# Real Time Recovery in Berth Allocation Problem in Bulk Ports


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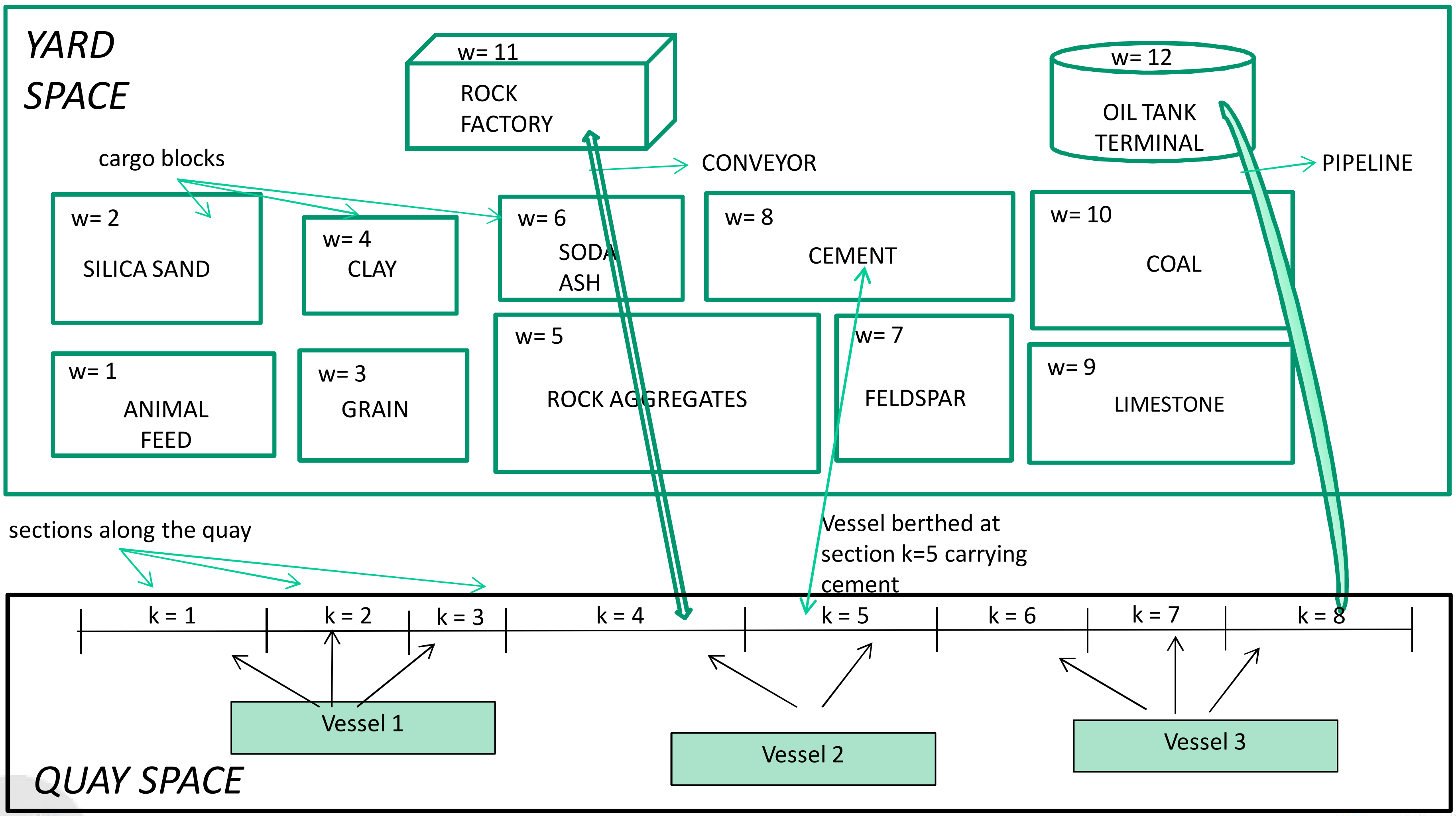
# Schematic Diagram of a Bulk Terminal



# Motivation

- High level of uncertainty in bulk port operations due to weather conditions, mechanical problems etc.
  - Actual arrival times of vessels can deviate from expected values making the baseline schedule infeasible
  - Disrupt the normal functioning of the port and require quick real time action.
- Very few studies address the problem of real time recovery using in port operations, while the problem has not been studied at all in context of bulk ports.
- Our research problem derives from the realistic requirements at the SAQR port, Ras Al Khaimah, UAE

# Research Objectives

- Develop real time algorithms for disruption recovery in berth allocation problem (BAP)

- For a given baseline berthing schedule, minimize the total realized costs of the updated schedule as actual arrival data is revealed. The total realized costs include

  - The total service cost of all vessels berthing at the port which is the sum total of the handling times and berthing delays of all vessels berthing in the planning horizon.

  - Inconsistent cost of rescheduling over space and time to account for the cost of re-allocating human labor, handling equipment and availability of cargo.

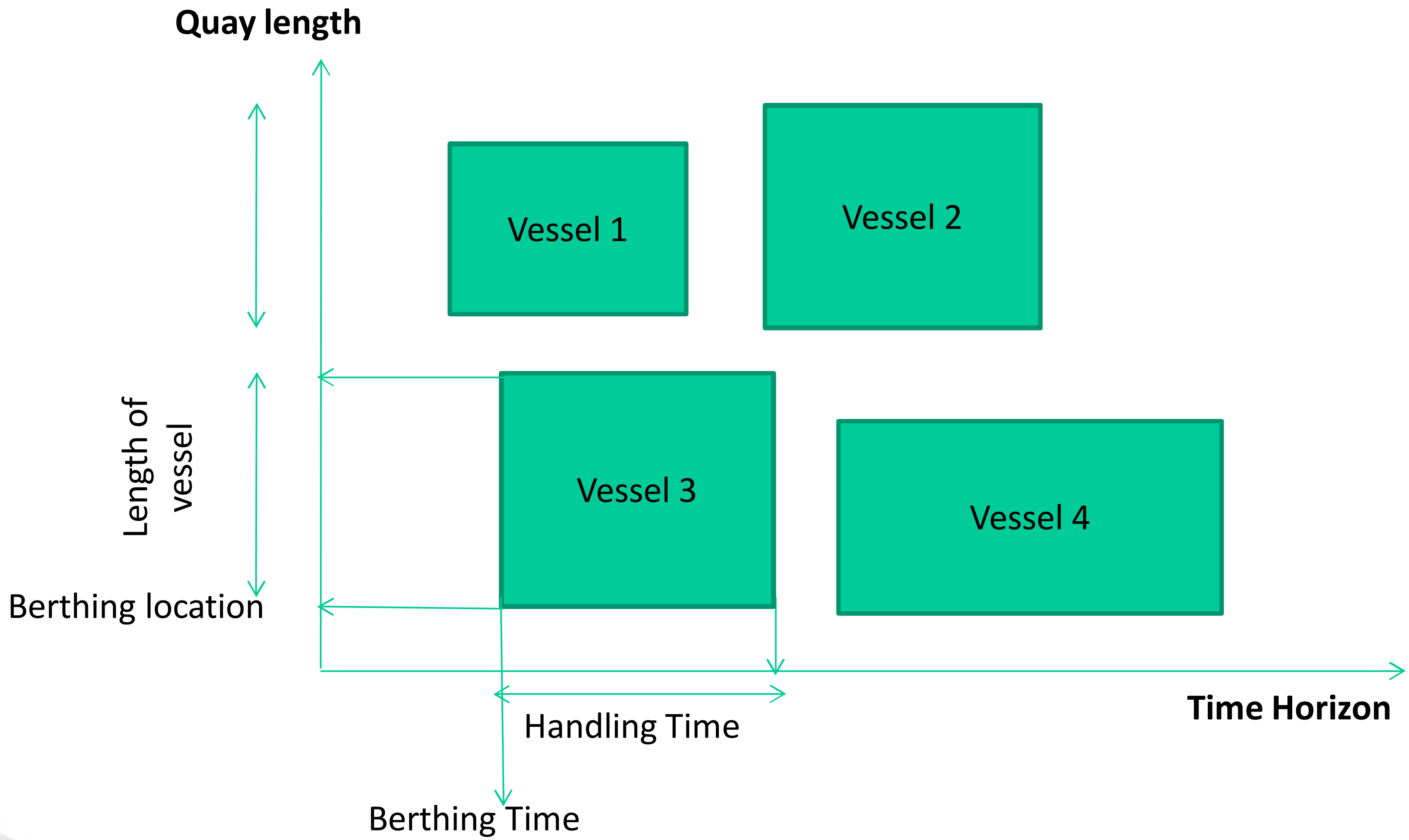
# Literature Review

- Very scarce literature on the use of operations research methods in context of bulk ports.
- Comprehensive literature surveys on BAP in container terminals can be found in Steenken et al. (2004), Stahlobock and Voss (2007), Bierwirth and Meisel (2010).
- OR literature related to BAP under uncertainty in container terminals
  - **Pro-active Robustness**
    - Stochastic programming approach used by Zhen et al. (2011), Han et al. (2010)
    - Define surrogate problems to define the stochastic nature of the problem: Moorthy and Teo (2006), Zhen and Chang (2012), Xu et al. (2012) and Hendriks et al. (2010)
  - **Reactive approach or disruption management**
    - Zeng et al.(2012) and Du et al. (2010) propose reactive strategies to minimize the impact of disruptions.

# Deterministic BAP: Problem Definition

- **Find**
  - Baseline berthing assignment and schedule of vessels along the quay without accounting for any uncertainty in information
- **Given**
  - Expected arrival times of vessels
  - Handling times dependent on
    - **Cargo type** on the vessel (the relative location of the vessel along the quay with respect to the cargo location on the yard)
    - Number of cranes operating on the vessel
- **Objective**
  - Minimize total service times (waiting time + handling time) of vessels berthing at the port

# BAP Solution



# GSPP Model

- Used in context of container terminals by Christensen and Holst (2008)

- Generate set P of columns, where each column $p \in P$ represents a feasible assignment of a single vessel in both space and time

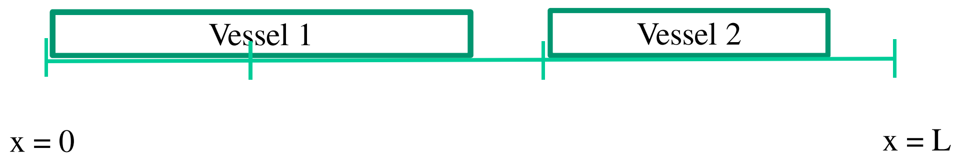
- Generate two matrices

  - Matrix A = $(A_{ip})$ ; equal to 1 if vessel $i \in N$ is the assigned vessel in the feasible assignment represented by column $p \in P$

  - Matrix B = $(b_p^{st})$ ; equal to 1 if section $s \in M$ is occupied at time $t \in H$ in column $p \in P$

  *Note: Assume integer values for all time measurements*

# GSPP Formulation: A simple example




- *|N|* = 2, *|M|* = 3, *|H|* = 3
- Vessel 1 cannot occupy section 3 owing to spatial constraints (does not have conveyor facility), vessel 2 arrives at time t = 1
- Constraint matrix P has 4 feasible assignments:

| | | | | |
|---|---|---|---|---|
| **Vessel 1** | 1 | 1 | 0 | 0 |
| **Vessel 2** | 0 | 0 | 1 | 1 |
| **Section 1 , Time 1** | 1 | 0 | 0 | 0 |
| **Section 1, Time 2** | 1 | 1 | 1 | 0 |
| **Section 1, Time 3** | 0 | 1 | 1 | 0 |
| **Section 2, Time 1** | 1 | 0 | 0 | 0 |
| **Section 2, Time 2** | 1 | 1 | 1 | 1 |
| **Section 2, Time 3** | 0 | 1 | 1 | 1 |
| **Section 3, Time 1** | 0 | 0 | 0 | 0 |
| **Section 3, Time 2** | 0 | 0 | 0 | 1 |
| **Section 3, Time 3** | 0 | 0 | 0 | 1 |

# GSPP Model Formulation

**Objective Function:**

$$\min \sum_{p \in P} (d_p \lambda_p + h_p \lambda_p)$$

**Constraints:**

$$\sum_{p \in P} (A_{ip} \lambda_p) = 1 \qquad \forall i \in N$$

$$\sum_{p \in P} (b_p^{st} \lambda_p) \leq 1 \qquad \forall s \in M, \forall t \in H$$

$d_p$ : *delay in service associated with assignment* $p \in P$

$h_p$ : *handling time associated with assignment* $p \in P$

$\lambda_p$ : binary parameter, equal to 1 if assignment $p \in P$ is part of the optimal solution

# Problem Definition: Real time recovery in BAP

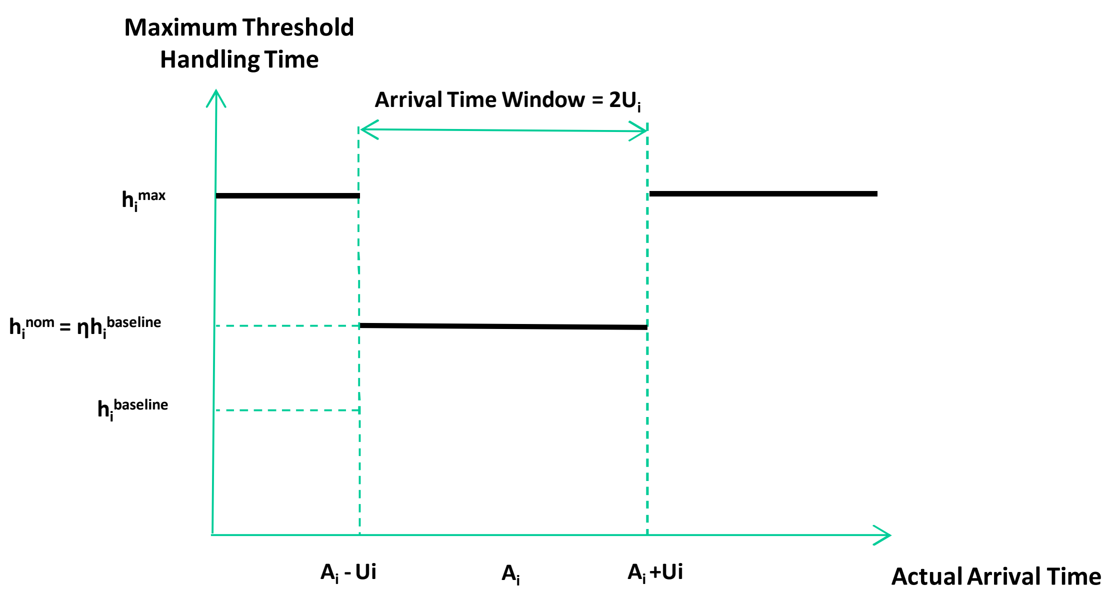
- **Objective:** For a given baseline berthing schedule, minimize the total realized costs including the total actual service costs and total cost of rescheduling in space and time

$$\min\ Z = \sum_{i \in N_u} (m_i - A_i + h_i) + \sum_{i \in N_u} (c_1 \,|\, b_i(k') - b_i(k) \,|\, + c_2 \mu_i \,|\, e'_i - e_i \,|)$$

# Problem Definition: Real time recovery in BAP

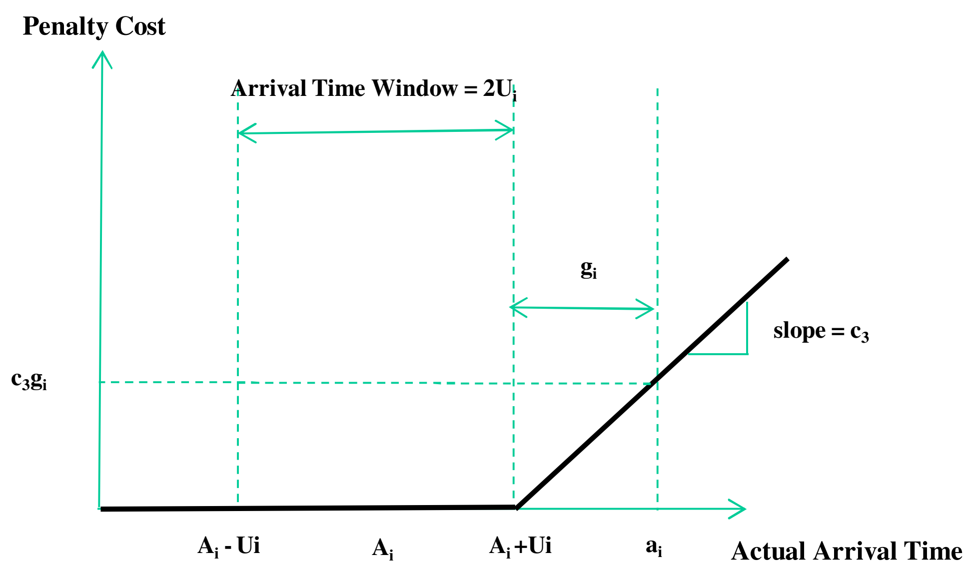
To maximize revenues earned by the port while guaranteeing a minimum level of service, we propose that the bulk terminal managers adopt and implement certain strategic measures

- **Handling Time Restrictions**: Impose an upper bound on the maximum handling time of a vessel *i* ϵ *N* if it arrives within a pre-defined arrival time window [$A_i$ –$U_i$, $A_i$+$U_i$]



# Problem Definition: Real time recovery in BAP

- **Penalty Cost on late arriving vessels:** Impose a penalty fees on vessels arriving beyond the right end of the arrival window, $A_i+U_i$



# Problem Definition: Real time recovery in BAP

- **Key Assumptions**
  - **Vessel Priorities:** In practice, if a vessel with higher priority arrives late, it may still be given preference over a vessel with low service priority.
  - **Release of information**: Each incoming vessel updates its exact arrival time a certain fixed time period $\tau$ before its actual arrival time, and once updated it does not change again.
  - **Future vessel arrivals:** At any time instant $t$, the arrival time of an unassigned vessel $i \in N_u$ that is not updated is assumed equal to the expected arrival time $A_i$ if current time $t$ is less than $A_i - \tau$, or otherwise assumed equal to $t + \tau$ . (The handling time restrictions are imposed accordingly.)

# Solution Algorithms

- **Optimization based recovery algorithm**
  - re-optimize the berthing schedule every time the arrival time of any vessel is updated and it deviates from its expected value.
  - the berthing assignment of a vessel determined after its arrival update is frozen and unchangeable
- **Heuristic based recovery algorithm**
  - once a vessel has arrived, assign it to the section(s) at or after its estimated berthing time (as per the baseline schedule) at which the total realized cost of all unassigned vessels is minimized (assuming all other unassigned vessels are assigned to the estimated berthing sections as per the baseline schedule)

$$\min\ Z = \sum_{i \in N_u} (m_i - A_i + h_i) + \sum_{i \in N_u} (c_1 \mid b_i(k') - b_i(k) \mid + c_2 \mu_i \mid e'_i - e_i \mid)$$

# Optimization based Recovery Algorithm

**Require**: Baseline schedule of set $N$ of vessels, set $M$ of sections

Initialize set $N_u$ of unassigned vessels to $N$

Initialize boolean array arrivalUpdated of size $N$ = false *forall* $i \in N$

Initialize counter = 0

**while** $| N_u | > 0$ and counter $\leq |H|$ **do**

  Initialize boolean shouldOptimize = false

  **for** $i = 1$ to $N$ **do**

    **if** arrivalUpdated[$i$] = false and counter $\geq a_i - \tau$ and $a_i \neq A_i$ **then**

      Set arrivalUpdated[$i$] = true

      Set $A_i = a_i$

      Set shouldOptimize = true

    **end if**

  **end for**

  **if** shouldOptimize **then**

    Re-optimize *forall* $i \in N_u$

  **end if**

  **for** i = 1 to $N_u$ **do**

    **if** counter = latest updated start time $m'_i$ **then**

      Assign vessel $i$ to latest updated location $b_i$(k')

      Set $N_u$ to $N_u - \{i\}$

    **end if**

  **end for**

  counter++

**end while**

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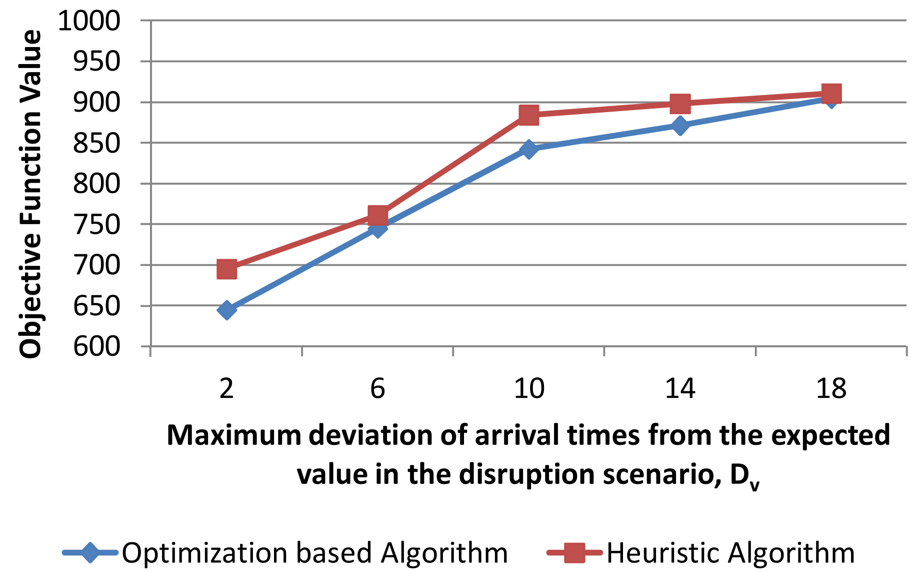
# Heuristic based Recovery Algorithm

```
Require: Baseline schedule of set N of vessels, set M of sections
    Initialize set N_u of unassigned vessels to N
    Initialize boolean array arrivalUpdated of size N = false  forall i ϵ N
    Initialize counter = 0
    while | N_u | > 0 and counter ≤ |H| do
        for berthing Schedule: b do
            if b.hasArrived AND !b.isAssigned then
                Set boolean foundSection = false
                for k = 1 to M do
                    if isStartSectionAvailable(b.vessel,k) then
                        foundSection = true;
                        break;
                    end if
                end for
                if foundSection AND counter ≥ b.estimatedBerthingTime then
                    Scan the entire quay and assign the vessel to the set of sections with minimum total
                    cost forall i ϵ N_u
                end if
            end if
        end for
        counter++
    end while
```

# Preliminary Results

- $|N|$=25 vessels, $|M|$= 10 sections, congested scenario, $c_1$ = 1.0, $c_2$ = 0.02, $U_i$ = 8 hours, $\tau$ = 5 hours, $\eta$ = 1.2

| $D_v$ | Optimization based algorithm | | Heuristic Algorithm |
|---|---|---|---|
| | Realized cost | Time | Realized Cost |
| 0 | 586.0 | 0.07 | 586.0 |
| 2 | 645.0 | 48.5 | 695.5 |
| 6 | 745.0 | 56.5 | 761.2 |
| 10 | 842.3 | 85.7 | 884.3 |
| 14 | 871.5 | 108.6 | 897.9 |
| 18 | 904.3 | 115.8 | 910.8 |




- Results averaged over 10 arrival disruption scenarios

- Optimization based algorithm outperforms the heuristic based approach, but computationally much more expensive

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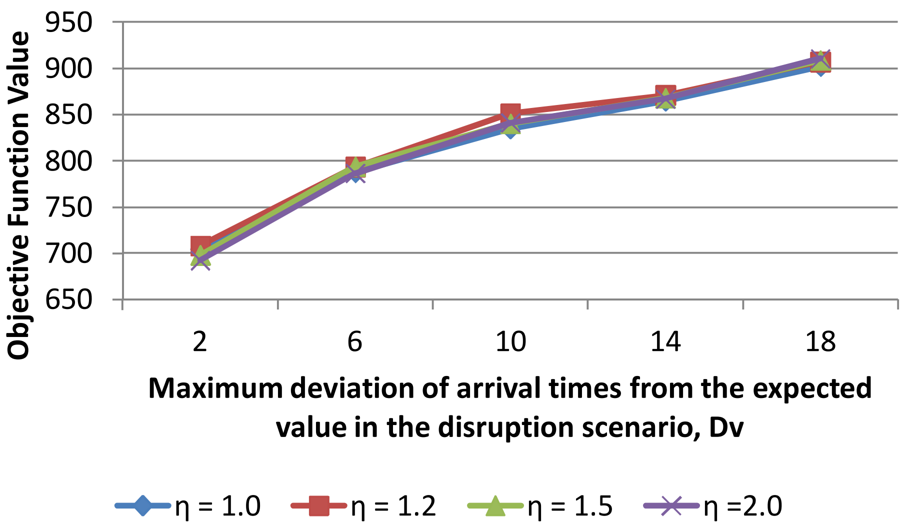
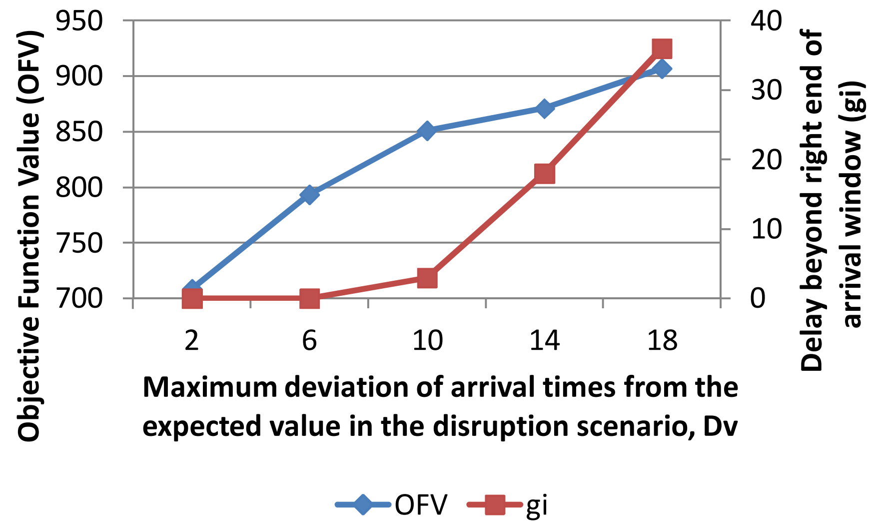
# Preliminary Results




- Results averaged over 100 arrival scenarios for every instance
- Higher values of $\eta$ do not significantly increase the total realized costs of the berthing schedule for different delay scenarios
- Scope to earn more revenue from the late arriving vessels for arrival beyond the permissible arrival window of the vessels

# Conclusions

- Addressed the problem of recovering a baseline berthing schedule in bulk ports in real time as actual arrival data is revealed.

- Discussed strategies that the port can adopt and implement to maximize their revenues while ensuring a desired level of service

- Developed two alternate solution algorithms to solve the BAP in real time in bulk ports with the objective to minimize the total realized costs of the updated schedule.

- Conducted simple numerical experiments to validate the efficiency of the algorithms. Optimization based approach outperforms the heuristic approach, but is computationally much more expensive.

# Ongoing and Future Work

- More extensive numerical analysis to determine
  - parameter values related to rescheduling of vessels including cost of shifting the vessel along the quay and cost of departure delay of a vessel
  - bounds on the maximum handling times for vessels arriving within the prescribed arrival window.
  - penalty cost function dependent on the late arriving vessels for arrival delay beyond the prescribed arrival window of the vessel
- Develop a robust formulation of the berth allocation problem in bulk ports with a certain degree of anticipation of variability in information.

# Thank you!