Modeling challenges in maritime fleet renewal problems

Giovanni Pantuso[1], Kjetil Fagerholt[1,2] and Stein W. Wallace[3]

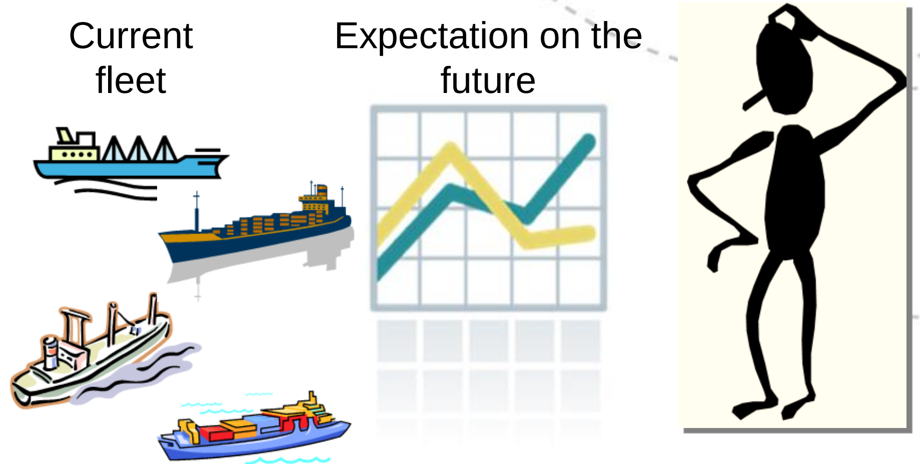
[1] Norwegian University of Science and Technology, Trondheim, Norway
[2] Norwegian Marine Technology Research Institute (MARINTEK), Trondheim, Norway
[3] Norwegian School of Economics, Bergen, Norway

ROUTE 2014, June 1-4, 2014

NTNU
Norwegian University of Science and Technology

The Maritime Fleet Renewal Problem

- We have a fleet of ships available, and have to find the best renewal in order to be efficient in the future (uncertain) shipping market
- Renewal decisions:
  - Building new ships
  - Buying second-hand ships
  - Selling available ships
  - Demolishing available ships



The Maritime Fleet Renewal Problem

- The Maritime Fleet Renewal Problem is a strategic planning problem, where decisions will have impact for a long time
- Will face uncertainty at a high level
- Even though we are interested only in strategic fleet renewal decisions, one must also consider tactical decisions, such as:
  - Chartering in/out (market interaction)
  - Fleet deployment (routing of the ships)

Modeling challenges

- How to model uncertainty?
- How to model the market interaction?
- What is an appropriate level of aggregation for modeling fleet deployment???

Wallenius Wilhelmsen Logistics (WWL)

Wallenius Wilhelmsen Logistics (WWL)

NTNU
Norwegian University of Science and Technology

Wallenius Wilhelmsen Logistics (WWL)

Wallenius Wilhelmsen Logistics (WWL)

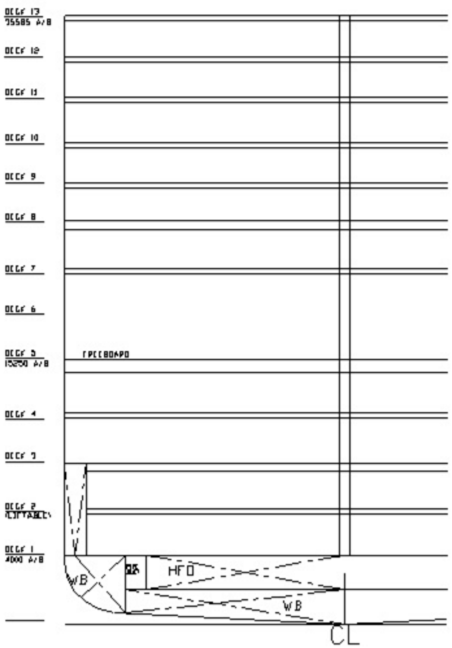
Wallenius Wilhelmsen Logistics (WWL)

NTNU
Norwegian University of
Science and Technology

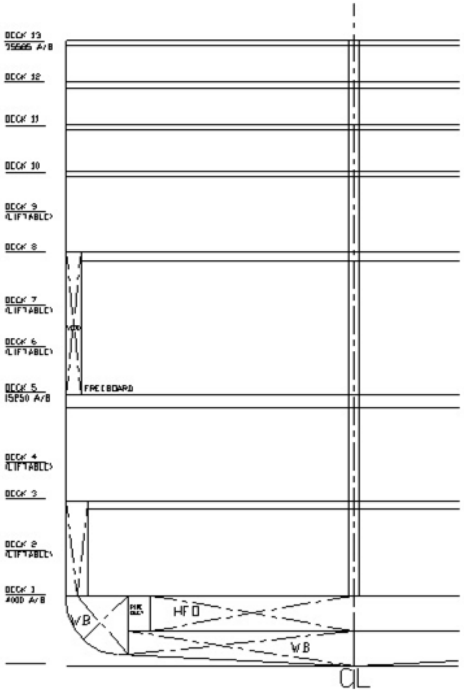
Wallenius Wilhelmsen Logistics (WWL)

Wallenius Wilhelmsen Logistics (WWL)

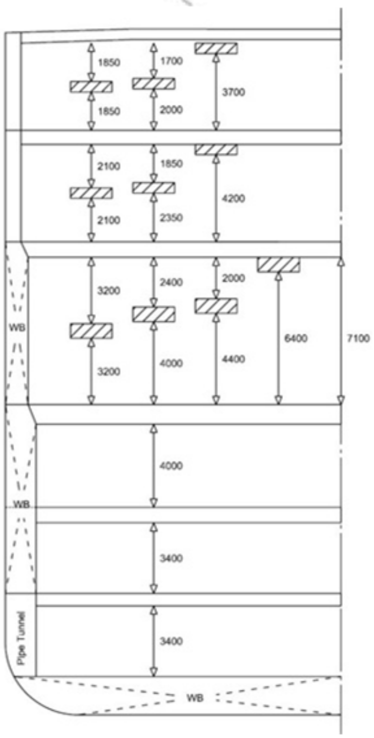
- About 60 ships in the current fleet



PCTC



LCTC



Ro-Ro

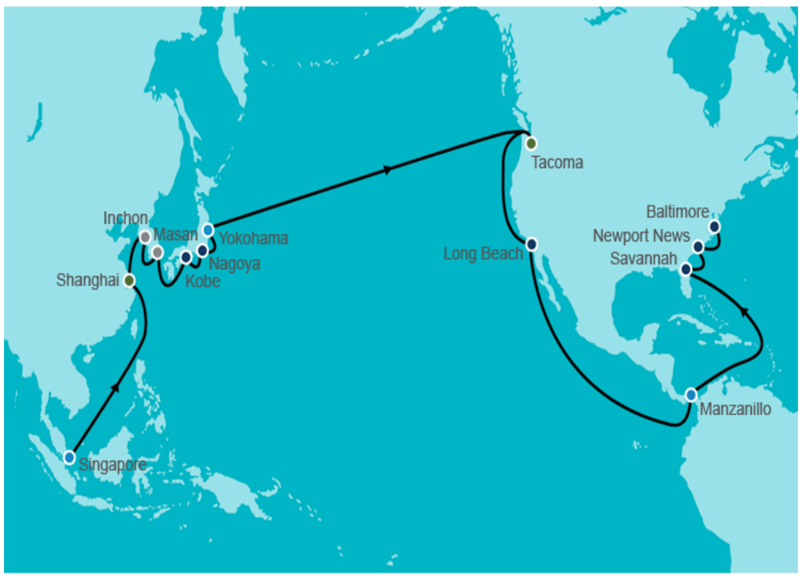
Pure Car and Truck Carrier

Large Car and Truck Carrier

Roll on-Roll off

Wallenius Wilhelmsen Logistics (WWL)

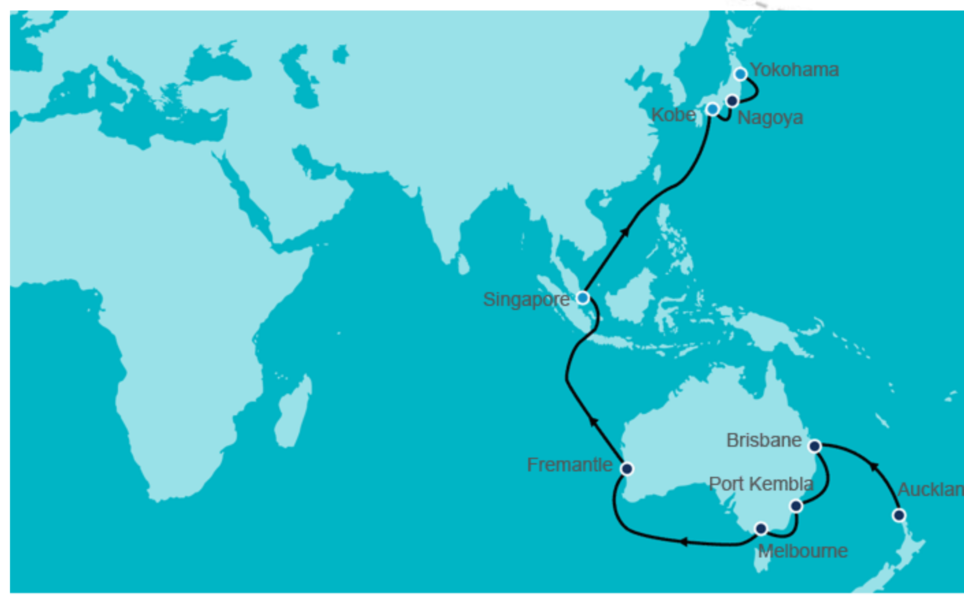
* Liner trades all over the world



Asia – North America Trade

Frequency
- Every 10 days
- Twice per month
- Once per month
- Hub Ports; Singapore is transhipment port to/fm SEA Express, Yokohama is transhipment port to/fm China Express, Manzanillo is transhipment port to/fm South America Trade.

WALLENIUS WILHELMSEN LOGISTICS



Oceania — Asia Trade

Frequency
- Every 10 days
- Transhipment Ports Kobe & Yokohama serve as transhipment ports for our China Express. Singapore as transhipment port to our SEA Express.

WALLENIUS WILHELMSEN LOGISTICS

Wallenius Wilhelmsen Logistics (WWL)

- By October every year WWL update their long-term strategy by making decisions such as:
  - Which and how many ships to buy/build?
  - Which and how many ships to dispose of?

  - They have to solve a **Maritime Fleet Renewal Problem**

The Model

- Multistage Mixed-Integer (at all stages) Stochastic Program
- Objective:
  - Minimization of the total expected cost for providing and operating the fleet
- Constraints
  - Fleet balance between subsequent periods
  - Demand satisfaction
  - Fleet deployment
    - Sailing time capacity
    - Ship load capacity
  - Chartering in/out

NTNU
Norwegian University of Science and Technology

The Model

$$\min \quad z = \sum_{s \in S} p_s \Bigg\{ \sum_{t \in T: t \leq \bar{T} - \bar{T}^L} \sum_{v \in V^N_{t+\bar{T}^L}} C^{NB}_{vts} y^{NB}_{vts} \tag{1a}$$

$$+ \sum_{t \in T \setminus \{\bar{T}\}} \sum_{v \in V_t} \Bigg(\sum_{f \in F^{SH}} C^{SH}_{fvts} y^{SH}_{fvts} \tag{1b}$$

$$- \sum_{f \in F^{SE}} R^{SE}_{fvts} y^{SE}_{fvts} - R^{SC}_{vts} y^{SC}_{vts} \Bigg) \tag{1c}$$

$$+ \sum_{t \in T \setminus \{0\}} \sum_{v \in V_t} \Bigg(\sum_{f \in F^{CI}} C^{CI}_{fvts} h^I_{fvts} - \sum_{f \in F^{CO}} R^{CO}_{fvts} h^O_{fvts} \tag{1d}$$

$$+ C^{OP}_{vt} y^P_{vts} - R^{LU}_{vt} l_{vts} + \sum_{r \in R_{vt}} C^{TR}_{vrts} x_{vrts} \Bigg) \tag{1e}$$

$$+ \sum_{t \in T \setminus \{0\}} \sum_{i \in N_t} C^{VO}_{its} s_{its} - \sum_{v \in V_{\bar{T}}} R^{SV}_{vs} y^P_{v\bar{T}s} \Bigg\} \tag{1f}$$

$$y^P_{vts} = y^P_{v,t-1,s} + \sum_{f \in F^{SH}} y^{SH}_{f,v,t-1,s} - \sum_{f \in F^{SE}} y^{SE}_{f,v,t-1,s} - y^{SC}_{v,t-1,s} \quad t \in T \setminus \{0\}, v \in V_t \setminus V^N_t, s \in S \tag{1}$$

$$y^P_{vts} = y^{NB}_{v,t-\bar{T}^L,s} \quad t \in T : t \geq \bar{T}^L, v \in V^N_t, s \in S \tag{2}$$

$$y^P_{vts} = Y^{NB}_{vt} \quad t \in T^S \setminus \{0\}, v \in V^N_t, s \in S \tag{3}$$

$$y^P_{v0s} = Y^P_v \quad v \in V_0, s \in S \tag{4}$$

$$\sum_{r \in R_{vt}} Z_{rv} x_{vrts} \leq Z_v \Big(y^P_{vts} + \sum_{f \in F^{CI}} h^I_{fvts} - \sum_{f \in F^{CO}} h^O_{fvts} - l_{vts} \Big) \quad t \in T \setminus \{0\}, v \in V_t, s \in S$$

$$\sum_{f \in F^{CO}} h^O_{fvts} + l_{vts} \leq y^P_{vts} \quad t \in T \setminus \{0\}, v \in V_t, s \in S$$

Minimization of:
Expenses for buying ships
-incomes for selling ships
+cost of operating the fleet

Ships flow conservation constraints

Sailing time consistency

The Model

$$q_{pvrts} \leq \bar{Q}_{vp} x_{vrts} \qquad t \in T \setminus \{0\}, v \in V_t, r \in R_{vt}, p \in P, s \in S$$

$$\sum_{p \in P \setminus \{\text{car}\}} q_{pvrts} \leq \bar{Q}_v^{NC} x_{vrts} \qquad t \in T \setminus \{0\}, v \in V_t, r \in R_{vt}, s \in S$$

$$\sum_{p \in P} q_{pvrts} \leq \bar{Q}_v x_{vrts} \qquad t \in T \setminus \{0\}, v \in V_t, r \in R_{vt}, s \in S$$

Capacity constraints

$$\sum_{v \in V_t} \sum_{r \in R_{ivt}} q_{pvrts} + s_{pits} \geq D_{pits} \qquad t \in T \setminus \{0\}, i \in N_t, p \in P, s \in S$$

Demand satisfaction

$$h^I_{fvts} \leq L^{CI}_{fvt} \qquad f \in F^{CI}, t \in T \setminus \{0\}, v \in V_t, s \in S$$

$$h^O_{fvts} \leq L^{CO}_{fvt} \qquad f \in F^{CO}, t \in T \setminus \{0\}, v \in V_t, s \in S$$

$$y^{SH}_{fvts} \leq L^{SH}_{fvt} \qquad f \in F^{SH}, t \in T \setminus \{\bar{T}\}, v \in V_t, s \in S$$

$$y^{SE}_{fvts} \leq L^{SE}_{fvt} \qquad f \in F^{SE}, t \in T \setminus \{\bar{T}\}, v \in V_t, s \in S$$

Fares tresholds

Optional constraints

$$\sum_{v \in V_t} \sum_{f \in F^{CH}} h^I_{fvts} \leq L^{CI} \qquad t \in T \setminus \{0\}, s \in S$$

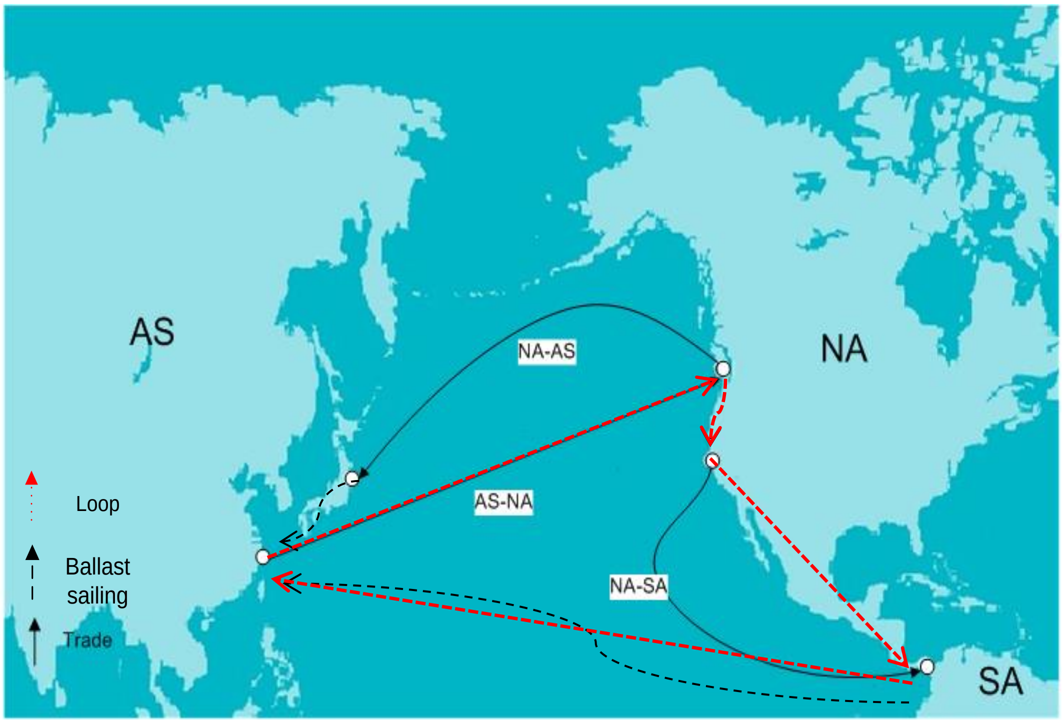
Charters upper bound

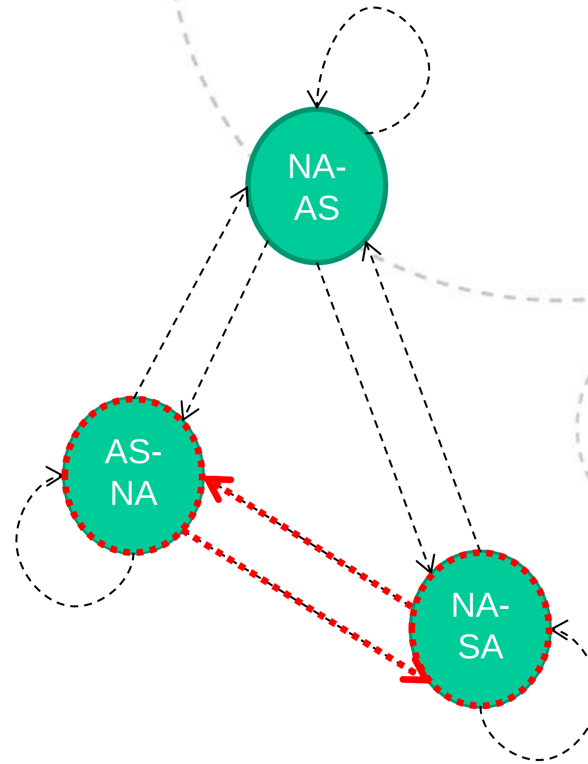
$$\sum_{v \in V_t} \sum_{r \in R_{ivt}} x_{vrts} \geq F_{it} \qquad t \in T \setminus \{0\}, i \in N_t^C, s \in S$$

Frequency constraints

Budget constraints

Modeling fleet deployment



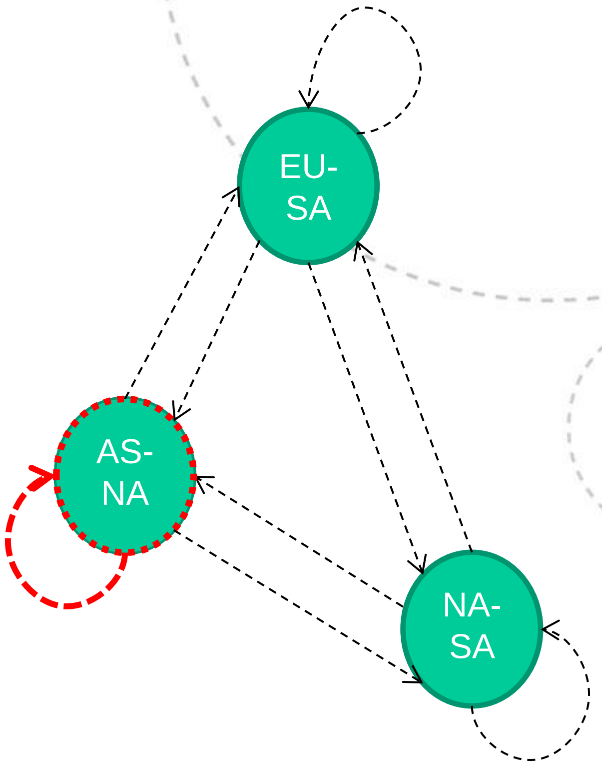


Cardinality of 2

- Generate a set of loops (i.e. a sequence of trades to visit)
- Cardinality of loops: # of trades serviced in the loop

Modeling fleet deployment

- We propose to have continuous variables specifying the number of times a given ship type performs a given loop in a time period
- Make sure that the total time available in a given period for each ship type is not exceeded
- Optimistic wrt geographical 'jumps' between loops
- Pessimistic wrt limitations due to the cardinality of the loops
- Will become more realistic when the cardinality of the loops included increases



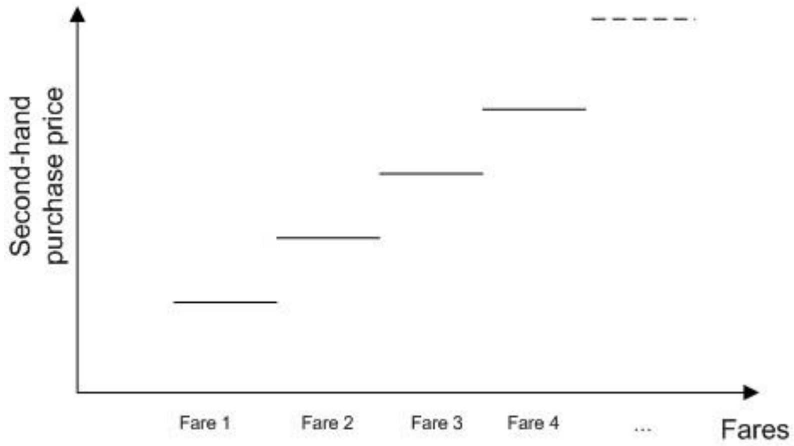
Cardinality of 1

Modeling market interaction

Finite Market

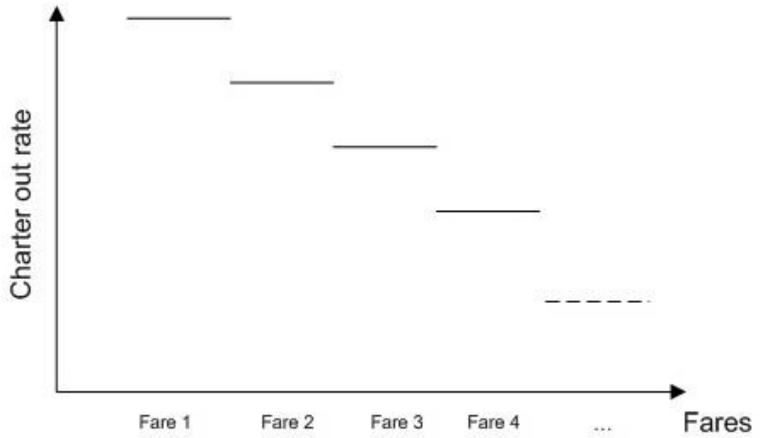
Second-hand ships:

Increasing marginal purchase cost, decreasing marginal selling revenue

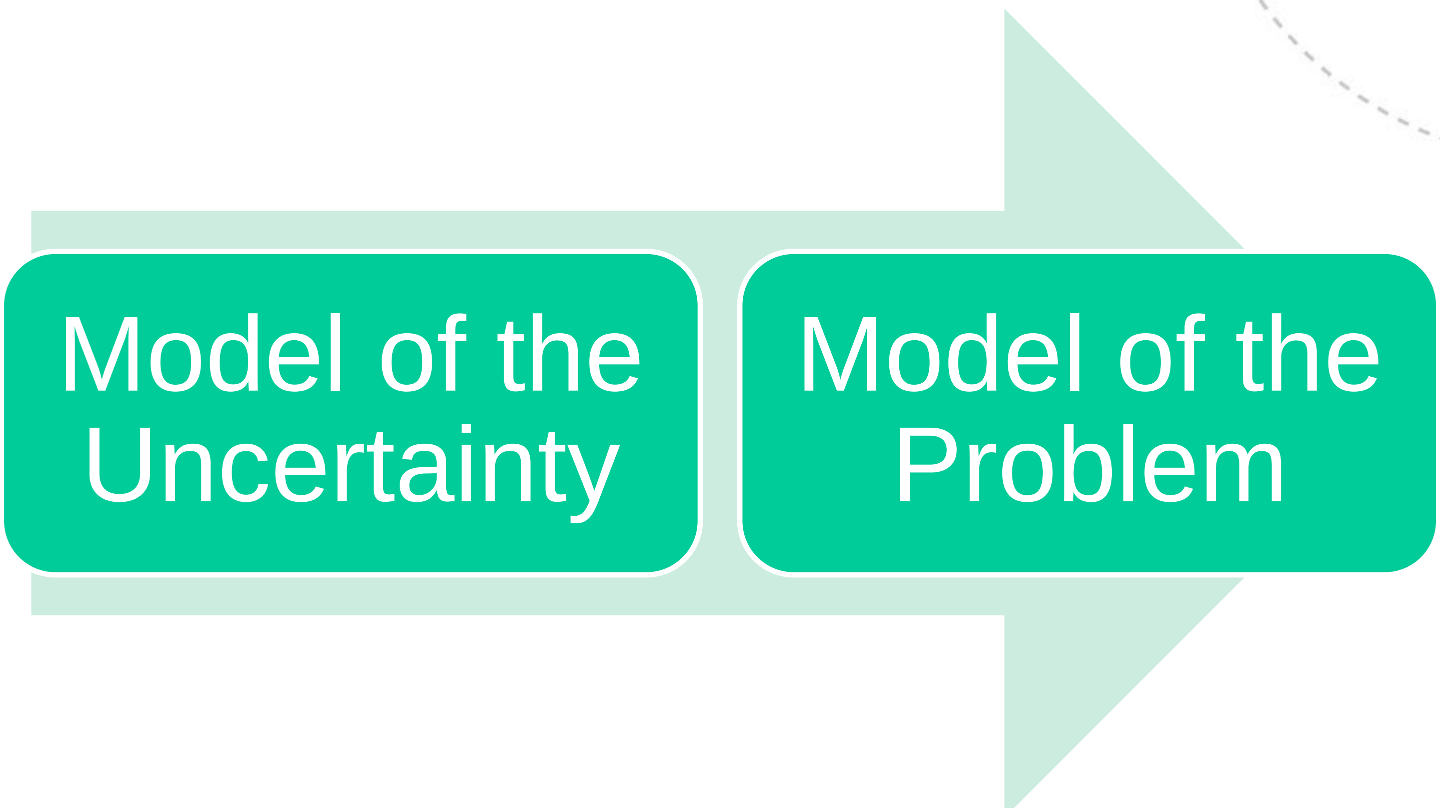


Charters:

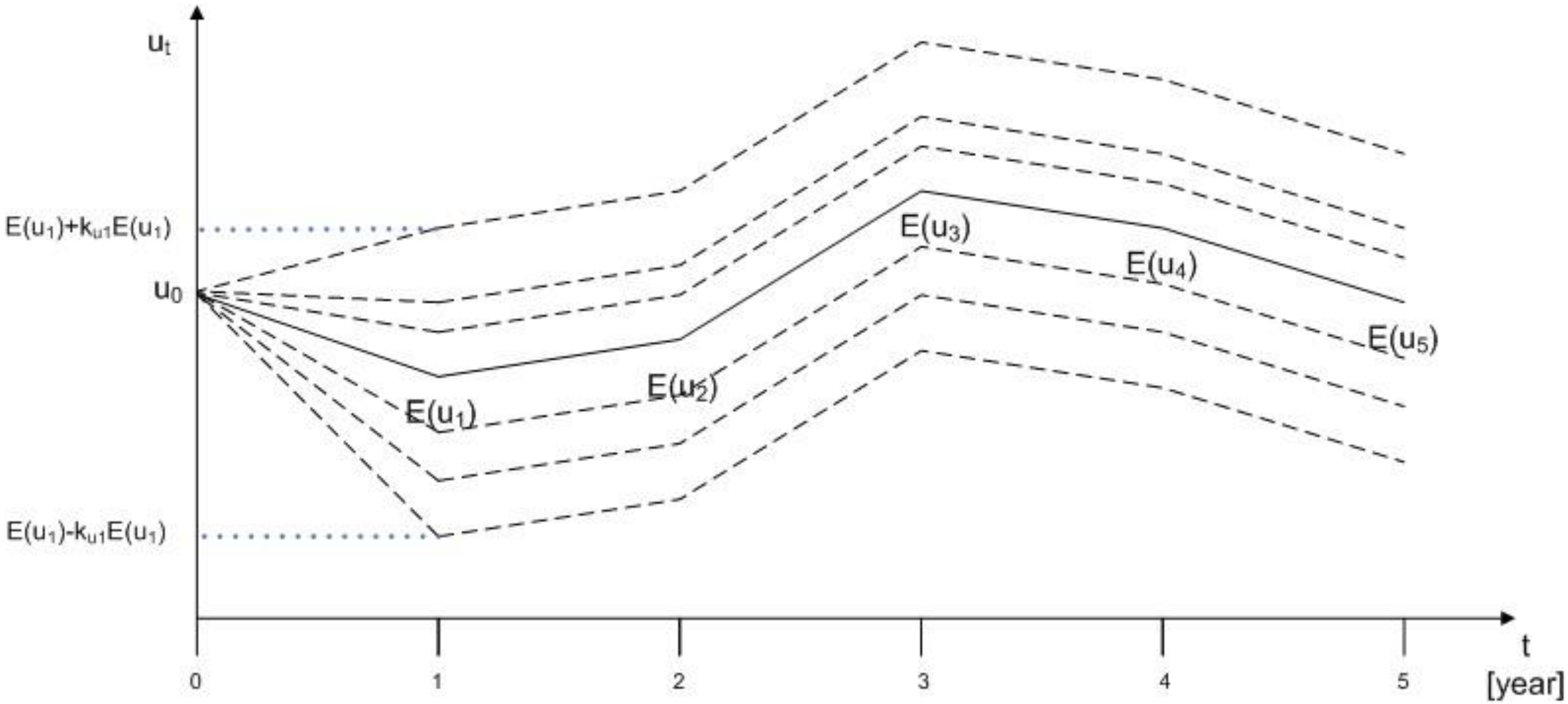
Increasing marginal charter in rate, decreasing marginal charter out rate



Decisions Under Uncertainty



Modeling uncertainty



Modeling uncertainty

- Six random variables:
  - Fuel price
  - Ship prices and charter rates
  - Steel price (demolition rates)
  - Demand of Cars
  - Demand of HH
  - Demand of BB
- Basic model: Uniform marginal distribution over a support [-k,+k]
- Correlations are assumed

Tests instances

Table 2 Ship types in the instances.

Ship type	Instance 6_5	8_8	10_12	Capacity [RT43] Car	HH	BB	Initial age [years]	Service speed [knots]
	# of ships in the initial fleet							
RORO1	0	0	0	6000	7500	4100	-2 [a]	20.8
RORO2	8	9	8	4000	5700	3400	22	16.5
RORO3	- [b]	-	10	4600	6800	3500	8	17.0
LCTC1	0	0	0	7600	3600	900	-2	18.5
LCTC2	9	11	9	7930	3600	1600	7	19.8
LCTC3	-	10	12	6930	2900	1600	16	17.8
PCTC1	0	0	0	6350	2900	1300	-2	18.5
PCTC2	10	12	7	6500	1900	800	3	18.5
PCTC3	-	13	10	6300	2000	500	21	16.5
PCTC4	-	-	9	6000	2100	400	8	16.8

[a] Negative ages, $-a$, indicate that ships of that type can be operated from period a and be ordered in period $a - \bar{T}_v^L$

[b] "-" indicates that the ship type is not considered in the instance

Table 3 Trades in the instances.

Trade	6_5	8_8	10_12	Length [nautical miles]	H_{tt} [services/year]
TR1	x	x	x	7 500	20
TR2	x	x	x	14 500	52
TR3	x	x	x	13 500	48
TR4	x	x	x	13 000	48
TR5	x	x	x	15 021	20
TR6		x	x	19 200	48
TR7		x	x	11 700	25
TR8		x	x	10 000	48
TR9			x	7 800	20
TR10			x	7 800	48
TR11			x	4 900	48
TR12			x	8 400	48

Tests & Results

Do we really need to use stochastic programming?

Tests & Results

The Value of the Stochastic Solution (VSS)

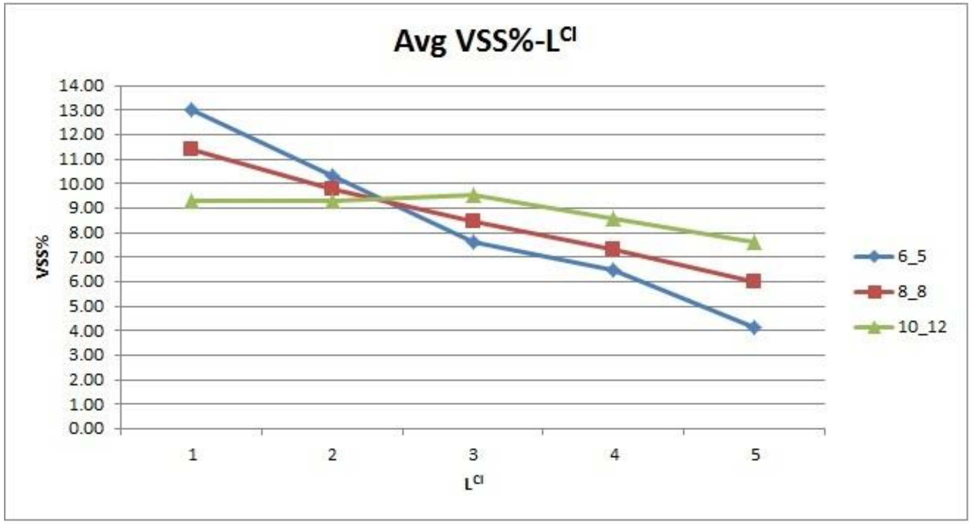
Table 4: VSS% and expected costs

	6_5	8_8	10_12
Avg VSS%	7.64	8.48	9.56
Max VSS%	8.91	9.22	10.40
Avg Expected cost SS [M US$]	1294.82	2136.49	2135.26
Avg Expected cost DS [M US$]	1393.76	2317.60	2339.36

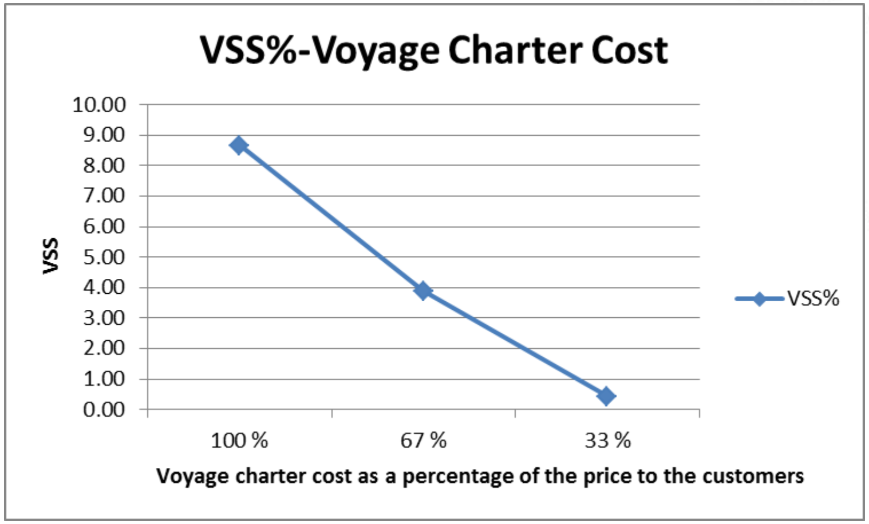
Using a stochastic program we can lower the expected cost by 7.6 to 10.5%! Why?

Tests & Results: Market interaction

VSS and charter availability



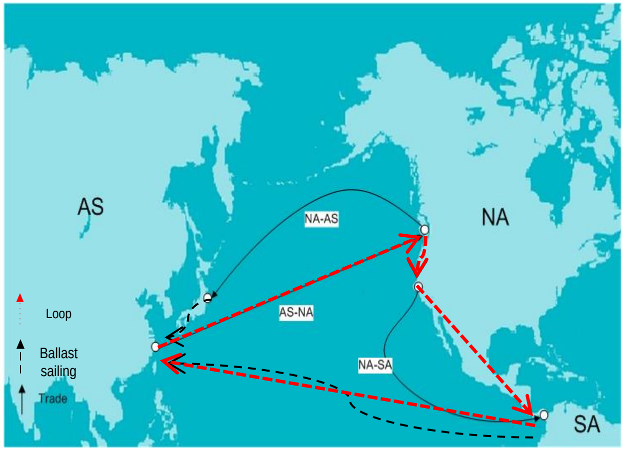
VSS and voyage charter cost



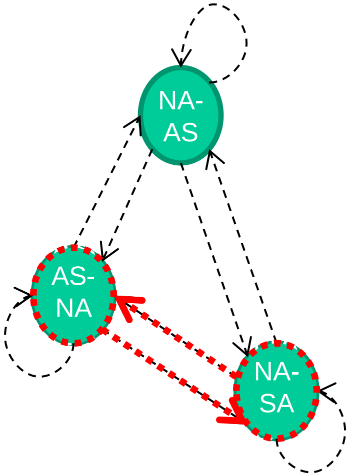
NTNU
Norwegian University of Science and Technology

Tests & Results: Deployment modeling

Expected costs and aggregation level in deployment modeling (cardinality of loops included)



Cardinality of 3



Cardinality of 2

Table 6 Expected cost and deployment information.

	Optimal objective value %		
C^{MAX}	6_5	8_8	10_12
1	167.23	163.24	168.52
2	100.00	100.00	100.00
3	99.95	99.75	98.49
4	99.93	99.70	-
5	99.94	99.73	-

Optimal objective values are expressed as a percentage of the optimal objective value for the case $C^{MAX} = 2$

What happens if we are wrong in estimating properties of stochastic variables?

- Modeling uncertainty is about capturing the important elements and simplifying the others
- Conclusions of case study:
  - It matters little if we are wrong in estimating correlations, support width and shape of distributions
  - It matters more if we are wrong in estimating the mean values
- Knowing what properties that matter can lead to more efficient data collection/analysis

Concluding remarks

- The MFRP is an important strategic planning problem, where decisions will have impact for a long time
- Considering uncertainty may have a high impact, but it depends on the market situation
  - In a limited market the VSS is high, while in an open market there will much more recourse possibilities (chartering, buying, selling, etc.)
- Even though we are interested only in strategic fleet renewal decisions, one must also include routing/deployment of ships
- Open research question: What is an appropriate level of aggregation for modeling tactical decisions in strategic decision-making?