Routing in maritime logistics

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SINTEF ICT

Outline

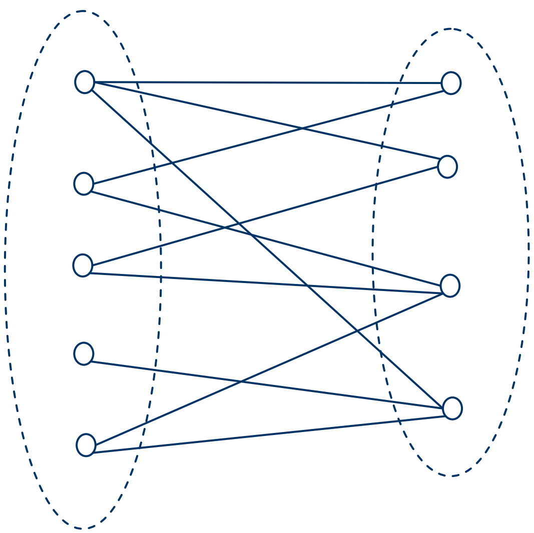
- Maritime routing
- Pickup and delivery variations
  - Free delivery location
  - Predefined number of visits
  - Inter arrival gap
- Generic library for maritime routing
  - Conceptual model
  - Construction heuristics
  - Computational results

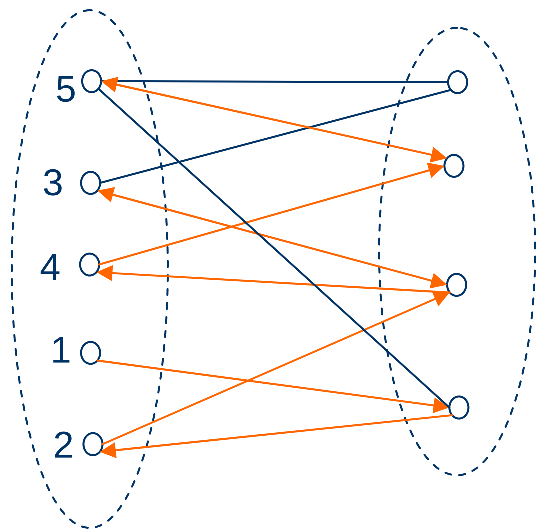
Maritime routing

- Pickup and delivery
  - No depot structure
  - Spot cargoes (pickup, delivery or both)
- Combined with inventory planning
  - Vessel size comparable to inventory capacity
  - Comparable number of supply and demand ports
- Contractual aspects
  - Volume limits over periods
  - Destination restrictions
  - Complex pricing mechanisms
  - Slots (time windows)
- Market considerations
  - Interaction with market prices
  - Downstream system
- Heterogeneous fleet

Pickup with free delivery location

- Assume homegenous fleet and full ship loads
- PDP, but delivery location is not set
- Income is destination dependent
- Cost on each sailing leg
- Maximize profit





Pickup orders Delivery locations

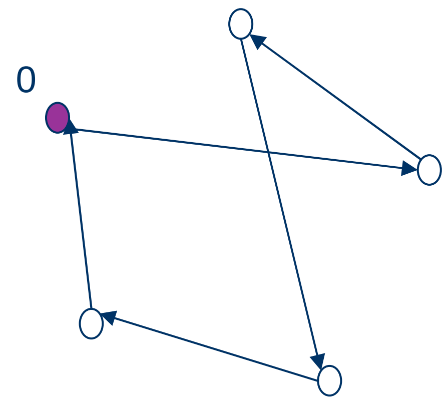
VRP transformation

P : pickup orders

D : delivery locations

c_{ik}: sailing cost going from i to k

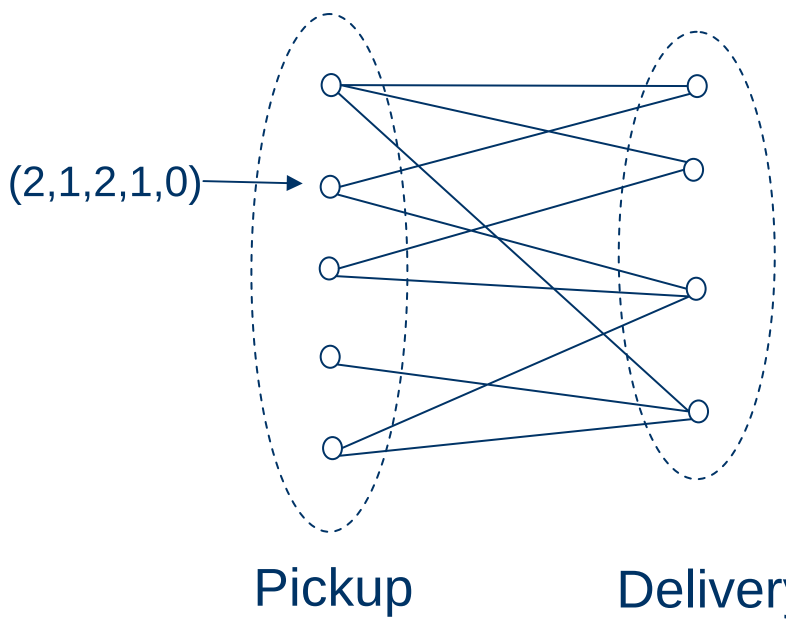
r_{ik}: income by sending order i to k

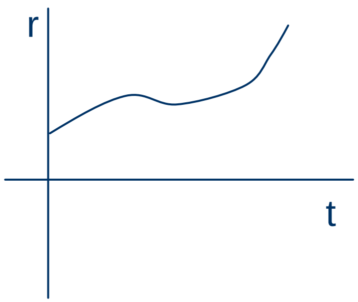


- Let
  - $d_{ij} = \min_{k \in D} (c_{ik} + c_{kj} - r_{ik})$
  - $d_{0i} = 0$
  - $d_{i0} = \min_{k \in D} (c_{ik} - r_{ik})$
- Then the problem is equivalent to an asymmetric VRP (TSP)

Extensions

- Introduce a sailing time t_{ik}
- Multiperiod problems $\Rightarrow$ VRPs with time windows
- Time dependent income $\Rightarrow$ VRPs with time dependent travel cost (and scheduling)

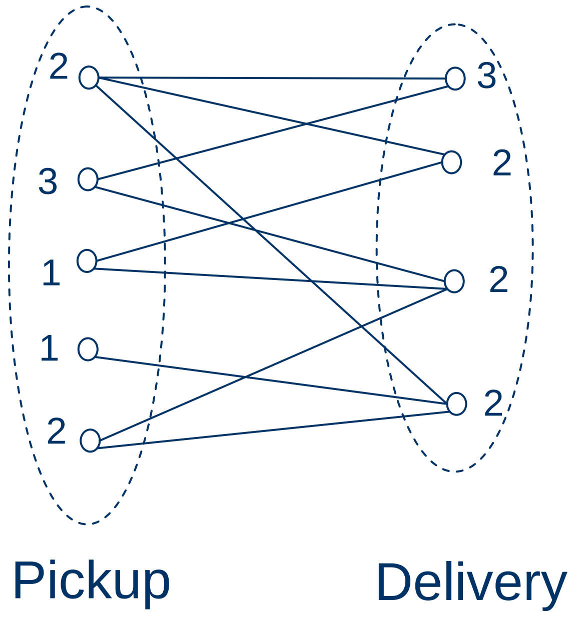




Extensions

- Given number of visits in each delivery location ⇒ VRP in a bipartite graph
- Minimum inter arrival gap ⇒ VRP with time separation on service time of orders

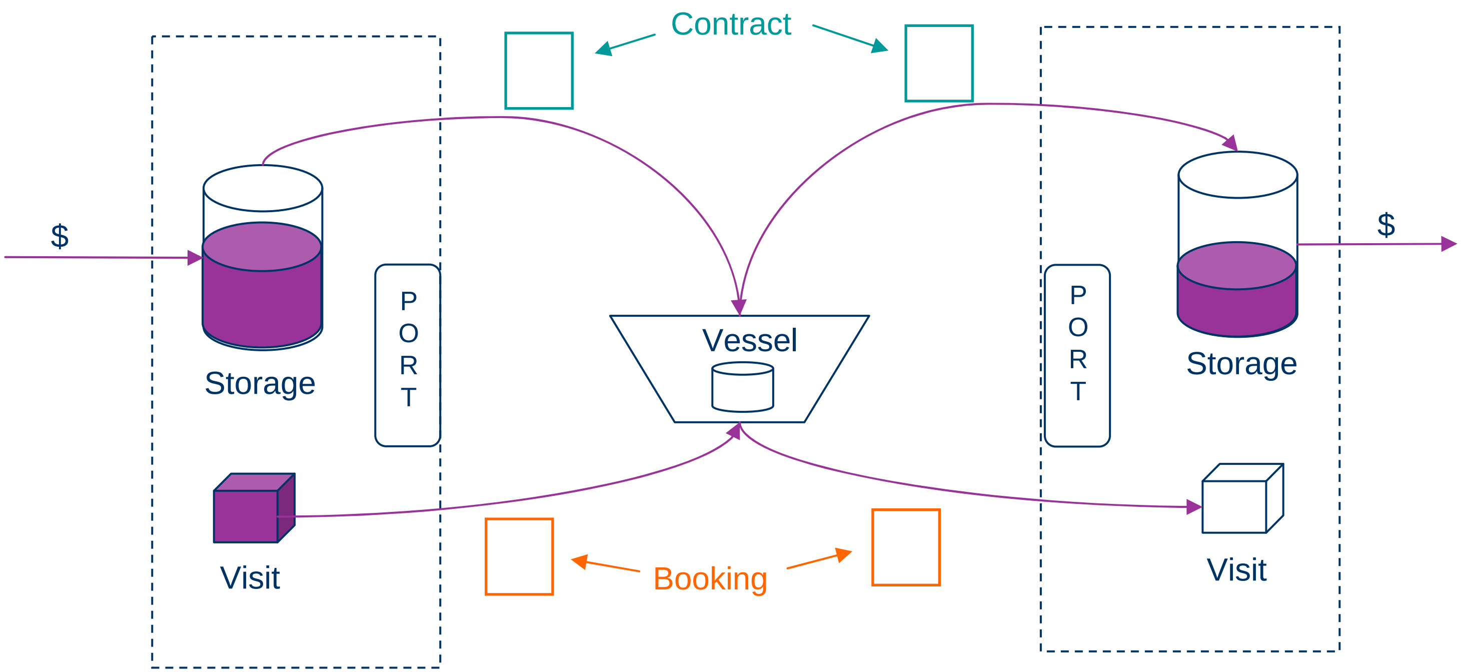
$$|t_i - t_j| \geq T$$



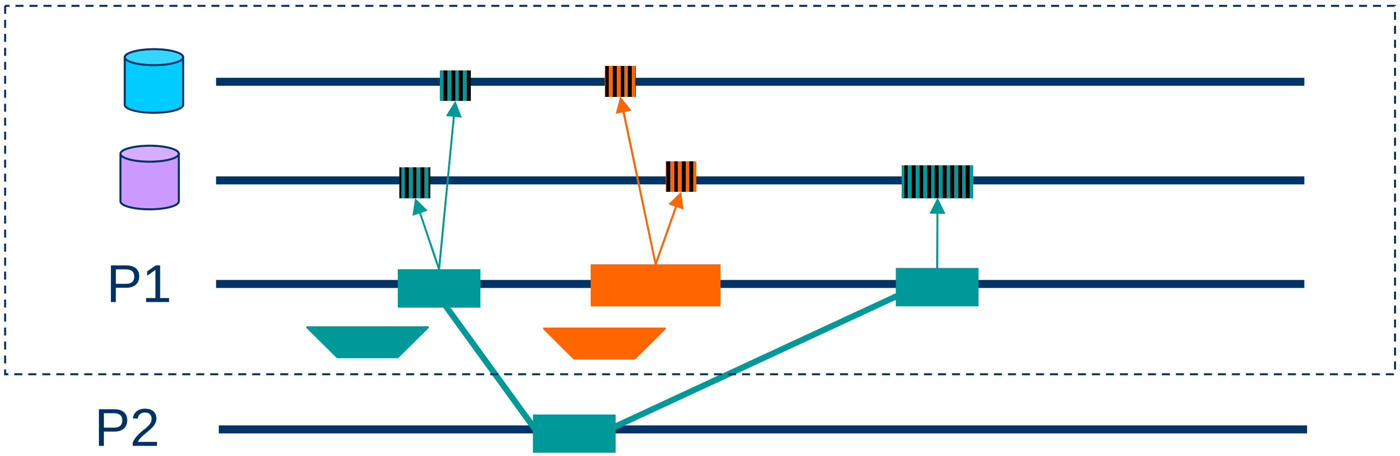
A generic library for maritime routing

- *Invent* - software library for maritime routing problems
- Developed as part of a strategic project in SINTEF
- Three test application areas
  - LNG transport
  - Bulk (cement) transport
  - Chemical (petroleum) tankers
- Based on a conceptual model
  - Realized as an XML format

Conceptual model



Solution structure



Constraints summary

- Time: Sailing time, load/unload rate, non-overlapping actions, cleaning time
- Inventory: Consistency of inventory levels, production/consumption, load/unload quantities and ship loads across actions
- Min/max inventory levels in port storages until last action
- Ship: Capacity, tank cleaning, tank/product compatibility, maintenance periods, draft limits, port compatibility, boil-off
- Bookings: time window, quantity interval
- Contracts: volume limits, destination restrictions, nominal volume, time slots

Objectives summary

- Sailing cost: ship and load dependent
- Port cost: ship dependent
- Service cost: duration of port call
- Waiting cost: ship dependent
- Cleaning cost: product/product dependent
- Contract income: quantity, time and destination/origin dependent
  - Profit sharing: purchase price can depend upon sales price
- Booking income: lumpsum, rate and relet cost
- Stream income: time dependent

Constructive heuristic

1. Determine the most critical storage (contract) or visit
2. Determine counterpart storage or visit that can receive/deliver the product involved
3. For each ship:
4. For all possible insertion points for a pickup and a delivery action into the ship's schedule:
5. Insert actions and attempt to assign times and quantities to make plan feasible
6. Select the best feasible insertion from step 5 and add to plan permanently
7. If critical events still exist, go to step 1

Step 5 (assign time and quantity)

- Large parts of the plan may be affected
  - Schedule for selected ship changes after new load action
  - Schedules for other ships are unchanged
  - Schedules may change for port storages visited by selected ship
- Many constraints to satisfy
- Roughly:
  - Assume small quantity and propagate time
  - Find maximum possible quantity
  - Do tank allocation
  - Set quantity, propagate time and quantities
  - Check feasibility

Step 6 (select insertion)

- Each feasible insertion is ranked by criteria:
  - Quantity, q
  - Extra time, t
  - Ship exploitation, q/Q
  - Efficiency, q/t
  - Cost efficiency, c/q
  - Income, r
  - Income efficiency, r/q
  - Random

- Each criterion has a weight
- Select insertion with least sum of weighted ranks

Example

w = 0.5

(1) B	0.5
(2) A	1.0
(3) C	1.5

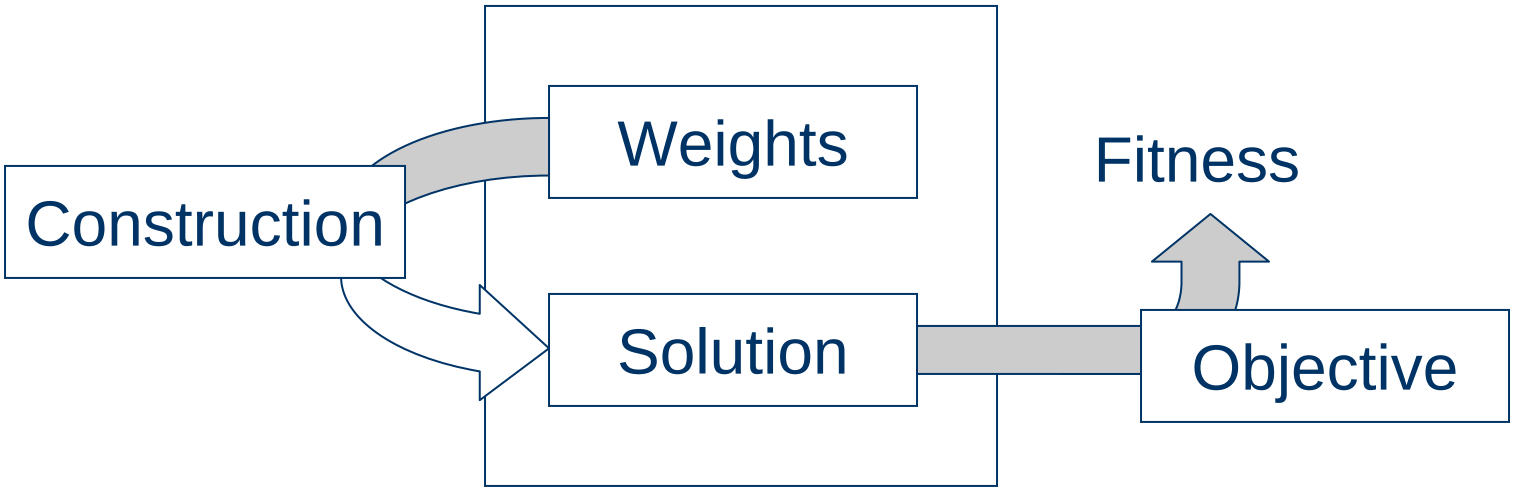
w = 0.3

(1) A	0.3
(2) C	0.6
(3) B	0.9

A	1.0	0.3	1.3
B	0.5	0.9	1.4
C	1.5	0.6	2.1

Genetic algorithm

- Individual = genome + phenotype
- Genome = a set of weights for rankings
- Phenotype = solution constructed by heuristic
- Fitness = solution's objective value



Genetic algorithm

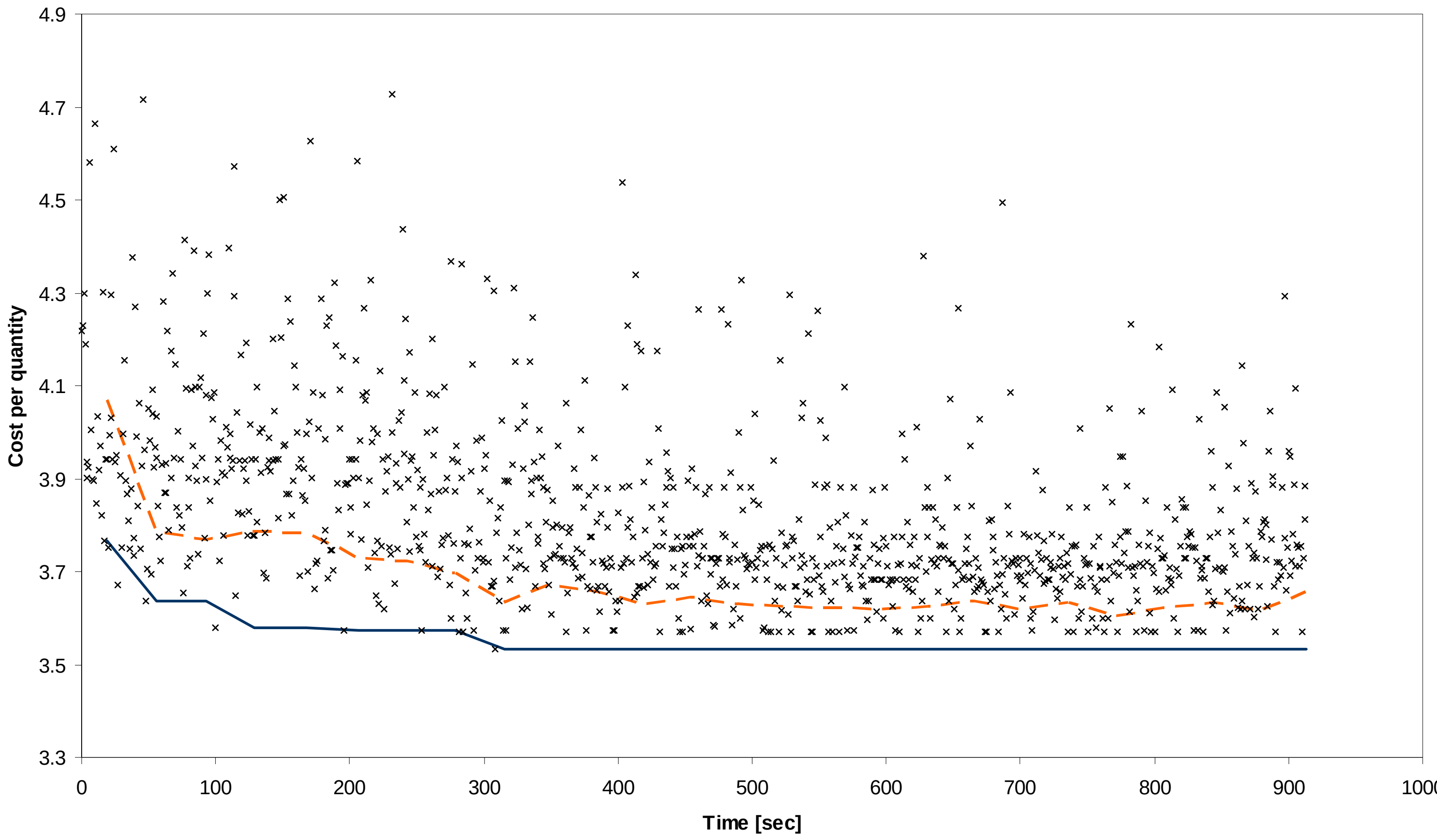
1. Start with *P* (=20) individuals from constructive heuristic with randomly generated genomes
2. Generate *N* (=40) new individuals
   - Select two individuals (parents) randomly
   - Draw each weight based on the parents' values
   - Generate new individual using the constructive heuristic

3. Take the *E* (=4) best individuals from the existing population(*elitism*)
4. Add the *N* new individuals to the population
5. Reduce the population to the *P* individuals with best fitness

Computational results

- **Real problem**
  - 5 production ports (1-6 storages at each port)
  - 30 consumption ports (1-4 storages at each port)
  - 61 storages (49 consumption and 12 production storages)
  - 11 product typs
  - 5 ships with 2 – 8 cargo holds (total capacity 23.300 tons)
  - 14 days planning horizon
- Feasible and reasonable solutions obtained for the real problem
- CPU time: Less than 15 minutes for 1000 individuals

Example run with GA



Current and future work

- Additional model elements
  - Virtual (accounting) storages
  - Inter arrival gaps
  - Constraints on the number of visits
  - LNG specific extensions (buoys)

- Algorithmic enhancements
  - Ruin-and-recreate
  - Local search
  - Constraint programming
  - Backtracking in construction