Identification of Economically Promising Port Architectures via Enumeration and Capacity Evaluation

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Presentation overview

• Motivation

• Overall process

• Enumeration of port architecture

• Capacity evaluation

• Result

• Concluding remarks
Motivation

- Port is a complex system

- Trade off between reducing cost and providing good service

Method to identify economically promising initial design with reasonable service level
Overall Process

1. Enumerate all feasible architecture
2. Find cost of architecture for each market
3. Identify best architecture for each market
Enumeration of port architecture

• It is impossible to find all feasible architecture by hand
  – Each part of system has several alternatives
  – Illogical combination

• Object Process Network (OPN) [1] is a tool for enumerating complex system architectures

• It automatically generates feasible architecture by using large number of options and relationship between options

Enumeration of port architecture

1. Set the boundaries
   - Container transportation system between containerships and the inland yard
# Enumeration of port architecture

## 2. Functions of the system

<table>
<thead>
<tr>
<th>Traditional mode</th>
<th>Offshore mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Moor/Stabilize</td>
<td>1. Moor/Stabilize (Ship &amp; unloading unit)</td>
</tr>
<tr>
<td>2. (Un)load</td>
<td>2. (Un)load (Ship &amp; unloading unit)</td>
</tr>
<tr>
<td>3. Provide space for berthing</td>
<td>3. Transfer ((un)loading unit &amp; travel unit)</td>
</tr>
<tr>
<td>4. Transfer (berth-yard)</td>
<td>4. Travel</td>
</tr>
<tr>
<td>5. Store</td>
<td>5. Moor/Stabilize (travel unit-Berth)</td>
</tr>
<tr>
<td></td>
<td>6. (Un)load (travel unit -Berth)</td>
</tr>
<tr>
<td></td>
<td>7. Form/unstack batch (at front berth-&gt;transfer unit)</td>
</tr>
<tr>
<td></td>
<td>8. Provide space for berthing</td>
</tr>
<tr>
<td></td>
<td>9. Transfer</td>
</tr>
<tr>
<td></td>
<td>10. Store</td>
</tr>
</tbody>
</table>
Enumeration of port architecture

3. Explore decision variables (DVs) and options of each function

<table>
<thead>
<tr>
<th>Function</th>
<th>Decision</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide space for berthing</td>
<td>Shape</td>
<td>parallel, perpendicular</td>
</tr>
<tr>
<td></td>
<td>Structure</td>
<td>floating quay, reclamation</td>
</tr>
<tr>
<td></td>
<td># of Side</td>
<td>one, two</td>
</tr>
</tbody>
</table>

4. Find logical constraints
   - Prevent the generation of illogical architectures
5. Build OPN model to generate feasible architectures
   - All feasible architecture are enumerated by selection one options for DVs
   - Traditional mode (9 feasible architectures of 16 total combination)
   - Offshore mode (128 feasible architectures of 13824 total combination)

<OPN model of offshore mode>
Enumeration of port architecture

5. Build OPN model to generate feasible architectures

<table>
<thead>
<tr>
<th>Ship unload resource</th>
<th>Transfer Resource to TU</th>
<th>Unit integration</th>
<th>height adjust</th>
<th>Berth Unload resource</th>
<th>Unload Resource location</th>
<th>Forming Batch</th>
<th>Berth Shape</th>
<th>Berth Structure</th>
<th>Berth Side</th>
<th>Berth Mixed</th>
<th>Transfer To yard</th>
<th>Arch #</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>RailRoRo</td>
<td>ports</td>
<td>no</td>
<td>perpendicular</td>
<td>reclamation</td>
<td>oneSide</td>
<td>N/A</td>
<td>RailRoRo</td>
<td>3</td>
<td>MFP [2]</td>
</tr>
<tr>
<td>normal</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>crane</td>
<td>units</td>
<td>no</td>
<td>parallel</td>
<td>floating</td>
<td>oneSide</td>
<td>N/A</td>
<td>truck</td>
<td>23</td>
<td>Mid stream operation [3]</td>
</tr>
<tr>
<td>normal</td>
<td>interface</td>
<td>no</td>
<td>yes</td>
<td>RailRoRo</td>
<td>ports</td>
<td>yes</td>
<td>parallel</td>
<td>reclamation</td>
<td>oneSide</td>
<td>N/A</td>
<td>truck</td>
<td>70</td>
<td>HMFP [4]</td>
</tr>
<tr>
<td>STS</td>
<td>STS</td>
<td>no</td>
<td>yes</td>
<td>TireRoRo</td>
<td>ports</td>
<td>no</td>
<td>parallel</td>
<td>reclamation</td>
<td>oneSide</td>
<td>N/A</td>
<td>TireRoRo</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>normal</td>
<td>interface</td>
<td>no</td>
<td>yes</td>
<td>TireRoRo</td>
<td>ports</td>
<td>yes</td>
<td>parallel</td>
<td>reclamation</td>
<td>oneSide</td>
<td>N/A</td>
<td>truck</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>STS</td>
<td>STS</td>
<td>no</td>
<td>yes</td>
<td>TireRoRo</td>
<td>ports</td>
<td>yes</td>
<td>parallel</td>
<td>reclamation</td>
<td>oneSide</td>
<td>N/A</td>
<td>truck</td>
<td>109</td>
<td>B type option [5]</td>
</tr>
</tbody>
</table>

<Subset of the results of OPN model of offshore mode>

Capacity evaluation

• Method to evaluate generated port design
  – Criteria: throughput, cost, and ship staying time

• Assumptions
  – Interarrival time and cargo volume/ship are deterministic and constant
  – Transfer unit conducts single cycle operation
  – Ship gets service right after entering port (No waiting time)
  – TU and berths make exclusive group to serve ship

• Some architectures are dominated by other architecture
  – One dominant architecture for traditional mode
  – Six dominant architecture for offshore mode
Capacity evaluation

• Ship service time approximation
  – To get average ship staying time of offshore mode with given number of resource
  – Three container flows of offshore mode
    • Ship to TU at ocean(\(\lambda_1\)) , TU at ocean to TU at berth(\(\lambda_2\)) , TU at berth to berth(\(\lambda_3\))
  – Maximum container flows of system (\(\mu\))
    \[\mu \leq \min\{\lambda_1, \lambda_2, \lambda_3\} =: \mu^*\]
  – First order approximation for the SST
    \[\text{SST} \approx \frac{\text{cargo volume}}{\mu^*}\]
Capacity evaluation

• Contention for transfer unit resources
  – Queueing time of TU occurs when number of transfer unit > number of servers
  – It depends on the arrival pattern of TU to the berths and docking points

\[
T_w = \frac{N_S \cdot T \cdot \sum_1^{\left\lfloor \frac{N_c}{N_S} \right\rfloor} n + \left( N_c - \left\lfloor \frac{N_c}{N_S} \right\rfloor \cdot N_s \right) \cdot \left\lfloor \frac{N_c}{N_S} \right\rfloor \cdot T}{N_c}
\]

Nc: Number of customer
Ns: Number of servers
T: Service time

<The assumed arrival pattern of MHs to their servers>
Capacity Evaluation

• Revised TU at ocean to TU at berth ($\lambda 2^*$)

\[
\frac{cTU}{tL + 2tT + tU} \quad \Rightarrow \quad \frac{cTU}{tL + 2tT + tU + T_{wb} + T_{wd}}
\]

- Working time
- Approximated waiting time at berth and docking point

$cTU$: capacity of TU
$tL$: time to load cargo
$tT$: time to travel
$tU$: time to unload cargo
$T_{wb}$: waiting time at berth (using equation for $T_w$ & appropriate input values)
$T_{wd}$: waiting time at docking point (using equation for $T_w$ & appropriate input values)
Capacity Evaluation

• Verification
  – Compare with result of simulation under same assumption
  – 154 systems and the average absolute gap between the SST approximation and the simulation was 6.49%.

<Graph of output of comparison>
Capacity Evaluation

- Algorithm to find cost of offshore architecture for a market

  1. Select market information (IAT, cargo volume/ship) and architecture

  2. Generate configuration list of architecture
     (# of TU, # of berth, # of truck and etc.)

  3. Calculate SST and remove configurations which do not provide service in < 24hours

  4. If SST > IAT, multiple $\left\lceil \frac{SST}{IAT} \right\rceil$ by the number of resource/ship

  5. Find minimum cost configuration among feasible configuration
Result

- Cheapest configuration cost of architecture for 100 markets
  - 0.146 M TEU/year ~ 2.4 M TEU/year
  - IAT change 1.5 ~ 30 hours
  - Cargo changes 500~ 4100 TEU

<cheapest configuration for each market condition that meets the SST<24hours restriction>
## Result

<table>
<thead>
<tr>
<th>IAT (Hour)</th>
<th>Cargo (TEU)</th>
<th>Arch 1</th>
<th>Arch 2</th>
<th>Arch 3</th>
<th>Arch 4</th>
<th>Arch 5</th>
<th>Arch 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>500</td>
<td>684</td>
<td>579</td>
<td>497.64</td>
<td>492.88</td>
<td>464.76</td>
<td>459.28</td>
</tr>
<tr>
<td>2</td>
<td>900</td>
<td>882</td>
<td>772</td>
<td>649.32</td>
<td>692.72</td>
<td>617.64</td>
<td>649.12</td>
</tr>
<tr>
<td>2.4</td>
<td>1300</td>
<td>1064</td>
<td>936</td>
<td>763.14</td>
<td>785.5</td>
<td>731.78</td>
<td>759.06</td>
</tr>
<tr>
<td>3</td>
<td>1700</td>
<td>1216</td>
<td>952</td>
<td>811.8</td>
<td>852.6</td>
<td>780.12</td>
<td>801</td>
</tr>
<tr>
<td>4</td>
<td>1700</td>
<td>912</td>
<td>714</td>
<td>638.52</td>
<td>625.1</td>
<td>594.08</td>
<td>582.1</td>
</tr>
<tr>
<td>6</td>
<td>2100</td>
<td>760</td>
<td>624</td>
<td>534</td>
<td>503.28</td>
<td>513.68</td>
<td>496.44</td>
</tr>
<tr>
<td>12</td>
<td>2500</td>
<td>480</td>
<td>356</td>
<td>317.36</td>
<td>310.6</td>
<td>297.04</td>
<td>297</td>
</tr>
<tr>
<td>24</td>
<td>3300</td>
<td>366</td>
<td>238</td>
<td>243.52</td>
<td>214.84</td>
<td>232.38</td>
<td>199.64</td>
</tr>
<tr>
<td>30</td>
<td>2100</td>
<td>190</td>
<td>163</td>
<td>133.5</td>
<td>125.82</td>
<td>128.42</td>
<td>130.2</td>
</tr>
</tbody>
</table>

*<The subset of cheapest configuration of six offshore architecture for given market condition>*
Concluding Remarks

• Method to finding proper initial design for a market
  – 9 and 128 feasible port architecture are enumerated
  – Ship service time approximation
  – Algorithm to find cheapest configuration of a offshore architecture
  – Minimum cost architecture and its configuration for 100 markets

• Future research
  – Multi criteria comparison
  – Simulation or queueing model for random data
  – Combination concepts with traditional and offshore mode
Comparison between traditional mode and offshore mode

<table>
<thead>
<tr>
<th>Construction period</th>
<th>1999~2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of quay</td>
<td>4</td>
</tr>
<tr>
<td>Length of quay</td>
<td>1400m</td>
</tr>
<tr>
<td>Total cost for quay</td>
<td>327B</td>
</tr>
<tr>
<td>Number of crane/quay</td>
<td>3</td>
</tr>
<tr>
<td>Cost/crane</td>
<td>6B</td>
</tr>
<tr>
<td>Number of YT</td>
<td>76</td>
</tr>
<tr>
<td>Main target ship</td>
<td>4000 TEU</td>
</tr>
<tr>
<td>Cost / yearly throughput</td>
<td>406.6B/1,600,000 = 254,125 Won/TEU</td>
</tr>
</tbody>
</table>

<Construction information of Gwang Yang port in Korea>

- A traditional port in Korea is more cost effective

- There is very expensive land rental cost and tax in Hong Kong
  - Mid stream has 1/3 cost due to depth of berth

- For collection of small market, having one MH is better than having each market have own crane