its costs has been a prerequisite of this development, and

M. Christiansen

K. Fagerholt

B. Nygreen



D. Ronen

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Outline

- Introduction to maritime transportation
- Maritime cargo routing
- Maritime inventory routing
- Trends relevant for ship routing and scheduling
- Concluding remarks

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Cargo ships

- Tankers
  - Carry liquids in bulk
- Bulk carriers
  - Carry dry bulk commodities
- Reefers
- Liquefied gas carriers
- Ro-ro ships
- Container ships
- General cargo vessels
- Etc…

Photo: Gary Blakeley

Cargo ships - ports

- Ships operate between ports
  - Loading (pickup) and unloading (delivery)
  - Supply of fuel, fresh water, etc…
- Physical limitations impose compatibility constraints between ships and ports
  - Draft, length, etc…
- Ships pay port fees
- Transhipment of containers
- Storages placed near ports
- Limited number of berths, cranes or pipes

Port operations are not focused here

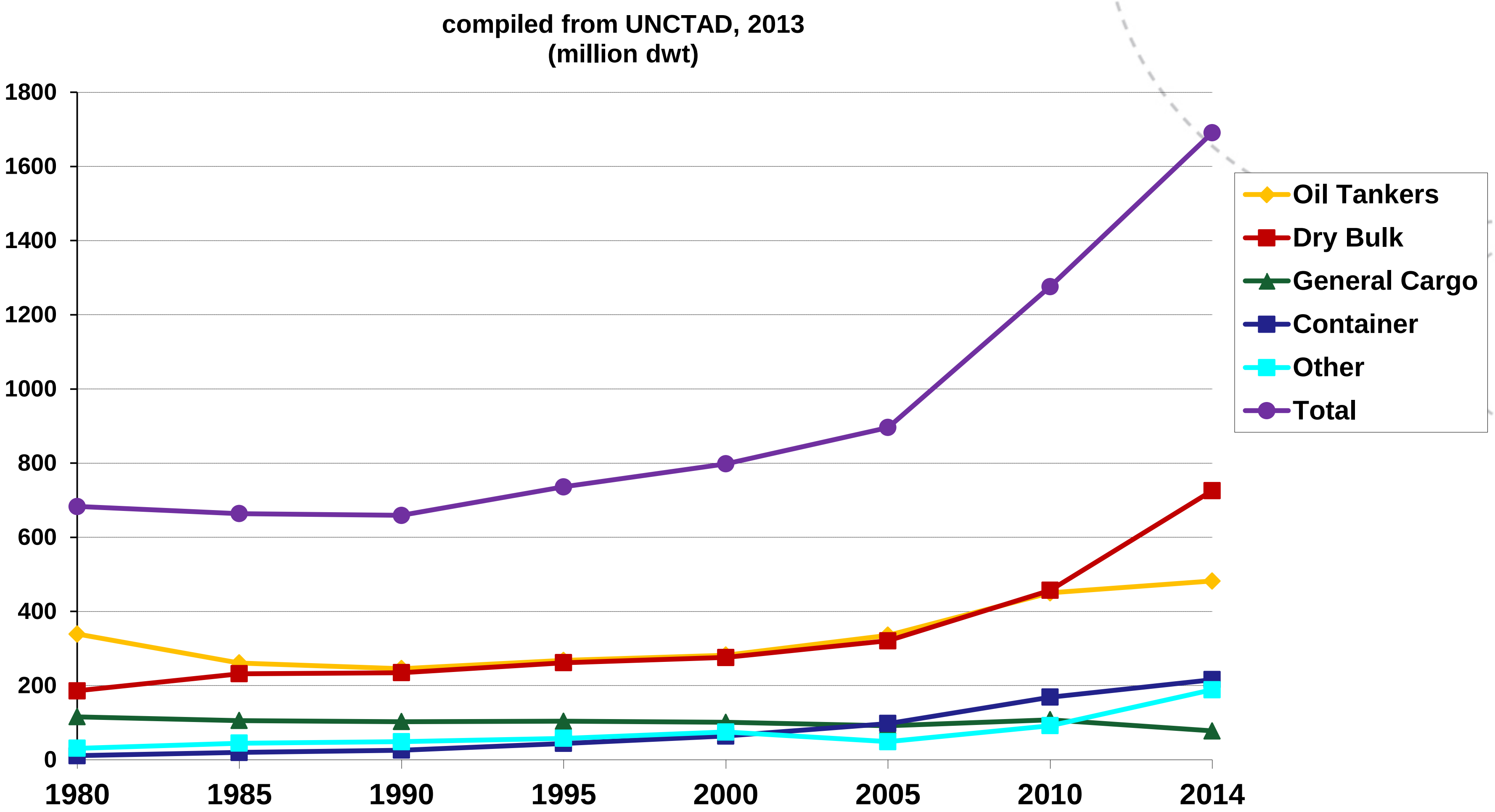
Maritime transportation - key figures

- Major mode of international trade
  - Around 90% of world trade is carried by the international shipping industry. (http://www.ics-shipping.org/shipping-facts/shipping-and-world-trade)

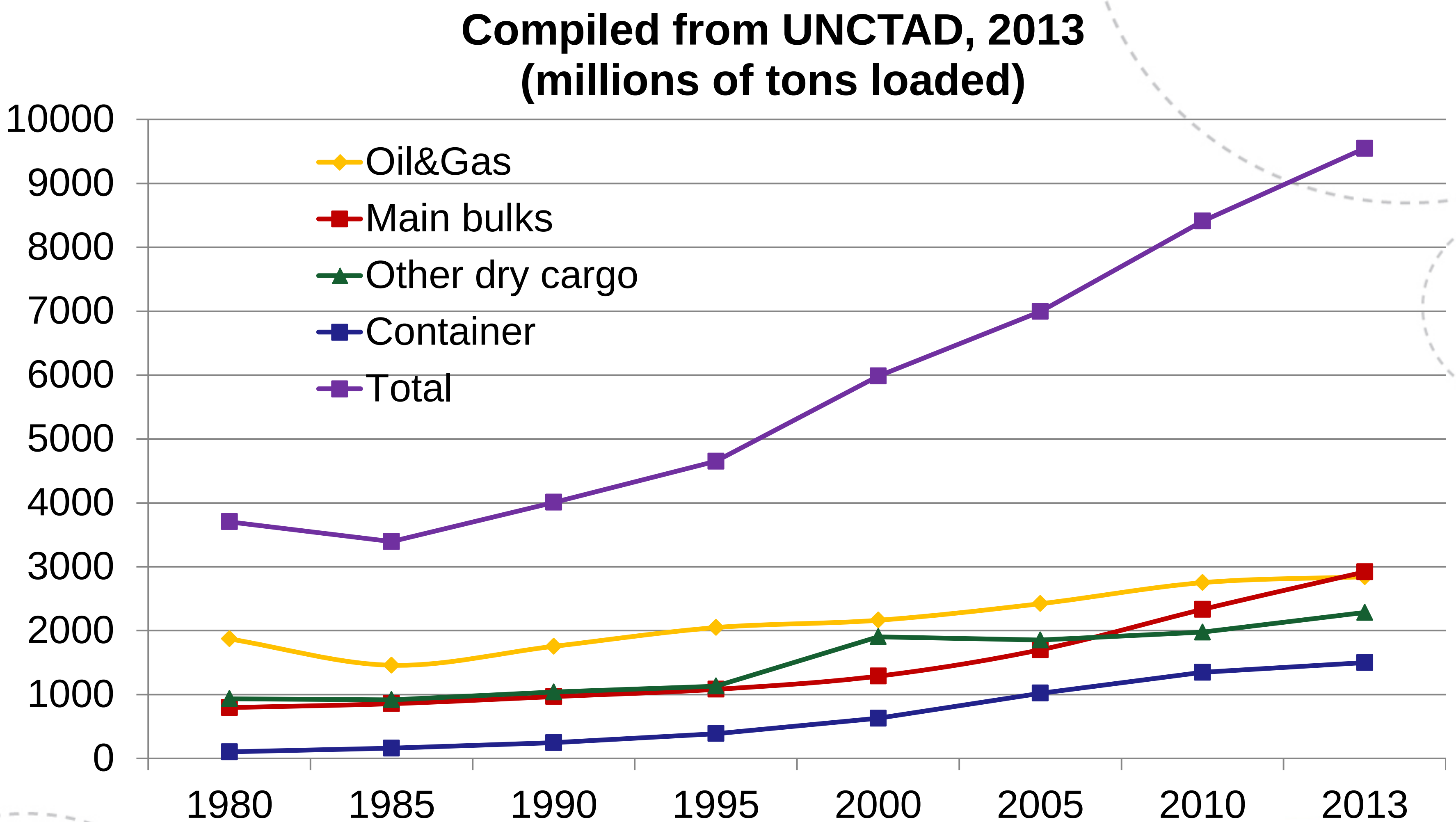
- Monopoly on transportation of large volumes between continents (deep sea shipping)

- Major role in domestic trades (short sea shipping) for countries with
  - Long shoreline (e.g. Norway)
  - Many rivers (e.g. USA)
  - Many islands (e.g. Greece)

World fleet


compiled from UNCTAD, 2013
(million dwt)
1800
1600
1400
1200
1000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2014
Oil Tankers
Dry Bulk
General Cargo
Container
Other
Total

World seaborne trade



Importance of proper ship routing

- Ships involve
  major investments and
  high operating costs:

<u>Example: A VLCC, 200.000 dwt:</u>

- Building cost: 100 mill. USD
- Daily TC rate: 70 000 USD
- Daily fuel costs: 50 000 USD
- Port fee: 100 000 USD
- Value of one cargo: 100 mill. USD

(figures only roughly estimated)

- The shipping industry has experienced a considerable change (consolidation in the manufacturing sector, increasing competition, profit margins reduced, mergers and pooling, extended logistic tasks)
- Good planning is crucial for survival:
  - Reducing costs
  - Increasing revenue by carrying spot cargoes
  - Giving important positive environmental effects
- Relatively little OR-work has been done in ship routing

Growth in number of publications

- General surveys on maritime ship routing and scheduling:

- Ronen, *EJOR* (1983)
  - 3 decades, 40 references
- Ronen, *EJOR* (1993)
  - 1 decade, 40 references
- Christiansen, Fagerholt and Ronen, *TS* (2004)
  - 1 decade, 80 references
- Christiansen, Fagerholt, Nygreen and Ronen, *EJOR* (2013)
  - 1 decade, 130 references

Basic modes of operation (Lawrence '72)

- **Industrial shipping**
  - Shipper(cargo owner) controls the fleet of vessels (owned or on TC)
  - Must ship the total demand while minimizing costs
  - Decisions: Routing and scheduling
  - Vertically integrated companies
- **Tramp shipping**
  - Combination of contract and optional spot cargoes
  - Ships follow the available cargoes, similar to a taxi service
  - Decisions: Routing/scheduling and selection of spot cargoes
  - Maximize profit
- **Liner shipping**
  - Ships follow a published schedule, similar to a bus line
  - Container, ro-ro and general cargo vessels

Planning levels

- **Strategic planning level (1-20 years)**
  - Market and trade selection (Contract evaluation)
  - Fleet size and mix decisions
  - Network design in liner shipping
- **Tactical planning level (1 week – 1 year)**
  - Ship scheduling for industrial and tramp shipping
  - Port management (inventory management, berth scheduling,…)
  - Fleet deployment in liner shipping
  - Empty container distribution
  - Berth scheduling – Allocation of ships to berths
- **Operational planning (1 day – 1 week)**
  - Environmental routing (Weather routing and ocean currents)
  - Speed selection for a sailing leg
  - Ship loading (Container stowage, Crane scheduling)
  - Booking of single orders in liner shipping

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Maritime cargo routing*

- Routing and scheduling of bulk cargoes
- Tactical planning level with planning horizon from 1 week to 1 year
- Focus on tramp shipping
- A cargo routing problem in industrial shipping can be obtained by including mandatory cargoes only
- Models and solution methods
- Extensions and variants

*Al-Khayyal and Hwang (2007) Inventory constrained maritime routing and scheduling for multi-commodity liquid bulk, part i: Applications and model. *EJOR.*

Tramp shipping: Planning process

- Mix of mandatory contract cargoes and optional spot cargoes
- Several daily requests for spot cargoes
- Negotiate spot cargoes and schedule the fleet
  - Continuous and interwoven process
- Objective: Maximize profit
- **Core business for many shipping companies**

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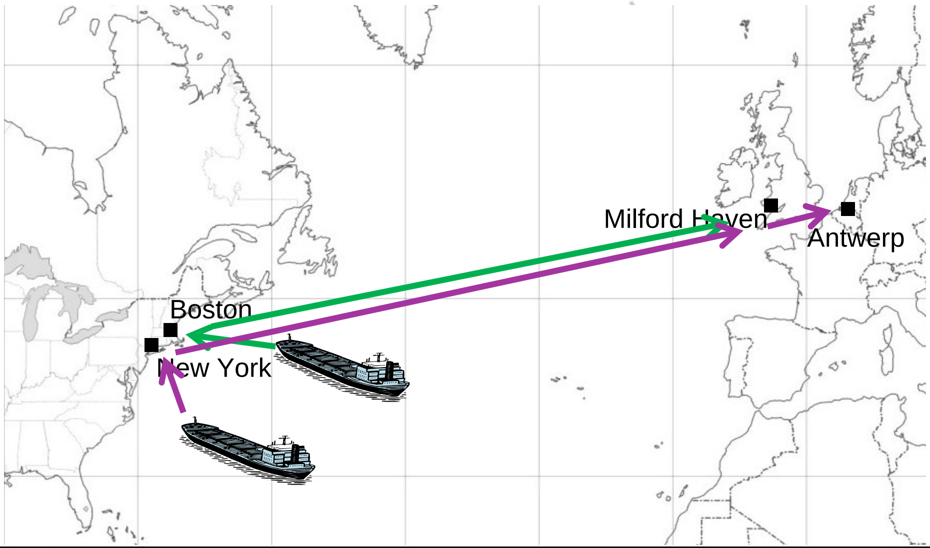
Maritime cargo routing

- Heterogeneous fleet of ships with different
  - Capacity
  - Speed
  - Initial position
- Set of cargoes to be lifted
  - Load and discharge port
  - Time windows
  - Quantity
  - Freight revenue
- Mix of contract (C) and optional spot (S) cargoes



Cargo	From	To	Quantity [ton]	Time window
1 (C)	Boston	Milford Haven	30.000	4/11-08 – 11/11-08
2 (C)	New York	Antwerp	30.000	5/11-08 – 12/11-08
3 (S)	New York	Milford Haven	20.000	5/11-08 – 12/11-08

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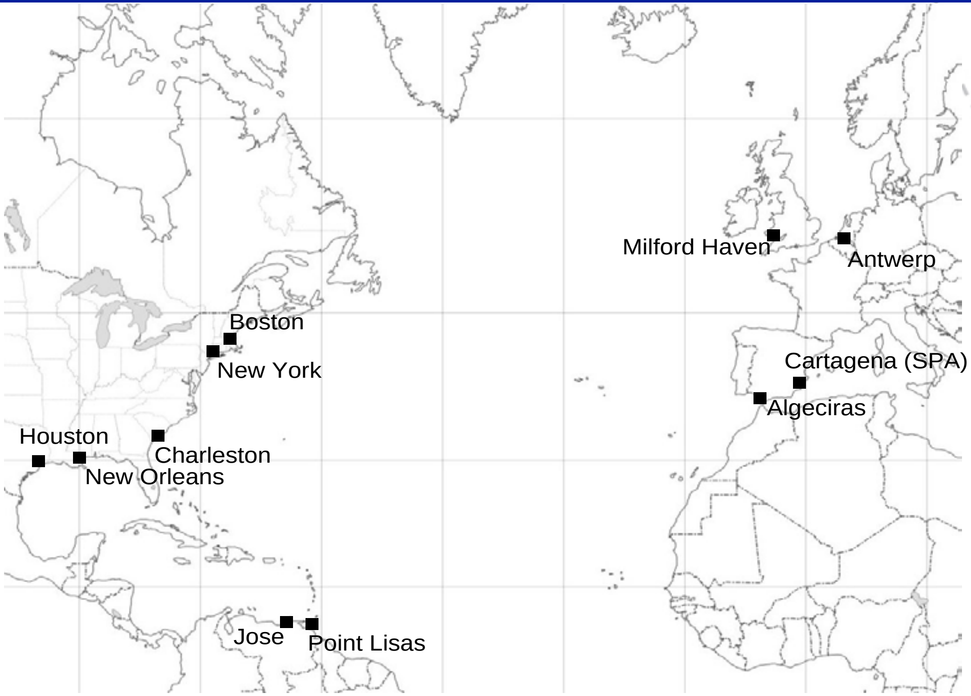
Example: Manual planning worksheet



UK/CONT	MEDIT	CARIB	US/GULF
Milford Haven – New York 40.000 ton MTBE 3/11-07 – 9/11-07 Antwerp – Boston 37.000 ton MTBE 5/11-07 – 10/11-07	Cartagena (SPA) – Houston 28.000 ton Methanol 15/11-07 – 19/11-07 Algeciras – Charleston 16.000 ton Methanol 15/11-07 – 20/11-07	Point Lisas – Houston 17.000 ton Methanol 4/11-07 – 10/11-07 Jose – New Orleans 30.000 ton Methanol 4/11-07 – 10/11-07 Jose – New York 18.000 ton Methanol 10/11-07 – 15/11-07	Houston – New York 18.000 ton MTBE 6/11-07 – 11/11-07
Cecilia Antwerp 2/11-07 Catharina Antwerp 7/11-07		Suzanna Jose 15/10-07	Alberta Boston 4/11-07 Maria Charleston 23/10-07

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Basic Maritime cargo routing

- Objective: Maximize profit (gross margin)
  - Revenue from transported cargoes – variable sailing costs (fuel costs, port costs, canal costs, etc.)

- Constraints
  - All mandatory contract cargoes must be transported once
  - Optional spot cargoes can be transported at most once
  - Routing constraints
  - Load management on board the ship
  - Time constraints
  - Ship capacity constraints

- Maritime Pickup and Delivery Problem with Time Window (PDPTW)

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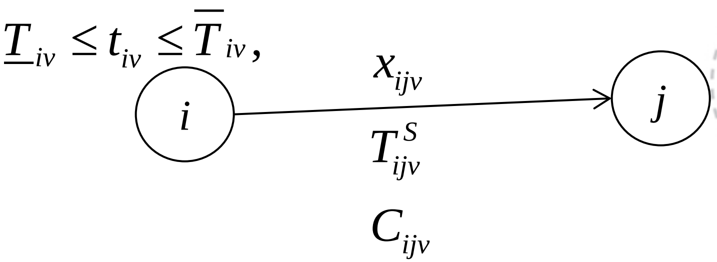
Maritime cargo routing model: Notation

- N is the total number of cargoes in the planning horizon

- Transporting cargo i generates a revenue P_i

- Node $N+i$ is the delivery (unloading) node corresponding to the pickup (loading) node i for cargo I

- Quantity of cargo i is Q_i while capacity of ship v is K_v



Maritime cargo routing model (1:2)

$$\max \sum_{i\in\mathcal{N}^C} P_i + \sum_{i\in\mathcal{N}^O} P_i y_i - \sum_{v\in\mathcal{V}} \sum_{(i,j)\in\mathcal{A}_v} C_{ijv} x_{ijv} ,$$

Revenue – variable costs

Subject to:

$$\sum_{v\in\mathcal{V}} \sum_{j\in\mathcal{N}_v} x_{ijv} = 1, \qquad i \in \mathcal{N}^C,$$

Contract cargoes must be transported once

$$\sum_{v\in\mathcal{V}} \sum_{j\in\mathcal{N}_v} x_{ijv} - y_i = 0, \qquad i \in \mathcal{N}^O,$$

Optional cargoes may be Transported once

$$\sum_{j\in\mathcal{N}_v} x_{o(v)jv} = 1, \qquad v \in \mathcal{V},$$

$$\sum_{j\in\mathcal{N}_v} x_{ijv} - \sum_{j\in\mathcal{N}_v} x_{jiv} = 0, \qquad v \in V, i \in \mathcal{N}_v \backslash \{o(v), d(v)\},$$

$$\sum_{i\in\mathcal{N}_v} x_{id(v)v} = 1, \qquad v \in \mathcal{V},$$

Routing constraints

Maritime cargo routing model (2:2)

$l_{iv} + Q_j - l_{jv} - K_v(1 - x_{ijv}) \leq 0,$ $l_{iv} - Q_j - l_{n+j,v} - K_v(1 - x_{i,n+j,v}) \leq 0,$	$v \in \mathcal{V}, (i,j) \in \mathcal{A}_v \mid j \in \mathcal{N}_v^P,$ $v \in \mathcal{V}, (i, n+j) \in \mathcal{A}_v \mid j \in \mathcal{N}_v^P,$	Load management on board the ship
$\sum_{j \in \mathcal{N}_v} Q_i x_{ijv} \leq l_{iv} \leq \sum_{j \in \mathcal{N}_v} K_v x_{ijv},$ $0 \leq l_{n+i,v} \leq \sum_{j \in \mathcal{N}_v} (K_v - Q_i) x_{n+i,jv},$	$v \in \mathcal{V}, i \in \mathcal{N}_v^P,$ $v \in \mathcal{V}, i \in \mathcal{N}_v^P,$	Ship capacity constraints
$t_{iv} + T_{iv}^P + T_{ijv}^S - t_{jv} - M_{ijv}(1 - x_{ijv}) \leq 0,$	$v \in \mathcal{V}, (i,j) \in \mathcal{A}_v,$	Time constraints
$\sum_{j \in \mathcal{N}_v} x_{ijv} - \sum_{j \in \mathcal{N}_v} x_{n+i,jv} = 0,$	$v \in \mathcal{V}, i \in \mathcal{N}_v^P,$	Cargo coupling constraints
$t_{iv} + T_{iv}^P + T_{i,n+i,v}^S - t_{n+1,v} \leq 0,$	$v \in \mathcal{V}, i \in \mathcal{N}_v^P,$	Precedence constraints
$\underline{T}_{iv} \leq t_{iv} \leq \overline{T}_{iv},$	$v \in \mathcal{V}, i \in \mathcal{N}_v,$	Time windows

$$l_{iv} \geq 0, \qquad v \in \mathcal{V}, i \in \mathcal{N}_v,$$

$$x_{ijv} \in \{0,1\}, \qquad v \in \mathcal{V}, (i,j) \in A_v,$$

$$y_i \in \{0,1\}, \qquad i \in \mathcal{N}^O.$$

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Maritime cargo routing: Path flow model

$$\max \sum_{i \in N^C} P_i + \sum_{i \in N^O} P_i y_i - \sum_{v \in V} \sum_{r \in R_v} C_{vr} x_{vr}$$

$$\sum_{v \in V} \sum_{r \in R_v} A_{ivr} x_{vr} = 1 \qquad \forall i \in N^C$$

$$\sum_{v \in V} \sum_{r \in R_v} A_{ivr} x_{vr} - y_i = 0 \qquad \forall i \in N^O$$

$$\sum_{r \in R_v} x_{vr} = 1 \qquad \forall v \in V$$

$$x_{vr} \in \{0,1\} \qquad \forall v \in V, r \in R_v$$

N^C - Set of contracted cargoes, i

N^O - Set of optional spot cargoes, i

V - Set of ships, v

R_v - Set of routes for ship v, r

P_i - Revenue for transporting cargo i

C_{vr} - Cost of sailing route r with ship v

A_{ivr} = 1 if route r for ship v services cargo i

x_{vr} = 1 if ship v sails route r

y_i = 1 if spot cargo i is transported

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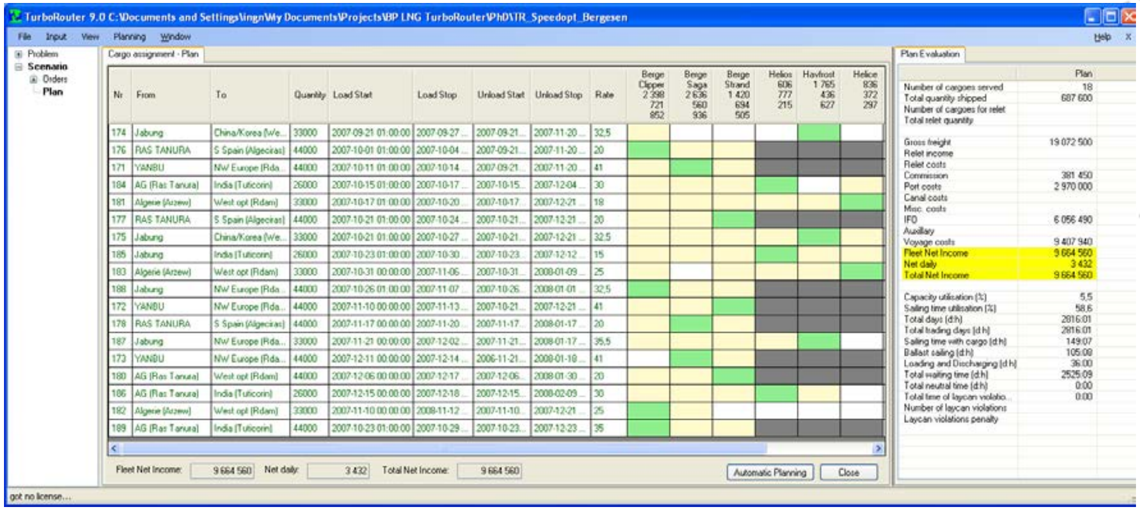
Maritime cargo routing: Solution methods

- Some existing research:
  - Column generation based on path-flow model (a priori[1)] or delayed[2)])
  - Multi-start local search heuristic[3)], Unified tabu search heuristic[4)]
  - Variable neighborhood search heuristic[5)]



- Both 3) and 4) are implemented as solvers in the DSS TurboRouter

1) Fagerholt and Christiansen (2000). A combined ship scheduling and allocation problem. *JORS*
2) Stålhane, Andersson, Christiansen, Cordeau, Desaulniers (2012). A branch-price-and-cut method for a ship routing and scheduling problem with split loads. *COR*
3) Brønmo, Christiansen, Fagerholt and Nygreen (2007) A multi-start local search heuristic for ship routing and scheduling – a computational study. *COR*
4) Korsvik, Fagerholt and Laporte (2010) A tabu search heuristic for ship routing and scheduling. JORS
5) Malliappi, Bennell, Potts (2011). A variable neighborhood search heuristic for tramp ship scheduling. *Computational Logistics*

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Planning flexibility

However, in real life the planner often has more flexibility than modelled in the basic tramp cargo routing and scheduling problem...

... thus the focus has recently been on model extensions that reflect common situations in tramp cargo routing

Maritime PDPTW with Split Loads (SL)

- Split loads - More than one ship can transport one cargo
- Splitting loads may
  - increase port costs
  - reduce sailing costs
  - give business opportunities (adding more spot cargoes to the solution)
- However, splitting loads interact with the routing decisions and affect several ships
- More interesting in deep-sea shipping than short-sea shipping. Why?
  - Sailing costs dominate port costs in deep-sea shipping

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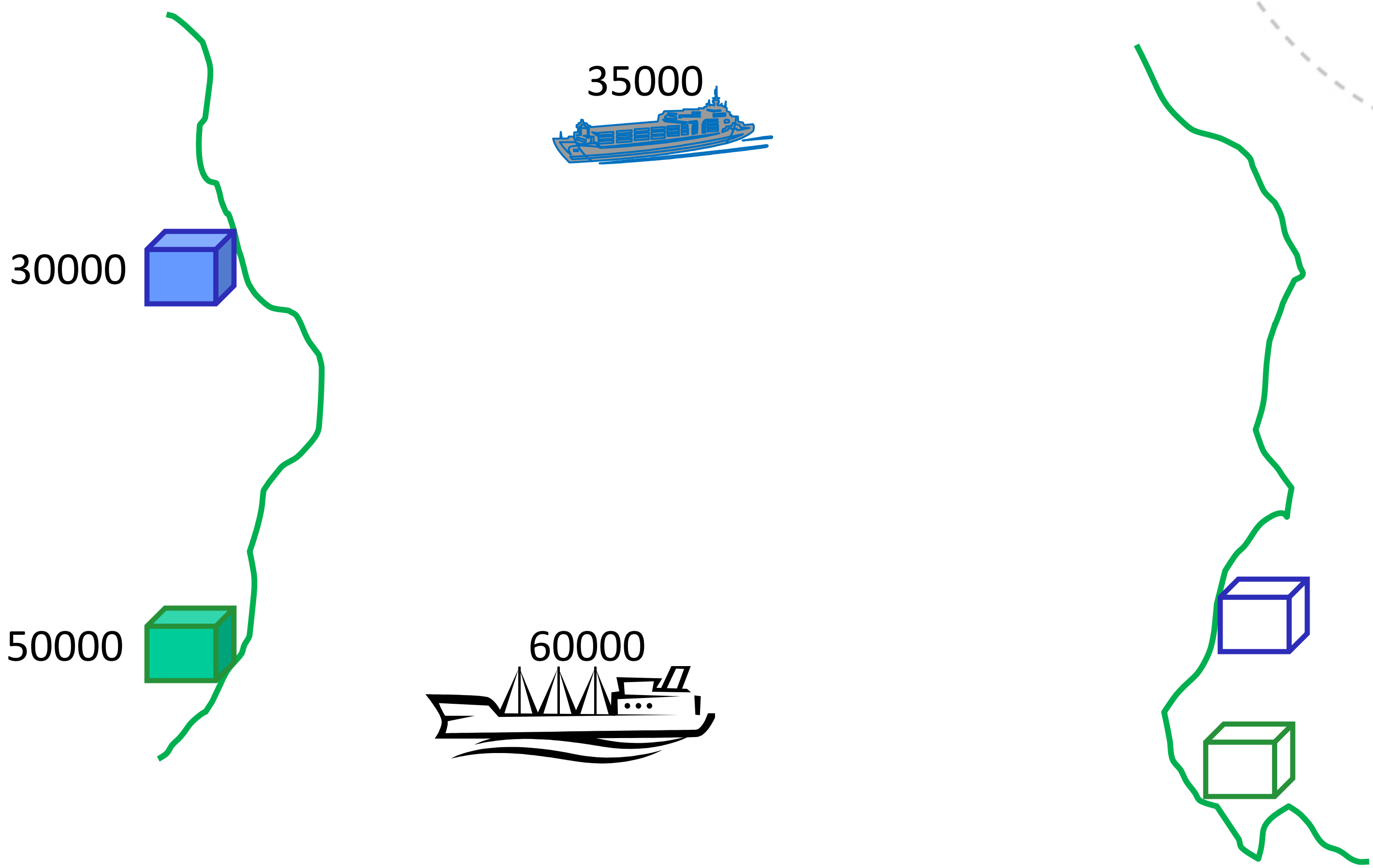
Example: Maritime PDPTWSL



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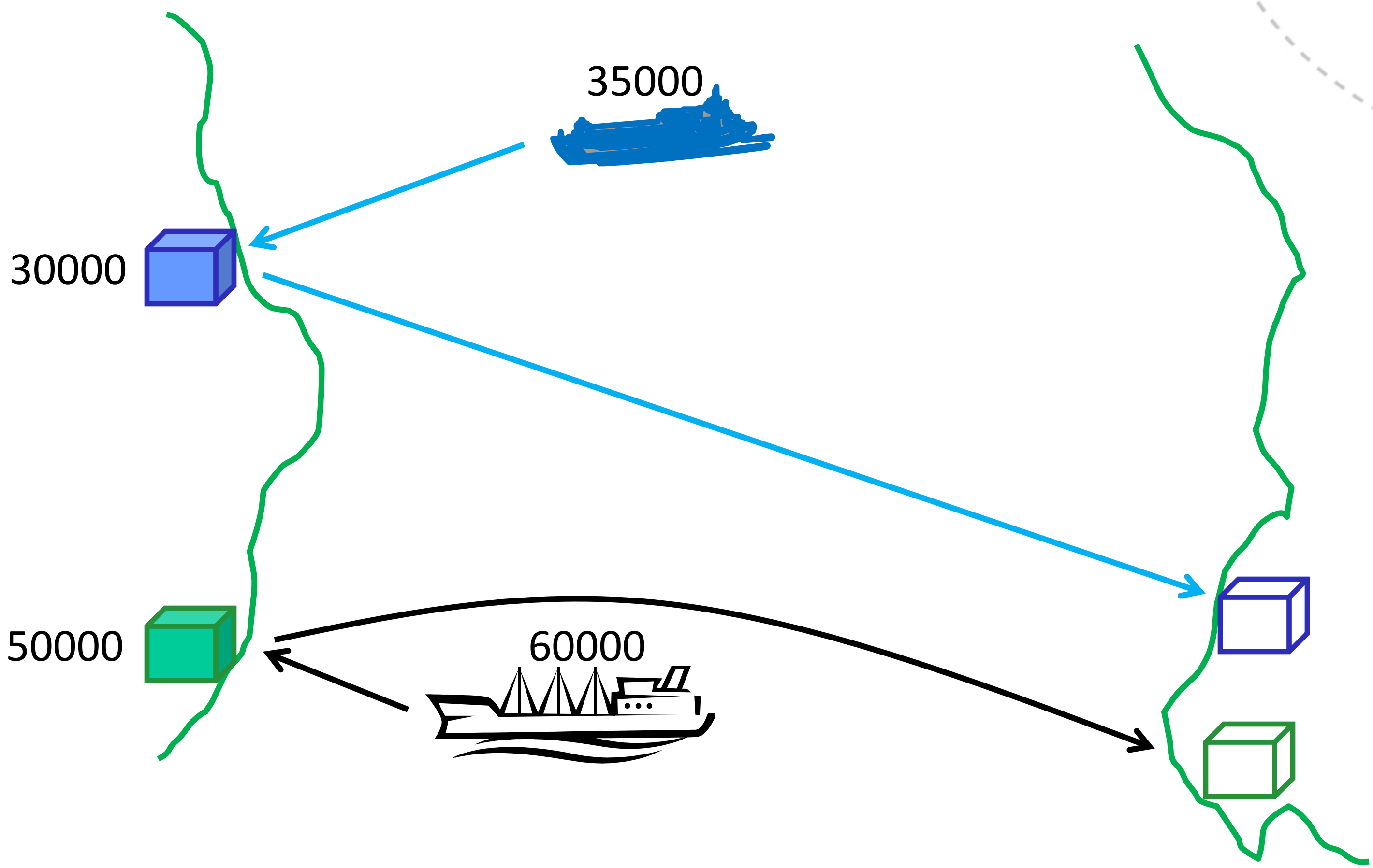
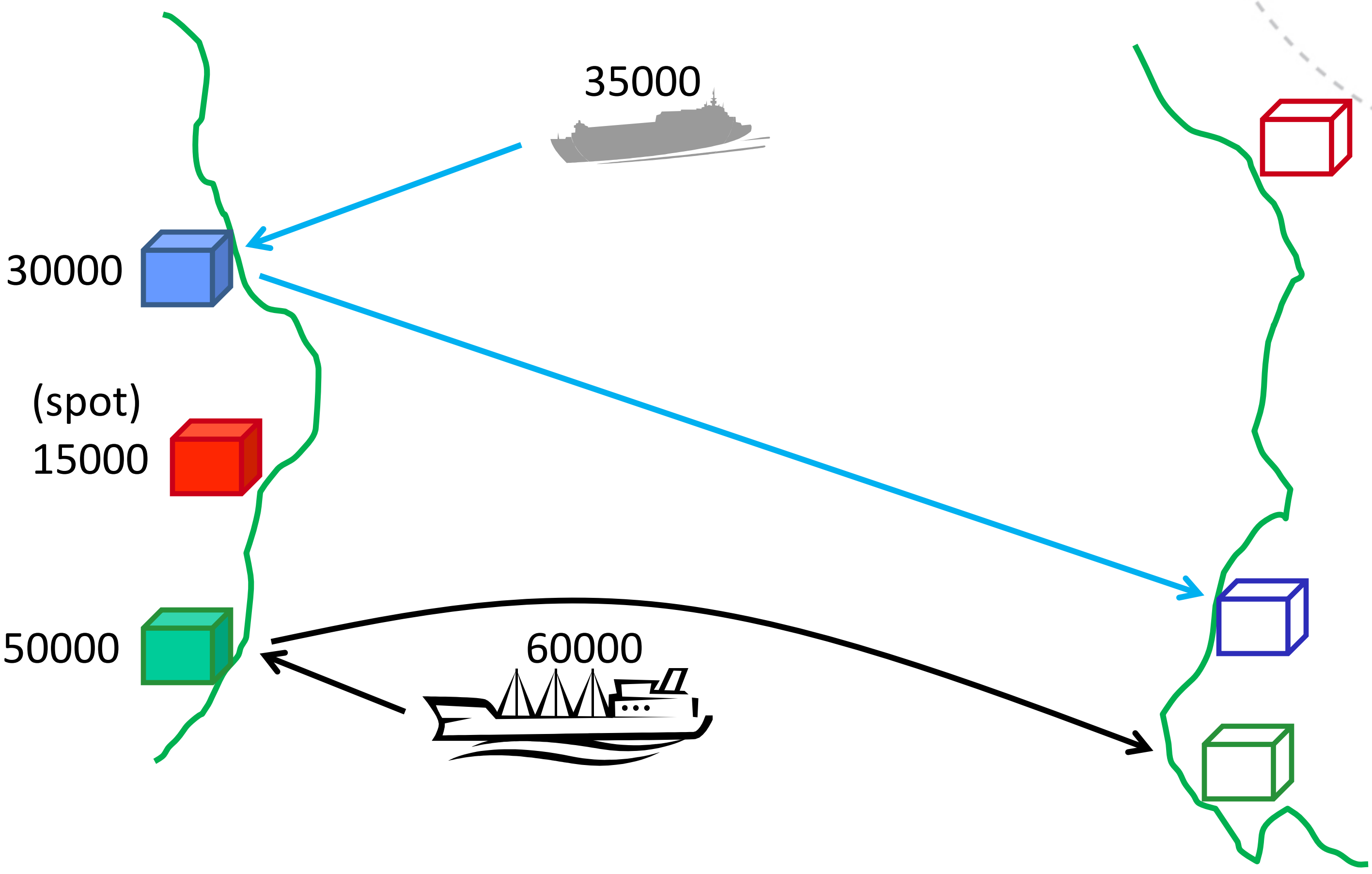
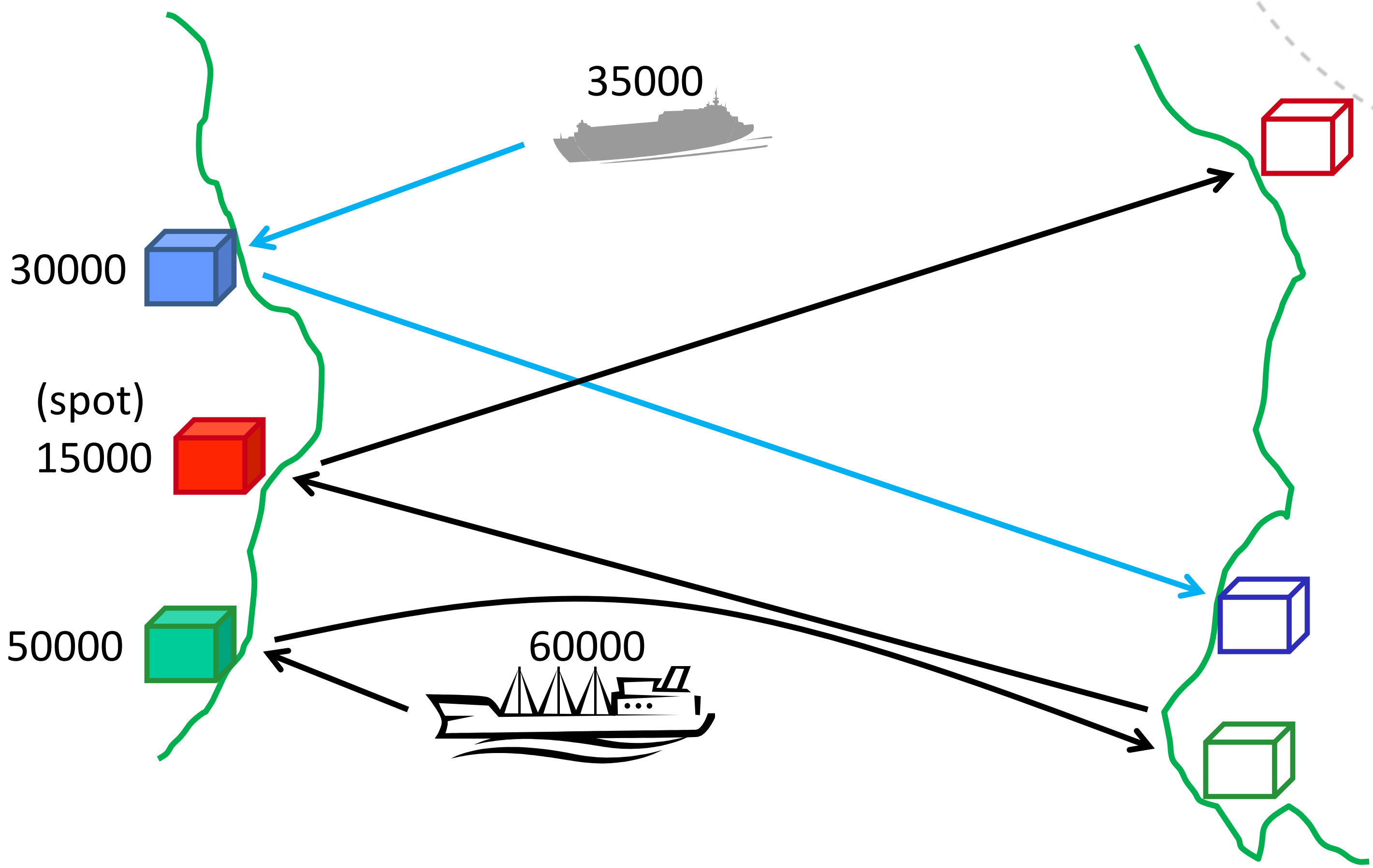
Example: Maritime PDPTWSL



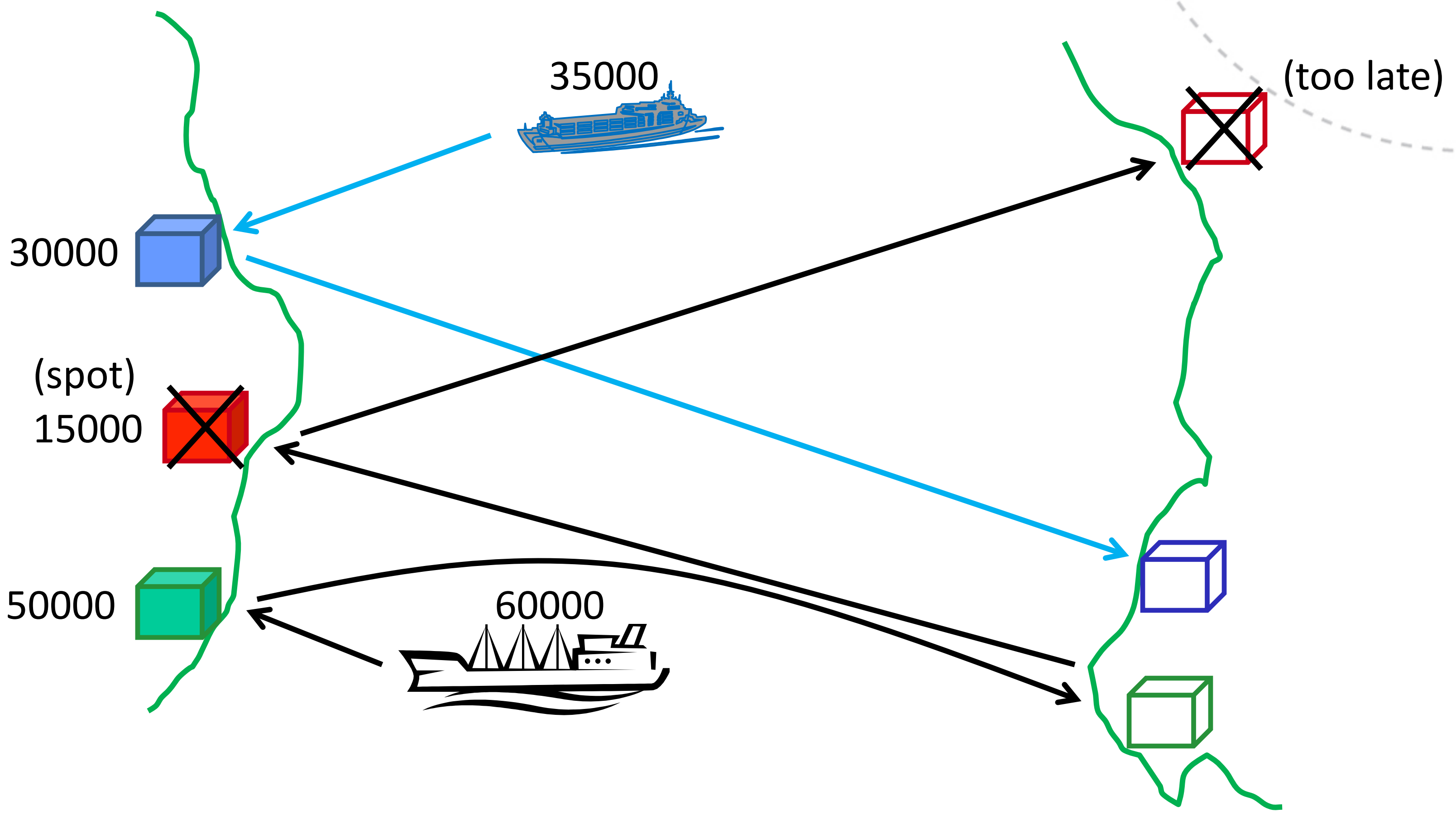
Example: Maritime PDPTWSL



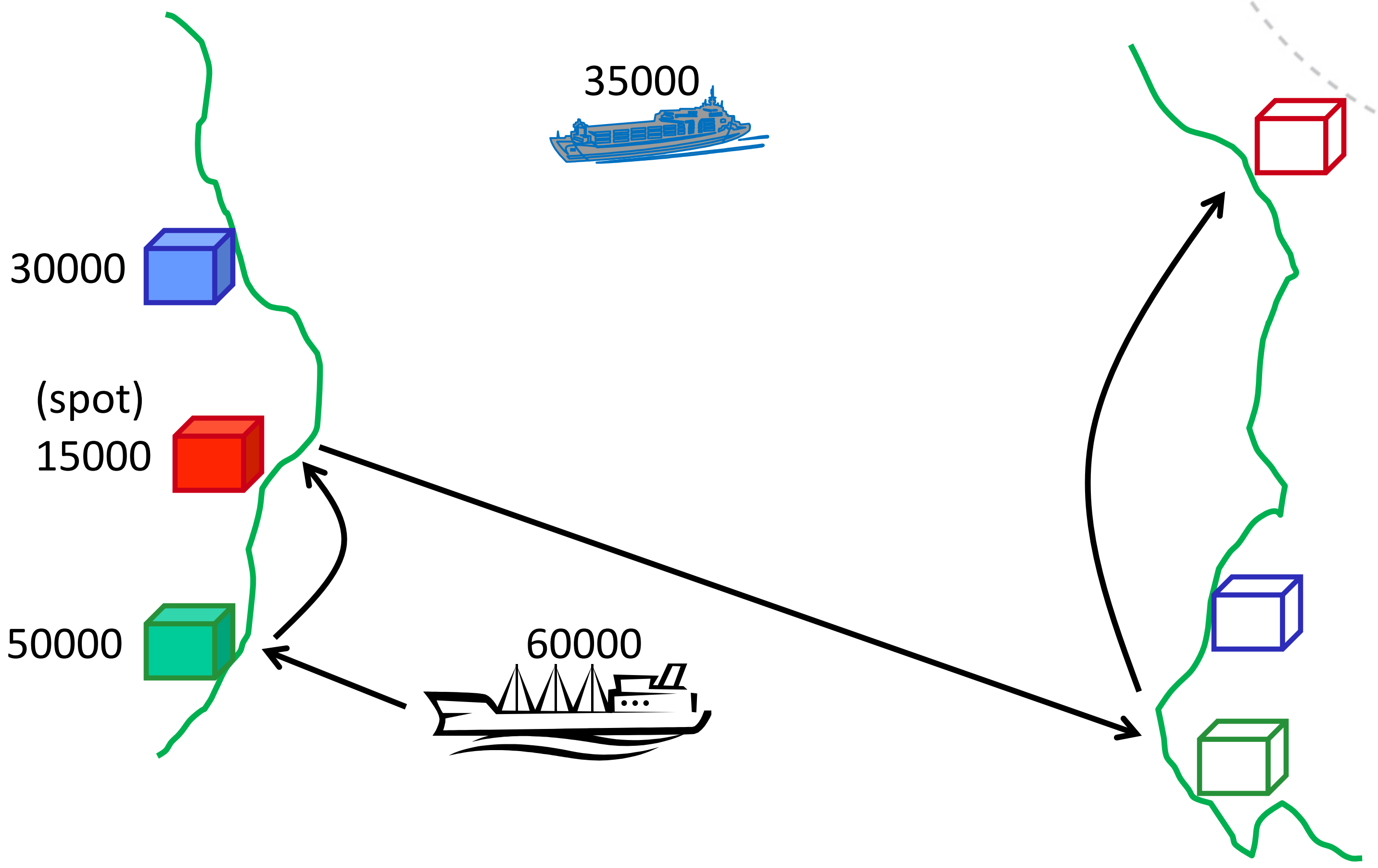
Example: Maritime PDPTWSL



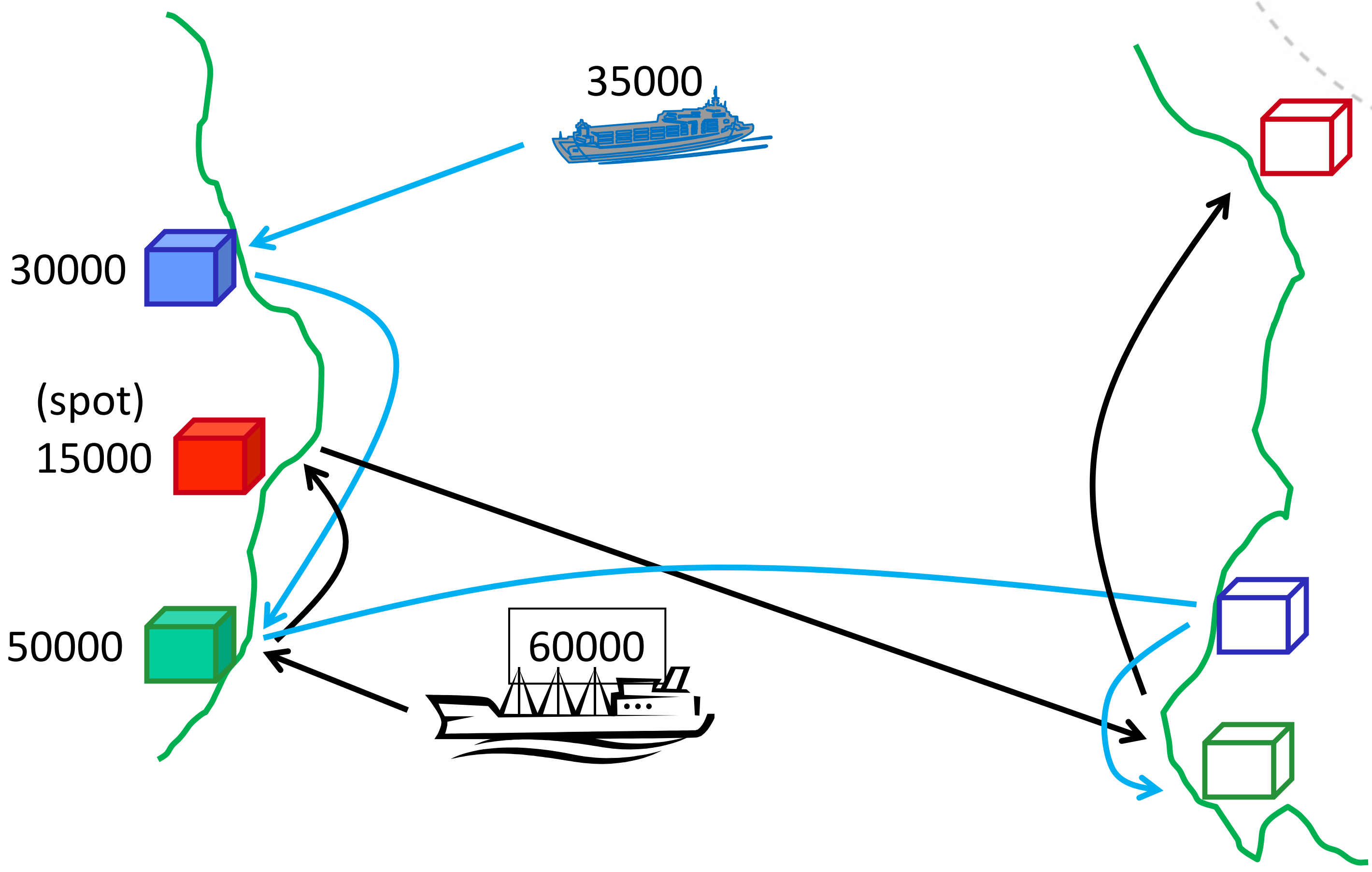
Example: Maritime PDPTWSL



Example: Maritime PDPTWSL



Example: Maritime PDPTWSL



Maritime PDPTWSL: Models and methods

- In arc flow model: New load variable(q_{iv}) and new load quantity constraints
- A priori column generation[1] : Cargo splitting is decided in master problem
- Branch-and-price method[2]
  - Columns for all routes with optimal quantities decided in the master problem
  - Columns including routes and delivery patterns (best)
- Large neighbourhood search heuristic[3]
- Testing shows huge effect on economic result by utilizing split loads

[1] Andersson, Christiansen and Fagerholt (2011) The maritime pickup and delivery problem with time windows and split loads. INFOR

[2] Stålhane, Andersson, Christiansen, Cordeau, Desaulniers (2012) Branch-price-and-cut for a maritime pickup and delivery problem with split loads. COR.

[3] Korsvik, Fagerholt and Laporte (2011) A large neighbourhood search heuristic for ship routing and scheduling with split loads. COR

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Complex maritime cargo routing

- Flexible cargo quantities
- Soft time windows
- Restricted opening hours in port
- Speed optimization
- Stowage considerations
- Bunkering decisions
- Dry-docking decisions
- Fleet size and mix
- Considering uncertainty
  - Modelling of market opportunities (TC and spot cargo rates fluctuate)
  - Sailing time and time spent in ports

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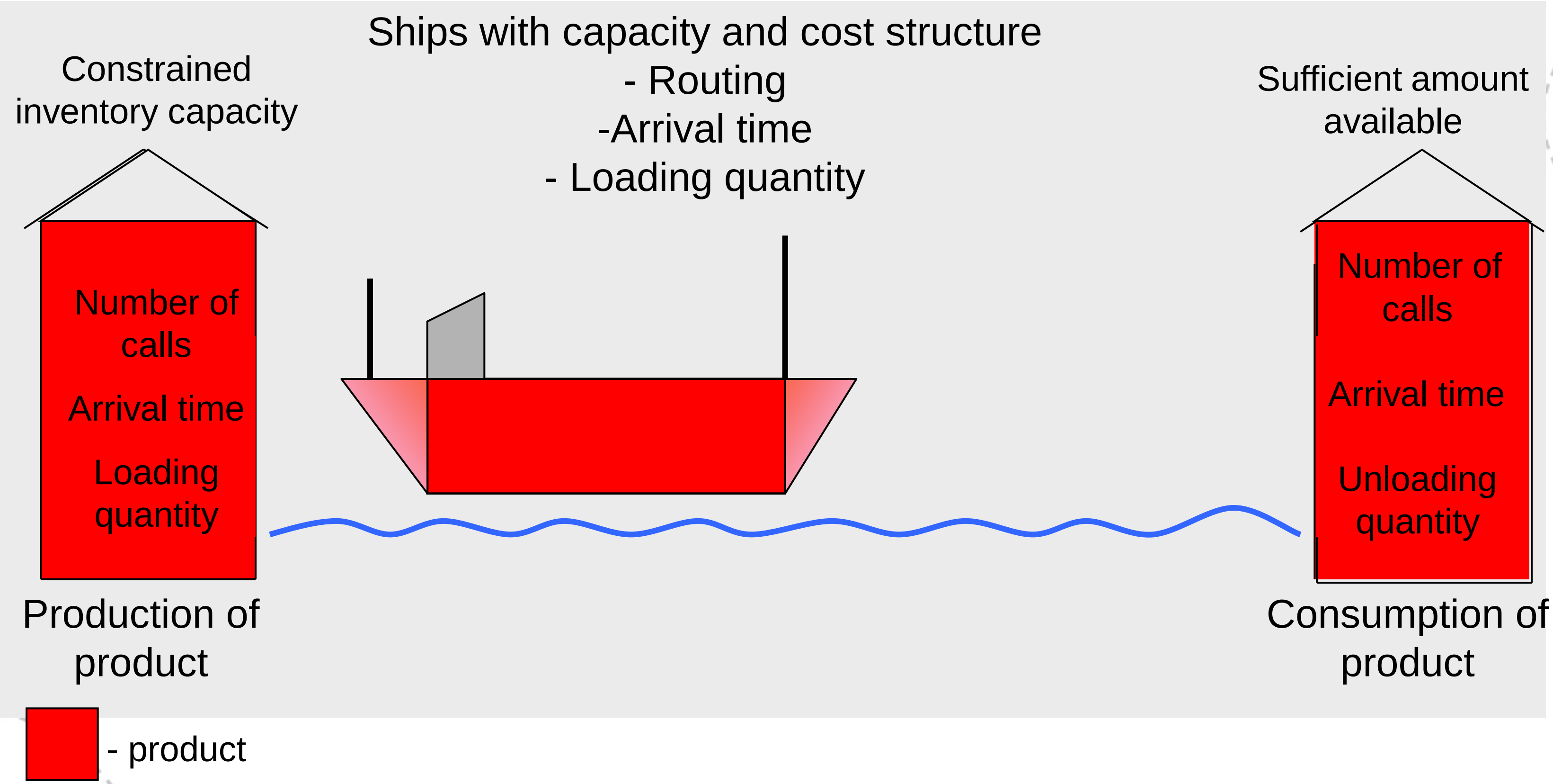
Maritime inventory routing

- Often, inventories exist at the loading and unloading ports of the sailing leg
- When one actor (producer, consumer or shipping company) has the responsibility for both transportation and inventories
  - ➢ **Maritime inventory routing problem (MIRP)**

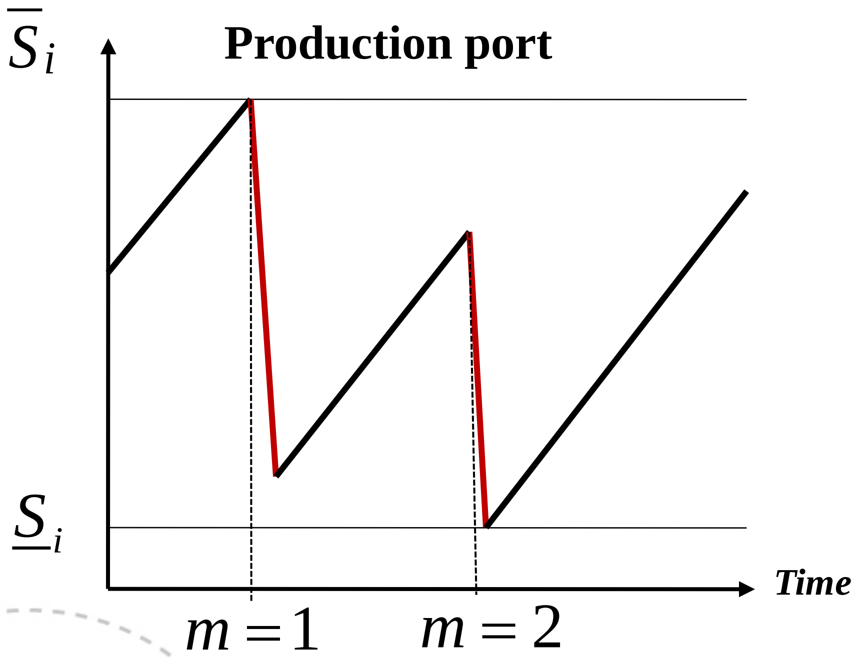
Basic MIRP:

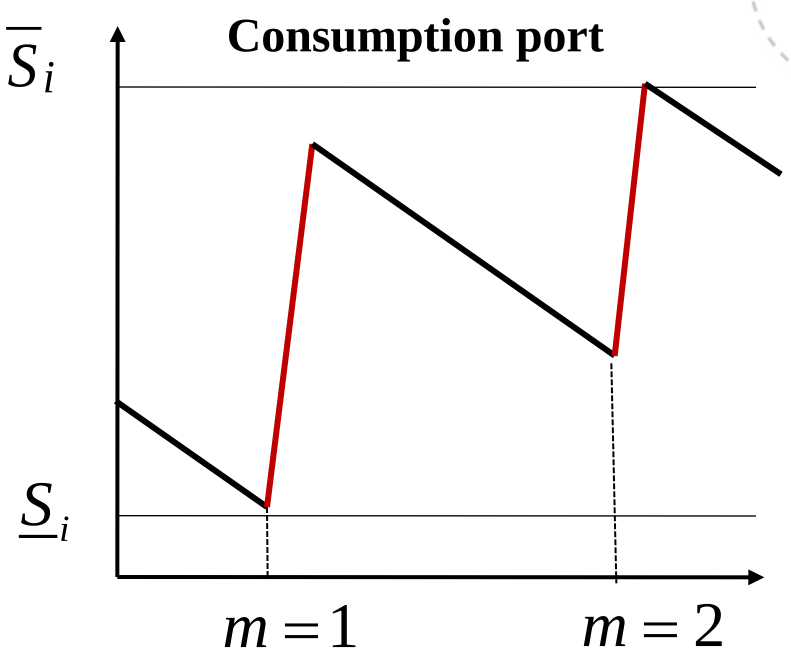
Design routes and schedules that minimize the transportation cost without interrupting production and consumption of a single product



Basic MIRP: Inventory management

- Single product
- Inventory storages in all ports
- Production/consumption rates are constant in time
- Port *i*, visit number *m:* port visit *(i,m)*



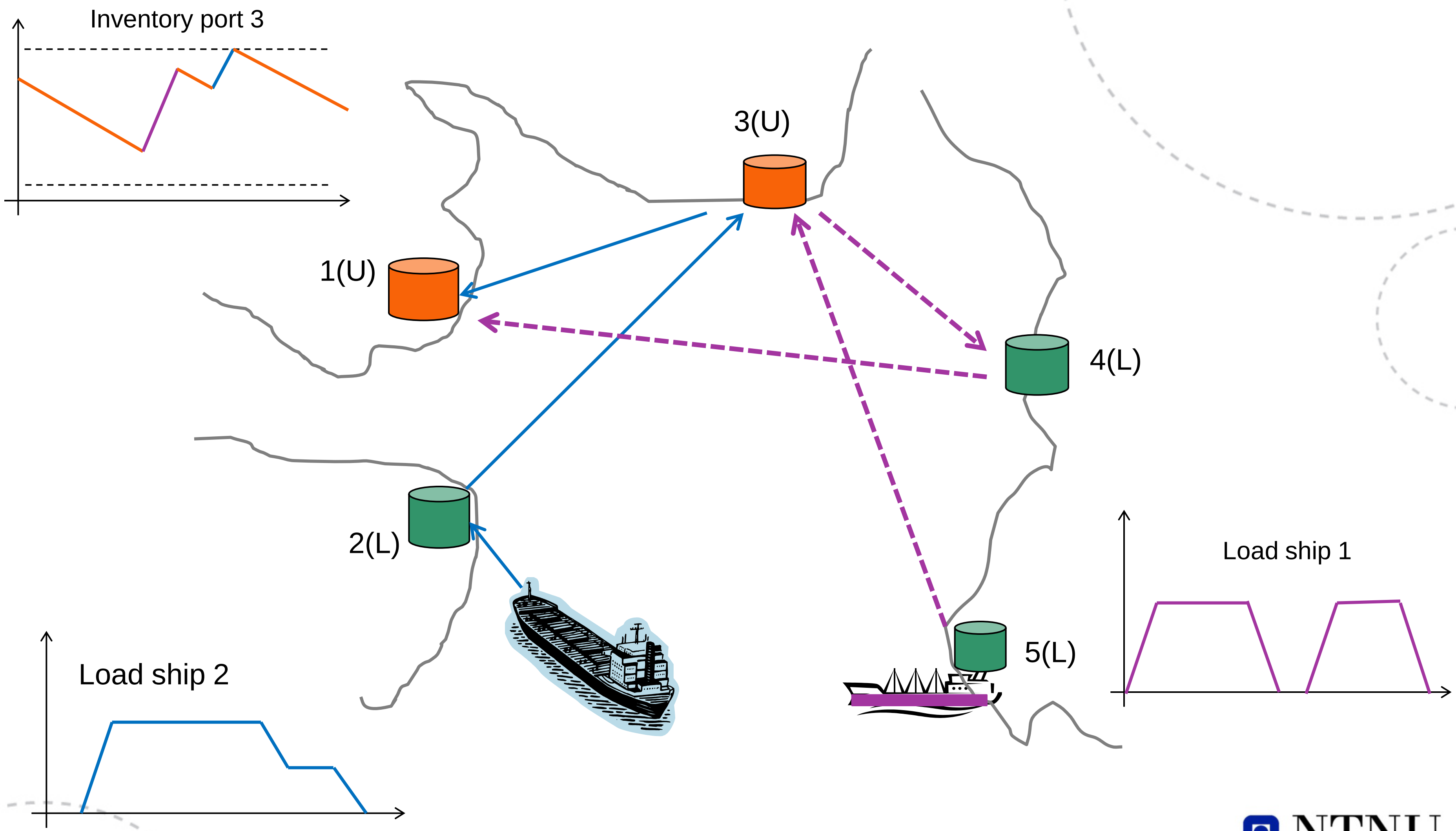


Basic MIRP: Routing and Scheduling

- Heterogeneous fleet of ships
- Generate routes including information about time to start service and (un)loading quantities
- Partial (un)loading, such that several (un)loading ports can be visited in succession

Geographical route	P1→D2→D1→P2→D1→P2→D2
Schedule	T1 T2 T3 T4 T5 T6 T7
Quantity	Q1 Q2 Q3 Q4 Q5 Q6 Q7

Basic MIRP: Example



Comparisons to other routing problems

- MIRP is different from maritime cargo routing due to
  - The number of visits at a node is predetermined
  - The quantity loaded/unloaded is normally fixed
  - Predefined pickup and delivery pair

  for maritime cargo routing

- MIRP is different from road-based IRP due to
  - Often one central supplier (depot) with large inventory capacities and many customers consuming a small amount
  - Asymmetry between each type of inventory
  - Small quantities are delivered compared to the maritime IRP
  - Finite planning horizon

  for road-based IRP

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Basic MIRP: Model description

- Minimise transportation and port costs
- Each port visit is made at most once
- Routing constraints
- Scheduling constraints
- Load management on board the ship
- Ship capacity constraints

Routing, scheduling, and load management for each ship

- Inventory balance constraints
- Inventory capacity constraints

Inventory management for each port

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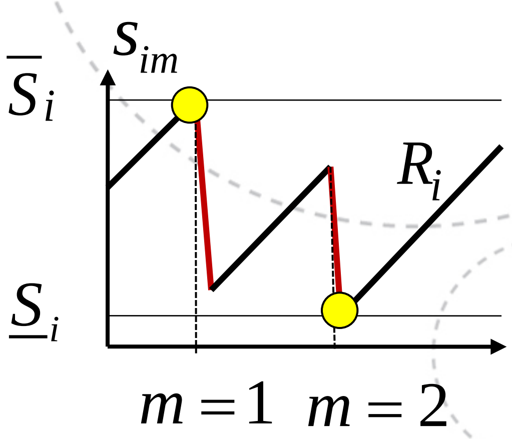
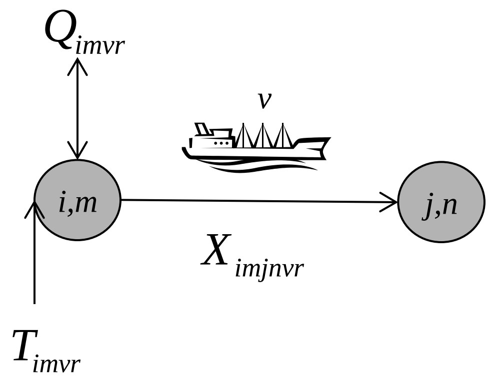
Basic MIRP: Path flow model (1:2)

- Master Problem
  - Production / consumption rate: R_i
  - Inventory management at port visit $(i,m), s_{im}$



- Path r for each ship v
  - Ship routing $X_{imjnvr}\lambda_{vr}$
  - Ship scheduling $T_{imvr}\lambda_{vr}$
  - Ship loading/unloading $Q_{imvr}\lambda_{vr}$



Basic MIRP: Path flow model (2:2)

$$\min \sum_{v \in V} \sum_{r \in R_v} C_{vr} \lambda_{vr},$$

$$\sum_{v \in V} \sum_{r \in R} A_{imvr} \lambda_{vr} \leq 1, \qquad \forall i \in N, m \in M_i,$$ Port visit

$$s_{i(m-1)} + \sum_{v \in V} \sum_{r \in R_v} \left[R_i (T_{imvr} - T_{i(m-1)vr}) - I_i Q_{i(m-1)vr} \right] \lambda_{vr} - s_{im} = 0, \qquad \forall i \in N, m \in M_i,$$ Inventory balance

$$\underline{S}_i \leq s_{im} \leq \overline{S}_i, \qquad \forall i \in N, m \in M_i,$$

$$\underline{S}_i \leq s_{im} + \sum_{v \in V} \sum_{r \in R_v} \left[R_i T_{iv}^Q Q_{imvr} - I_i Q_{imvr} \right] \lambda_{vr} \leq \overline{S}_i, \qquad \forall i \in N, m \in M_i,$$ Inventory limits

$$\sum_{r \in R_v} \lambda_{vr} = 1, \qquad \forall v \in V,$$ Convexity

$$\sum_{r \in R_v} X_{imjnvr} \lambda_{vr} \in \{0,1\}, \qquad \forall i \in N, m \in M_i,$$

$$j \in N, n \in M_i, v \in V,$$

$$\lambda_{vr} \geq 0, \qquad \forall v \in V, r \in R_v.$$

Basic MIRP: Solution methods (1:4)

- Very complex problem to solve due to high degree of freedom
  - No predetermined number of port visits,
  - Variable (un)loading quantities
  - No pickup and delivery pairs,
  - No time windows for arrival
  - Problem specific issues

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Basic MIRP: Solution methods (2:4)

- Branch-and-cut methods
  - Agra, Andersson, Christiansen , Wolsey (2013). A maritime inventory routing problem: Discrete time formulations and valid inequalities. *Networks**
  - Agra, Christiansen, Delgado (2013). Mixed integer formulations for a short sea fuel oil distribution problem*. Transportation Science*
  - Furman, Song, Kocis, McDonald, Warrick (2011) Feedstock routing in the ExxonMobil downstream sector*. Interfaces*
  - Rocha, Grossmann, Poggi de Aragão (2013). Cascading knapsack inequalities: reformulation of a crude oil distribution problem. Annals of Operations Research

*Reformulating the arc flow formulations: Fixed charge network flow formulations with side constraints reduces the integrality gaps from 83% in average to 36% in average. Cuts reduce the gaps to 6 % in average.

Basic MIRP: Solution methods (3:4)

- Several branch-and-price approaches
    - Christiansen (1999). Decomposition of a Combined Inventory and Time Constrained Ship Routing Problem**,** Transportation Science
    - Engineer, Furman, Nemhauser, Savelsbergh, Song (2012). A branch-price-and-cut algorithm for single-product MIRP. *Operations Research*
    - Grønhaug, Christiansen, Desaulniers and Desrosiers (2010). A Branch-and-price method for a liquefied natural gas inventory routing problem. *Transportation Science*
    - Hewitt, Nemhauser, Savelsbergh, Song (2013). A Branch-and-Price guided search approach to maritime inventory routing. Computers & Operations Research
    - Persson, Göthe-Lundgren (2005). Shipment planning at oil refineries using column generation and valid inequalities. European journal of Operational Research
    - Rakke, Andersson, Christiansen, Desaulniers (2014). A new formulation based on customer delivery patterns for a maritime inventory routing problem*. Transportation Science*

    - Columns: ship routes and schedules including information about (un)load quantities

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Basic MIRP: Solution methods (4:4)

Heuristics

- Agra, Christiansen, Delgado, Simonetti (2014). Hybrid heuristics for a maritime short sea inventory routing problem. *European Journal of Operational Research*
- Christiansen, Fagerholt, Flatberg, Haugen, Kloster, Lund (2010). Maritime inventory routing with multiple products: A case study from the cement industry, *European Journal of Operational Research*
- Dauzére-Pérès, Nordli, Olstad, Haugen, Koester, Myrstad, Teistklub, Reistad. (2007). Omya Hustadmarmor optimizes its supply chain for delivering calcim carbonate slurry to European paper manufacturers. *Interfaces*
- Flatberg, Haavardtun, Kloster, Løkketangen (2000). Combining exact and heuristic methods for solving a vessel routing problem with inventory constraints and time windows. *Ricerca Operativa*
- Goel, Furman, Song, El-Bakry (2012). Large neighborhood search for LNG inventory routing. Journal of Heuristics
- Papageorgiou, Cheon, Nemhauser, Sokol (2014). Approximate dynamic programming for a class of long-horizon maritime inventory routing problems. To appear in Transportation Science
- Rakke, Stålhane, Moe, Andersson, Christiansen, Fagerholtt, Norstad (2011). “A rolling horizon heuristic for creating a liquefied natural gas annual delivery program”. *Transportation Research C*
- Song, Furman (2013). A maritime inventory routing problem: practical approach. *Computers and Operations Research*
- Stålhane, Rakke, Moe, Andersson, Christiansen, Fagerholt (2012). A Constructive and Improvement Heuristic for a Liquefied Natural Gas Inventory Routing Problem. *Computers and Industrial Engineering*

Complex MIRPs

- Multiple products
- Constant, time varying or variable consumption/production rate
- Inventory constraints in either production or consumption ports
  - Contracts with given quantities and time windows in the other type of ports
- Combined inventory routing and tramp shipping
- Combining inventory routing with other planning aspects
  - Consider larger parts of the supply chain (for instance include production)

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Outline

- Introduction to maritime transportation
- Maritime cargo routing
- Maritime inventory routing
- Trends relevant for ship routing and scheduling
- Concluding remarks

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Business trends (1:3)

- Mergers and collaborations
  - To increase market power and gain flexibility in the services
  - Larger fleet and more complex transportation pattern
- New generation of planners
  - With computer experience and more academic background
- Focus on supply chains (SC)
  - Integration along the SC (cargo owner and shipping company)
  - Vendor managed inventory systems
  - Shipping integrated into a multimodal door-to-door SC
- An increasing LNG activity
  - Challenging inventory routing problems

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Business trends(2:3)

- Oversupply of tonnage
  - Years with global financial crisis. Economic situation has brightened, but multiple risks threaten for a stable world economy
  - Slow steaming and use of less costly paths
- Global climate changes
  - Increased accessibility in the Arctic region
- External conditions changes rapidly
  - Planning problems changes

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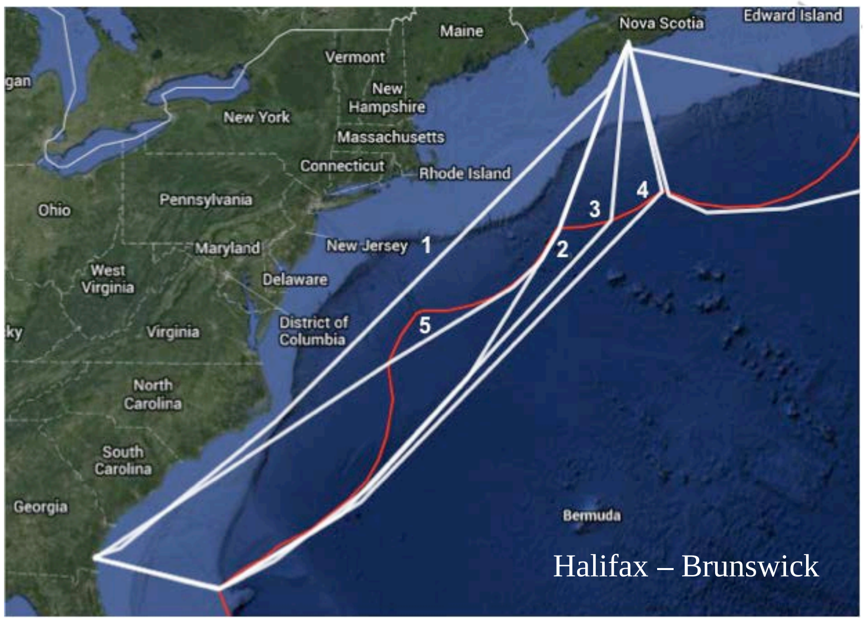
Business trends(3:3)

- Stricter regulations for emissions of greenhouse gases and Emission Control Area (ECA) regulations)
  - Use different fuels when sailing inside and outside ECAs
  - Sailing route options between two ports
  - Sailing speed optimization (third power relationship between bunker fuel consumption and speed



Maritime transport research trends (1:2)

- Number of maritime transport (MT) articles is increasing
- Most MT articles present special versions of basic problems with tailor-made solution methods
- Several benchmark suites have appeared
  - MIRPLib (http://mirplib.scl.gatech.edu/),
  - LINER-LIB (http://linerlib.org/)
  - Library for tramp and industrial ship routing and scheduling (http://iot.ntnu.no/users/larsmahv/benchmarks/)
- Both exact and heuristic solution methods
- Now, also more theoretical models and basic research that are less grounded in real operations

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Maritime transport research trends (2:2)

- MIRP, LNG and offshore supply vessel routing have attracted increasing attention
- Fast growth of the containership fleet
  - Similar growth in research on liner network design and related topics
- Strategic planning issues: fleet size and mix (fleet renewal), contract evaluation
- Varying price of bunker fuel and new environmental regulations
  - Sailing speed (third power relationship between bunker fuel consumption and speed)
  - Alternative routes between two ports
  - Affect planning at strategic, tactical and operational level
- Dynamic and stochastic maritime ship routing and scheduling

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Outline

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Concluding remarks

- Focused on ship routing and scheduling
- Ship scheduling has high potential for improvements by optimizing fleet utilization (a few % - 25 %)
- Still many shipping companies build their complete routes and schedules manually
- A few DSSs are described in the literature
- An increasing number of publications and groups working on maritime transportation problems
- Rich real problems and external conditions changes rapidly
- Many remaining planning problems to consider
- Need for more research on models, theory and solution methods

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INTERNATIONAL O.R.

MARITIME TRANSPORT OPTIMIZATION:

AN OCEAN OF OPPORTUNITIES

Shipping company planners face complex problems every day. Now, thanks to O.R., help is on the way.

BY MARIELLE CHRISTIANSEN, KJETIL FAGERHOLT, GEIR HASLE, ATLE MINSAAS AND BJORN NYGREEN

Today's globalization would be impossible without modern, cost-effective merchant ships crossing the seas. World trade was 17 times as high at the end of the 20th century as it was 50 years previously. A shipping industry that has steadily lowered its costs has been a prerequisite of this development, and there are no signs that the world economy will rely any less heavily on sea transport in the future.

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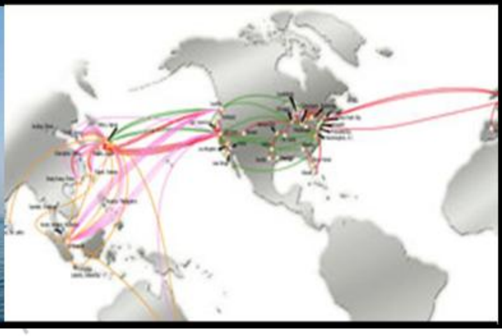

Optimization of Maritime Transportation

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