The Berth Allocation Problem in Bulk Ports

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Outline

- Motivation
- Introduction to bulk ports
  - Bulk port operations and equipment
  - Case Study of SAQR
- Research Objectives
- Berth Allocation Model
- Preliminary Results
- Conclusions
Motivation

- Significantly less attention to bulk port terminals than container terminals in the field of large scale optimization.

- High level of uncertainty due to weather conditions, mechanical problems etc.
  - Disrupt the normal functioning of the port.
  - Require quick real time action.

- The major objective of planning robust port operations is to minimize operational costs while maximizing system reliability.
Bulk terminal operations

- Vessel and Berth Activities

- Ship Loading or Discharge
- Apron to Storage Transfer
- Storage
- Intermodal transfer and inland distribution
Case Study: SAQR Port, Ras Al Khaimah, UAE

- Biggest bulk port in the entire middle east, handling 30 million tons of bulk and assorted cargo annually

- Deals with a wide variety of imported and exported commodities - aggregates, cement, coal, clinker, iron ore, feldspar, clay, soda ash, petroleum products etc.

- Wide range of equipment facilities including MHC’s, shovels, loaders

- Variable demand across different berths owing to fixed specialized equipment facilities and environmental reasons.
- Port Layout

- 12 berths, with alongside depth of 12.2 meters at mean low water spring tide
- 8 x 200 meters bulk handling berths, 3 x 200 meters container handling berths and 1 general purpose roll-on/roll-off berth
- Conveyors at berths 5 and 7; pipelines at berths 6, 7 and 11
Research challenges

- **Key issues and sources of disruption at SAQR**: High waiting times and delays at berths owing to
  - Congestion at berths
  - Unavailability of required number and type of equipment when needed
  - *Uncertainty in arrivals* of vessels and cargo trucks
Research Objectives

- **Integration of the two crucial problems of berth allocation and yard allocation** for better coordination between berthing and yard activities

- Include *robustness* in planning process to account for uncertainties in arrival times of vessels and cargo trucks which lead to unforeseen disruptions and delays in operations.

- Develop methodologies and algorithms that can be extended to other domains such as container ports, railways and airlines.
The Berth Allocation Problem
Problem Definition

- **Find**
  - Berthing assignment and schedule of vessels along the quay

- **Given**
  - Time windows on arrivals of vessels
  - Handling times dependent on berthing position and cargo type

- **Objective**
  - Minimize total service times of vessels berthing at the port
BAP Solution

Quay Space (section number)

Vessel a

Vessel j

Vessel i

Vessel b

\[ L_j \]

\[ S_j \]

\[ L_i \]

\[ S_i \]

\[ m_i \]

\[ h_i \]

\[ m_j \]

\[ h_j \]

Time
Discretization

- Discrete Layout
- Continuous Layout
- Hybrid Layout
- Our Model
BAP Model

Objective Function

\[
\min \sum_{i \in N} (m_i - a_i + h_i)
\]

Decision variables:

- \(m_i\): starting time of handling of vessel \(i \in N\);
- \(a_i\): arrival time of vessel \(i \in N\);
- \(h_i\): total handling time of vessel \(i \in N\);
BAP Model

Dynamic vessel arrival constraints

\[ m_i - a_i \geq 0 \quad \forall i \in N, \]
\[ a_i = A_i r_i + U_i (1 - r_i) \quad \forall i \in N, \]

\( A_i \) expected arrival time of vessel \( i \in N \);

\( U_i \) upper bound to the arrival time of vessel \( i \in N \);
BAP Model

- Non overlapping constraints
- Section covering constraints
- Draft Restrictions

\[(d_k - D_i)x_{ik} \geq 0 \quad \forall i \in N, \forall k \in M,\]

\[D_i\] draft of vessel \(i \in N;\)

\[d_k\] draft of section \(k \in M;\)
BAP Model

Determination of Handling Times

\[ h_i \geq h_k^{iw} p_{isk} Q_i s_k \]

\( \forall i \in N, \forall k \in M, w \in W_i \)

\( Q_i \) quantity of cargo to be loaded on or discharged from vessel \( i \)

\( h_k^{iw} \) handling time for unit quantity of cargo \( w \in \) when vessel \( i \in N \) is berthed in section \( k \in M \).
Generation of Instances

- Instances based on data from SAQR port
  - Quay length of 1600 meters and vessel lengths in the range 80-260 meters

- Test 5 instances each for \(N\) = 5, 10 and 15 vessels, and \(M\) = 10, 20 and 30 sections

- Choosing the discretization along the quay is critical!

- Rate of handling is 15 hours per \(10^4\) tonnes per crane, and number of cranes dependent on length of each section

- Drafts of all vessels \(D_i\) are less than the minimum draft along the quay.
Preliminary Results

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<tr>
<td>M</td>
<td>obj</td>
</tr>
<tr>
<td>10</td>
<td>52.5</td>
</tr>
<tr>
<td>20</td>
<td>29.03</td>
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<tr>
<td>30</td>
<td>29.42</td>
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- Solved in less than a second
- Objective function value much less for larger number of sections
- Solved within few seconds
- Objective function decreases with increase in number of sections
<table>
<thead>
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<th>N = 15</th>
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<tr>
<td>M</td>
<td>Obj (gap%)</td>
<td>t (s)</td>
</tr>
<tr>
<td>10</td>
<td>120.00 (5.17%)</td>
<td>7200</td>
</tr>
<tr>
<td></td>
<td>118.48 (4.08%)</td>
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<tr>
<td></td>
<td>117.50 (0.00%)</td>
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<td>111.31 (0.00%)</td>
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<tr>
<td></td>
<td>112.20 (0.00%)</td>
<td>25.81</td>
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<tr>
<td>20</td>
<td>118.14 (0.10%)</td>
<td>7200</td>
</tr>
<tr>
<td></td>
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<td>112.74</td>
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</table>

- Most instances solved within few seconds
- Objective function decreases with increase in number of sections
- Arrival times are more critical for larger lengths of sections
Summary of Results

- All instances up to 10 vessels solved within few seconds.
- Most instances containing 15 vessels solved within few seconds.
- Improvement in solution quality with increase in number of sections.
- Arrival times are more critical when sections are larger in length!
Future Work

- Sensitivity analysis for different parameters in the current model
- Model the BAP using a column generation based approach
- Account for uncertainties!
- Possibly explore heuristic approaches for faster results
- Integration of the berth allocation problem with yard allocation
Thank you!