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

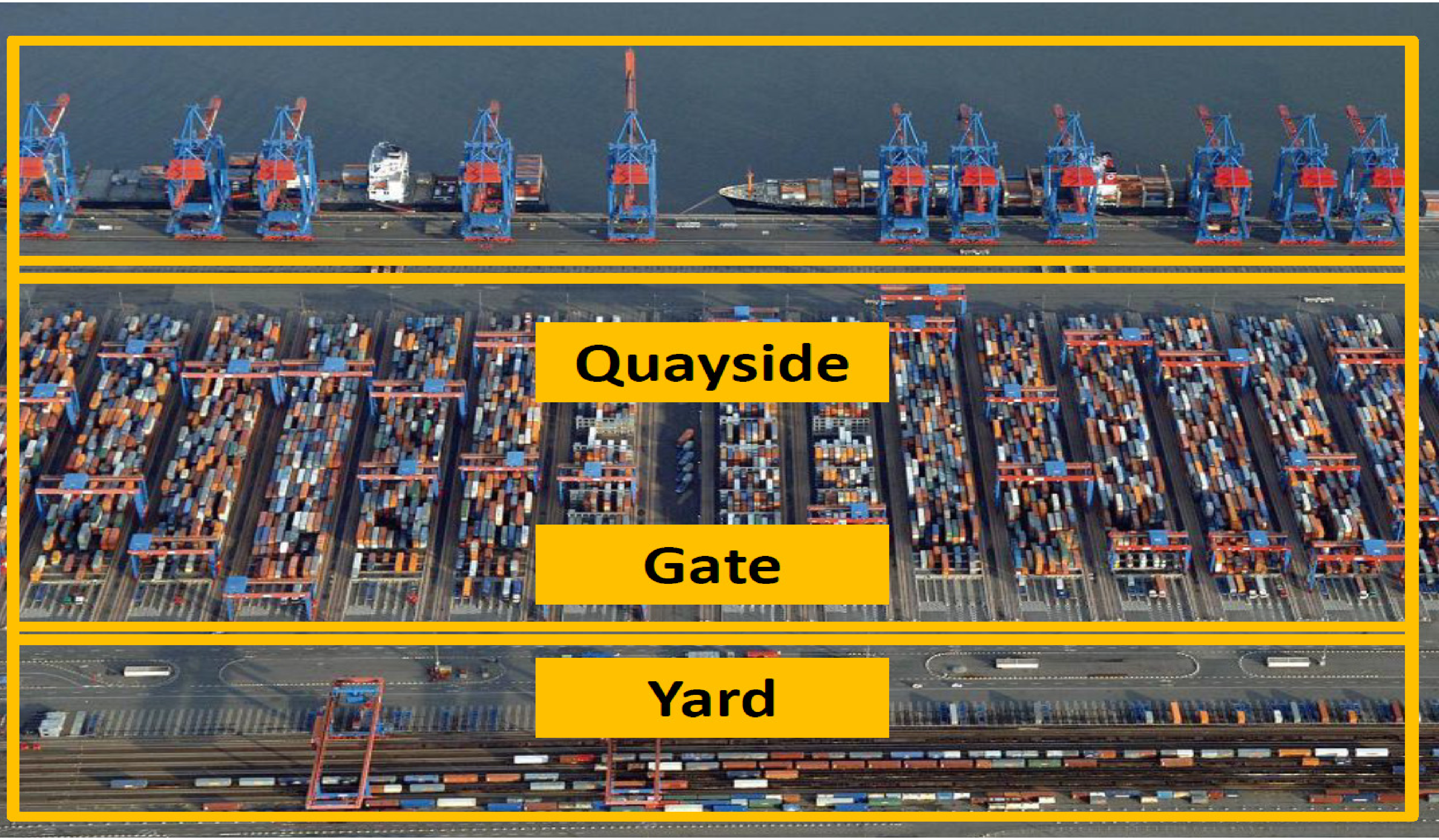
- Containerized trade accounts for 25% of total dry cargo (UNCTAD, 2008)

- 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)

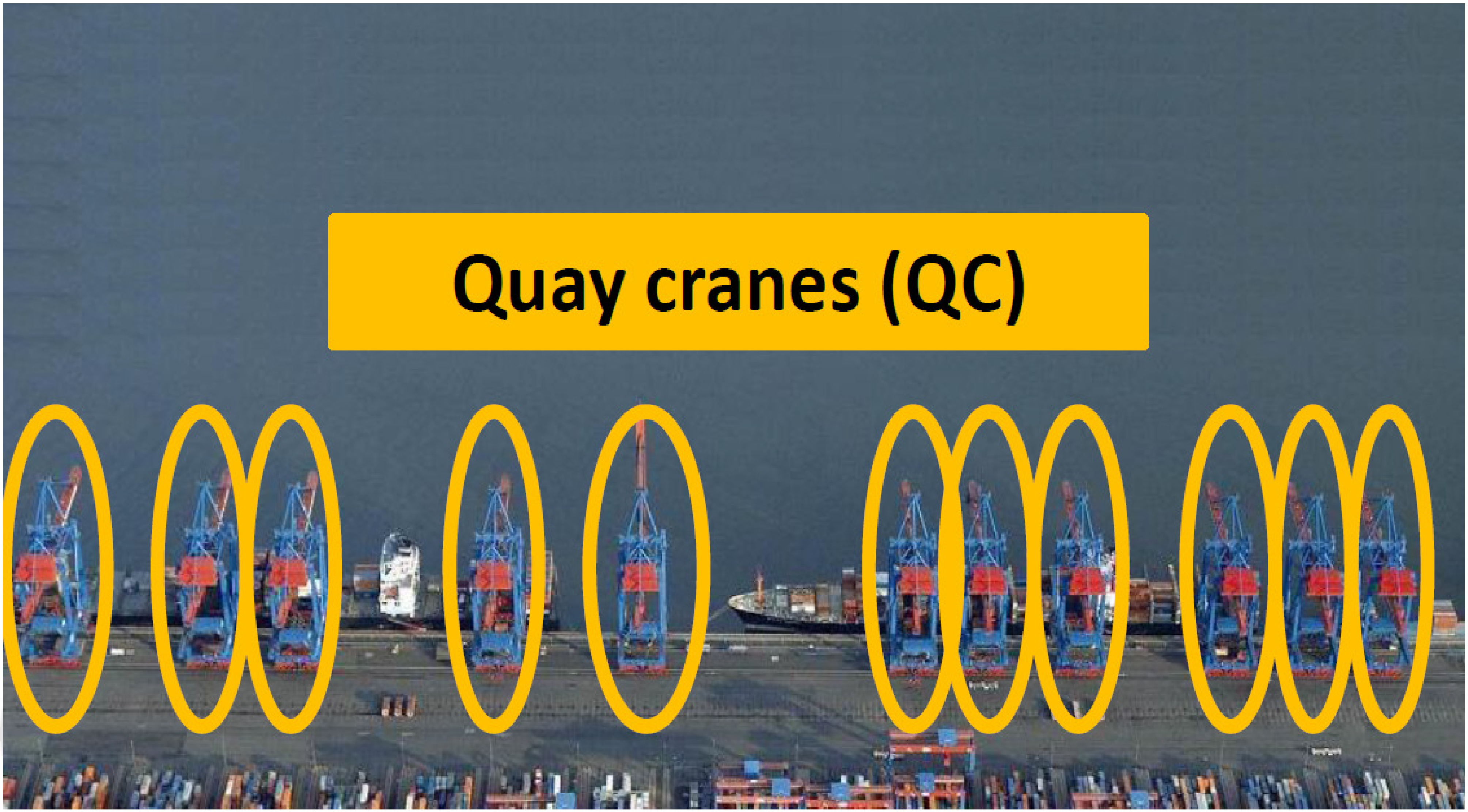
Layout of a Container Terminal



The Quay

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

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)

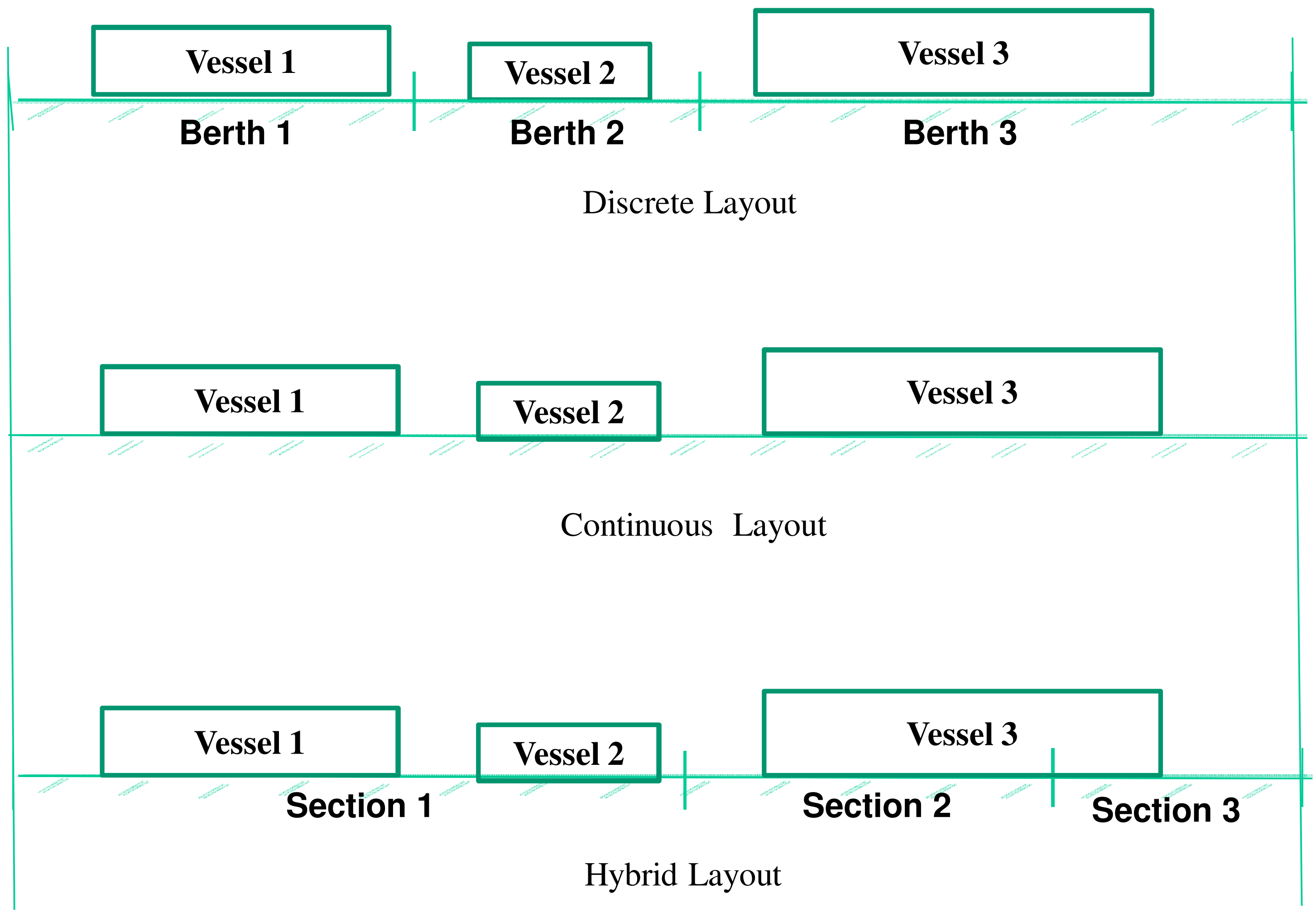
- Projected handling time
  - Deterministic (known in advance and unchangeable)
  - Dependent on berthing positions, number and work schedule of assigned cranes

- 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



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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

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Mathematical Formulation

- **Model**

$$\min \sum_{i \in N} (m_i - a_i)$$

$$s.t. \; m_i - a_i \geq 0 \qquad \forall i \in N,$$

$$\sum_{k \in M} (k x_{jk}) + B(1 - y_{ij}) \geq \sum_{k \in M} (k x_{ik}) + 1 \qquad \forall i, j \in N, i \neq j,$$

$$m_j + B(1 - z_{ij}) \geq m_i + C_i \qquad \forall i, j \in N, i \neq j,$$

$$y_{ij} + y_{ji} + z_{ij} + z_{ji} \geq 1 \qquad \forall i, j \in N, i \neq j,$$

$$\sum_{k \in M} x_{ik} = 1 \qquad \forall i \in N,$$

$$\sum_{k \in M} (d_k - D_i) x_{ik} \geq 0 \qquad \forall i \in N,$$

$$\sum_{k \in M} (l_k - L_i) x_{ik} \geq 0 \qquad \forall i \in N$$

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