ANALYSIS AND OPTIMIZATION OF CHASSIS MOVEMENTS IN TRANSPORTATION NETWORKS WITH CENTRALIZED PROCESSING OF CHASSIS FACILITIES

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Schematic of centralized processing of chassis concept

Direct transaction with terminal

Transaction routed through CPF
Transaction Types

**Type 1**
Bobtail + chassis + export → bobtail

**Type 2**
Bobtail → grounded(chassis + import)

**Type 3**
Bobtail → wheeled(chassis + import)

**Type 4**
Bobtail + chassis + export → grounded(chassis + import)

**Type 5**
Bobtail + chassis + export → wheeled(chassis + import)
Transaction Types

**Type 1**
Bobtail + chassis + export → bobtail

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Bobtail + chassis + export → wheeled(chassis + import)

Chassis transactions where offsite chassis exchange may be beneficial

Chassis transactions where offsite chassis exchange likely more costly
### Terminology

- $J$ Number of TCs collaborating with the CPFs
- $K$ Number of potential sites for CPFs
- $L$ Number of participating MTs
- $TC_j$ The $j^{th}$ trucking company $j \in [1, \ldots, J]$
- $CPF_k$ The $k^{th}$ chassis processing facility $k \in [1, \ldots, K]$
- $MT_l$ The $l^{th}$ marine terminal $l \in [1, \ldots, L]$
- $n_{jl}$ Number of import transactions from $TC_j$ to $MT_l$
- $m_{jl}$ Number of export transactions from $TC_j$ to $MT_l$
- $U_k$ Storage capacity of chassis at $CPF_k$
- $U_{k,0}$ Initial Storage capacity of chassis at $CPF_k$
- $C_{T_jF_k}$ Cost of transactions between $TC_j$ and $CPF_k$
- $C_{F_kM_l}$ Cost of transactions between $CPF_k$ and $MT_l$
- $C_{T_jM_l}$ Cost of transactions between $TC_j$ and $MT_l$
- $x_{jkl}$ Number of import transactions from $TC_j$ to $MT_l$ routed through $CPF_k$
- $y_{jl}$ Number of import transactions routed directly from $TC_j$ to $MT_l$
- $\alpha_{jkl}$ Number of export transactions from $TC_j$ to $MT_l$ routed through $CPF_k$
- $\beta_{jl}$ Number of export transactions routed directly from $TC_j$ to $MT_l$
Import Only Formulation

\[
\begin{align*}
\text{min} & \quad \sum_{j=1}^{J} \sum_{k=1}^{K} C_{TjFk} \left( \sum_{l=1}^{L} x_{jkl} \right) + \sum_{k=1}^{K} \sum_{l=1}^{L} C_{FKMl} \left( \sum_{j=1}^{J} x_{jkl} \right) + \sum_{j=1}^{J} \sum_{l=1}^{L} C_{TjMl} y_{jl} \\
\text{s.t.} & \quad \sum_{k=1}^{K} x_{jkl} + y_{jl} = n_{jl} \quad j = 1, \ldots, J; \quad l = 1, \ldots, L \\
& \quad \sum_{j=1}^{J} \sum_{l=1}^{L} x_{jkl} \leq U_{k} \quad k = 1, \ldots, K \\
& \quad x_{jkl} \in \mathbb{N}^{0} \quad j = 1, \ldots, J; \quad l = 1, \ldots, L; \quad k = 1, \ldots, K \\
& \quad y_{jl} \in \mathbb{N}^{0} \quad j = 1, \ldots, J; \quad l = 1, \ldots, L
\end{align*}
\]
Import and Export Formulation

\[
\begin{align*}
\min & \quad \sum_{j=1}^{J} \sum_{k=1}^{K} C_{T_{F_k}} \left( \sum_{l=1}^{L} x_{jkl} \right) + \sum_{j=1}^{J} \sum_{k=1}^{K} C_{F_{M_l}} \left( \sum_{l=1}^{L} x_{jkl} \right) + \sum_{j=1}^{J} \sum_{l=1}^{L} C_{T_{M_l}} y_{jl} \\
& \quad + \sum_{j=1}^{J} \sum_{k=1}^{K} C_{T_{F_k}} \left( \sum_{l=1}^{L} \alpha_{jkl} \right) + \sum_{j=1}^{J} \sum_{l=1}^{L} C_{F_{M_l}} \left( \sum_{j=1}^{J} \alpha_{jkl} \right) \\
& \quad + \sum_{j=1}^{J} \sum_{l=1}^{L} C_{T_{M_l}} \beta_{jl} \\
\text{s.t.} & \quad \sum_{k=1}^{K} x_{jkl} + y_{jl} = n_{jl} \quad j = 1, \ldots, J; \ l = 1, \ldots, L \\
& \quad \sum_{k=1}^{K} \alpha_{jkl} + \beta_{jl} = m_{jl} \quad j = 1, \ldots, J; \ l = 1, \ldots, L \\
& \quad \sum_{j=1}^{J} \sum_{l=1}^{L} (x_{jkl} - \alpha_{jkl}) \leq U_{k,0} \quad k = 1, \ldots, K \\
& \quad \sum_{j=1}^{J} \sum_{l=1}^{L} (x_{jkl} - \alpha_{jkl}) \geq U_{k,0} - U_{k} \quad k = 1, \ldots, K \\
& \quad x_{jkl} \in \mathbb{N}^0 \quad j = 1, \ldots, J; \ l = 1, \ldots, L; \ k = 1, \ldots, K \\
& \quad y_{jl} \in \mathbb{N}^0 \quad j = 1, \ldots, J; \ l = 1, \ldots, L \\
& \quad \alpha_{jkl} \in \mathbb{N}^0 \quad j = 1, \ldots, J; \ l = 1, \ldots, L; \ k = 1, \ldots, K
\end{align*}
\]
Limited Chassis Processing Facility Usage

\( N_{cpf} \)  Maximum number of allowable CPFs
\( z_k \)  Variable identifying if CPF k has any transactions

\[
z_k = \begin{cases} 
1, & \sum_{j=1}^{J} \sum_{l=1}^{L} x_{jkl} \geq 0, \ k = 1, \ldots, K \\
0, & \text{otherwise}
\end{cases}
\]

(15)

\[
\sum_{k=1}^{K} z_k \leq N_{cpf}
\]

(16)

\[
z_k = \begin{cases} 
1, & \sum_{j=1}^{J} \sum_{l=1}^{L} (x_{jkl} + \alpha_{jkl}) \geq 0, \ k = 1, \ldots, K \\
0, & \text{otherwise}
\end{cases}
\]

(17)

\( N_{cpf} \)  Maximum number of allowable CPFs
\( z_k \)  Variable identifying if CPF k has any transactions
Long Beach region TC, CPF and MT locations.

<table>
<thead>
<tr>
<th>CPF ID</th>
<th>Capacity</th>
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<tbody>
<tr>
<td>1</td>
<td>7467</td>
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<tr>
<td>2</td>
<td>4048</td>
</tr>
<tr>
<td>3</td>
<td>16779</td>
</tr>
<tr>
<td>4</td>
<td>6350</td>
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<td>5</td>
<td>20551</td>
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<td>20469</td>
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<td>14</td>
<td>1877</td>
</tr>
<tr>
<td>15</td>
<td>2258</td>
</tr>
<tr>
<td>16</td>
<td>6959</td>
</tr>
</tbody>
</table>
Marine Terminal Locations

Port of Long Beach and Los Angeles
This map contains all container terminals for the port of LA and LB.

Legend
- POLA APM Terminals Pacific
- POLA California United Terminals
- POLA China Shipping - WBCT
- POLA Eagle Marine Services, APL, GGS
- POLA Evertop Terminal Services
- POLA TraPac, Inc
- POLA Yang Ming Transport - WBCT
- POLA Yusen Terminals, Inc
- POLB ITS
- POLB LECT
- POLB Pacific Container Terminal
- POLB SSA (MSC, Zim, SMA/CGM)
- POLB SSA - Pier A
- POLB TTI
### POLB and POLA import and export statistics for 2015

<table>
<thead>
<tr>
<th></th>
<th>loaded import</th>
<th>loaded export</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEU POLB</td>
<td>3,625,263</td>
<td>1,525,560</td>
</tr>
<tr>
<td>TEU POLA</td>
<td>4,159,462</td>
<td>1,786,913</td>
</tr>
<tr>
<td>TEU Total (Year)</td>
<td>7,784,725</td>
<td>3,312,473</td>
</tr>
<tr>
<td>TEU Total Avg (Day)</td>
<td>21,328</td>
<td>9,075</td>
</tr>
</tbody>
</table>
Case Study Assumptions

- Seventy-one trucking companies which service the POLB and POLA were identified for use in this case study
  - Selected using drayage directory with all TCs that operate within the Los Angeles County
  - List narrowed down to TCs which use chassis
  - TCs which did not include addresses were eliminated, arriving at the seventy-one TCs used in this study

- Number of daily transactions between marine terminals and trucking companies assumed to be a fixed identical integer value between each trucking company and each marine terminal
  - Selected to control for a total number of daily transactions for the combination of all trucking companies
  - In the initial analysis the number of total import transactions was fixed at 50,000 FEU import transactions whereas later analysis used 10,000 and 5,000 FEU import and export transactions to more closely match terminal traffic through the POLB and POLA as noted above

- Additional Processing Time (P) defined as follows used to compare results of different optimization scenarios

\[
P = T_{MT} - T_{CPF}
\]

where \(T_{MT}\) = (Avg chassis retrieval time at a MT) and \(T_{CPF}\) = (Avg chassis retrieval time at a CPF)
Number of transactions routed through CPFs at optimality, as a function of P

Total number of transactions routed through each CPF or directly to the MT for the optimal solution. In this figure: (i) only import transactions are considered; (ii) all CPFs are available; (iii) the full model is used (including all 101 nodes of TCs, CPFs and MTs).
Percent improvement in total travel time at optimality. The improvement is calculated as the percent decrease in total travel time from the case (a) When all transactions are routed to the MTs; to the case (b) When transactions are routed to optimally. The percent improvement is plotted against the number of available CPFs. In this Figure: (i) both import and export transactions are considered; (ii) two values of the parameter P are studied (P=600 sec, and P=1200 sec); (iii) the full model is used (including all 101 nodes of TCs, CPFs and MTs).
Optimal solution 1-3 CPFs available
Ranking of CPF candidate locations

Ranking of CPF candidate locations ($P = 600$ sec)
Sensitivity Analyses Performed

- Analyzed Impact of
  - Number of CPFs used
  - CPF capacity
  - Total Number of Transactions
  - Ratio of Import to Export Transactions
CPF rankings vs CPF capacity – import and export.

<table>
<thead>
<tr>
<th>CPF #</th>
<th>CPF Ranking</th>
<th>cost function output (total travel time in seconds * 10^7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline CPF Capacity</td>
<td>Unlimited CPF Capacity</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>15</td>
</tr>
<tr>
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<td>16</td>
<td>7</td>
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<td>3</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6</td>
</tr>
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Change in optimal solution
Change in top 5 ranked solution
## Impact of Total Transactions

<table>
<thead>
<tr>
<th>Total Transactions</th>
<th>Imports</th>
<th>Exports</th>
<th>Difference</th>
<th>CPF Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>7500</td>
<td>2500</td>
<td>5000</td>
<td>2500</td>
<td>3 15 6 15 1 15 3 16 6 16</td>
</tr>
<tr>
<td>15000</td>
<td>5000</td>
<td>10000</td>
<td>5000</td>
<td>3 15 6 15 3 16 1 15 6 16</td>
</tr>
<tr>
<td>22500</td>
<td>7500</td>
<td>15000</td>
<td>7500</td>
<td>3 15 6 15 3 16 6 16 3 12</td>
</tr>
<tr>
<td>30000</td>
<td>10000</td>
<td>20000</td>
<td>10000</td>
<td>3 15 6 15 3 16 6 16 3 12</td>
</tr>
</tbody>
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</thead>
<tbody>
<tr>
<td>37500</td>
<td>12500</td>
<td>25000</td>
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<td>6 15 3 15 3 16 6 16</td>
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<td>52500</td>
<td>17500</td>
<td>35000</td>
<td>17500</td>
<td>6 15 6 16 3 15 3 16 3 6</td>
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<tr>
<td>60000</td>
<td>20000</td>
<td>40000</td>
<td>20000</td>
<td>6 15 6 16 3 15 3 16 3 6</td>
</tr>
</tbody>
</table>

Change in optimal solution
Change in top 5 ranked solution
Total travel time vs export surplus / deficit

Percent change in total travel time for optimal solution as compared to case with equal numbers of imports and exports versus the ratio of exports and imports for a fixed total number of transaction (exports + imports). In this example import and export transactions were considered and the full model including all nodes (TCs, CPFs and MTs) was used.
Summary / Conclusions

- Concept of Centralized Processing of Chassis explored
  - Linear mathematical framework defined for optimization of total travel time by TCs
  - Case study using the ports of Long Beach and Los Angeles was performed
  - Sensitivity analysis performed
  - Initial Discrete Model Simulation Created

- Results
  - For POLB and POLA if the CPF locations offered a 10 minute improvement in chassis retrieval time, improvements in total travel time between 5-10 percent could be expected
  - Optimal locations and CPF combinations were recommended which could be selected to optimize total travel time for a variety of cost constraints
  - Sensitivity analyses indicated that CPF capacities, total numbers of transactions, and import / export ratios had little impact on the ranking of CPFs wrt total travel time
Potential Follow On Activities

- Further development of discrete simulation model and characterization of total travel time over a wider variety of real-life scenarios
  - Daily traffic variations
  - Queuing at the marine terminal and chassis retrieval locations
  - Other random variations which represent a more realistic environment

- Further development of the analytical model to include
  - Stochastic processes
  - Assessment of the impact on emissions
  - Modifications to optimize for total cost including actual cost of establishing and maintaining CPFs