Decision aid methodologies in Transportation

Lecture 7: Introduction to Optimization in Maritime Transport

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Outline

- Introduction to Maritime Transport
- Port Operations and Optimization Problems
  - Fleet assignment, ship routing and scheduling
  - Berth Allocation
  - Quayside Operations
  - Yard Operations
- Berth Allocation Problem Formulation
- Summary
Shipping and Maritime Transport

- Major transportation mode of international trade
- Three modes of operations:
  - Industrial shipping: the cargo owner also owns the ship
  - Tramp shipping: operates on demand to transfer cargo
  - Liner shipping: operates on a published schedule and a fixed port rotation
Shipping and Maritime Transport

- Ships carry different type of freight:
  - Solid bulk
  - Liquid bulk
  - Containers

- Containerized trade accounts for 25% of total dry cargo (UNCTAD, 2008)

- Annual growth rate: 9.5% for containers vs. 5.3% for general cargo (between 2000 and 2008)
Shipping and Maritime Transport

- Optimization problems in Maritime Shipping
  - design of optimal fleets in size and mix
  - ship routing (sequence of ports)
  - ship scheduling (temporal aspects)
  - fleet deployment (assignment of vessels to routes)
Layout of a Container Terminal
The Quay

Berthing positions or Berths
The Quay

Ships or Vessels
The Quay

Quay cranes (QC)
Quayside Operations

- **Berth allocation**
  - Assign vessels to berthing positions
  - Schedule incoming vessels

- **Quay crane assignment & scheduling**
  - Assign quay cranes to moored vessels
  - Schedule their movements
The Yard
The Yard

Yard blocks
The Yard

Yard cranes
Yard Operations

- **Yard/block allocation**
  - Assign a block in the yard to groups of unloaded containers

- **Storage space allocation**
  - Assign a slot within the block to every container

- **Yard crane allocation and scheduling**
  - Assign yard cranes to yard blocks
  - Schedule their movements and their workload
Transfer and Gate Operations

- **Transfers**
  - From quay to yard / from yard to gate
  - Fleet management / scheduling of trucks and AGV

- **Gate operations**
  - Retrieve stored containers
  - Loading of trucks and trains
Optimization Problems and Solution Process

- **Problem Definition**
  - What are we trying to model?
  - What are the assumptions and/or approximations?

- **Mathematical Model**
  - Objective Function
  - Constraints
  - Data

- **Solution Algorithm**
  - Exact approaches (MIP solver, column generation etc.)
  - Heuristic Approaches (greedy heuristic, tabu search etc.)

- **Results**
The Berth Allocation Problem

- Berth Layout (discrete, continuous or hybrid)
- Vessel characteristics such as length of the vessel (including clearance), draft of the vessel
- Arrival times
  - Static arrivals (no expected arrival times or they impose only a soft constraint)
  - Dynamic arrivals (berthing cannot start before expected arrival times)
- Projected handling time
  - Deterministic (known in advance and unchangeable)
  - Dependent on berthing positions, number and work schedule of assigned cranes
- Latest departure times (maximum waiting + handling time) may be prescribed
- Objective Function
  - Minimize total delays of all vessels
  - Minimize make-span of the planning operations
Berthing Layout

Discrete Layout

Continuous Layout

Hybrid Layout
Mathematical Formulation

- **Problem Type**: Discrete berthing layout with dynamic vessel arrivals and given handling times

- **Decision Variables**
  - $m_i$: start time of handling of vessel $i$
  - $x_{ik}$: binary parameter equal to 1 if vessel $i$ is assigned to $k$ berth; 0 otherwise
  - $y_{ij}$: binary parameter equal to 1 if vessel $i$ is assigned to the left of $j$ vessel without overlapping; 0 otherwise
  - $z_{ij}$: binary parameter equal to 1 if handling of vessel $i$ finishes before handling of vessel $j$; 0 otherwise
Mathematical Formulation

- **Model**

\[
\begin{align*}
\min \quad & \sum_{i \in N} (m_i - a_i) \\
\text{s.t.} \quad & \sum_{i \in N} (m_i - a_i) \geq 0 \\
& \sum_{k \in M} (k x_{jk}) + B (1 - y_{ij}) \geq \sum_{k \in M} (k x_{ik}) + 1 \\
& m_j + B (1 - z_{ij}) \geq m_i + C_i \\
& y_{ij} + y_{ji} + z_{ij} + z_{ji} \geq 1 \\
& \sum_{k \in M} x_{ik} = 1 \\
& \sum_{k \in M} (d_k - D_i) x_{ik} \geq 0 \\
& \sum_{k \in M} (l_k - L_i) x_{ik} \geq 0
\end{align*}
\]

\( \forall i \in N, \quad \forall i, j \in N, i \neq j, \quad \forall i, j \in N, i \neq j, \quad \forall i \in N, \quad \forall i \in N \)
Solution Analysis

- Generate instances preferably based on real data from the port if available

- Solve the model using MIP solver. Typically, MIP solvers fail to produce optimal results for larger sized instances

- Develop heuristic approaches to produce sub-optimal results for larger sized instances OR more sophisticated exact solution methods to obtain optimal results.
Summary

- Many decision problems in port terminals
- Modeled as optimization problems (MIPs)
- Optimization is helpful in
  - Reducing costs
  - Improve productivity and efficiency
  - Reduce delays / Speed up operations