Decision Aid Methodologies In Transportation

Lecture 5: Maritime transportation problem

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Maritime transport
Shipping and maritime transport

- Major transportation mode of international trade
- Three modes of operations:
  1. **Industrial shipping**: the cargo owner also owns the ship
  2. **Tramp shipping**: operates on demand to transfer cargo
  3. **Liner shipping**: operates on a published schedule and a fixed port rotation
- Ships carry different type of freight:
  1. Solid bulk
  2. Liquid bulk
  3. Containers
Optimization problems in maritime shipping

1. Design of optimal fleets in size and mix
2. Ship routing (sequence of ports)
3. Ship scheduling (temporal aspects)
4. Fleet deployment (assignment of vessels to routes)
Optimization problems in container terminals
Containerized trade

- Containerized trade accounts for 25% of total dry cargo (UNCTAD, 2008)
- Annual growth rate: 9.5% between 2000 and 2008
## Container terminal ranking

<table>
<thead>
<tr>
<th>RANK</th>
<th>PORT</th>
<th>2010 (M-TEU)</th>
<th>2011 (M-TEU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shanghai, China</td>
<td>29.07</td>
<td>31.74</td>
</tr>
<tr>
<td>2</td>
<td>Singapore, Singapore</td>
<td>28.43</td>
<td>29.94</td>
</tr>
<tr>
<td>3</td>
<td>Hong Kong, China</td>
<td>23.7</td>
<td>24.38</td>
</tr>
<tr>
<td>4</td>
<td>Shenzhen, China</td>
<td>22.51</td>
<td>22.57</td>
</tr>
<tr>
<td>5</td>
<td>Busan, South Korea</td>
<td>14.18</td>
<td>16.17</td>
</tr>
<tr>
<td>6</td>
<td>Ningbo-Zhoushan, China</td>
<td>13.14</td>
<td>14.72</td>
</tr>
<tr>
<td>7</td>
<td>Guangzhou Harbor, China</td>
<td>12.55</td>
<td>14.26</td>
</tr>
<tr>
<td>8</td>
<td>Qingdao, China</td>
<td>12.01</td>
<td>13.02</td>
</tr>
<tr>
<td>9</td>
<td>Dubai, United Arab Emirates</td>
<td>11.6</td>
<td>13.01</td>
</tr>
<tr>
<td>10</td>
<td>Rotterdam, Netherlands</td>
<td>11.14</td>
<td>11.88</td>
</tr>
</tbody>
</table>
Container terminal layout
Operations in container terminals

- Quay Crane
- Yard Crane
- Truck
- Discharging container flow
- Loading container flow

Vessel
Quayside
Berth Allocation Problem (BAP)
Quay Crane Assignment Problem (QCAP)
Quay Crane Scheduling Problem (QCSP)
Yardside
Yard operations

- **Yard/block allocation problem**: Assign a block in the yard to groups of unloaded containers
- **Storage space allocation problem**: Assign a slot within the block to every container
- **Yard crane allocation and scheduling problem**:
  1. Assign yard crane to yard blocks
  2. Schedule their movement and their workload
Transfer operations

1. From quay to yard / from yard to gate
2. Fleet management / scheduling of trucks and AGV
Berth allocation problem

The BAP can be depicted in a Time-space Diagram.

\[
S \quad v_3 + s_3 \quad u_3 \quad c_3 = u_3 + p_3 \quad T
\]
Berth allocation problem

Parameters:
- $S$, the length of the continuous berth
- $T$, the length of the planning horizon
- $n$, the number of vessels, $n = |V|$
- $p_i$, the processing time for Vessel $i$, $i \in V$
- $s_i$, the size of Vessel $i$, $i \in V$
- $a_i$, the arrival time of Vessel $i$, $i \in V$
- $w_i$, the weight assigned for Vessel $i$, $i \in V$

Decision Variables:
- $u_i$, the mooring time of Vessel $i$, $i \in V$
- $v_i$, the starting berth position occupied by Vessel $i$, $i \in V$
- $c_i$, the departure time of Vessel $i$, $i \in V$
- $x_{ij} \in \{0, 1\}$, 1 if and only if Vessel $i$ is completely on the left of Vessel $j$ in the Time-space Diagram
- $y_{ij} \in \{0, 1\}$, 1 if and only if Vessel $i$ is completely below Vessel $j$ in the Time-space Diagram
Berth allocation problem

\[ \min \sum_{i \in V} w_i (c_i - a_i) \]

s.t.

\[ u_j - u_i - p_i - (x_{ij} - 1) \cdot T \geq 0, \quad \forall i, j \in V, i \neq j \]
\[ v_j - v_i - s_i - (y_{ij} - 1) \cdot S \geq 0, \quad \forall i, j \in V, i \neq j \]
\[ x_{ij} + x_{ji} + y_{ij} + y_{ji} \geq 1, \quad \forall i, j \in V, i \neq j \]
\[ x_{ij} + x_{ji} \leq 1, \quad \forall i, j \in V, i \neq j \]
\[ y_{ij} + y_{ji} \leq 1, \quad \forall i, j \in V, i \neq j \]
\[ p_i + u_i = c_i, \quad \forall i \in V \]
\[ a_i \leq u_i \leq (T - p_i), 0 \leq v_i \leq (S - s_i), u_i, v_i \in \mathbb{R}^+ \quad \forall i \in V \]
\[ x_{ij} \in \{0, 1\}, y_{ij} \in \{0, 1\}, \quad \forall i, j \in V, i \neq j \]
Quay crane scheduling problem

An illustrative example:

\textbf{QC 1}: 1, 3; \textbf{QC 2}: 2, 4.

\[ T=0 \]
Quay crane scheduling problem

An illustrative example:

**QC 1:** 1, 3; **QC 2:** 2, 4.
Quay crane scheduling problem

An illustrative example:

QC 1: 1, 3; QC 2: 2, 4.
An illustrative example:

**QC 1**: 1, 3; **QC 2**: 2, 4.
Quay crane scheduling problem

An illustrative example:

**QC 1:** 1, 3; **QC 2:** 2, 4.

T = 3
Quay crane scheduling

Parameters:
- \( i, j \): the index for ship bay
- \( k, l \): the index for QC;
- \( m \): the number of QCs;
- \( n \): the number of bays;
- \( p_i \): the workload of Bay \( i \) \((1 \leq i \leq n)\);
- \( M \): a sufficiently large positive constant number.

Decision variables:
- \( C_{\text{max}} \): the makespan for the berthed vessel;
- \( C_i \): the completion time of Bay \( i \) \((1 \leq i \leq n)\);
- \( X_{ik} \): 1, if Bay \( i \) is handled by QC \( k \); 0, otherwise \((1 \leq i \leq n)\);
- \( Y_{ij} \): 1, if Bay \( i \) completes no later than Bay \( j \) starts; 0, otherwise \((1 \leq i \leq n)\).
Quay crane scheduling problem

\[\begin{align*}
\text{min} & \quad C_{\text{max}} \\
\text{s.t.} & \quad C_{\text{max}} \geq C_i, \quad \forall 1 \leq i \leq n \\
& \quad C_i - p_i \geq 0, \quad \forall 1 \leq i \leq n \\
& \quad \sum_{k=1}^{m} X_{ik} = 1, \quad \forall 1 \leq i \leq n \\
& \quad C_i - (C_j - p_j) + MY_{ij} \geq 0, \quad \forall 1 \leq i, j \leq n \\
& \quad (C_j - p_j) + M(1 - Y_{ij}) - C_i \geq 0, \quad \forall 1 \leq i, j \leq n \\
& \quad M(Y_{ij} + Y_{ji}) \geq \sum_{k=1}^{m} kX_{ik} - \sum_{l=1}^{m} lX_{jl} + 1, \quad \forall 1 \leq i < j \leq n \\
& \quad X_{ik}, Y_{ij} \in \{0, 1\}, \quad \forall 1 \leq i, j \leq n, \forall 1 \leq k \leq m \\
& \quad C_{\text{max}}, C_i \in \mathbb{R}^+, \quad \forall 1 \leq i \leq n
\end{align*}\]
Heuristics
**Heuristics**

**Definition:**
A heuristic is a technique designed for solving a problem more quickly when classic methods are too slow, or for finding an approximate solution when classic methods fail to find any exact solution. This is achieved by trading optimality, completeness, accuracy, and/or precision for speed.

**Examples:**
1. Knapsack problem
2. Traveling salesman problem
3. Quay crane scheduling problem