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

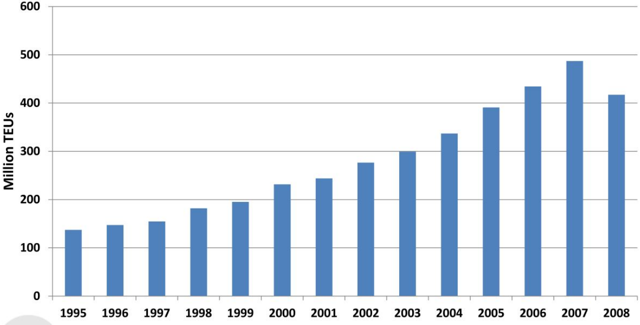
Optimization problems in maritime shipping

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

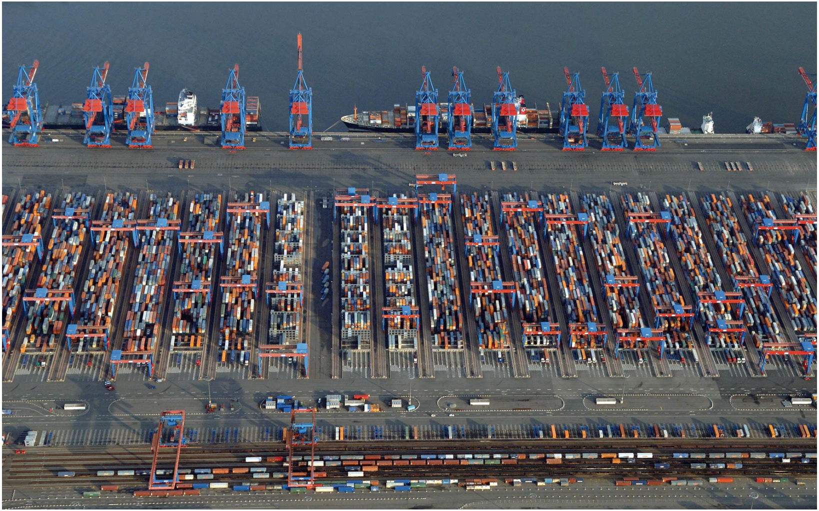
- Containerized trade accounts for 25% of total dry cargo (UNCTAD, 2008)
- Annual growth rate: 9.5% between 2000 and 2008



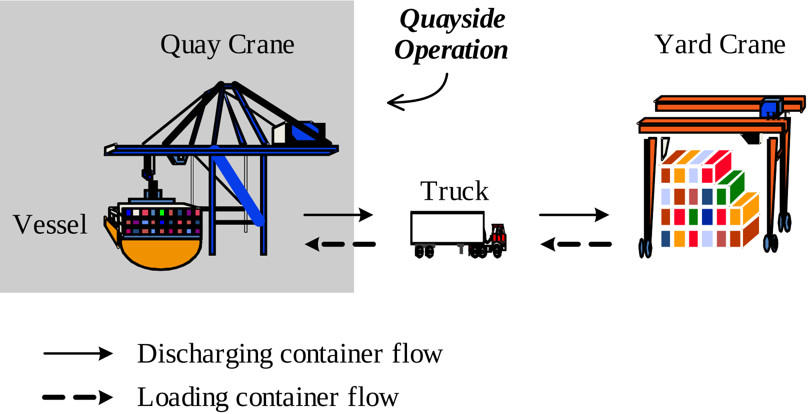
Container terminal ranking

RANK	PORT	2010 (M-TEU)	2011 (M-TEU)
1	Shanghai, China	29.07	31.74
2	Singapore, Singapore	28.43	29.94
3	Hong Kong, China	23.7	24.38
4	Shenzhen, China	22.51	22.57
5	Busan, South Korea	14.18	16.17
6	Ningbo-Zhoushan, China	13.14	14.72
7	Guangzhou Harbor, China	12.55	14.26
8	Qingdao, China	12.01	13.02
9	Dubai, United Arab Emirates	11.6	13.01
10	Rotterdam, Netherlands	11.14	11.88

Container terminal layout

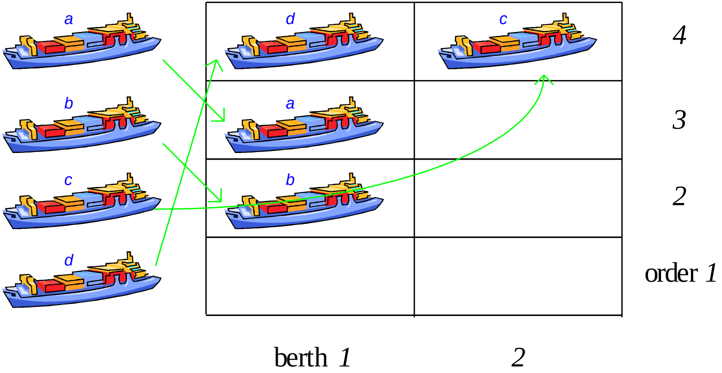


Operations in container terminals

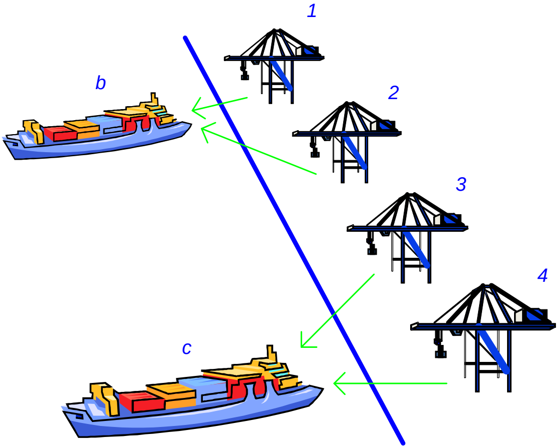


Quayside

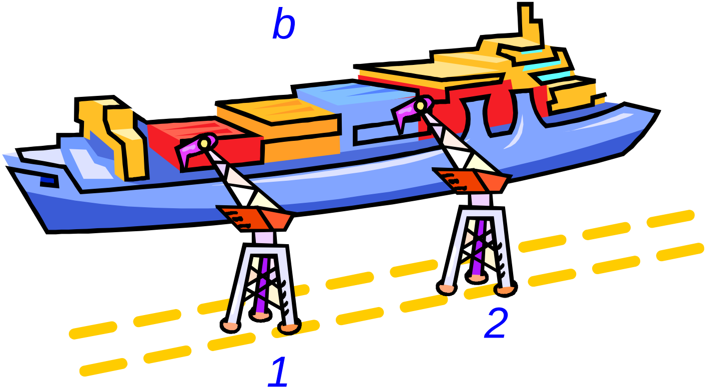
Berth Allocation Problem (BAP)



Quay Crane Assignment Problem (QCAP)



Quay Crane Scheduling Problem (QCSP)



Yardside

Yard operations

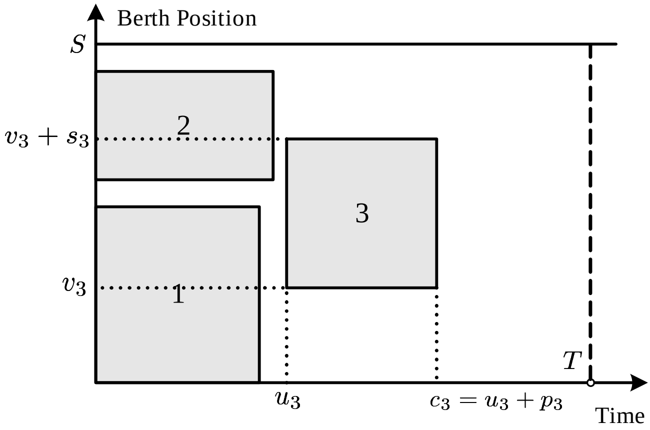
- **Yard/block allocation problem**: Assign a block in the yard to groups of unloaded containers
- **Storage space allocation problem**: Assign a slot within the block to every container
- **Yard crane allocation and scheduling problem**:
    1. Assign yard crane to yard blocks
    2. Schedule their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



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

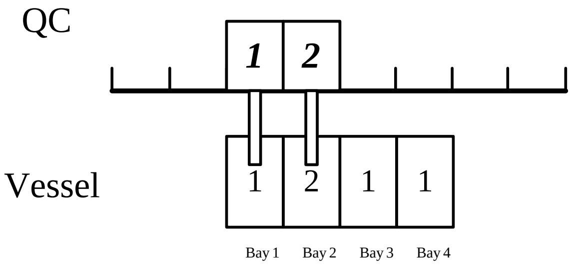
$$
\begin{aligned}
\min \quad & \sum_{i \in V} w_i (c_i - a_i) \\
\text{s.t.} \quad & \\
& u_j - u_i - p_i - (x_{ij} - 1) \cdot T \geq 0, \qquad \forall\, i, j \in V, i \neq j \\
& v_j - v_i - s_i - (y_{ij} - 1) \cdot S \geq 0, \qquad \forall\, i, j \in V, i \neq j \\
& x_{ij} + x_{ji} + y_{ij} + y_{ji} \geq 1, \qquad \forall\, i, j \in V, i \neq j \\
& x_{ij} + x_{ji} \leq 1, \qquad \forall\, i, j \in V, i \neq j \\
& y_{ij} + y_{ji} \leq 1, \qquad \forall\, i, j \in V, i \neq j \\
& p_i + u_i = c_i, \qquad \forall\, i \in V \\
& a_i \leq u_i \leq (T - p_i), 0 \leq v_i \leq (S - s_i), u_i, v_i \in \Re^+ \quad \forall\, i \in V \\
& x_{ij} \in \{0, 1\}, y_{ij} \in \{0, 1\}, \qquad \forall\, i, j \in V, i \neq j
\end{aligned}
$$

Quay crane scheduling problem

An illustrative example:

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

T=0

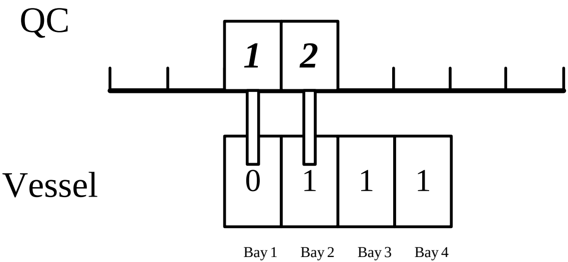


Quay crane scheduling problem

An illustrative example:

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

T=1

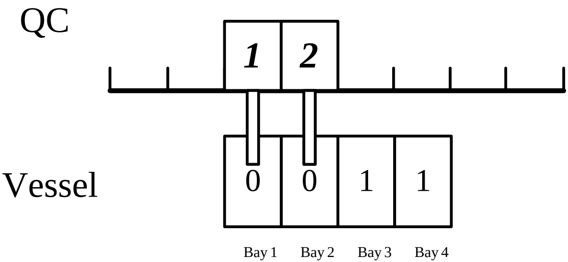


Quay crane scheduling problem

An illustrative example:

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

T=2

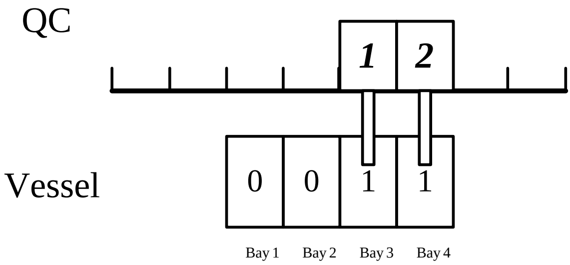


Quay crane scheduling problem

An illustrative example:

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

T=2

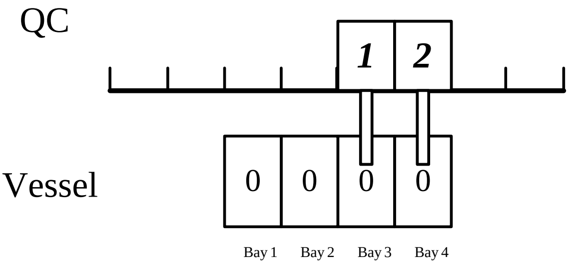


Quay crane scheduling problem

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:

- $C_{\max}$: 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

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