Integrated Planning for Small Package Carriers

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Outline

- Planning process for small package carriers
  - Load matching and routing
  - Equipment balancing
- Literature
- Modeling approaches
  - Traditional multi-commodity flow approach
  - Alternative complex variable approach
- Computational results
- Current and future research directions
Planning process for small package carriers

- What are small package carriers?
- Planning process broken into four sequential subproblems
  1. Load planning problem
  2. Load matching and routing
  3. Equipment balancing
  4. Driver scheduling problem
Planning process for small package carriers

- **Load planning problem**
  - Determine routing or path for each package
  - Service commitments and sort capacities must not be violated
  - Assign volume to a trailer type
Planning process for small package carriers

- **Load matching and routing problem**
  - Route all loads from origin to destination within time window
  - Non-linear cost structure: *single trailer combination* vs. *double trailer combination*
  - May incur circuitous mileage to move load as part of double combination
Planning process for small package carriers

- **Equipment balancing**
  - Delivering loads from origin to destination causes some areas of the network to accumulate trailers and others to run out
  - Redistribute trailers so that no such imbalances occur

- **Driver scheduling**
  - Take output of load matching and equipment balancing problems and assign drivers to each tractor movement
Planning process for small package carriers

1. Load planning problem
2. Load matching and routing
3. Equipment balancing
4. Driver scheduling problem
Planning process for small package carriers

1. Load planning problem
2. *Load matching and routing*
3. *Equipment balancing*
4. Driver scheduling problem
Specific integrated load matching and routing and equipment balancing problem (ILMREBP) not considered in the literature to the best of our knowledge

Bodies of related literature

- General multi-commodity flows
- Multi-commodity flows with non-linear arc costs
- Express package industry
- Time windows
- Empty balancing
Multi-commodity flow based model

- Use time-space network to capture time constraints

- Decision variables
  - $x_{ijk}$ – flow of commodity $k$ on arc $(i,j)$
  - $y_{ij}$ – flow of empty trailers on arc $(i,j)$
  - $s_{ij}$ – flow of single trailer combinations on arc $(i,j)$
  - $d_{ij}$ – flow of double trailer combinations on arc $(i,j)$
Multi-commodity flow based model

\[
\begin{align*}
\text{min} & \quad \sum_{(i,j) \in A} c_{ij}^s s_{ij} + \sum_{(i,j) \in A} c_{ij}^d d_{ij} \\
\text{s.t.} & \quad \sum_{i:\{(j,i)\in A\}} x_{ijk} - \sum_{i:\{(i,j)\in A\}} x_{ijk} = b_{jk} \quad \forall j \text{ in } V, k \text{ in } K \\
& \quad s_{ij} + 2d_{ij} = \sum_{k \in K} x_{ijk} + y_{ij} \quad \forall (i,j) \text{ in } A \\
& \quad \sum_{j \in V_f} \left( \sum_{k \in K} b_{jk} + \sum_{i:\{(j,i)\in A\}} y_{ji} - \sum_{i:\{(i,j)\in A\}} y_{ji} \right) = 0 \quad \forall f \text{ in } F \\
& \quad x_{ijk}, y_{ij}, s_{ij}, d_{ij} \text{ in } Z^+ 
\end{align*}
\]
Multi-commodity flow based model

- **Problem size**
  - Large number of constraints ($|V| |K| + |A| + |F|$)
  - 1,100 facilities; 24,000 inter-facility arcs; 15,000 commodities routed daily in the United States network
  - Time space network increases the number of nodes and arcs

- **VERY** fractional LP relaxation
  - Incentive to send $\frac{1}{2}$ double trailers instead of single trailers because of cost structure

- Problem does not converge to a feasible solution even after relaxing time requirements
Cluster-based modeling approach

- Instead of considering the movement of trailers along each arc, consider groups of trailers which move together.

- A *cluster* is a set of loads, a set of empties, the routes they take, and the tractor configurations that pull them.
  - Every load moves completely from origin to destination.
  - Only define clusters which are time feasible.
Cluster-based modeling approach
Cluster-based modeling approach

\[ \text{min } \sum_c c_c x_c \]

s.t. \[ \sum_c \delta^l_c x_c = 1 \quad \forall \ l \text{ in } L \]

\[ \sum_c \eta^f_c x_c = 0 \quad \forall \ f \text{ in } F \]

\[ x_c \text{ in } \mathbb{Z}^+ \]
Cluster-based modeling approach

- Creation of clusters using *partial enumeration* and *cluster templates*

<table>
<thead>
<tr>
<th>One load</th>
<th>Two loads same destination</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>One load + empty</td>
<td>Double empty</td>
</tr>
<tr>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
</tr>
</tbody>
</table>
Computational Results

- Moderately sized data set
  - 2,000 loads; 250 facilities

- Cluster-based model converged to an integer solution within 15 seconds
  - Within a few minutes, within 0.73% of the optimal solution using the subset of clusters
  - Still incentive to split empties into $\frac{1}{2}$ double empty combinations—optimality gap of 0.51% after three hours

- Results show more than 5% improvement relative to data from a major US carrier
Symmetry in Cluster-based Approach

- Many loads have the same origin, destination, and time window
  - Can be thought of as multiple copies of a single commodity
  - Affects the number of clusters generated and performance in the branch and bound tree

\[
\begin{align*}
\min & \quad \sum_c c_c x_c \\
\text{s.t.} & \quad \sum_c \delta_k^c x_c = b_k \quad \forall \ k \in K \\
& \quad \sum_c \eta^f_c x_c = 0 \quad \forall \ f \in F \\
& \quad x_c \in \mathbb{Z}^+ 
\end{align*}
\]
Future research directions

- Addressing the ½ double empty problem
- Timing issues
  - A priori expanding the time windows and seeing the effect on solution quality
  - Controlling the arrival of late loads to a facility
- Expansion of problem scope
  - Assigning volume to a trailer type (28’ or 40”)