

# Integrated Load Matching and Equipment Balancing for Express Package Networks

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# Importance of Transportation Industry

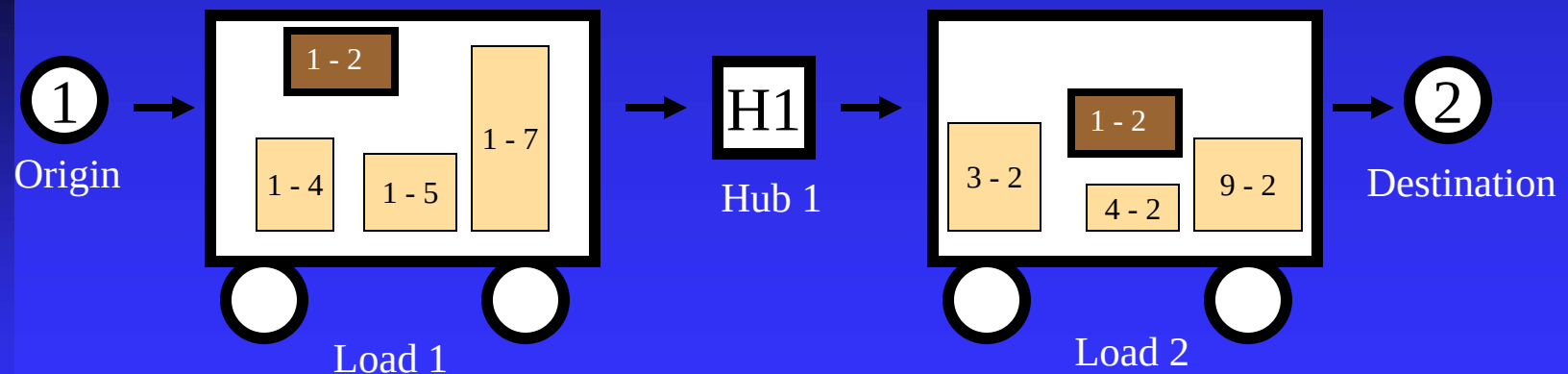
- Critically important in supporting nearly all aspects of everyday life
- Staggering amount of goods move through the US freight network
  - ◆ In 1998, more than 15 billion tons worth over \$9 trillion were moved
- Transportation-related goods and services account for 11% of US GDP
  - ◆ Only housing, health-care, and food account for a greater share

# Small Package Carriers

- Small package carriers are a key player in the transportation industry
- Transport tens of millions of packages *daily*
- Often provide expedited service in very short time windows
- Complex network, large volume of packages, tight time constraints, need to allocate extensive resources (handling facilities, labor force, trucks and aircraft, etc.) result in many challenging planning problems

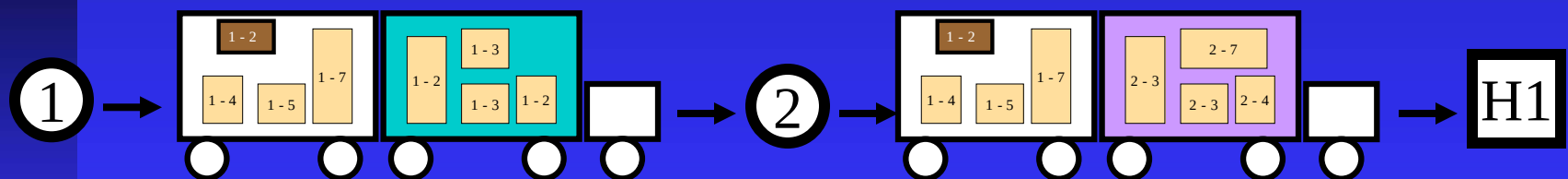
# Express Package Networks

- 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*



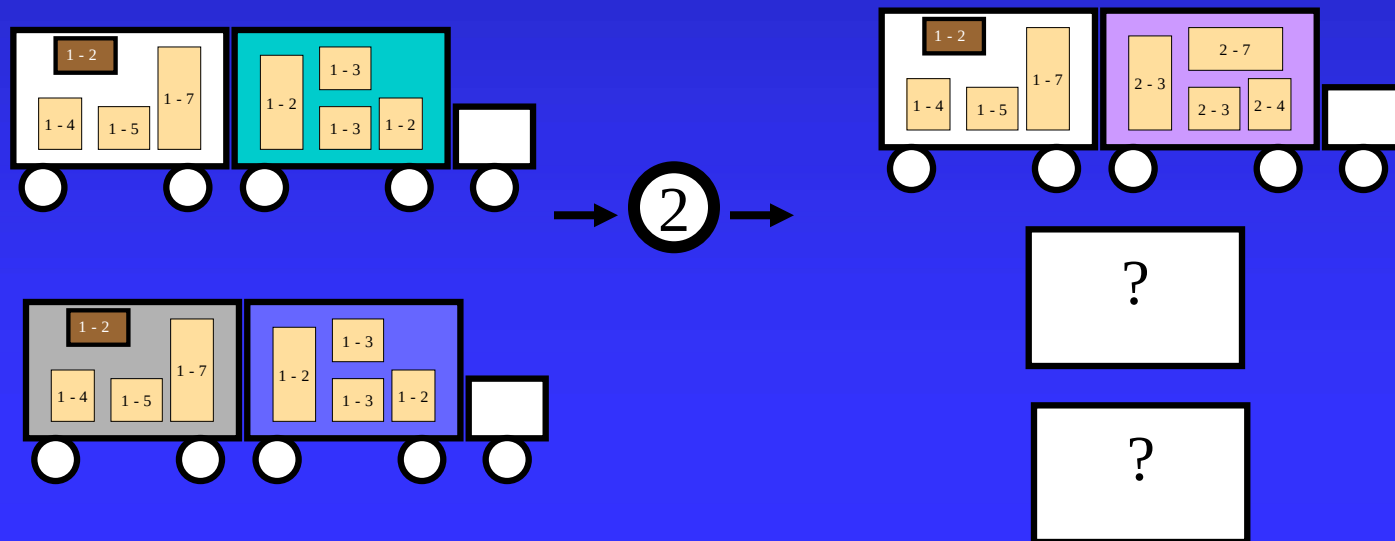
# Load Matching

- 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
- Arc-based 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 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:



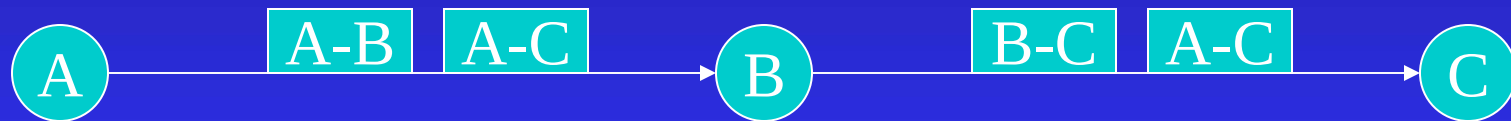
# Example Cluster

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



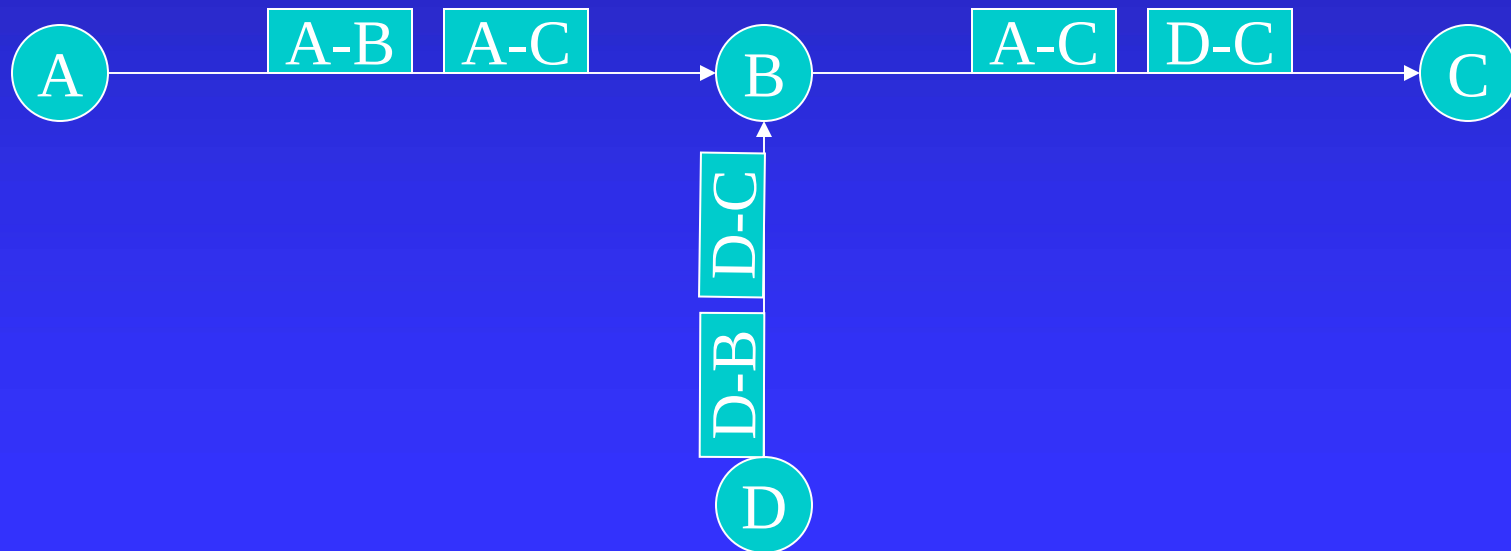
# Example Cluster

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
- $\delta_{il}$  is defined to be 1 if cluster  $i$  contains load  $l$  and 0 otherwise
- $\lambda_{if}$  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
- The LP relaxation is strengthened
- Timing issues are imbedded within the variable definition
- The number of constraints is greatly reduced
- Expanded solution space – the set of meet locations does not have to be limited to carrier facilities
- 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

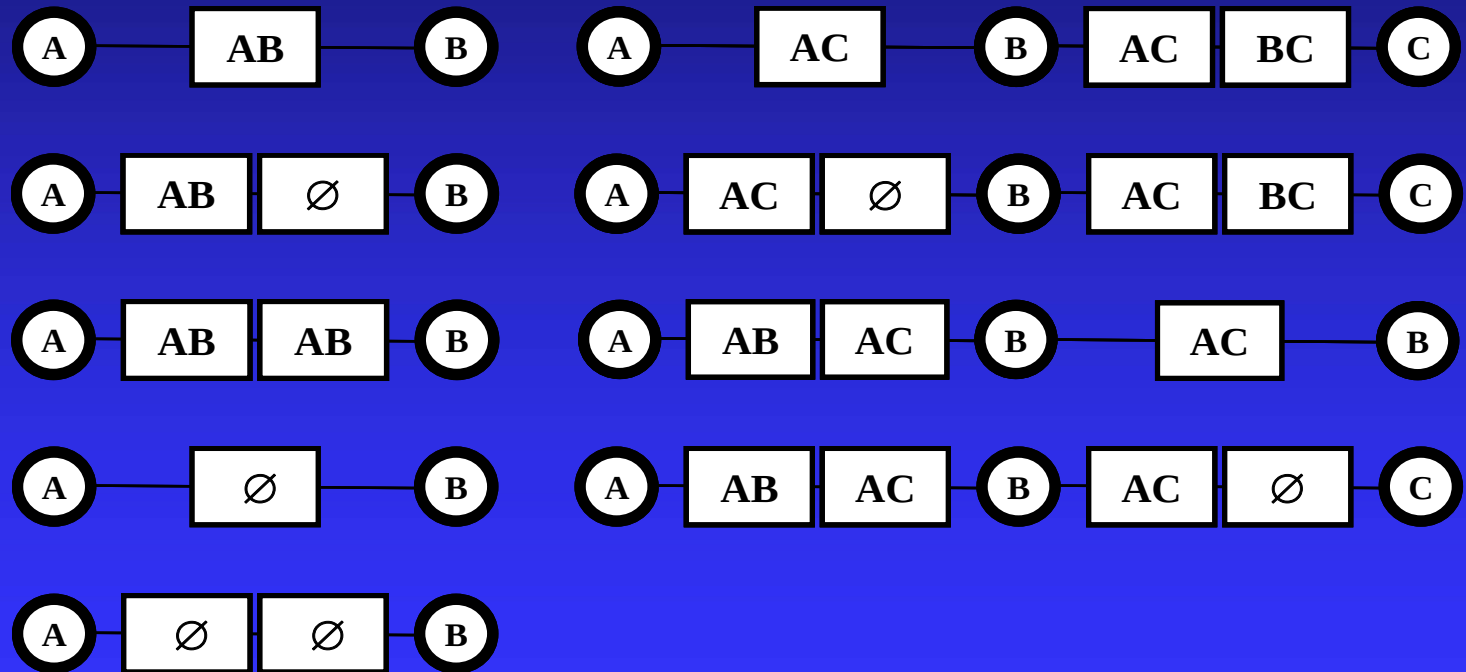
# Preliminary Computational Results

- Data set from major express package carrier
  - ◆ 2,000 loads
  - ◆ 600 nodes
  - ◆ Time windows extremely tight for the loads

# Approach One

- Traditional MCF formulation *with time requirements relaxed*
- Did not converge to an integer *feasible* solution
- Even without the effects of labeling nodes by both time and space, too many variables to branch on because of incentive to split all single trailers

# Approach Two



## Approach Two, cont.

- Alternative formulation converged to an integer feasible solution within 15 seconds
- Within 2 minutes, within 1% of the optimal solution (relative to given clusters)
- 5% improvement over carrier's current approach
- We expect equal or greater improvement in the full national network
  - ◆ More relaxed time windows
  - ◆ More long-haul moves to consider

# Next Steps

- Additional cluster types
- Strengthening LP relaxation
- Column generation
- Expanding scope of problem (building loads, routing drivers, etc.)