
Integrated Planning for Small Package Carriers

Sarah Root

University of Michigan

Industrial and Operations Engineering

Joint work with Amy Cohn and Alex Wang

Support provided by a fellowship from the UPS Foundation

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
-

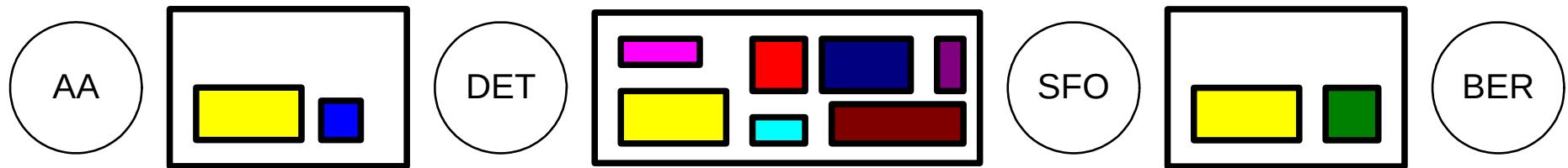
Planning process for small package carriers

- 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*

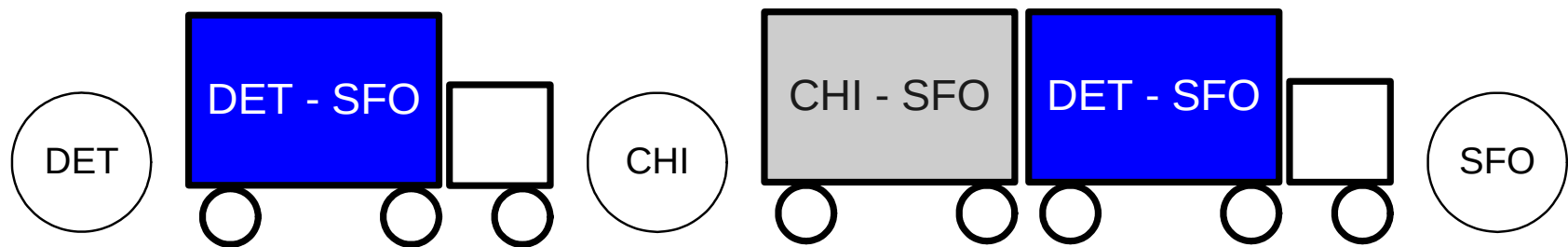
- Determine routing or path for each package
- Service commitments and sort capacities must not be violated
- Assign volume to a trailer type



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
-

Literature Review

- 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

$$\min \sum_{(i,j) \in A} c_{ij}^s s_{ij} + \sum_{(i,j) \in A} c_{ij}^d d_{ij}$$

$$\text{s.t.} \quad \sum_{i:(j,i) \in A} x_{jik} - \sum_{i:(i,j) \in A} x_{ijk} = b_{jk} \quad \forall j \text{ in } V, k \text{ in } K$$

$$s_{ij} + 2d_{ij} = \sum_{k \in K} x_{ijk} + y_{ij} \quad \forall (i,j) \text{ in } A$$

$$\sum_{j \in V_f} \left(\sum_{k \in K} b_{jk} + \sum_{i:(j,i) \in A} y_{ji} - \sum_{i:(i,j) \in A} y_{ji} \right) = 0 \quad \forall f \text{ in } F$$

$$x_{ijk}, y_{ij}, s_{ij}, d_{ij} \text{ in } \mathbb{Z}^+$$

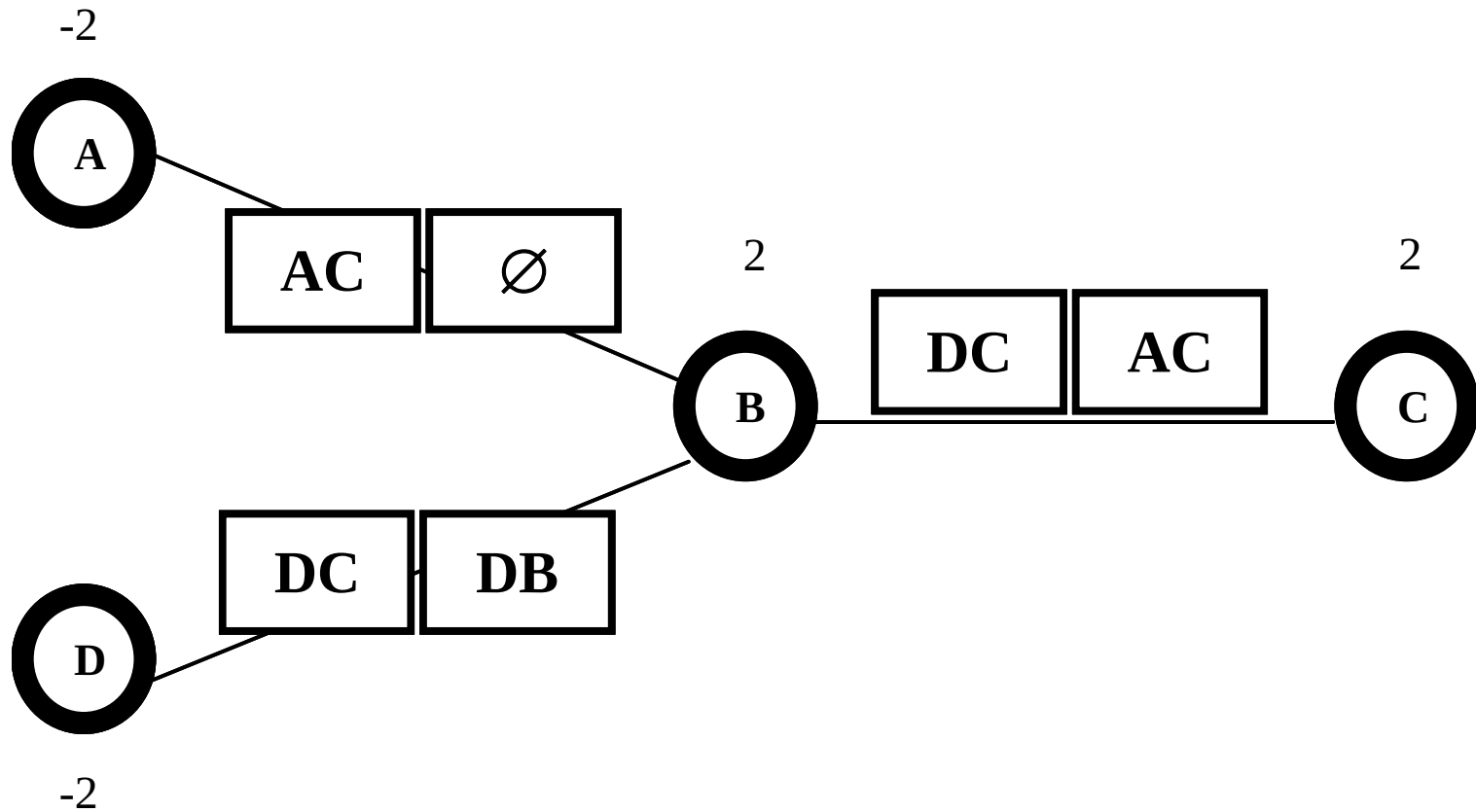
Multi-commodity flow based model

- 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

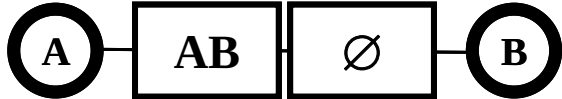


Cluster-based modeling approach

$$\begin{aligned} \min \quad & \sum_c c_c x_c \\ \text{s.t.} \quad & \sum_c \delta_c^l x_c = 1 \quad \forall l \text{ in } L \\ & \sum_c \eta_c^f x_c = 0 \quad \forall f \text{ in } F \\ & x_c \text{ in } \mathbb{Z}^+ \end{aligned}$$

Cluster-based modeling approach

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

One load  A diagram showing a horizontal line connecting two circular nodes labeled 'A' and 'B'. Between them is a rectangular box labeled 'AB'.	Two loads same destination  A diagram showing a sequence of nodes and boxes: a circular node 'A' connected to a rectangular box 'AC', which is connected to a circular node 'B'. Node 'B' is then connected to another rectangular box 'AC', which is connected to a third rectangular box 'BC', which is finally connected to a circular node 'C'.
One load + empty  A diagram showing a horizontal line connecting two circular nodes labeled 'A' and 'B'. Between them are two rectangular boxes: the first is labeled 'AB' and the second is empty, containing only the empty set symbol $\emptyset$.	Double empty  A diagram showing a horizontal line connecting two circular nodes labeled 'A' and 'B'. Between them are two empty rectangular boxes, each containing only the empty set symbol $\emptyset$.

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

$$\begin{aligned} \min \quad & \sum_c c_c x_c \\ \text{s.t.} \quad & \sum_c \delta_c^k x_c = b_k & \forall k \text{ in } K \\ & \sum_c \eta_c^f x_c = 0 & \forall f \text{ in } F \\ & x_c \text{ in } \mathbb{Z}^+ \end{aligned}$$

Future research directions

- Addressing the $\frac{1}{2}$ 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')
-