Decision aid methodologies in transportation

Lecture 6 (part-2): Container terminal management

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Outline

- ✓ Introduction to maritime transport
- ✓ Overview container terminals
- ✓ Operations and optimization problems
- ✓ The Berth Allocation Problem
- ✓ The Quay Crane Scheduling Problem
- ✓ Conclusion

Shipping and Maritime Trasport

- 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

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Shipping and Maritime Transport

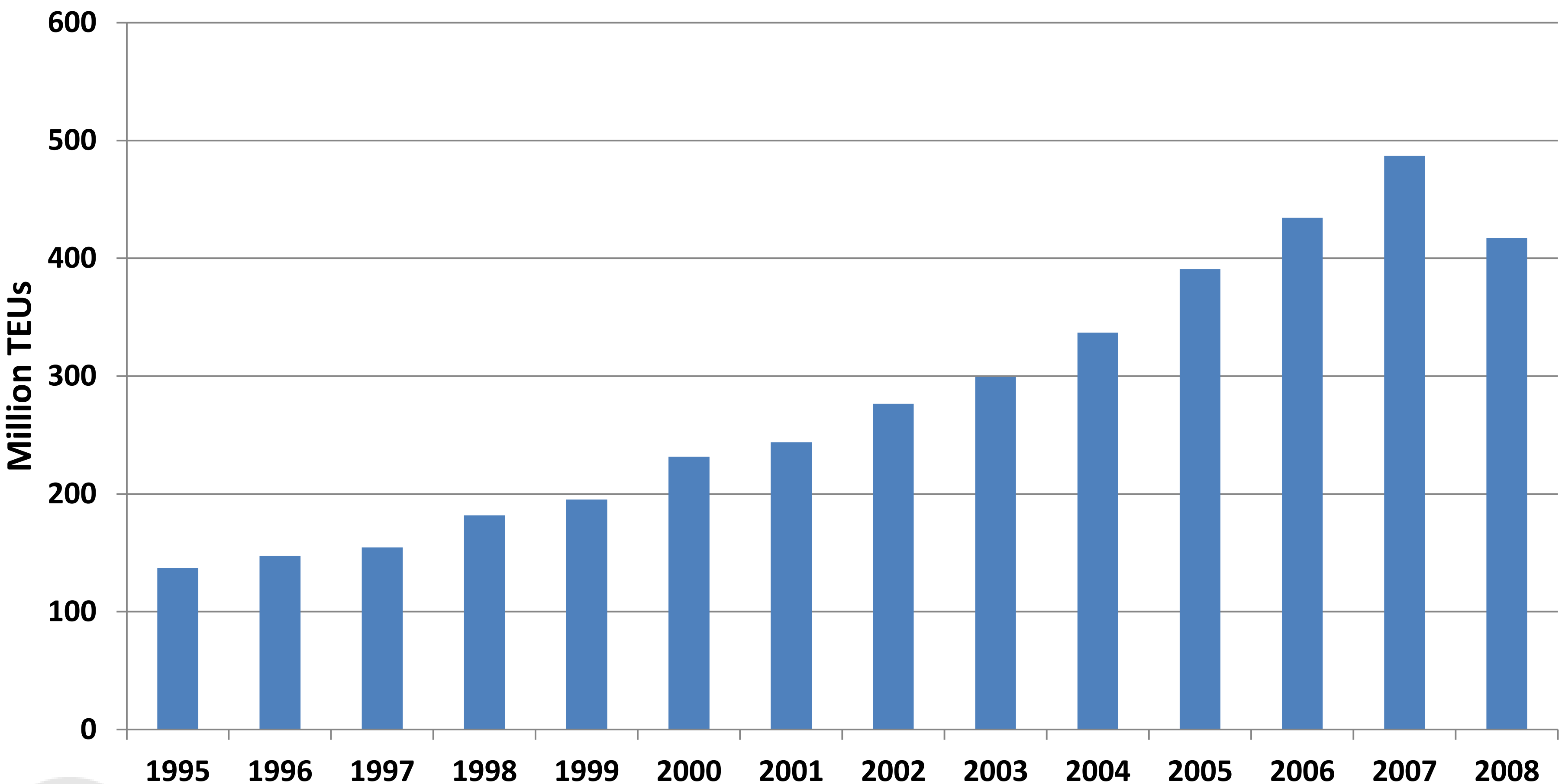
Optimization problems in Maritime Shipping

- design of optimal fleets in size and mix
- ship routing (sequence of ports)
- ship scheduling (temporal aspects)
- fleet deployment (assignment of vessels to routes)

Shipping and Maritime Trasport

- 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)

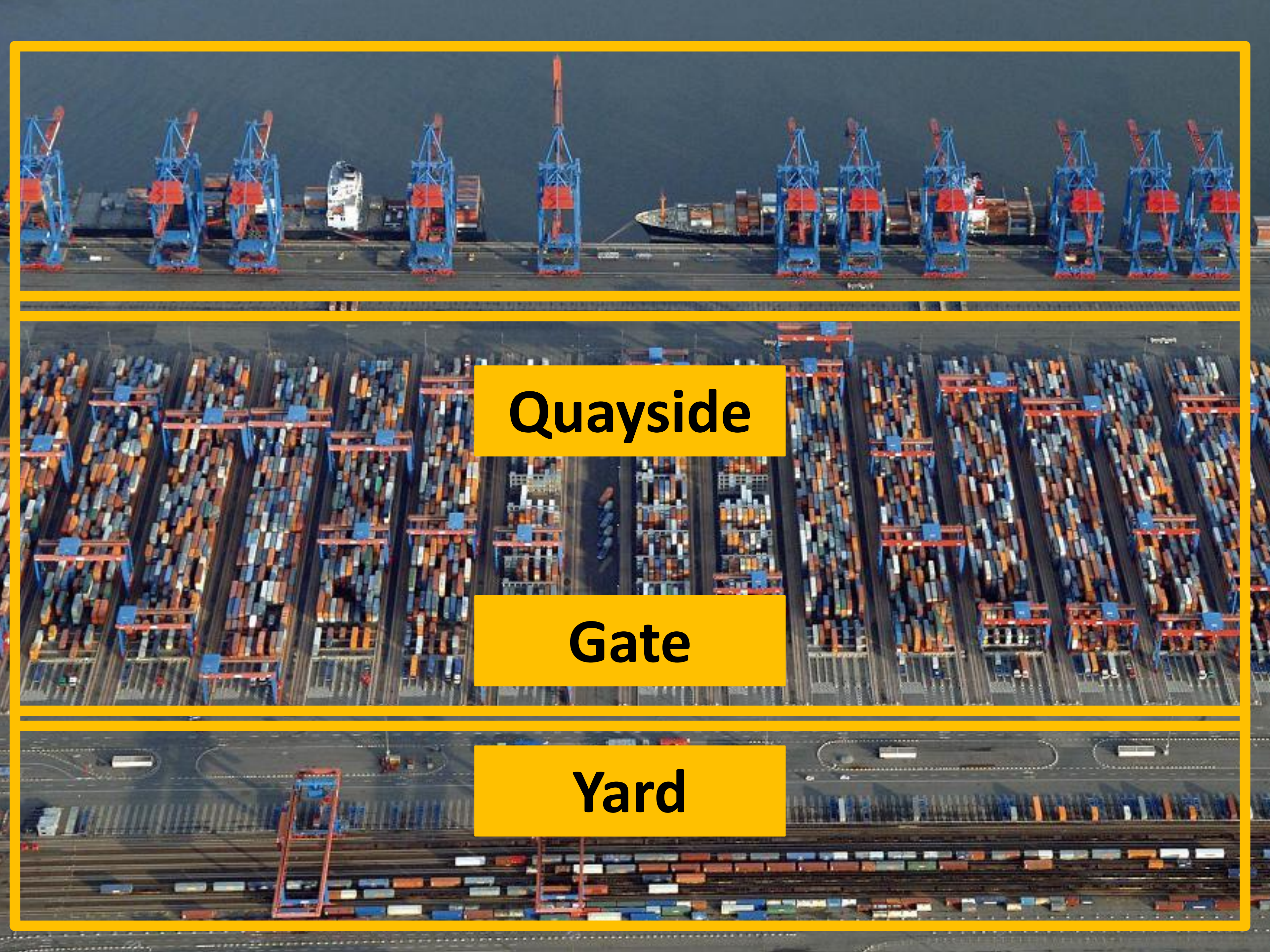
Container world trade



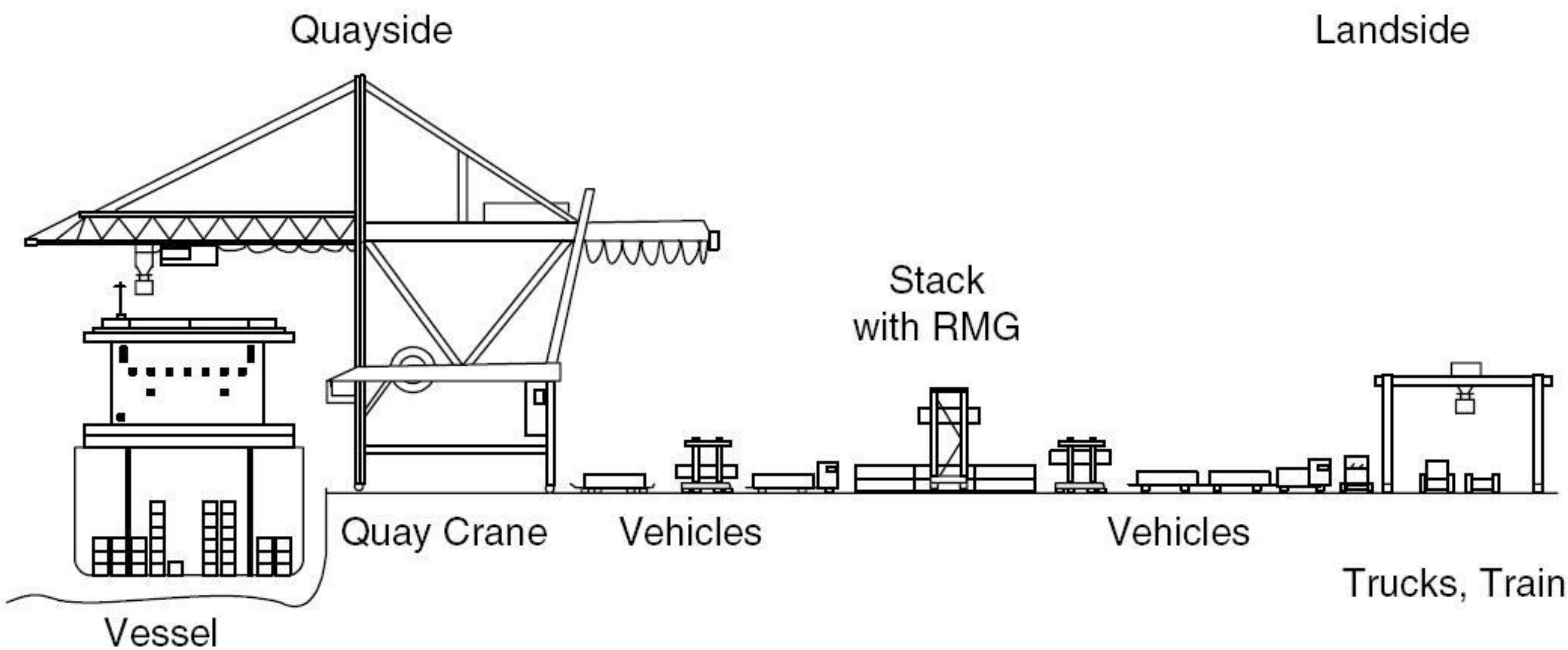
Top container terminals

Million TEU

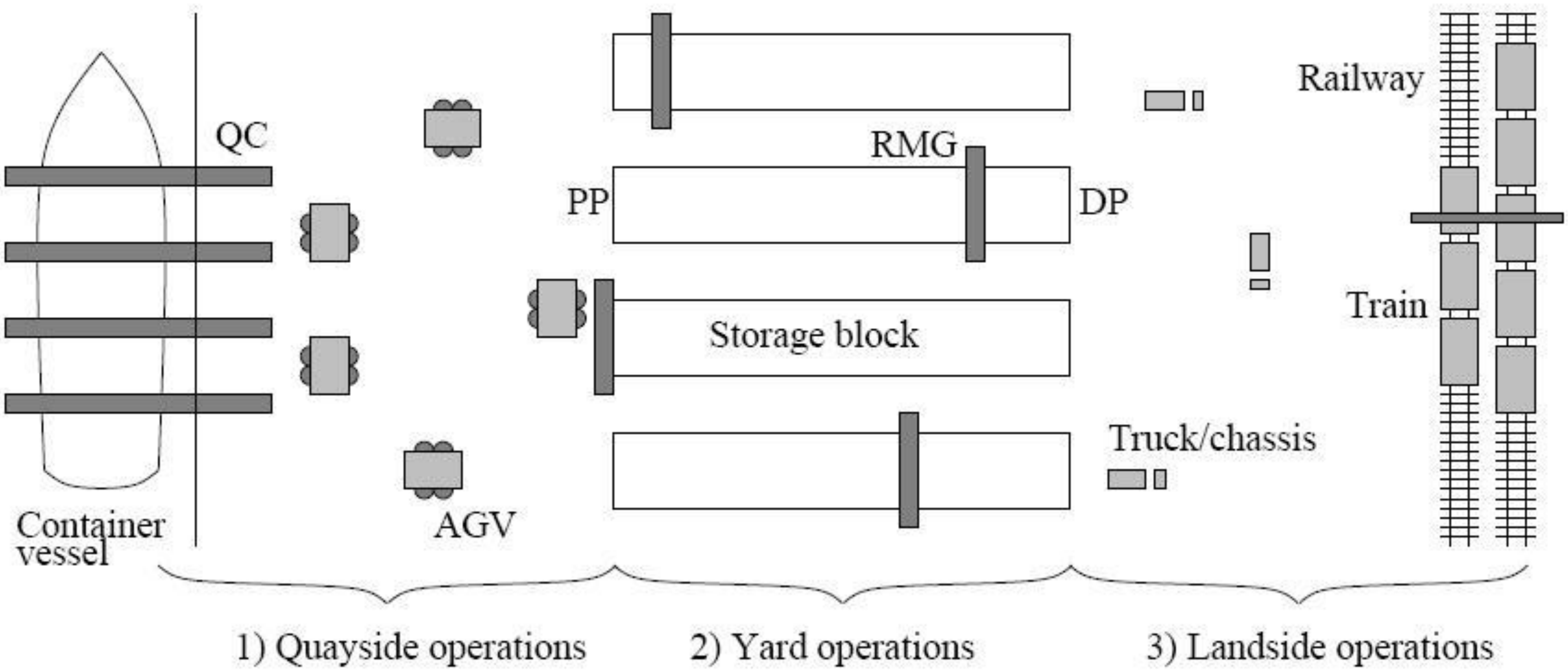
Worldwide	**1999**	**2007**	**2008**	**2009**
1 Singapore (Singapore)	15.9	27.9	29.9	25.9
2 Shangai (China)	4.2	26.1	28.0	24.9
3 Hong Kong (China)	16.2	23.9	24.5	21.1
Europe				
1 Rotterdam (Netherlands)	6.2	10.7	10.8	9.7
2 Antwerp (Belgium)	3.6	8.1	8.7	7.3
3 Hamburg (Germany)	3.8	9.9	9.7	7.0


Quayside
Gate
Yard

Scheme of a container terminal



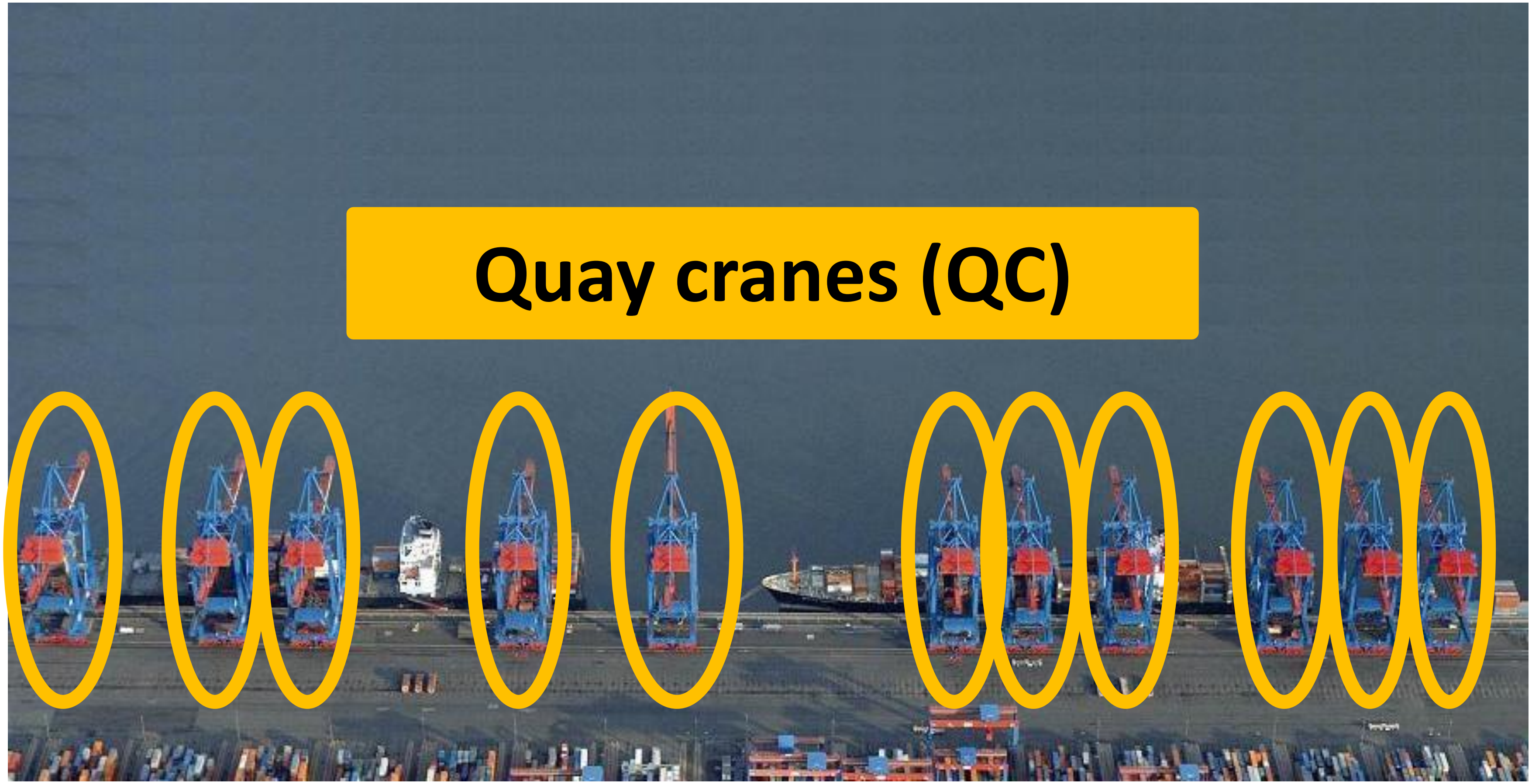
Scheme of a container terminal



The Quay

The Quay

The Quay



Quayside operations

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

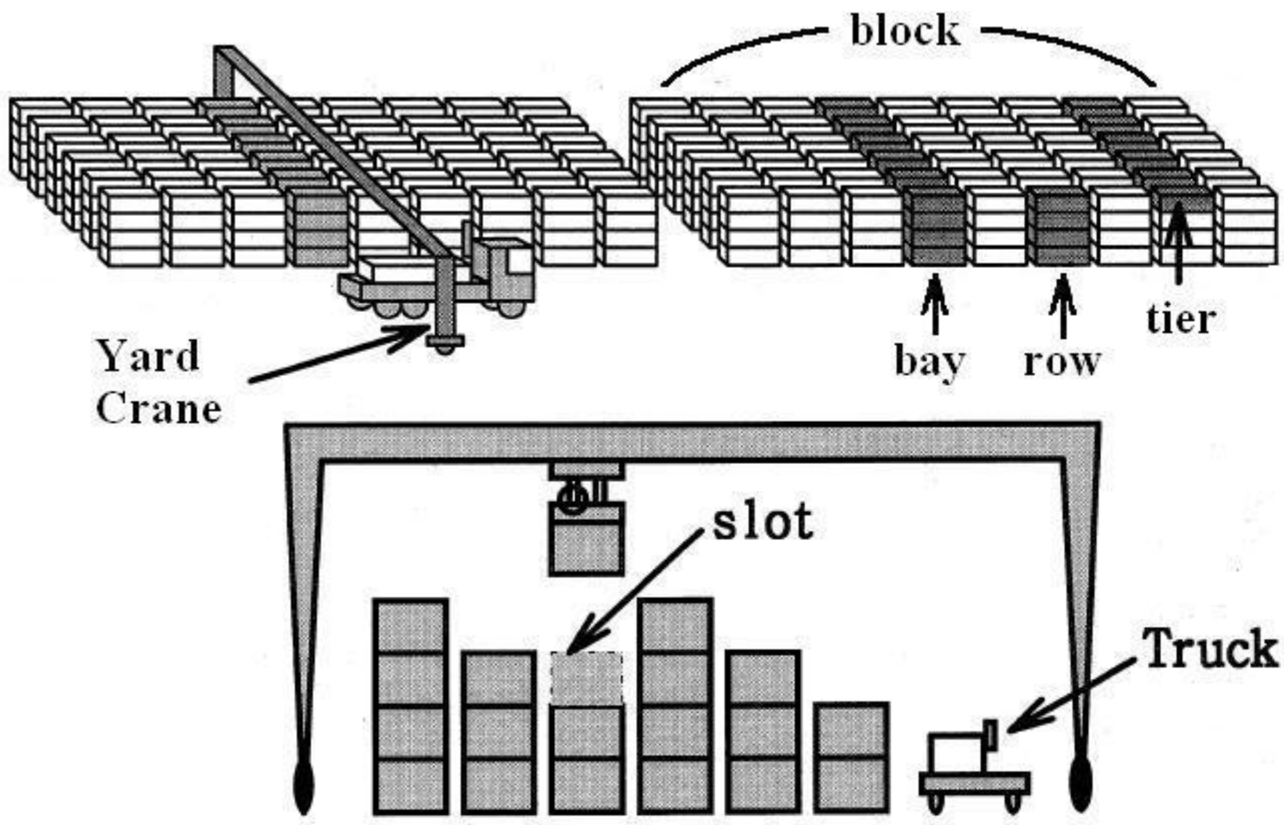
- **Quay crane assignment & scheduling**
  - Assign quay cranes to moored vessels
  - Schedule their movements

The Yard

The Yard

The Yard

The Yard



Yard operations

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

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Transfers 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 & Solution process

1. Problem definition
   - Data
   - Objective
   - Constraints
2. Mathematical model
   - Equations
3. Solution algorithm
   - MIP solver
   - Heuristics / Exact approaches
4. Results

The Berth Allocation Problem

Given:

- A set of incoming vessels
- A set of discrete berths / A continuos quay
- A time horizon
- Time windows on the vessels’ arrival time
- Vessels’ length
- Vessels’ expected handling time

The Berth Allocation Problem

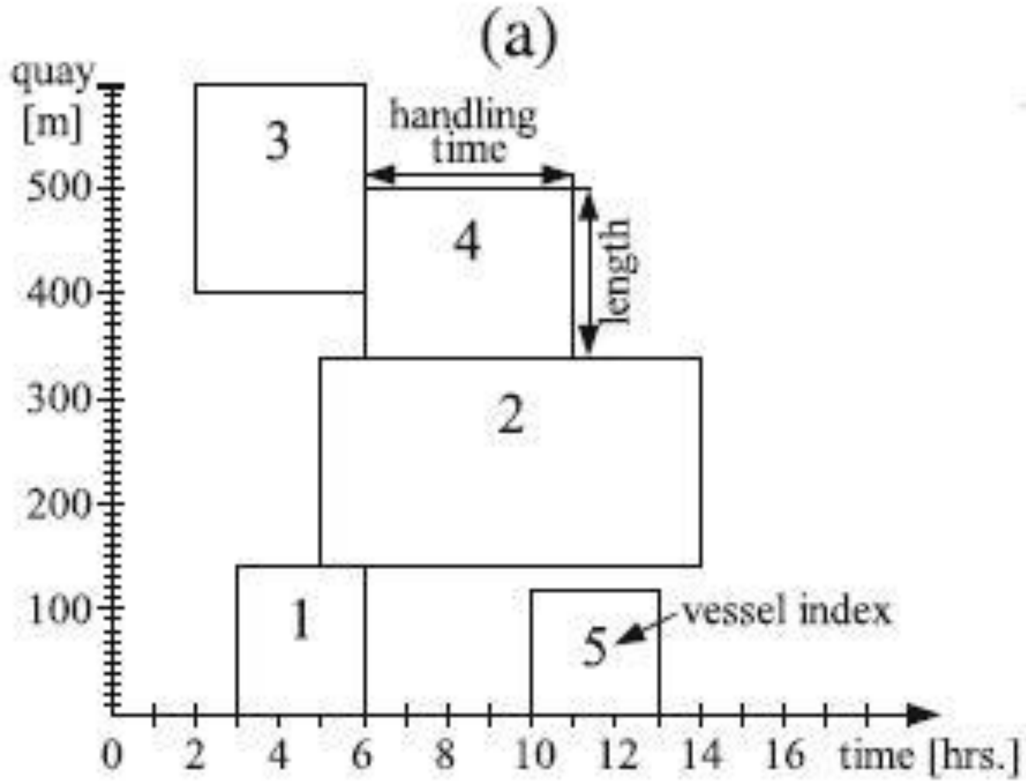
We aim to:

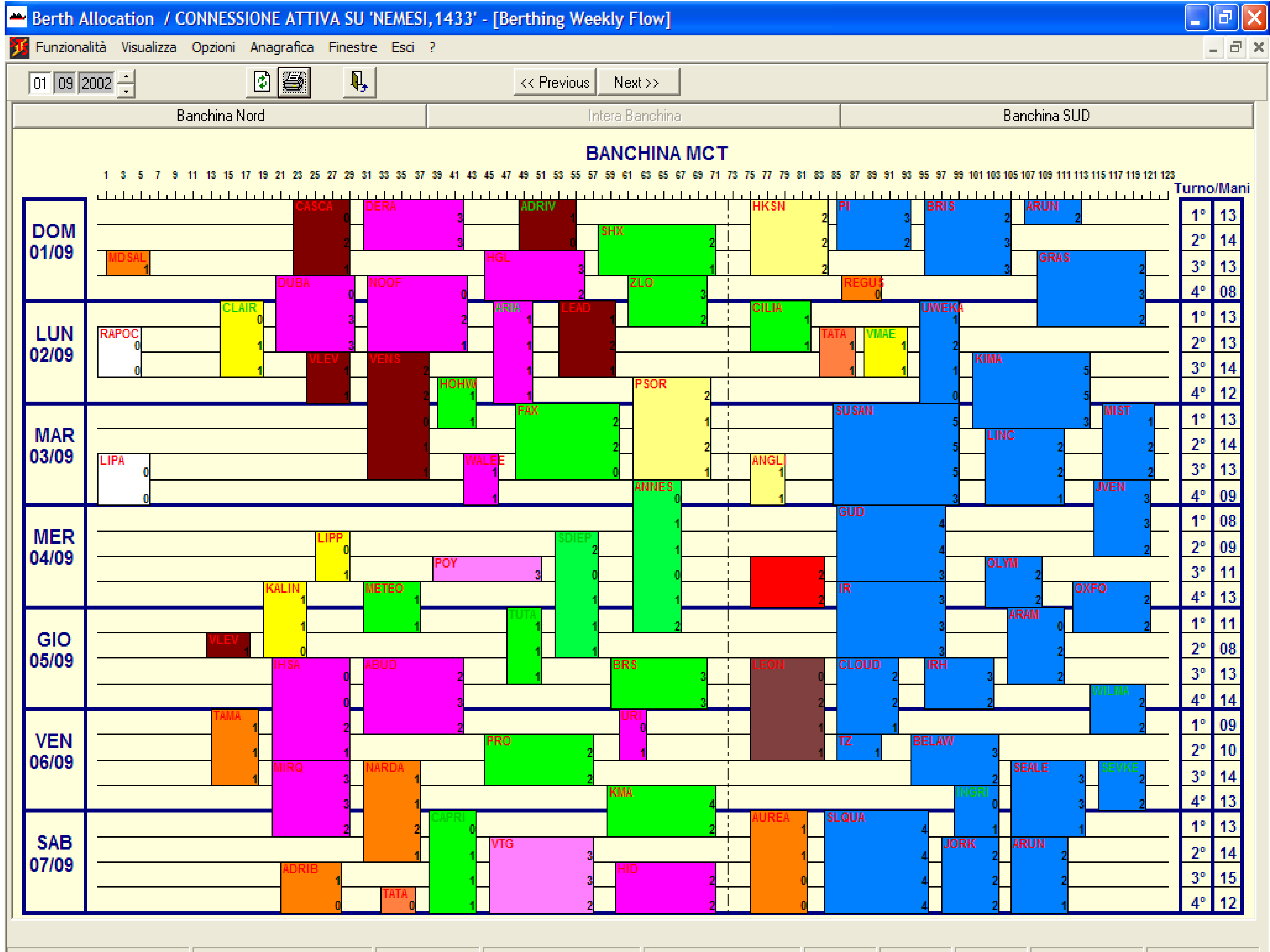
- Assign ships to berths
- Schedule the ships in every berth

Such that:

- A cost function is minimized
- All vessels arrive within their time window
- No overlap in space and time

A berth allocation plan




Berth Allocation / CONNESSIONE ATTIVA SU 'NEMESI,1433' - [Berthing Weekly Flow]
Funzionalità Visualizza Opzioni Anagrafica Finestre Esci ?
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Next >>
Banchina Nord
Intera Banchina
Banchina SUD
BANCHINA MCT
Turno/Mani
DOM 01/09
LUN 02/09
MAR 03/09
MER 04/09
GIO 05/09
VEN 06/09
SAB 07/09
CASCA
DERA
ADRIV
HKSN
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ARUN
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MDSAL
HGL
GRAS
DUBA
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HID
TATA

The mathematical model

Decision variables:

- x(i,j,k) : 1 if vessel j is assigned to berth k right after vessel i
- T(i) : arrival time of vessel i

Objective function:

- minimize cost / maximize profit

Constraints:

- do not overlap in space and time
- arrival within the time window

The mathematical model

$$\min \quad \sum_{i\in N}\sum_{k\in M} v_i \left(T_i^k - a_i + h_i^k \sum_{j\in N\cup\{d\}} x_{ij}^k \right) \tag{11}$$

s.t.

$$\sum_{k\in M}\sum_{j\in N\cup\{d\}} x_{ij}^k = 1 \qquad \forall i \in N \tag{12}$$

$$\sum_{j\in N\cup\{d\}} x_{o,j}^k = 1 \qquad \forall k \in M \tag{13}$$

$$\sum_{i\in N\cup\{o\}} x_{i,d}^k = 1 \qquad \forall k \in M \tag{14}$$

$$\sum_{j\in N\cup\{d\}} x_{ij}^k = \sum_{j\in N\cup\{o\}} x_{ji}^k \qquad \forall k \in M,\ i \in N \tag{15}$$

$$T_i^k + h_i^k - T_j^k \le (1 - x_{ij}^k) M_{ij}^k \qquad \forall k \in M,\ (i,j) \in A \tag{16}$$

$$a_i \le T_i^k \qquad \forall k \in M,\ i \in N \tag{17}$$

$$T_i^k + h_i^k \sum_{j\in N\cup\{d\}} x_{ij}^k \le b_i \qquad \forall k \in M,\ i \in N \tag{18}$$

$$s^k \le T_o^k \qquad \forall k \in M \tag{19}$$

$$T_d^k \le e^k \qquad \forall k \in M \tag{20}$$

$$x_{ij}^k \in \{0,1\} \qquad \forall k \in M,\ (i,j) \in A \tag{21}$$

$$T_i^k \in \mathbb{R}^+ \qquad \forall k \in M,\ i \in V \tag{22}$$

The mathematical model

- General purpose solvers (Cplex, Gurobi, etc.)
- Fail because the problem is too complex
- Only small instances are solved
- It takes ages to provide a solution for real size instances

The solution algorithms

- Heuristic algorithm
    - Provide feasible solution, not the optimal one
    - Use simple rules and is fast
- Exact algorithm
    - Designed for this specific problem
    - Use sophisticated techniques
    - Provide optimal solutions

Computational results

Instance		DBAP+	HVRPTW+	GSPP		T²S	Difference[d]
		Solved	Solved	Time	Value	Value	(%)
25×5	01	÷	÷	5.99	759	759	
	02	÷	÷	3.70	964	965	0.1
	03	÷	÷	2.95	970	974	0.4
	04	÷	÷	2.72	688	702	2.0
	05	÷	÷	6.97	955	965	1.0
	06	÷	÷	3.10	1129	1129	
	07	÷	÷	2.31	835	835	
	08	÷	÷	1.92	627	629	0.3
	09	÷	÷	4.76	752	755	0.4
	10	÷	÷	6.38	1073	1077	0.4
Mean		**0**	**0**	**4.08**			**0.5**
25×7	01	√	√	3.62	657	667	1.5
	02	√	√	3.15	662	671	1.4
	03	÷	÷	4.28	807	823	2.0
	04	÷	÷	3.78	648	655	1.1
	05	÷	√	3.85	725	728	0.4
	06	÷	÷	3.60	794	794	
	07	÷	÷	3.54	734	740	0.8
	08	÷	÷	3.93	768	782	1.8
	09	√	√	3.73	749	759	1.3
	10	√	√	3.82	825	830	0.6
Mean		**4**	**5**	**3.73**			**1.1**

The Quay Crane Scheduling Problem

Given

- A set of moored vessels
- A set of holds for every vessel
- A set of quay cranes
- The processing time of holds by a quay crane

The Quay Crane Scheduling Problem

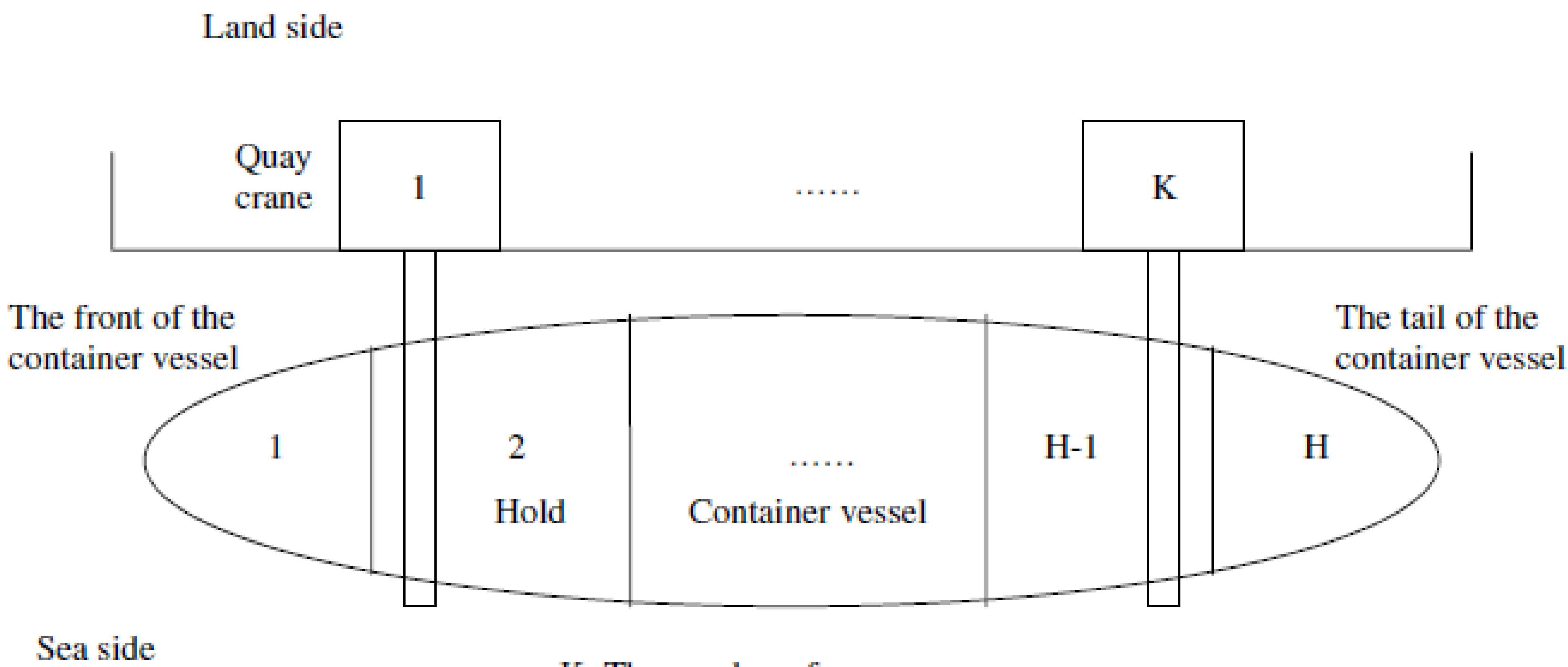
We aim to

- Assign quay cranes to holds
- Schedule the quay cranes in time

Such that

- The latest completion time is minimized
- No overlap between cranes occurs

The Quay Crane Scheduling Problem



K: The number of quay cranes
H: The number of holds

The mathematical model

Decision variables

- X(h,k) : 1 if hold h is handled by crane k
- Y(h,h’): 1 if hold h finishes before h’ starts
- C(h) : completion time of hold h

Constraints:

- Every hold must be performed by one crane
- Precedence constraints
- Interference constraints

The mathematical model

Minimize:

$$\max_h C_h \tag{1}$$

Subject to:

$$C_h - p_h \geqslant 0 \quad \forall 1 \leqslant h \leqslant H \tag{2}$$

$$\sum_{k=1}^{K} X_{h,k} = 1 \quad \forall 1 \leqslant h \leqslant H \tag{3}$$

$$C_h - (C_{h'} - p_{h'}) + Y_{h,h'} M > 0 \quad \forall 1 \leqslant h, h' \leqslant H \tag{4}$$

$$C_h - (C_{h'} - p_{h'}) - (1 - Y_{h,h'})M \leqslant 0 \quad \forall 1 \leqslant h, h' \leqslant H \tag{5}$$

$$M(Y_{h,h'} + Y_{h',h}) \geqslant \sum_{k=1}^{K} kX_{h,k} - \sum_{l=1}^{K} lX_{h',l} + 1 \quad \forall 1 \leqslant h < h' \leqslant H \tag{6}$$

$$X_{h,k}, Y_{h,h'} = 0 \text{ or } 1 \quad \forall 1 \leqslant h, h' \leqslant H, \ \forall 1 \leqslant k \leqslant K \tag{7}$$

Results

Experiment No.	Size (holds $\times$ cranes)	CPLEX		GA	
		Value	CPU (s)	Value	CPU (s)
1	6×2	341	10.87	341	5.41
2	6×3	282	128.20	282	5.28
3	7×2	436	437.39	436	5.33
4	7×3	299	8014.58	299	5.53
5	8×2	448	11889.95	448	5.79
6	8×3	330	344951.97	330	5.48

Summary

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