Capacity and Queueing Evaluation of Port systems with Offshore Container Unloading

Woo-sung Kim, Jong Hoe Kim, Hyoyoung Kim, Hyeyon Kwon and James R. Morssion
KAIST, Department of Industrial and Systems Engineering

LOGMS 2010
BUSAN, KOREA
September 15, 2010
Presentation overview

• Introduction
• Throughput analysis
  - Bounds on the number of mobile harbor fleets: Ideal ship service
  - Ship service time approximation: MH delays at the land berth and ships
  - Petri net model
• Queueing analysis
  - Approximation for the number of MHs and berths to achieve a given service level
  - Approximation for cycle time of a ship
• Concluding Remarks
Introduction

• As the volume of trade between nations has grown, worldwide maritime container transport has followed.

< Global container shipping [1]>

Introduction

• Constructing new berth requires substantial time, is very costly.

< Busan port, South Korea >
Introduction

- Mobile harbor system can be one of alternative solution.
- In here, we study evaluation techniques for mobile harbor system.
- We assume that a group of mobile harbors operate together (Fleet).
Introduction

• We develop several evaluation techniques for ship staying time of mobile harbor system.

Are Inter-arrival times sufficient?

Throughput Analysis

YES

Approximation I

Sufficient land berth?

Approximation II

Less intuition

But exact

Petri-net model

NO

Queueing Analysis

Insufficient land berth?
Throughput analysis: Bounds on the number of mobile harbors

Assumption: 1. All unloading operation finish before the next container ship arrives. 2. Infinite land berths.

- If unloading time is longer than travel time and releasing time, two MH fleets are required.
Throughput analysis: Bounds on the number of mobile harbors

Assumption: All unloading operation finish before the next container ship arrives. (Therefore, all resources can provide service to one ship).

- If unloading time is longer than travel time and releasing time, two MH fleets are required.
Throughput analysis: Bounds on the number of mobile harbors

Assumption: All unloading operation finish before the next container ship arrives. (Therefore, all resources can provide service to one ship).

- If unloading time is longer than travel time and releasing time, two MH fleets are required.
Throughput analysis: Bounds on the number of mobile harbors

Assumption: All unloading operation finish before the next container ship arrives. (Therefore, all resources can provide service to one ship).

- If unloading time is longer than travel time and releasing time, two MH fleets are required.
Throughput analysis: Ship service time approximation

With similar idea, we can obtain lower bound on the number of mobile harbor fleets required to provide uninterrupted service to incoming ships.

\[ n_{MH} \geq \begin{cases} 
2 \cdot \min \left( \left\lfloor \frac{n_{TU}}{c_{MH} \cdot n_{D}} \right\rfloor, \left\lfloor \frac{2Tr+R}{U} \right\rfloor + 1 \right), \\
\min \left( \left\lfloor \frac{n_{TU}}{c_{MH} \cdot n_{D}} \right\rfloor, \left\lfloor \frac{2Tr+R}{U} \right\rfloor + 1 \right) + \left\lfloor \frac{(U+2Tr+R)-(\frac{n_{TU}}{c_{MH} \cdot n_{D}} \cdot U)}{L} \right\rfloor, \\
2 \cdot \min \left( \left\lfloor \frac{n_{TU}}{c_{MH} \cdot n_{D}} \right\rfloor, \left\lfloor \frac{2Tr+R}{U} \right\rfloor + 1 \right) + \left\lfloor \frac{(U+2Tr+R)-(\frac{n_{TU}}{c_{MH} \cdot n_{D}} \cdot U+\frac{n_{TU}}{c_{MH} \cdot n_{D}} \cdot L)}{U} \right\rfloor, \\
\end{cases} \]

Using the relation, we can obtain an approximation for the service time below:

Approximation I.

\[ E[SST] \approx n_{MH} \times \frac{2c_{MH} \cdot n_{D}}{V_s} \]

There are two restrictions.
- There may not be sufficient berths (hence, it is a lower bound).
- Mooring time is not considered.
Throughput analysis: Relaxing ideal service assumption

- Considering the restrictions, we develop another ship service time approximation with finite berth resources.
- There are three container flows in the mobile harbor system.
Throughput analysis: Relaxing ideal service assumption

- Considering the restrictions, we develop another ship service time approximation with finite berth resources.
- There are three container flows in the mobile harbor system.
Throughput analysis: Relaxing ideal service assumption

- Considering the restrictions, we develop another ship service time approximation with finite berth resources.
- There are three container flows in the mobile harbor system.
Throughput analysis: Relaxing ideal service assumption

- The maximum container throughput is less than the bottleneck capacity at each of three flow.
  
  \[ \mu \leq \min\{\lambda_1, \lambda_2, \lambda_3\} =: \mu^* \]

- Then SST can be obtained below:

  \[
  \text{SST} \approx \frac{nTU}{\mu^*} 
  \]

- Finally, we can obtain the approximation II for ship service time.

  \[
  \text{SST} \approx \frac{nTU}{\min(nD, nMH) * V_s, \frac{cTU}{cMH V_s} + 2 * \frac{d}{V_t} + \frac{cMH}{V_b} + T_{wb} + T_{ws}} 
  \]

- Gap between the approximation II and the simulation is 6.49%.
Throughput analysis: Petri net model

• Petri net is a graphical and mathematical modeling tool that can be used for many systems.
• We develop petri net model.

Bars represent events.
• Circles represent conditions.
Throughput analysis: Petri net model

- We can represent cycle time as below:

\[
\max \left\{ \frac{nD}{r_3 + r_1 + 2r_2 + r_3 + r_8}, \frac{nTU}{2r_1 + 2r_2 + 2r_3 + r_4 + r_5 + r_6 + r_7}, \frac{nMH}{r_1 + 2r_2 + r_3 + r_4 + r_5 + r_6 + r_7 + r_8}, \frac{nB}{nD + nMH + nTU}, \frac{nD + nMH}{nB + nMH + nTU} \right\}
\]

- The petri net analysis provides an exact value for the throughput.

- It is difficult to model the complexity of a MH system as a decision free Petri net.
Queueing analysis: Approximation for cycle time of a ship

• Employing fleet concept, we can model the system as a modified M/G/c queueing system.
Queueing analysis: Approximation for cycle time of a ship

First, we estimate ship service time.

\[
E[SST] \approx \frac{nTU}{nD \times V_s} + \left[ \frac{nTU}{nD \times cMH} - 1 \right] \times \frac{2d}{V_t} + \frac{nTU}{V_b} + \frac{1}{2} \frac{nC}{V_b} \frac{\rho_b^m}{(1 - \rho_b^m)}
\]

Then, using the SST, we can estimate cycle time of a ship.

\[
E[CT] \approx E[SST] + \left( \frac{2d}{V_t} \right) \left( 1 + \frac{C_S^2}{2} \right) \frac{\rho_s^n}{(1 - \rho_s^n)}
\]

Comparing with simulation, we can see that the errors are in 7%.

<table>
<thead>
<tr>
<th>Group of berths</th>
<th># of MH fleets</th>
<th>Simulation</th>
<th>Approximation</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>8</td>
<td>60.60</td>
<td>64.30</td>
<td>6.11%</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>58.77</td>
<td>58.62</td>
<td>0.26%</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>23.72</td>
<td>23.10</td>
<td>2.61%</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
<td>23.63</td>
<td>22.58</td>
<td>4.44%</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>17.31</td>
<td>16.99</td>
<td>1.85%</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>16.86</td>
<td>16.15</td>
<td>4.21%</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>14.53</td>
<td>15.23</td>
<td>4.81%</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>14.12</td>
<td>14.73</td>
<td>4.32%</td>
</tr>
</tbody>
</table>
Queueing analysis: Number of MHs and berths to achieve a service level

- M/M/c queueing model
- We employ service level metric: W/S ratio (the waiting time to service time ratio).

<table>
<thead>
<tr>
<th>Number of TU/group</th>
<th>Number of berth/group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>0.458552</td>
</tr>
<tr>
<td>9</td>
<td>0.420892</td>
</tr>
<tr>
<td>10</td>
<td>0.380961</td>
</tr>
<tr>
<td>11</td>
<td>0.344007</td>
</tr>
<tr>
<td>12</td>
<td>0.311507</td>
</tr>
<tr>
<td>13</td>
<td>0.299763</td>
</tr>
<tr>
<td>14</td>
<td>0.285772</td>
</tr>
<tr>
<td>15</td>
<td>0.271129</td>
</tr>
<tr>
<td>16</td>
<td>0.259436</td>
</tr>
</tbody>
</table>
Concluding remarks

• We develop several techniques to evaluate the mobile harbor system.

• To test approximations, we develop simulations of the mobile harbor system.

• These analysis techniques may be improved by consideration of how they may support each other.