

Equipment Matching and Balancing for an Express Package Network

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October, 2004

INFORMS Denver

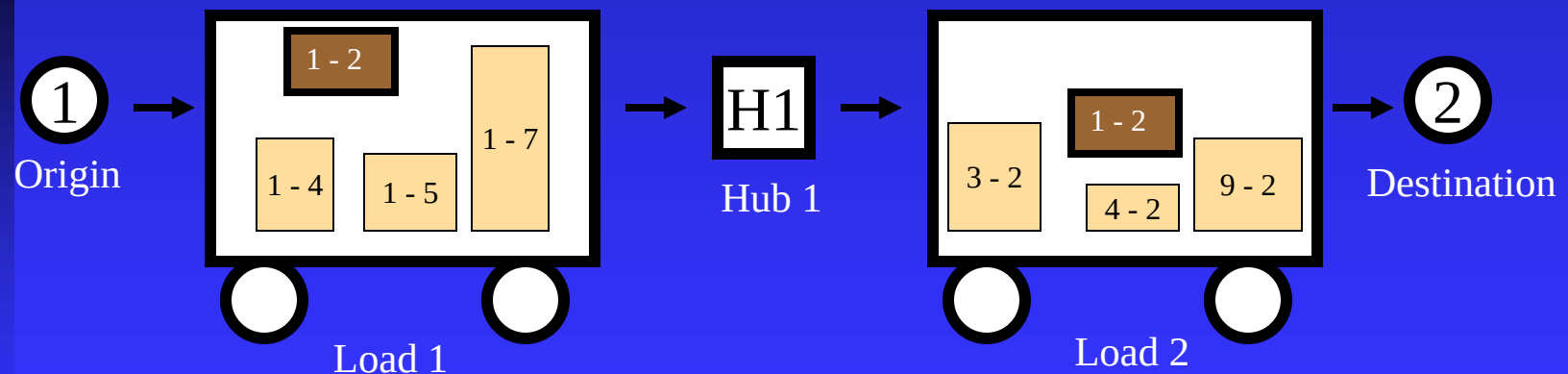


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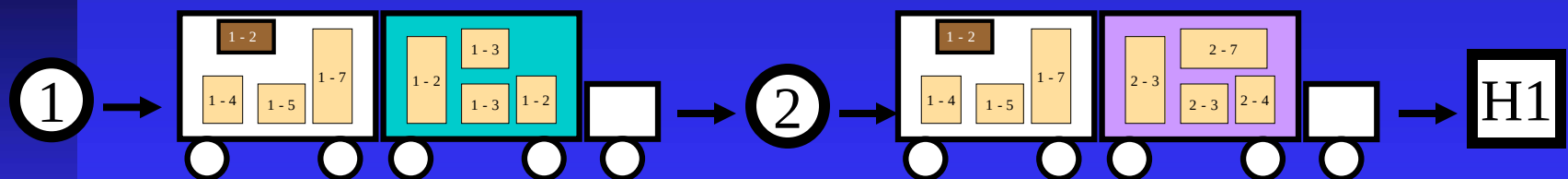
Express Package Networks

- Packages move from origin to destination via one or more hubs at which freight is unloaded, sorted, and reloaded
- Each trailer movement is called a *load*



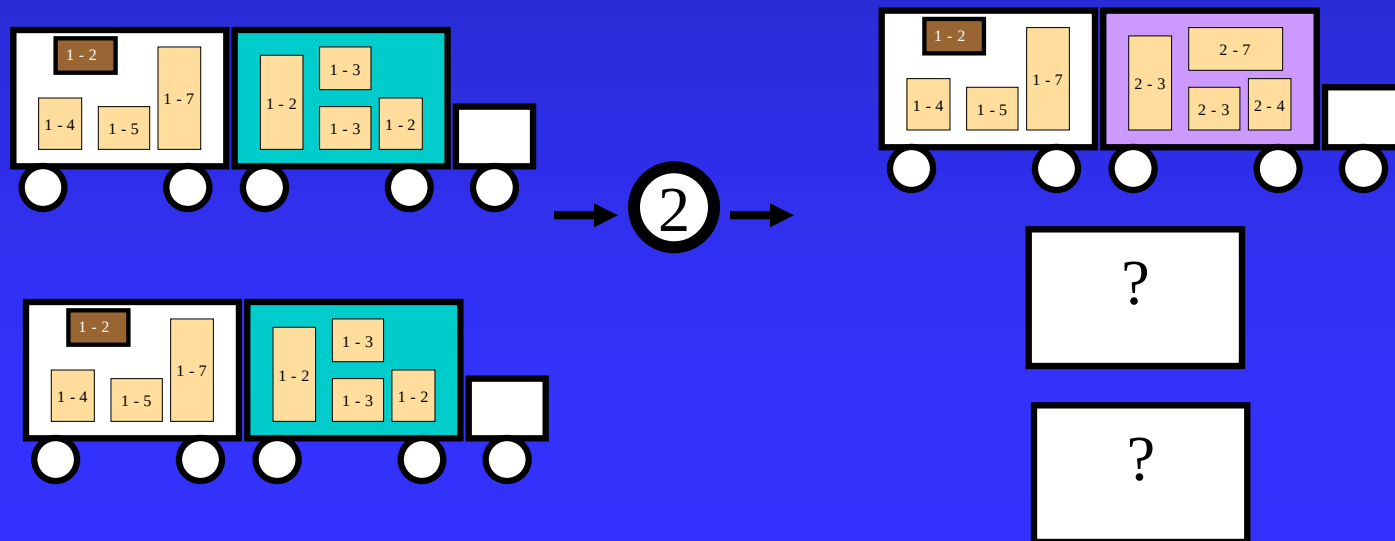
Load Matching

- Loads (trailers) are often coupled with other trailers for reduced transportation cost
 - ◆ The cost of pulling two trailers behind the same tractor is less than twice the cost of pulling a single trailer
- Loads may stop at intermediate points along the way to re-configure the tractor



Equipment Balancing

- Loaded trailer movements can result in system imbalances – some locations have more outbound loads than inbound, others more inbound than outbound
- We need to move empty trailers throughout the system to regain balance



Integrated Load Matching and Equipment Balancing Problem

- What loads should be matched?
 - ◆ When is it worth driving extra miles to combine two trailers?
- How should empty trailers be redistributed throughout the system?
 - ◆ At each location, total trailer flow out must equal total flow in
- Can we make these two decisions together for even greater savings?
 - ◆ Loaded and empty trailers can be paired together

Problem Description: Inputs

- Set of loads (each load has an origin, destination, trailer type, earliest available time, and latest delivery time)
- Permissible tractor configurations between each pair of locations
- Cost per mile of each configuration
- Mileage and travel time between each pair of locations

Problem Description: Constraints

- Loads must move contiguously in space and time from origin to destination
- Loads must satisfy time windows
- Link-specific tractor configuration rules must be observed
- Each location must be balanced (i.e. total number of trailers in must equal total number out, including both loaded and empty trailers)

Problem Description: Objective

Minimize total transportation cost,
incorporating cost function for different
modes and configurations

MCF Model with Side Constraints

- This can be thought of as a multi-commodity flow problem with side constraints
- Each load is a commodity that must be moved from origin to destination
- Side constraints are needed to ensure timing restrictions, linearize the objective function, and balance the network

Challenges of MCF

- How do we model the non-linear objective function to capture the benefit of different tractor configurations?
- How do we capture meets occurring at out-of-network locations?
- How do we incorporate timing issues?

Challenges of MCF

■ Problems:

- ◆ Very large number of nodes, constraints
 - ◆ If a time/space network is used to capture time constraints, grows even more
 - ◆ If non-facility meet points are permitted, grows further
- ◆ Weakness of LP relaxation – half a double is always better than a whole single

Alternative Model: Load Clusters

- As an alternative, we define the notion of a *load cluster* – a set of interconnected loads, the path each load takes, and the tractor configurations used to combine these loads
 - ◆ All loads must move fully from origin to destination
 - ◆ All loads must satisfy their time windows
 - ◆ No outside loads can be partially included in the configurations

Example Cluster

A load from A to B moves directly, as a single trailer:



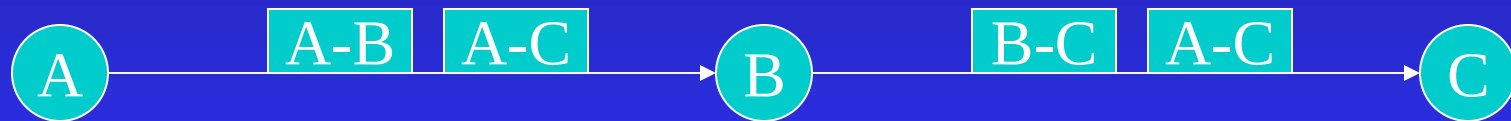
Example Cluster

A load from A to B moves directly, in combination with an empty trailer:



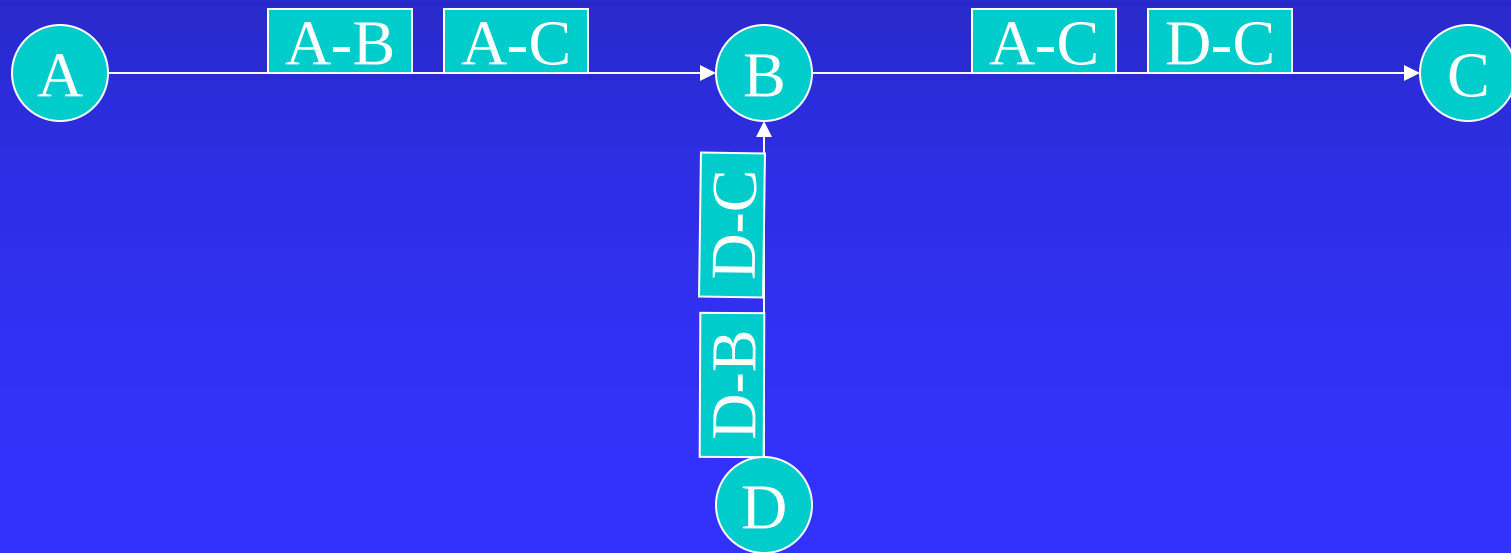
Example Cluster

Loads from A to B and A to C move via B, where the A to B load is dropped off and a load from B to C is picked up:



Example Cluster

Loads from A to B and A to C move via B,
as do loads from D to B and D to C:



The Load Cluster Model

- L is the set of loads
- C is the set of load clusters
- c_i is the cost of load cluster i
- F is the set of facilities
- δ_{il} is defined to be 1 if cluster i contains load l and 0 otherwise
- λ_{if} is the net surplus of trailers at facility f relative to cluster i
- x_i is a binary variable that takes value 1 if cluster i is chosen and 0 otherwise

The Load Cluster Model

$$\text{Min.} \quad \sum_{i \in C} c_i x_i$$

$$\text{St} \quad \sum_{i \in C} \delta_{il} x_i = 1 \quad \forall l \in L$$

$$\sum_{i \in C} \lambda_{if} x_i = 0 \quad \forall f \in F$$

$$x_i \in \{0, 1\} \quad \forall i \in C$$

Benefits

- The objective function is linear
- Timing issues are imbedded within the variable definition
- The number of constraints is greatly reduced
- The LP relaxation is strengthened
- Expanded solution space – the set of meet locations does not have to be limited to hubs or even to centers
- Multiple transportation modes can easily be incorporated

Drawbacks

- The key drawback to this approach is the exponential number of variables
- In practice, many of those combinations need not be included

Controlling Number of Variables

- Not all load clusters need to be considered – we can disregard many due to *infeasibility*, *dominance*, and *indifference*
- We can also use *column generation* to leverage the dual information to help us find useful load clusters
- We can also take a heuristic approach, based on considering only a subset of the load clusters, to find good solutions quickly

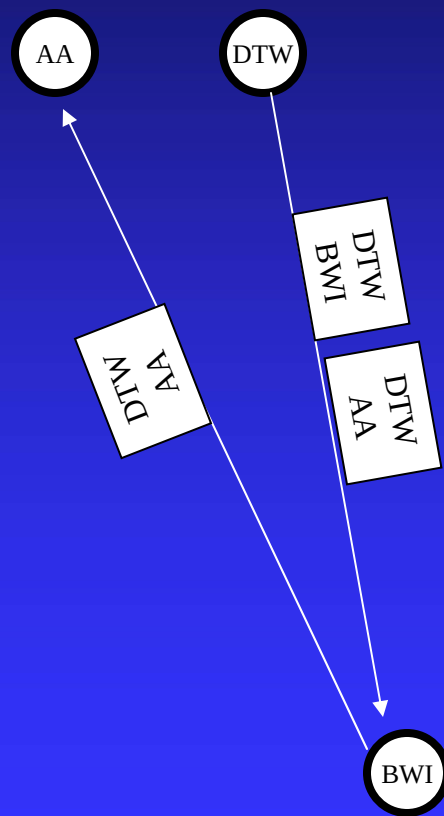
Infeasibility

- We can disregard any load cluster that...
 - ◆ ...violates time constraints
 - ◆ ...violates highway restrictions on tractor configurations
 - ◆ ...does not move its loads exhaustively and exclusively

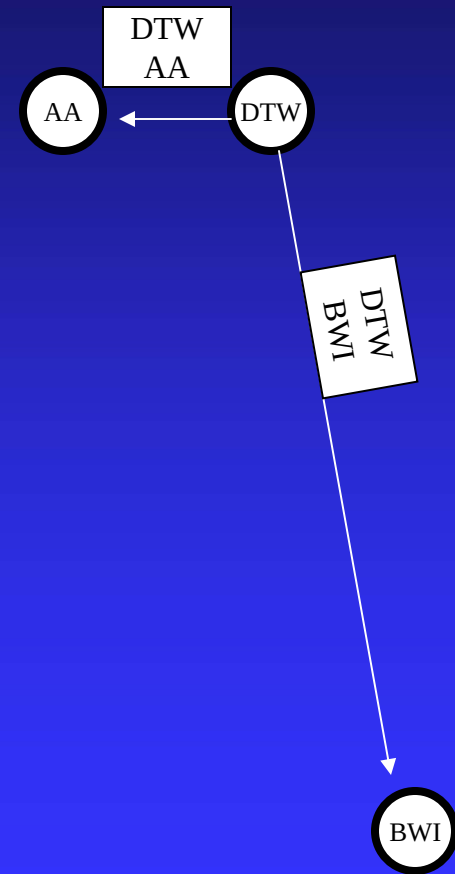
Dominance

- We say that one load cluster is *dominated* by another load cluster (or by a set of load clusters) if they cover the same loads and have the same impact on balance but the first has higher cost
- We can disregard all dominated load clusters

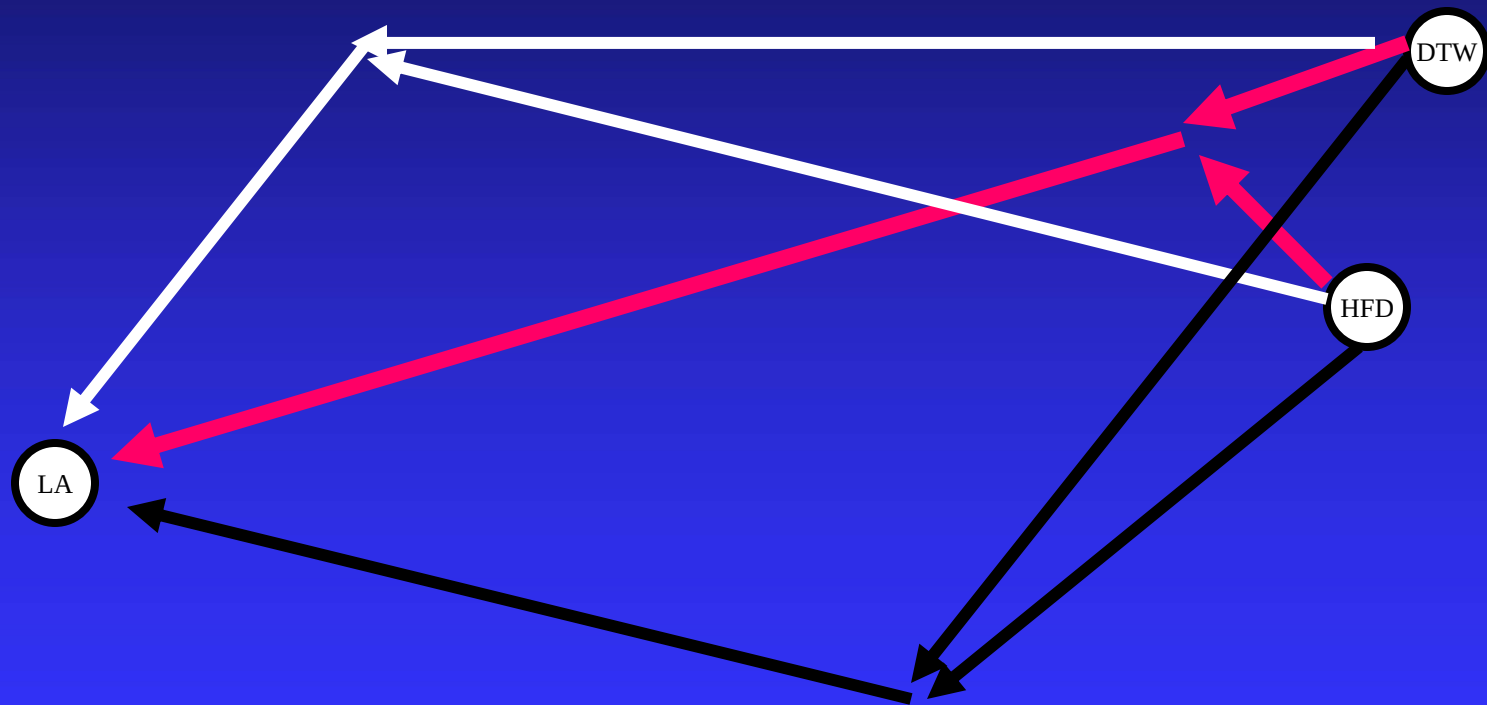
Dominance Example



VS.



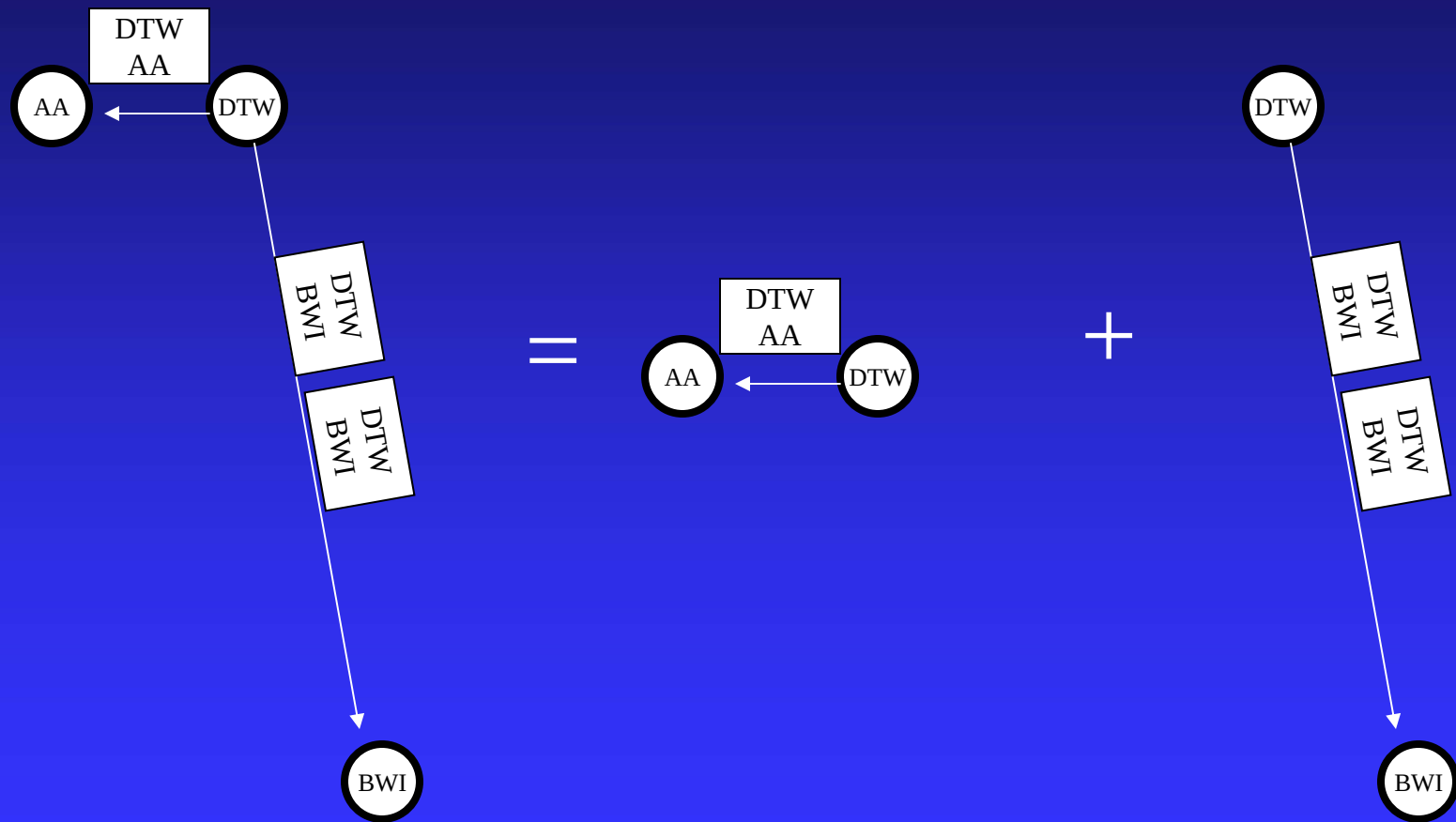
Dominance Example



Indifference

- We say that we are *indifferent* between one load cluster and another (or a set of load clusters) if they cover the same loads, have the same impact on balance, and have the same cost
- We can disregard all load clusters (except one) to which we are indifferent

Indifference



Column Generation

- The reduced cost of a load cluster has three components:
 - ◆ Its true cost
 - ◆ The (negative of the) duals for all the loads it covers
 - ◆ The (negative of the) dual for each center affected by the cluster, times the imbalance of that center
- The dual values can be attributed to loads

Column Generation, cont.

- The pricing problem still has to contend with the challenges of the original problem
 - ◆ Non-linear cost function
 - ◆ Timing issues
 - ◆ Out-of-network meet points
- Enumerative-based approaches are promising

Heuristic Approach

- Strong heuristic solutions are often obtainable and of value in practice – user controls trade-off between solution time and quality
- Heuristic approach is defined by considering only a limited set of columns
 - ◆ An initial set of “simple clusters”
 - ◆ Prior experience – e.g. load clusters that have been used in the past
 - ◆ Greedy approach – construct new clusters based on loads with high dual values

Current Status and Future Research

- We have implemented and are testing the initial approach
 - ◆ Limited cluster types
 - ◆ No column generation
 - ◆ Very fast; strong LP relaxation
- We will next benchmark results against current solutions from our industry partner
- We will then begin generating columns heuristically
- We will also work to solve the pricing problem exactly for a simplified version (e.g. no out-of-network meets, limited number of swaps per load, etc.)
- Long-term goal is to expand scope of problem (building loads, routing drivers, etc.)