Optimization Models for Block Re-design Problem

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11-06-2018

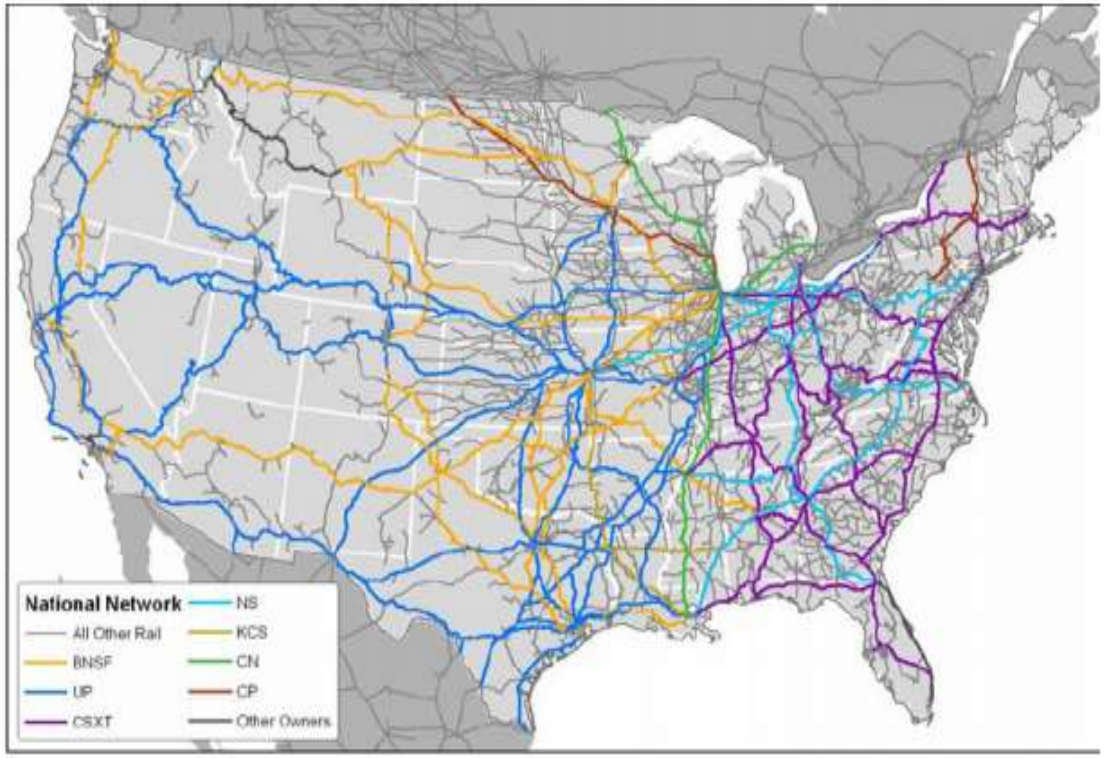
Outline

- **Motivation and Problem Definition**
- **Related Literature**
- **Model Formulation**
- **Solution Strategies**
- **Computational Results**
- **Conclusion**

Freight Railroads: Overview

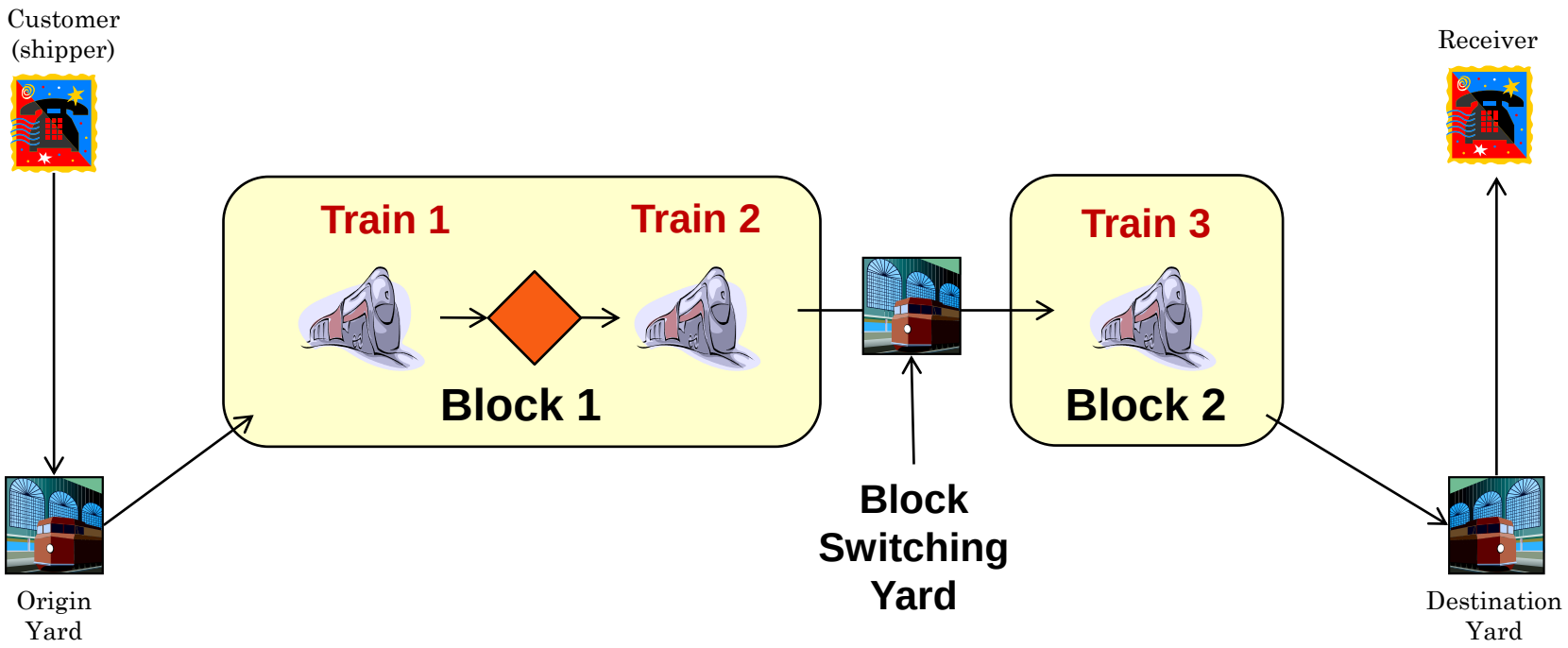
US Freight Railroads:

- **42%** of total freight, more than any mode of transportation
- A typical Class I railroad:
  - 8000 new shipments/day
  - 1300 trains/day
  - 32,500 miles network
- Demand projected to increase by **88%** in next **20** years
- **1%** increase in service reliability can lead to an increase of **5%** in revenue (Hallowell, 1998)



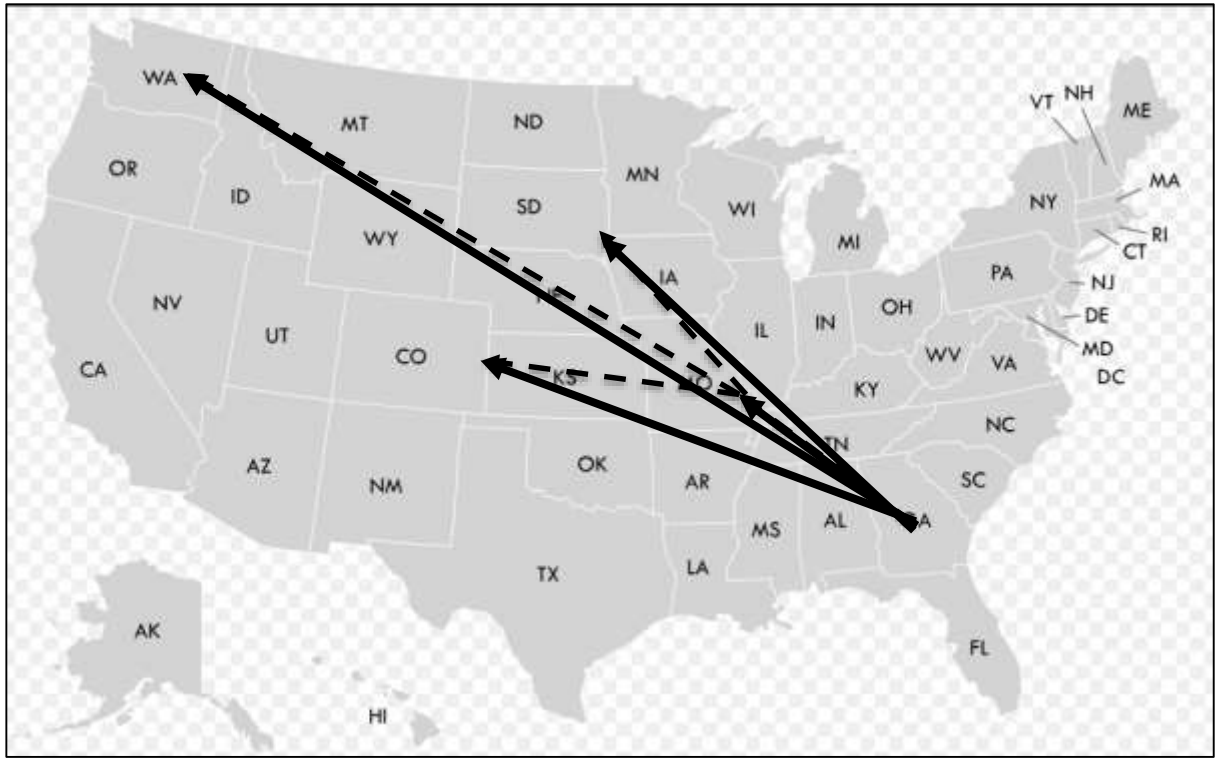
1 https://www.bnsf.com/tour/
2 Surface Transportation Board Research Reports

Operations in Shipment Movement

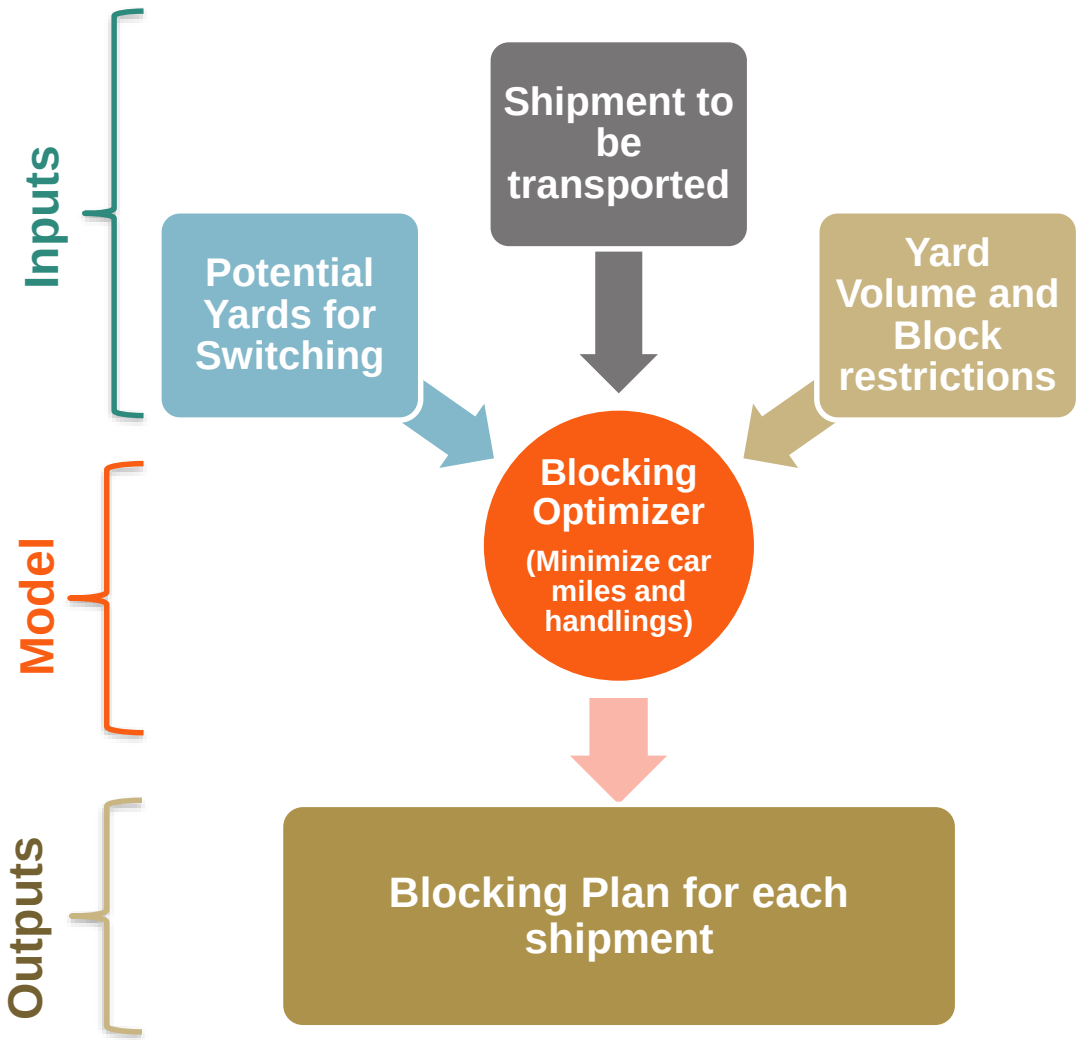


- **Routing Policies**: Blocking Policies, Block-to-Train Assignments, Train Schedules
- **Train Capacities**: Multiple metrics of capacity, varying with segment
- **Block Switching Operations**: Yard operations, Classification

Blocking in Freight Railroads



Railroad blocking is essentially a consolidation problem – similar to that encountered in postal service design



When are Blocking Changes Required?

- **Relieving Congested Yards**
  - Changes in blocking plan to re-route traffic out of congested yard(s)
  - Blocking network may or may not change
- **Changes in Traffic Pattern**
  - Volume increases between origins and destinations
  - Blocking plan changes to better match Train Service Plan
- **Alternate Routing Plan for Restricted Traffic**
  - Restrictions based on material type or shipment characteristics
  - Traffic between same origin destination pair may follow different blocking plan
- **Directional Separation of Traffic**
  - Yard switching efficiency may increase depending on how traffic is blocked

Literature Review

- Algorithmic Blocking Model by Carl Van Dyke (1986, 1988)
- Keaton (1989, 1992)
- Newton, Barnhart, and Vance (1998)
- Barnhart and Vance (2000)
- Ahuja, Jha, and Liu (2007)
- Ahuja, Jha, and Sahin (2008)
- Fugenschuh et al. (2018)

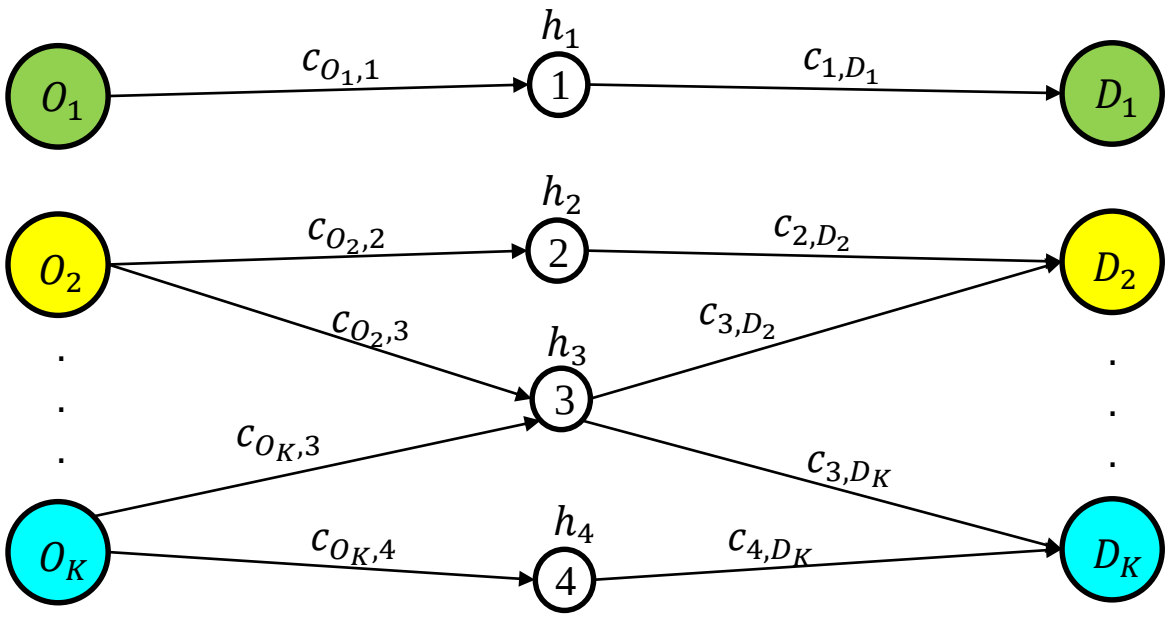
Blocking Redesign: Problem Introduction

- **Given**
  - Shipments to be transported during a planning horizon
  - The current routes of the shipments (Current Blocking Plan)
  - Set of congested yards and required volume changes at the congested yards
  - Restriction on shipment routes
- **Decision**
  - Modified Blocking Plan
  - New Block Sequence for each rerouted shipment
- **Constraints**
  - α% volume reduction at congested yard
  - $< \beta$% volume increase at other constrained yards
  - Routing restrictions for hazardous, high-wide, and other restricted traffic
- **Objective**
  - Minimize the total transportation cost: car miles + handling cost

Parameters and Definitions

Sets

T	Planning horizon
W	Set of shipments to be transported during planning horizon
K	Set of unique OD pairs
B	Set of candidate blocks
B^c	Set of blocks in current blocking plan
N	Set of nodes in network
S	Set of locations where shipments can switch



Parameters

o_k	Origin of commodity $k \in K$
d_k	Destination of commodity $k \in K$
u_i	Switching capacity of node $i \in N$
v_i	Current switching volume of node $i \in N$
h_i	Handling cost at node $i \in N$
g_i	Maximum outdegree of node $i \in N$

Decision Variables

y_{ij}	1 if block (i,j) is present in the modified blocking network
x_{ij}^k	1 if OD pair $k \in K$ uses block (i,j) in the modified blocking plan

Model Formulation

Objective

$$Z = min \sum_{k \in K} \sum_{(i,j) \in B} (d_{ij} v_k + h_i v_k) x_{ij}^k$$

Flow Conservation

$$\sum_{(i,j) \in \delta^+(i)} x_{ij}^k - \sum_{(j,i) \in \delta^-(i)} x_{ji}^k = \begin{cases} 1 & if\ i = o_k \\ 0 & if\ i \neq o_k\ and\ \ i \neq d_k \\ -1 & if\ i = d_k \end{cases} \quad \forall\, k \in K$$

Yard Switching Capacity

$$\sum_{(j,i) \in \delta^-(i)} \sum_{\substack{k \in K, \\ d_k \neq i}} v_k x_{ji}^k \leq u_i \quad \forall\, i \in N$$

Yard Outdegree

$$\sum_{(i,j) \in \delta^+(i)} y_{ij} \leq g_i \quad \forall\, i \in N$$

Forcing Constraints

$$x_{ij}^k \leq y_{ij} \quad \forall\, (i,j) \in B, k \in K$$

Model Formulation (Contd.)

Block Additions and Deletions

$$p_{ij} \geq y_{ij} - y_{ij}^{0}$$

$$q_{ij} \geq y_{ij}^{0} - y_{ij} \qquad \forall\ (i,j) \in B$$

Block Changes Restrictions

$$\sum_{(i,j) \in A} p_{ij} + q_{ij} \leq C$$

Non – negativity

$$0 \leq X_{ij}^{k} \leq 1\ ,\ Y_{ij} = 0 \text{ or } 1, p_{ij} \geq 0, q_{ij} \geq 0 \quad \forall\ (i,j) \in B,\ k \in K$$

Algorithmic Enhancements & Heuristic Approaches

Problem Reduction Approaches:

- Node merging rules
- Deviation from Shortest Paths
- Directional Routing constraints

Heuristic Approaches:

- Iterative Shortest Path Approach
- Dual-Ascent based Heuristic
- Local Improvements based on Optimal Flow Solution
- Block Covering for Optimal Physical Path Flow

Algorithmic Enhancements & Heuristic Approaches

Exact Optimization

Problem Reduction Approaches

- Node merging
- Deviation from Shortest Paths
- Directional Routing Restrictions

Heuristic

Heuristic Approaches

- Iterative Shortest Path
- Dual Ascent
- Optimal Flow based Local Improvements
- Optimal Physical Path based Blocks

Computational Results: Setup

Test cases

- Computational tests on 3 test instances
- Horizon Length: 28 days
- Number of blocks: 3182
- Number of shipments: ~253k

Computational Environment

- CPLEX 12.7 with Python 3.5
- TOSHIBA TECRA Z40-C laptop with 2.40 GHz Intel Core i5 and 8GB RAM
- Maximum allowed time limit: 1 hour
- Multi-thread (Parallel) Processing

Model Size

Base Model	Reduced Model
• Variables: 3.99 million • Constraints: 3.22 million	• Variables: 1.02 million • Constraints: 449k

Computational Results: Setup

Dataset	Method	Variables	Constraints	Solution Time (in seconds)
Dataset 1	All Yards Uncapacitated	3,993,808	3,220,127	24
	Selective Yards Capacitated	3,993,808	3,220,134	26
	All Yards Capacitated	3,993,808	3,220,397	31
Dataset 2	All Uncapacitated	14,138,688	11,399,737	158
	Selective Capacitated	14,138,688	11,399,742	364
	All Yards Capacitated	14,138,688	11,400,007	490
Dataset 3	All Uncapacitated	4,365,168	3,519,547	21
	LP - few constraints	4,365,168	3,519,549	22
	All Yards Capacitated	4,365,168	3,519,817	45

Solution times comparison (in seconds)

Test Case	Without Reduction	With Reduction
Dataset 1	26	7 (107)
Dataset 2	22	-
Dataset 3	372	11 (180)

- Number of variables and constraints decreases by 70-90%
- Solution times decrease by 60-95%
- Preprocessing time is significant.

Conclusion & Future Work

- Developed optimization model to re-design a blocking plan while considering yard capacity constraints, shipment route restrictions, and other business constraints

- Developed problem reduction approaches to eliminate variables and constraints and optimization=based heuristic approaches to quickly obtain an upper-bound

- Tested developed models with three real-life datasets and showed efficacy of developed solution approaches