A heuristic for rich maritime inventory routing problems

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Outline

- SINTEF
- Introduction
- Model
- Algorithms
- Test cases
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.

* Data from SINTEF’s 2009 annual report
SINTEF: Organization

- Board
- President Executive Vice Presidents
- Corporate Staff
- SINTEF’s Council

6 Research Divisions:
- SINTEF Marine
- SINTEF Petroleum and Energy
- SINTEF Building and Infrastructure
- SINTEF Materials and Chemistry
- SINTEF ICT
- SINTEF Technology and Society

SINTEF Holding

* Data from SINTEF’s 2009 annual report
SINTEF ICT: Organization

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

9 Research Departments

- Applied mathematics
- Acoustics
- Microsystems and nanotechnology
- Cooperative and trusted systems
- Communication systems
- Instrumentation
- Software engineering safety and security
- Applied cybernetics
- Optical measurement systems and data analysis

* Data from SINTEF’s 2009 annual report
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

* Data from SINTEF’s 2009 annual report
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

Business Areas

Routing
Sequencing
Scheduling
Time tabling
Planning and Design
Misc.

Research Theme

Customers

Research Partners

[Image of a diagram illustrating the relationships between business areas, research themes, and research partners.]
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

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11 10 9 8 7 6 5 4 3 2 1 Team 4
12 11 10 9 8 7 6 5 4 3 2 1 Team 3
13 12 11 10 9 8 7 6 5 4 3 2 1 Team 2
14 13 12 11 10 9 8 7 6 5 4 3 2 1 Team 1
Transport: Invent

- Production port
- Consumption port
- Product 1
- Product 2

Locations:
- Kjøpsvik
- Mo i Rana
- Trondheim
- Karmøy
- Årdal
- Brevik
- Alta
Literature


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
Construction: shipment insertion

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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

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<th>Start</th>
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### Test case 2

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</table>
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
A heuristic for rich maritime inventory routing problems

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