A heuristic for rich maritime inventory routing problems

Oddvar Kloster, Truls Flatberg, Geir Hasle

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Outline

- SINTEF
- Introduction
- Model
- Algorithms
- Test cases

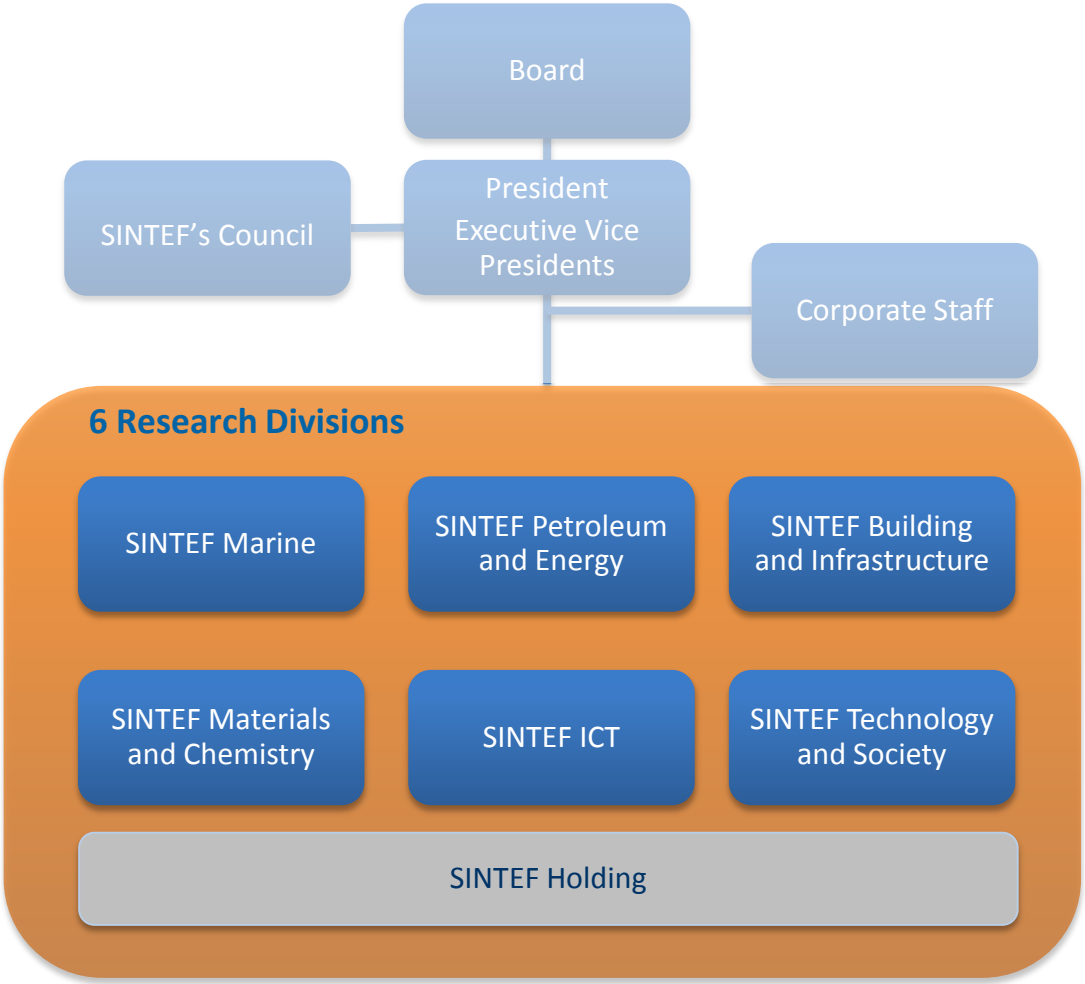
SINTEF

Technology for a better society

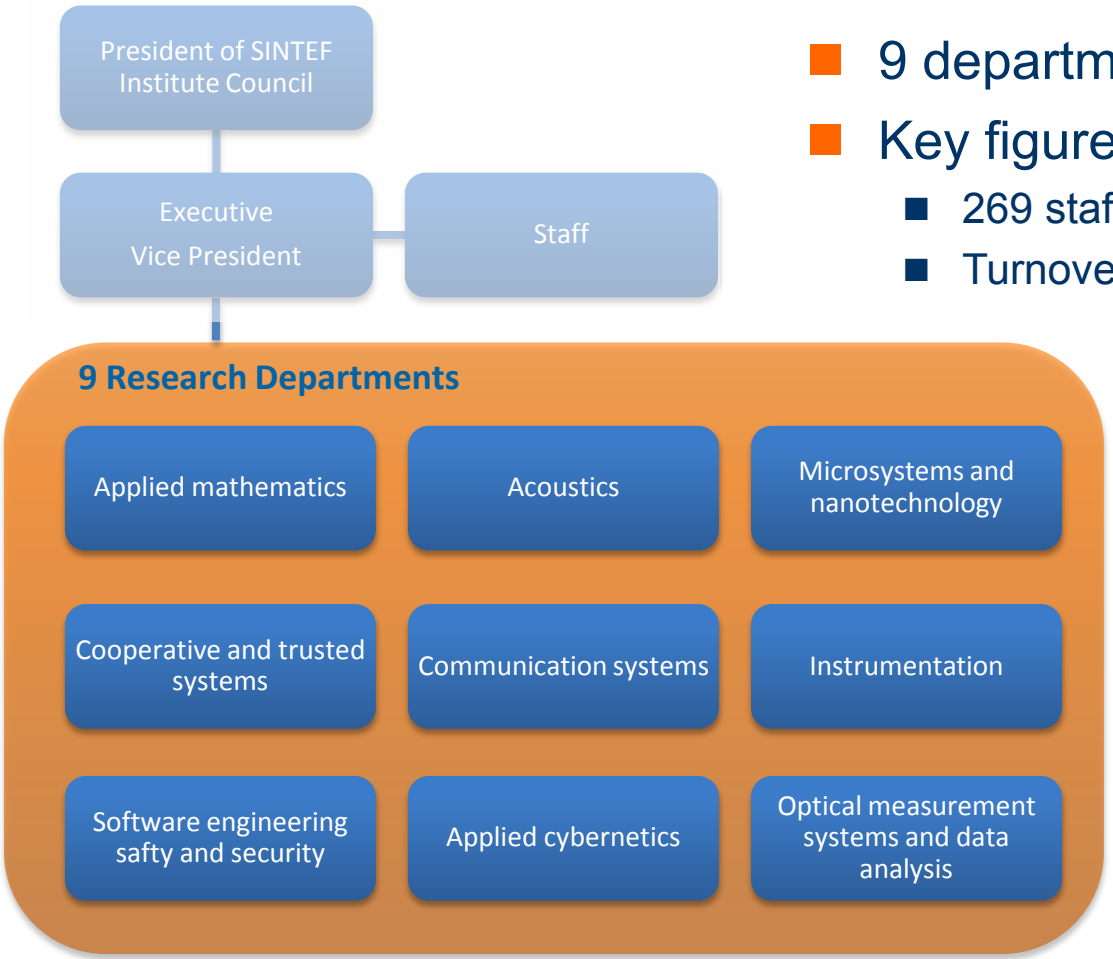
SINTEF

- Established 1950 by the Norwegian Institute of Technology.
- The largest independent research organization in Scandinavia.
- A non-profit organization.
- Vision "Technology for a better society".
- Key Figures
  - 2123 Employees from 67 different countries.
  - 2755 MNOK in turnover (about € 340M).
  - 7216 projects for 2200 customers.
  - Offices in Norway, USA, Brazil, Macedonia, United Arab Emirates, Denmark.

SINTEF: Organization

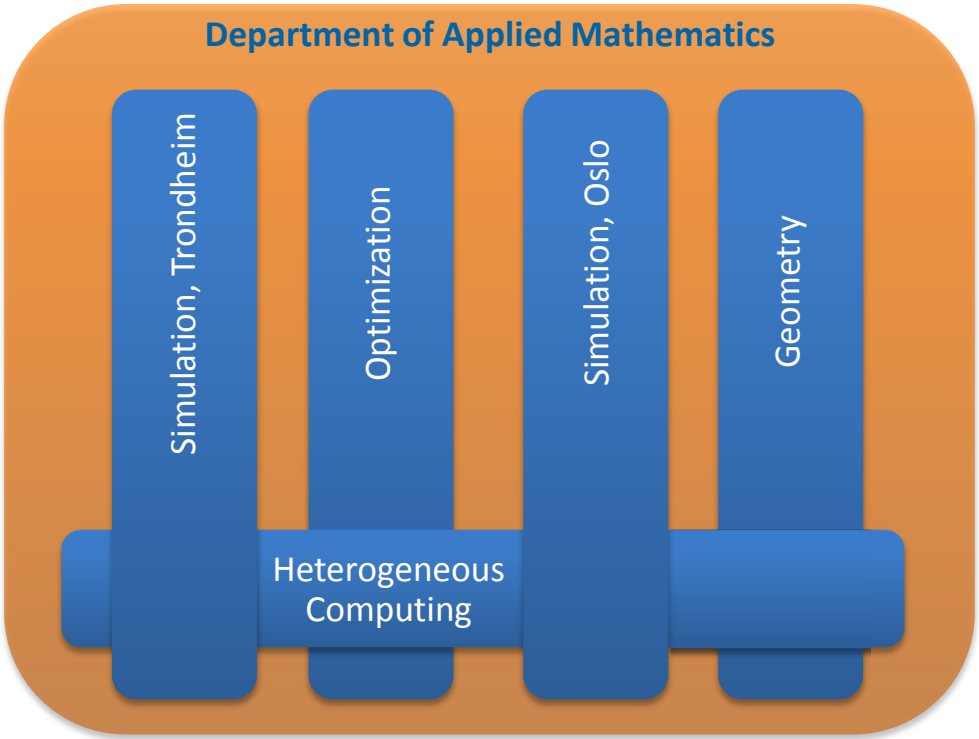


SINTEF ICT: Organization



- Offices in Oslo and Trondheim
- 9 departments
- Key figures 2009
  - 269 staff
  - Turnover 336 million NOK

Department of Applied Mathematics



- Offices in Oslo and Trondheim
- Consists of 5 research groups
  - Geometry
  - Optimization
  - Simulation
  - Visualization
  - Heterogeneous computing
- Key figures 2009
  - 38 employees
  - 45 MNOK turnover

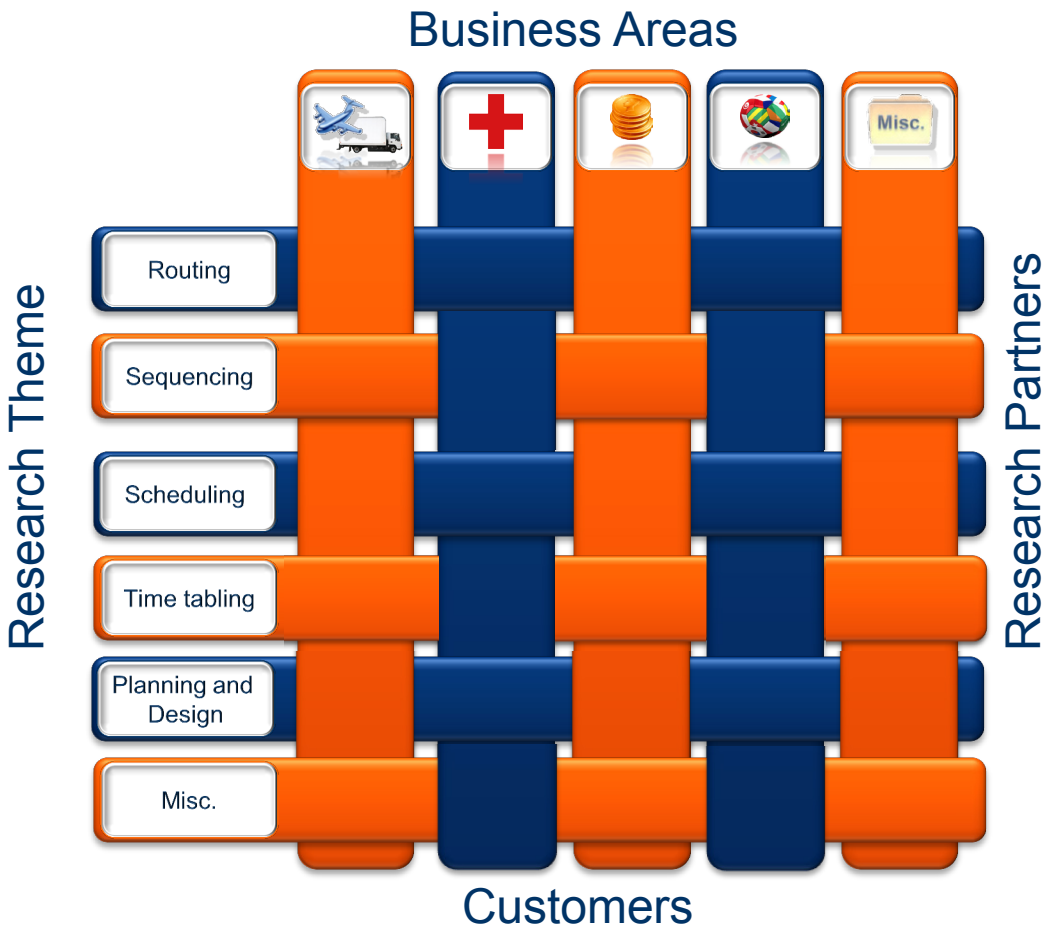
Optimization group

- **Focus**
  - 20 years of basic and applied research in discrete optimization
- **Employees**
  - 8 researchers, 1 software engineer
- **Activities**
  - Basic research
  - Applied research
  - Consultancy
- **Products and Services**
  - Models and algorithms
  - Software (stand alone, plugin, components, libraries)
  - Reports, scientific papers

Customers and Partners

- Industry
- Public Sector
- Research Council of Norway
- European Commission
- Research Institutes
- Universities

Business Areas & Research Themes



Finance: NetranS

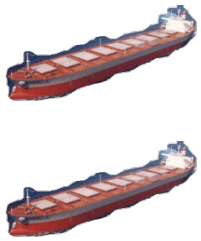
- **Customer:** VPS, owned by Oslo Stock Exchange
- **Challenge:** Maximizing the total value of transactions at Oslo Stock Exchange.
  Typical size: 150 000 transactions, value NOK 150 billion
- **Solution:** MIP solved by CPLEX. Decomposition due to problem size.
- **Result:** Runs twice daily. High clearing percentage.

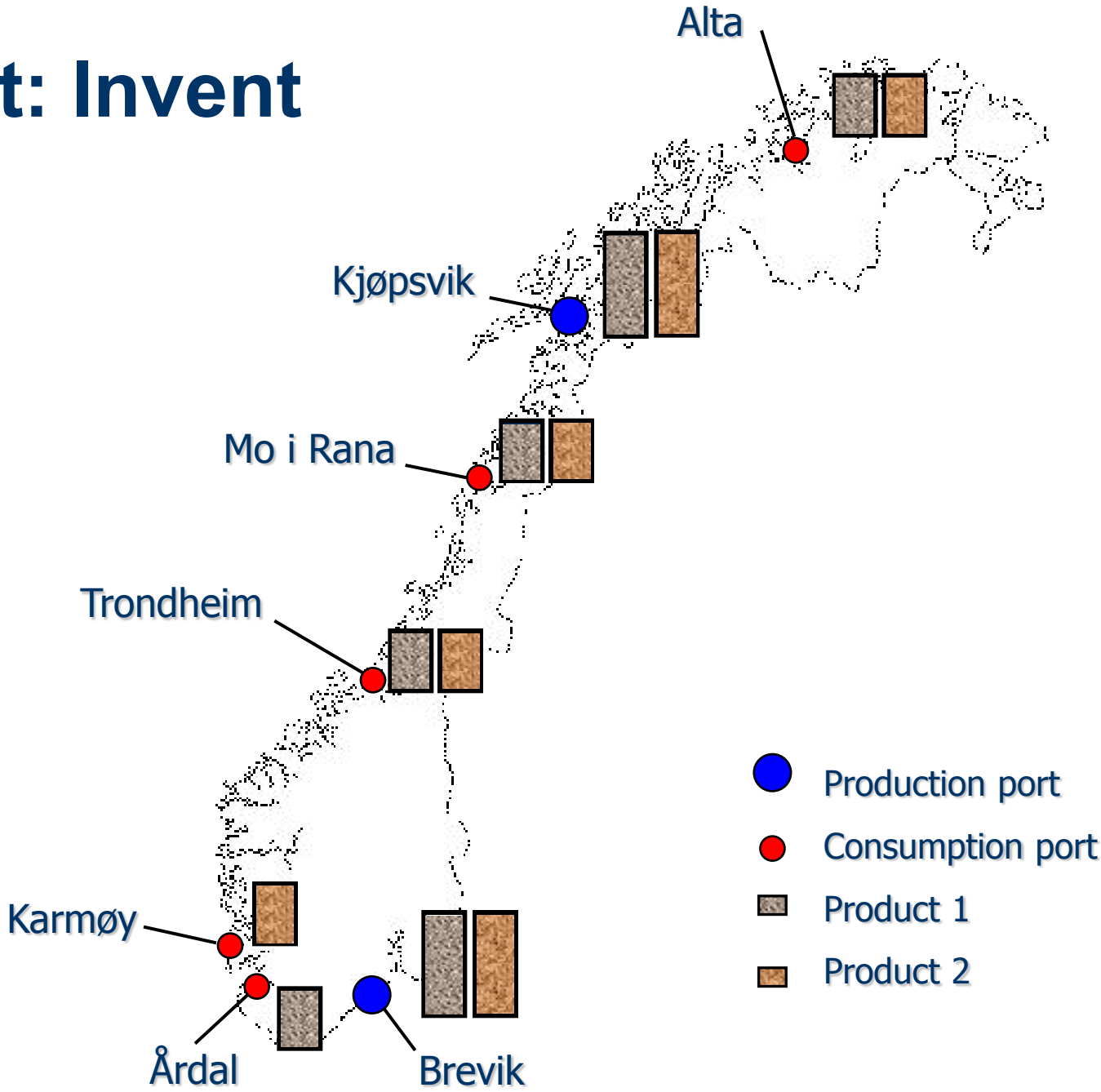
Sports: NFF Scheduling

- SINTEF makes the schedule for the Norwegian top divisions
- Two-stage process where the pattern is constructed first
  - No ”break” between round 1 and 2, nor between 25 and 26 (last round)
  - Minimum number of breaks
  - Minimum distance between ”same” match type (home and away)
  - Anti-teams
- Allocation of the teams to placeholder
  - Specific matches on specific days
  - Specific home or away - start and finish

Round	1	2	3	4	5	6	7	8	9	10	11	12	13
Team 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Team 2	1	14	3	4	5	6	7	8	9	10	11	12	13
Team 3	13	1	2	14	4	5	6	7	8	9	10	11	12
Team 4	12	13	1	2	3	14	5	6	7	8	9	10	11
Team 5	11	12	13	1	2	3	4	14	6	7	8	9	10

Transport: Invent





Literature

Andersson H., A. Hoff, M. Christiansen, G. Hasle, A. Løkketangen (2010).
Industrial Aspects and Literature Survey: Combined Inventory Management and Routing.
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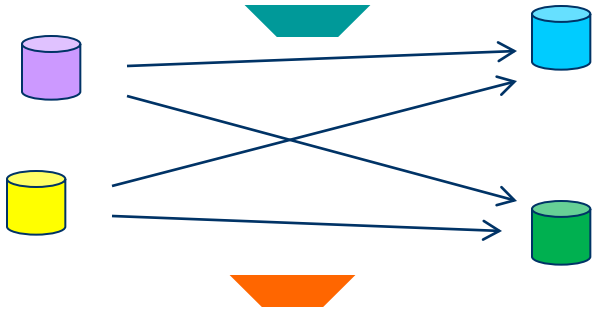
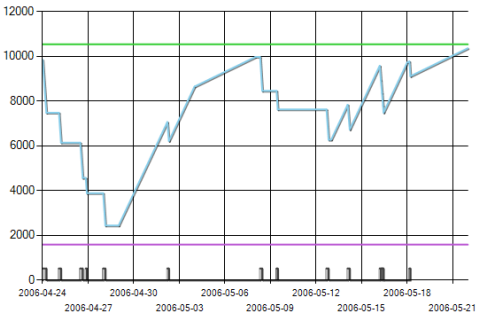
M. Christiansen, K. Fagerholt, G. Hasle, A. Minsaas, B. Nygreen (2009). ***Maritime Transport Optimization: An Ocean of Opportunities.*** ORMS Today 36 (2), 28-31.

Maritime inventory routing

- One or more products
- Production ports
- Consumption ports
- Finite storage capacity
- Production/consumption rate
- Fleet of vessels





- Route vessels to avoid stockout/overflow

Maritime inventory routing

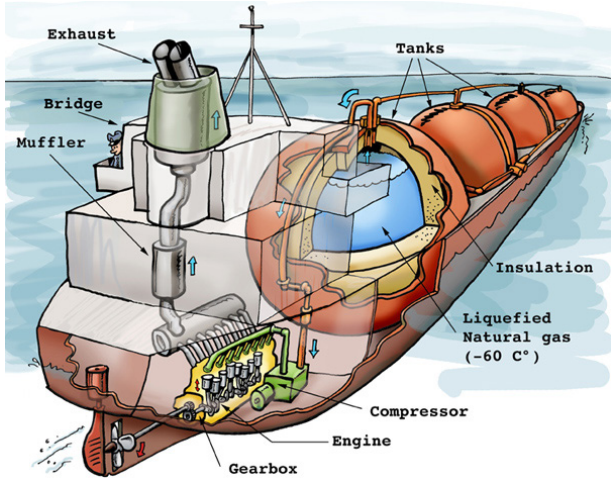
- Characteristics
  - Often no central depot
  - Often no fixed quantities and time windows
  - Continuous operation
  - Tightly coupled
- Many variants with specific constraints
- Three applications used as pilot studies
  - Cement - multiple products, short horizon
  - Chemical tankers - tramp and inventory, multiple products, tank allocation, cleaning
  - LNG - single product, long term, contracts, full loads

Invent model features (1)

- Products
  - Measured by quantity, weight and volume
  - Fixed density, or dependent on production site
  - Cleaning may be required between products, incurring cleaning time and cost
- Vessels
  - Sailing time/distance/cost table per vessel
  - Laden volume/weight capacity
  - Stowage:
    - Simple stowage (max products)
    - Or stowage in one or more tanks with volume capacities
  - Availability, maintenance periods

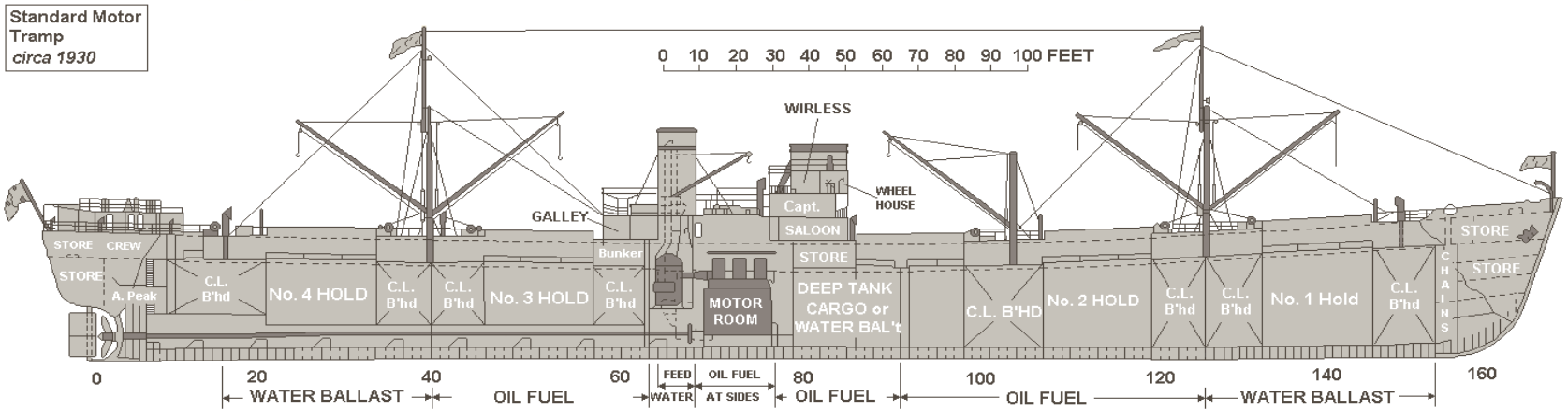
Invent model features (2)

- Inventories in ports
  - Min and max volume and weight capacity
  - Per vessel/product load and discharge rates
  - Variable production/consumption rates
  - Partly interruptible production/consumption
  - Port closure periods
- Contracts
  - Limit the amounts lifted in certain periods
  - Define prices
  - Restrict origins/destinations
  - Restrict cargo size
  - Impose time slots



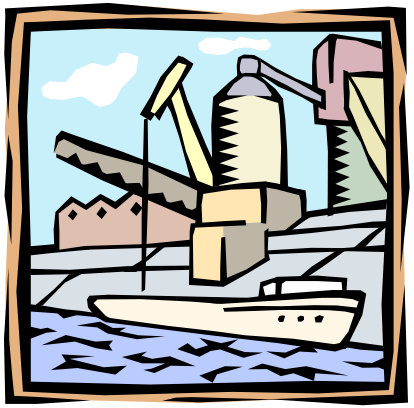
Invent model features (3)

- Bookings
- Transportation demands not related to inventories
- Laycan, quantity limits
- Pickup or delivery only, or both



Invent model features (4)

- Priority on inventories and contracts
- Vessel-port compatibility
- Arrival and departure load limits (draft restrictions)
- Restrict # visits to inventory in period
- Inter-arrival gaps
- Boil-off
  - Product evaporates during sailing
- Full vessel loads
  - Leave from production ports with full loads
  - Discharge completely in consumption port except for boil-off needs



Invent model – Objectives

- Objective components
  - Income (contract, stream, booking)
  - Cost (sailing, port stay, cleaning)
  - Performance (quantity transported)
  - Penalized constraints (stockout/overflow)
- Combined objectives
  - Scalarization
  - Hierarchical

Invent - Solution strategy

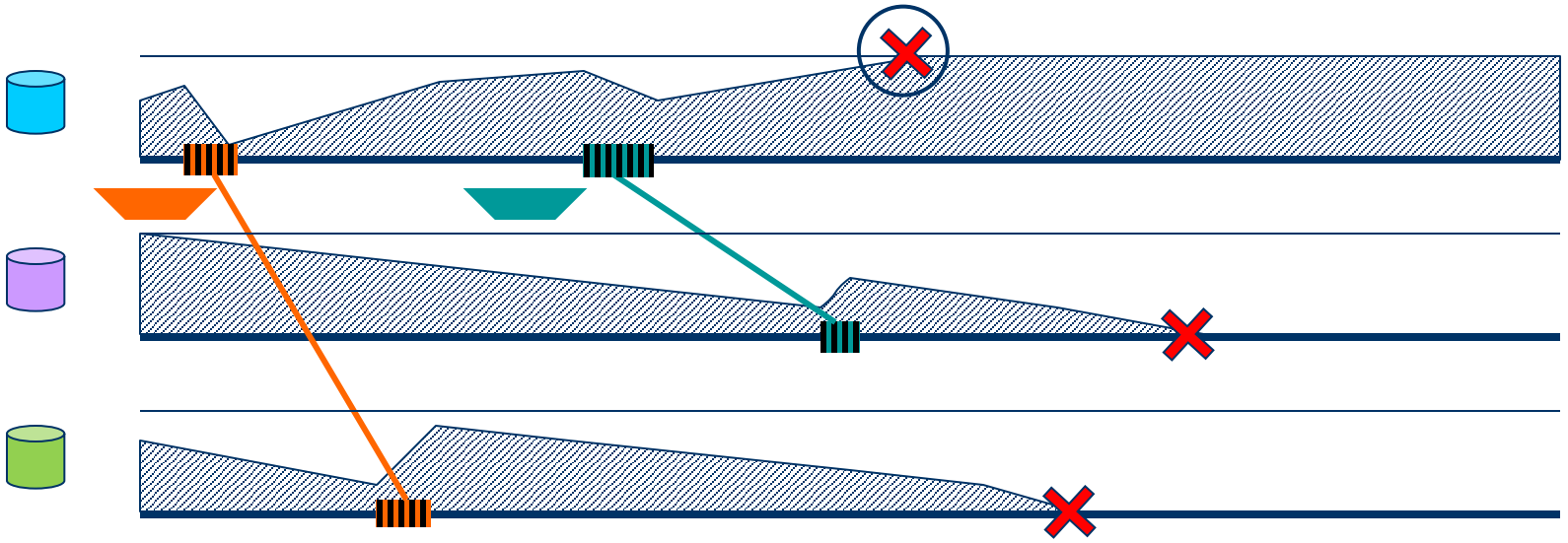
- Rolling horizon context
- Heuristic construction and optimization
- Violate constraints by doing too little → penalize
  - Stockout/overflow
  - Unserviced booking
  - Contract limit not met
  - Too few visits in time period
- Reduce penalty by adding shipments
- … in a greedy fashion
- Try to resolve conflicts using delays

Construction: overview

- Start with “empty” plan
- Identify earliest (highest priority) violated constraint
- Generate shipments
- Rank shipments
- Add best shipment and repeat
- If no fix found, forget violation
- … until there are no more violations

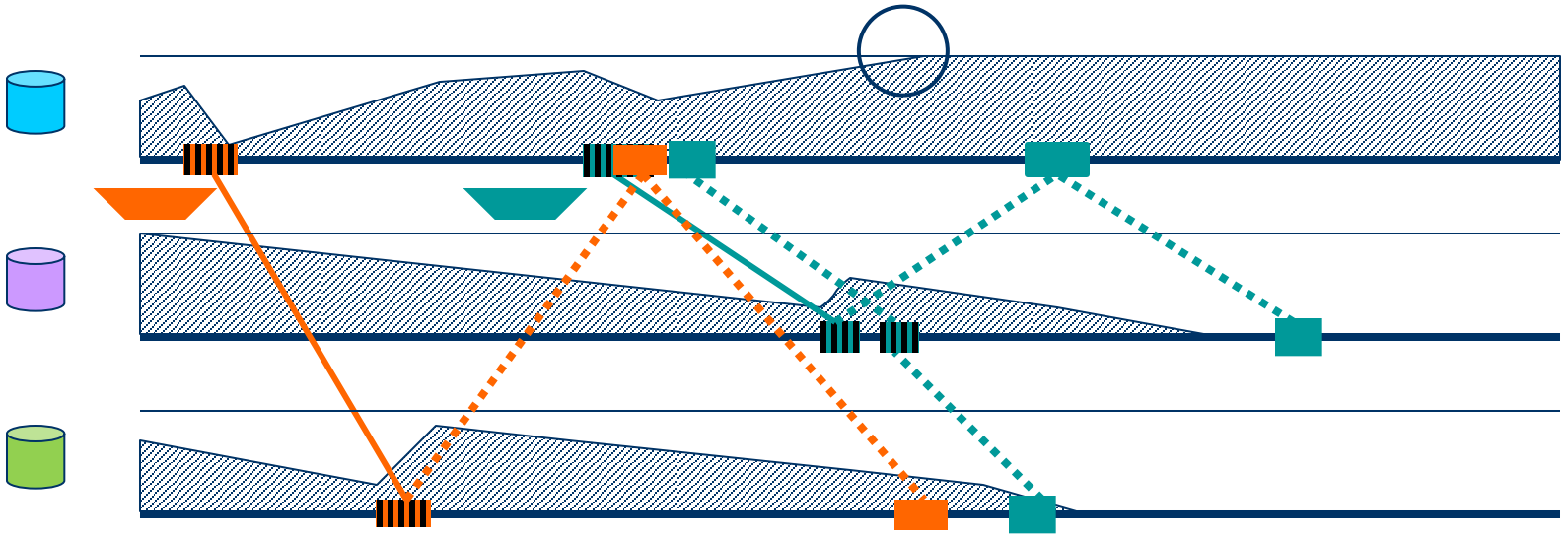
Construction: select penalty to fix

- Stockout/overflow
- Unserviced booking
- Contract limit
- Too few visits in time period



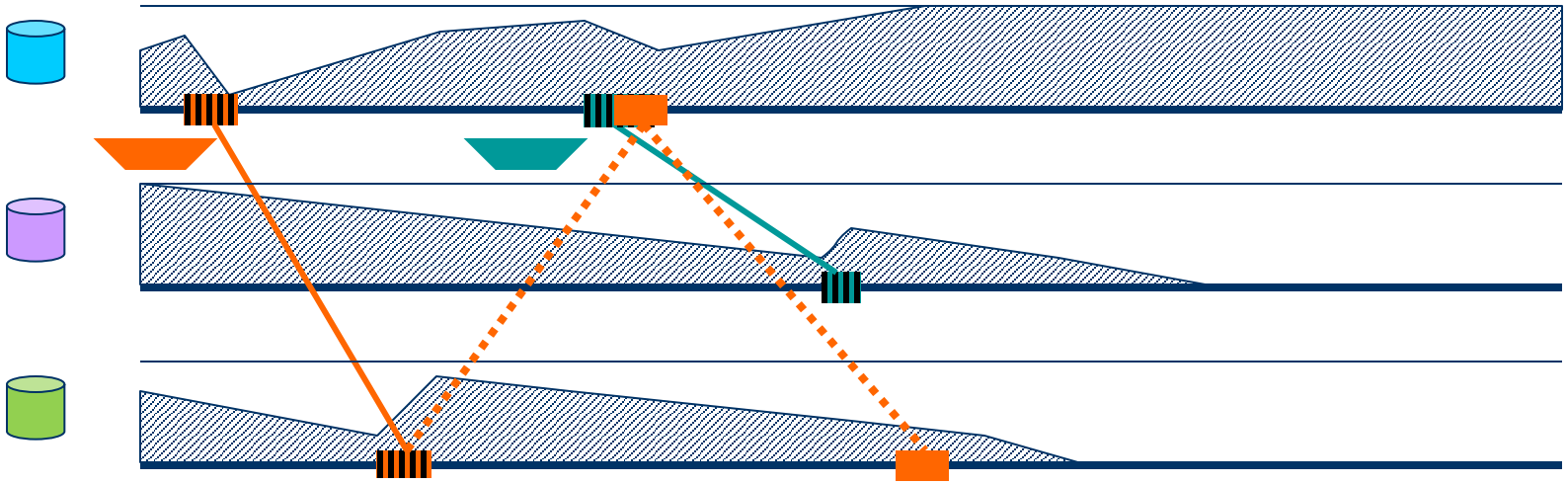
Construction: shipment generation

- Choose
  - (Contract)
  - Counterpart inventory
  - (Counterpart contract)
  - Vessel
  - Insertion points



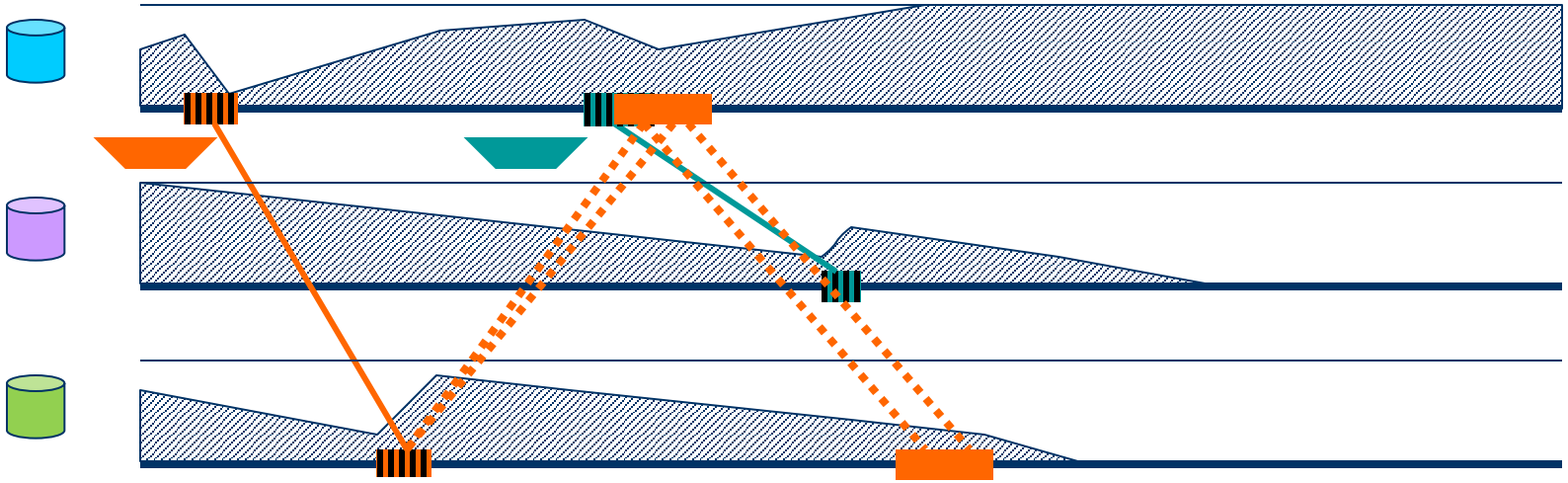
Construction: shipment insertion

- Large parts of the plan may be affected
  - Schedule for selected vessel changes after new load action
  - Schedules for other vessel are unchanged
  - Schedules may change for inventories visited by selected vessel
- Many constraints to satisfy



Construction: shipment insertion

- Assume small quantity and propagate time
- Find maximum possible quantity (including tank allocation)
- Set quantity, propagate time and quantities
- Insert tank cleaning actions
- Explore delays
- When necessary, delay and repeat



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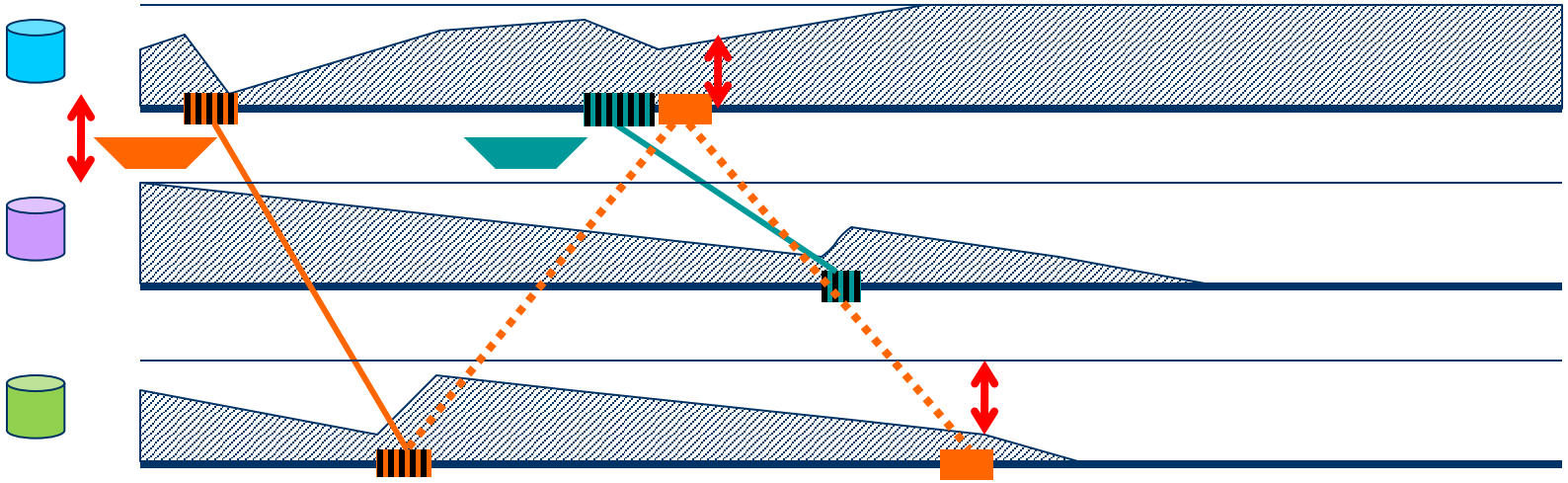

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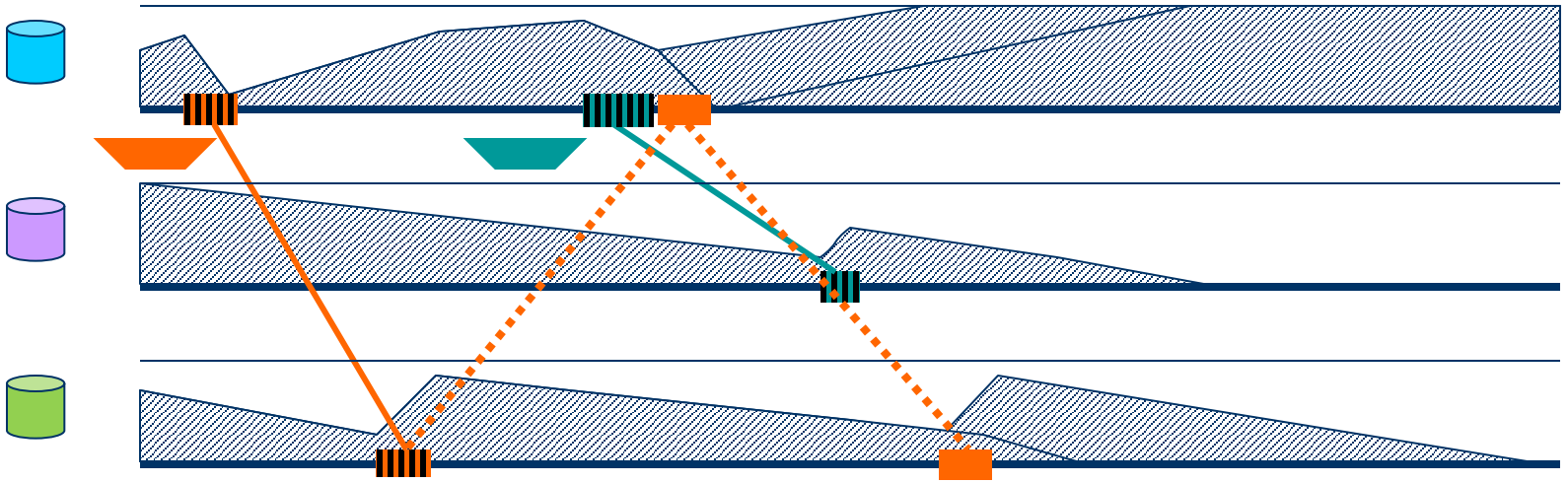

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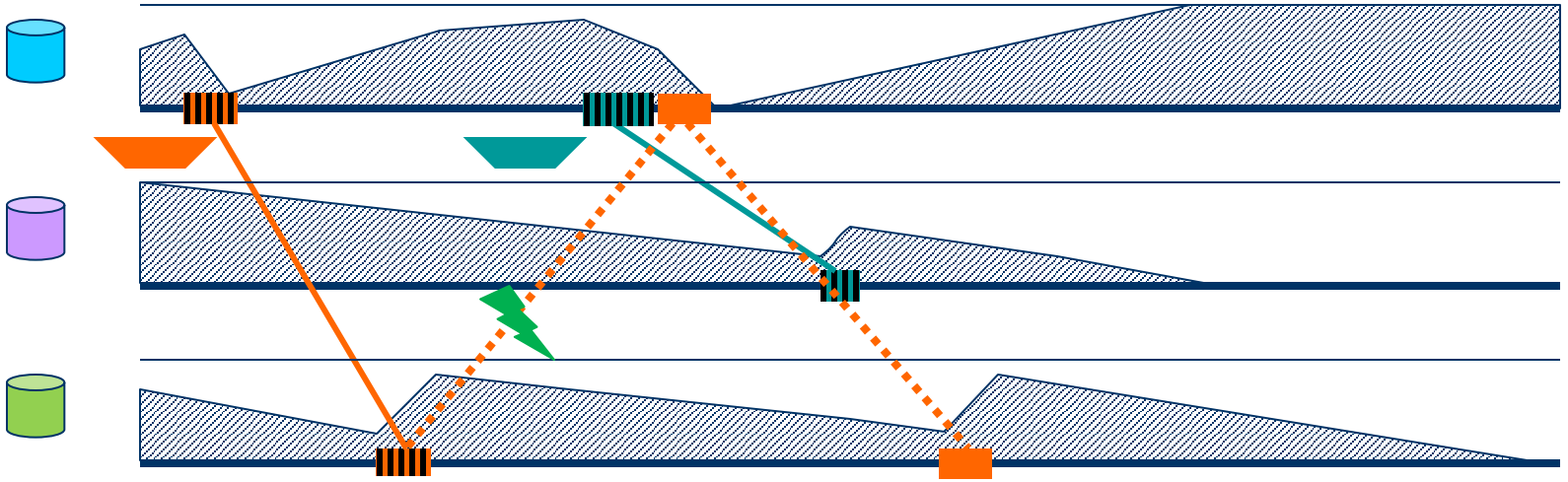

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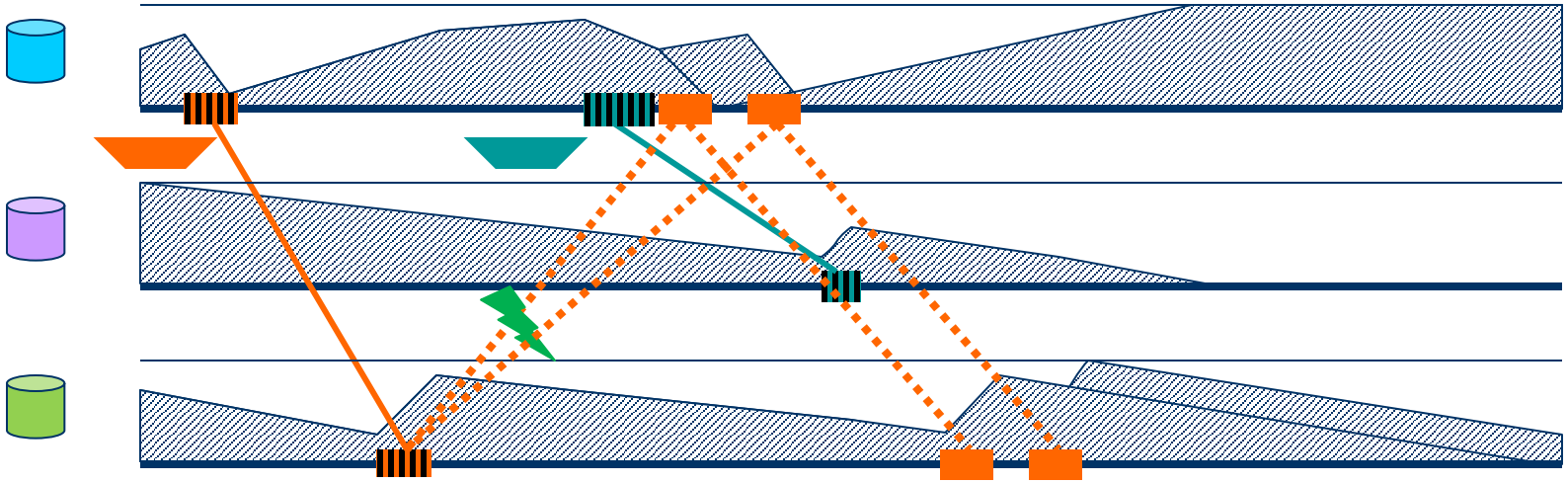


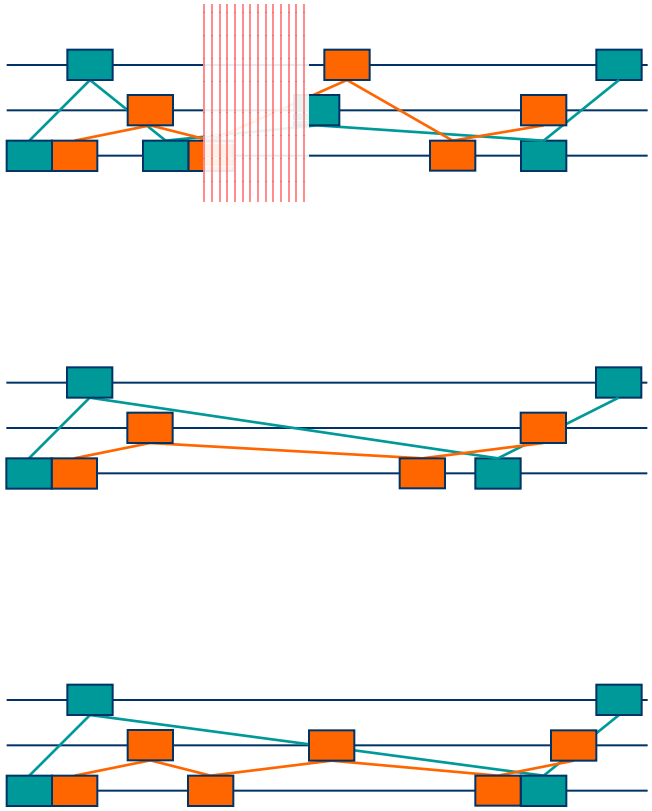
Construction: shipment selection

- Evaluate shipments according to objective function
- Randomly perturb the scores
- Select the best

Optimization

- Remove a bit of the solution
  - Any shipment starting or ending in random (~10%) interval
- Compact solution
- Regenerate the missing part
- Accept if better
  - or best of the recently seen
- Repeat

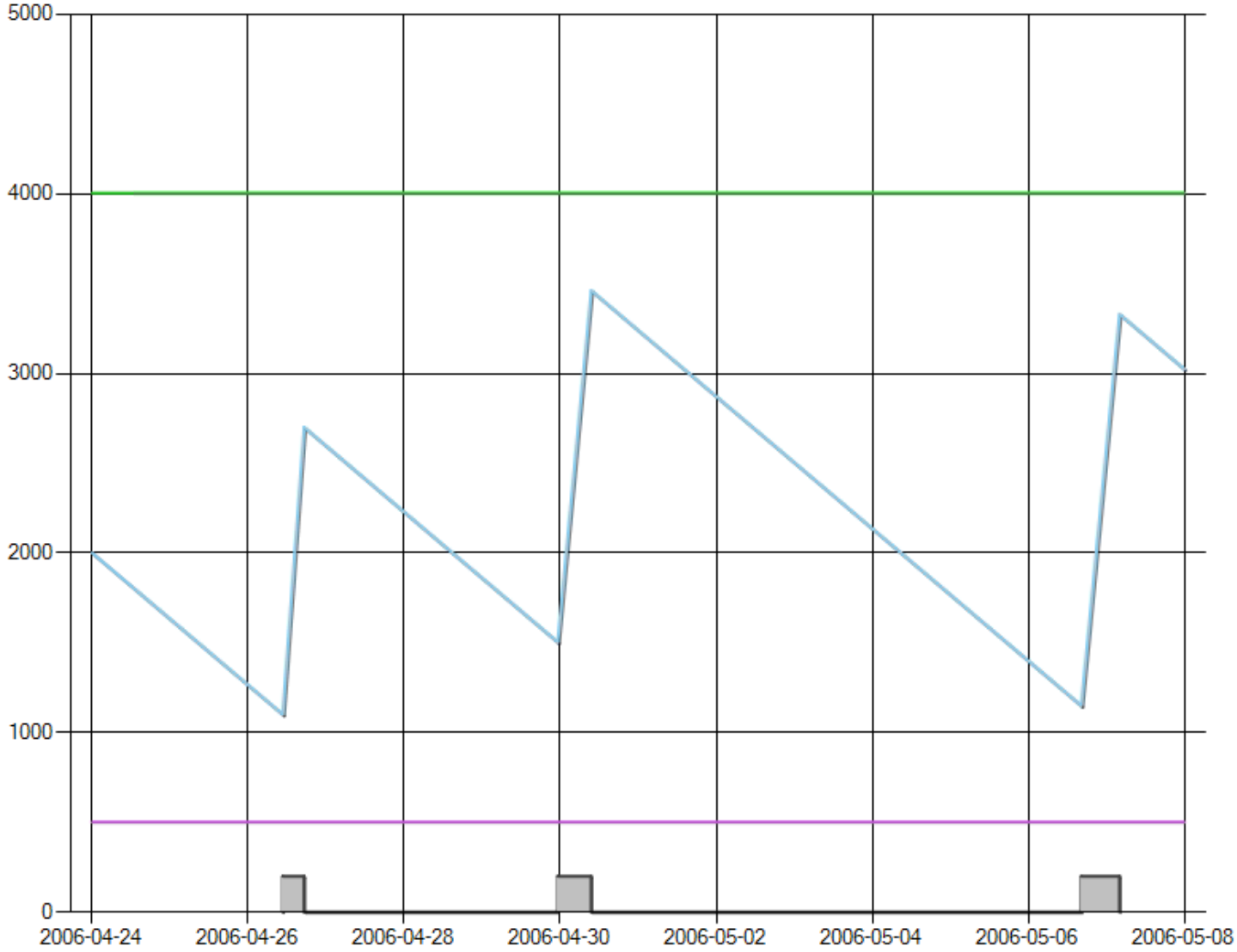
- Classical LS



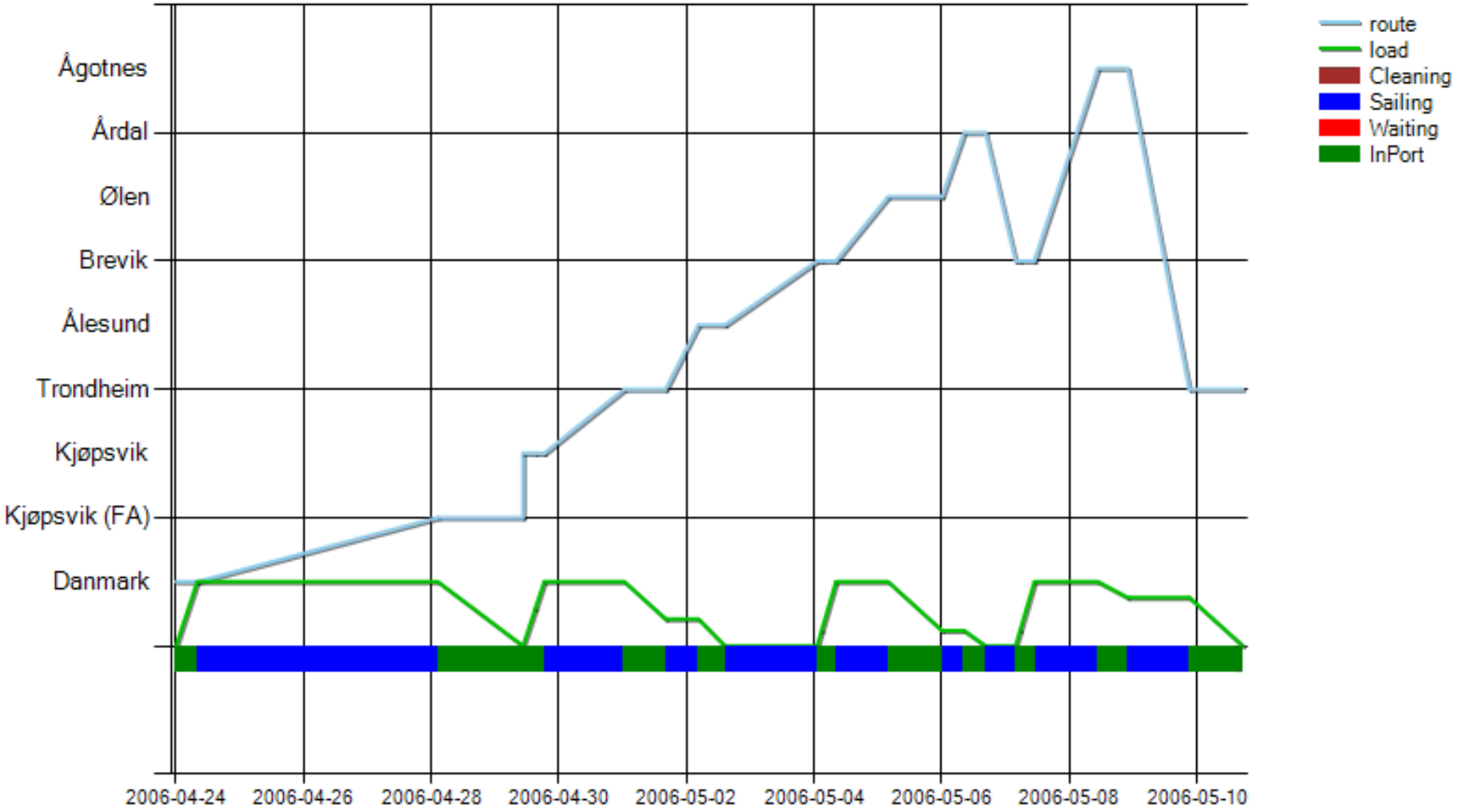
Test case – Cement

- Cement along the Norwegian coast
- 11 products
- 63 inventories in 35 ports
- 5 vessels
- 14 days
- Objective:
  - Avoid stockouts (high weight)
  - Operations cost
- 100 initial solutions
- 1000 iterations

Inventory levels



Vessel movements



Test case – Chemical products

- Chemical tankers across the Atlantic
- 14 products
- 7 vessels
- 6 months horizon
- 4 inventories
- 62 bookings
- Tank allocation, cleaning
- Objective:
  - Avoid stockouts (high weight)
    → No stockout/overflow
  - Income - operations cost
    → 1.57e7
    → 12 bookings not taken

Algorithm parameters

- Initial generation: Single or best of 100
- Accept: Improving or best of last 5
- Average over 10 runs

Test case 1			
		Accept criterion	
		Improve	Best of last 5
Start	Single	-4.06E+05	-3.73E+05
	Best of 100	-4.02E+05	-3.79E+05

Test case 2			
		Accept criterion	
		Improve	Best of last 5
Start	Single	1.52E+07	1.50E+07
	Best of 100	1.57E+07	1.54E+07

Test cases – LNG1

- 7 synthetic test cases
- One product
- 1-3 producers, 2-3 consumers, 1-3 vessels
  - Largest has 3/3/5
- 30, 60 and 90 days horizon
- Objective: Sailing + port + waiting costs
- Run time: 2 min
- Solutions: 1-15 shipments

Test cases - LNG1

- Comparison with exact method based on column generation, simpler model:
- 9 cases: difference 2-5%
- 9 cases: difference 15-20%
- 3 cases (largest): No exact solution found
  2 heuristic solutions have stockouts
  1 is fully feasible

Test cases - LNG2

- Real life problem from LNG transportation
- One product, LNG, full loads, w/boil-off
- 14 vessels
- 5 producers, 8 consumers
- 6 months time horizon
- Solution
  - ~75 shipments
  - One minor stockout
  - Customer is happy

Further work

- Model extensions
  - Berths
  - Alternative stowage/cleaning models
  - Mixed production/consumption
- Optimization
  - Alternative removal
  - LS operators
  - Guidance heuristics

Conclusions

- Maritime inventory routing problems are important and challenging
- There is a diversity of applications
- We have developed a rich model and a heuristic
- Good quality solutions in reasonable time
- Clients are happy
- More work needed

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