Solving Real-Life Railroad Blocking Problems

Winner of 2006 Daniel H. Wagner Prize

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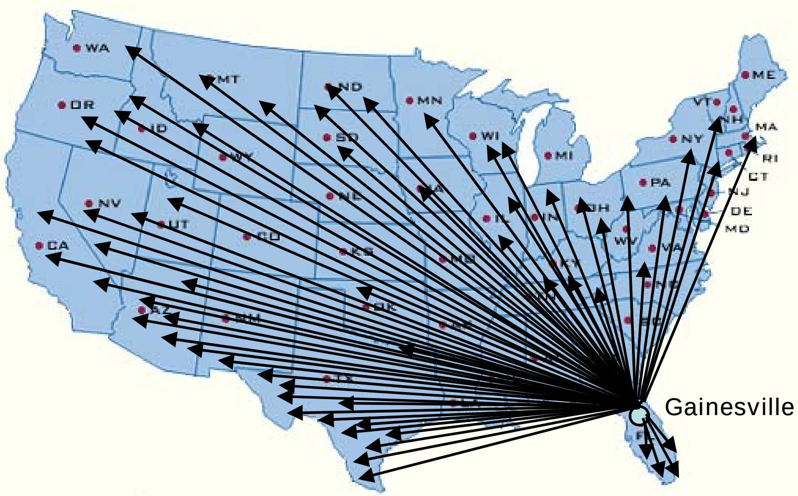
InnovativeScheduling

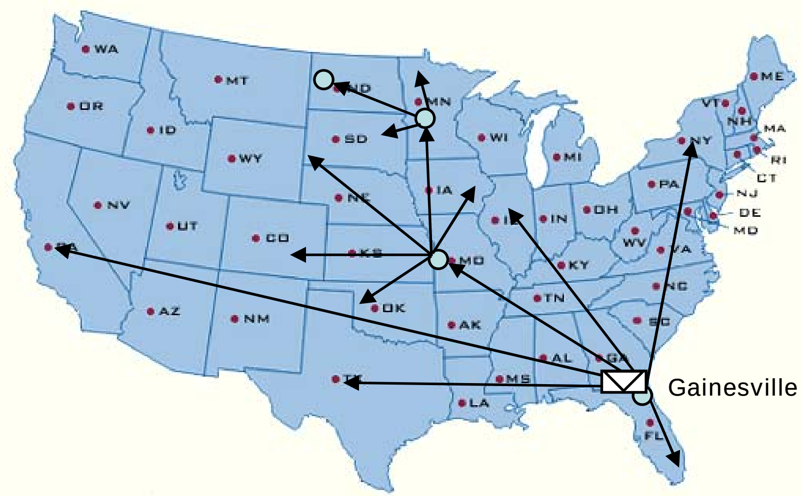
Presentation Outline

- **The Railroad Service Design**
- The Railroad Blocking Problem
- The VLSN Search Algorithm
- Case Studies
- Innovative Railroad Blocking Optimizer (Decision Support System)

Consolidation Problem

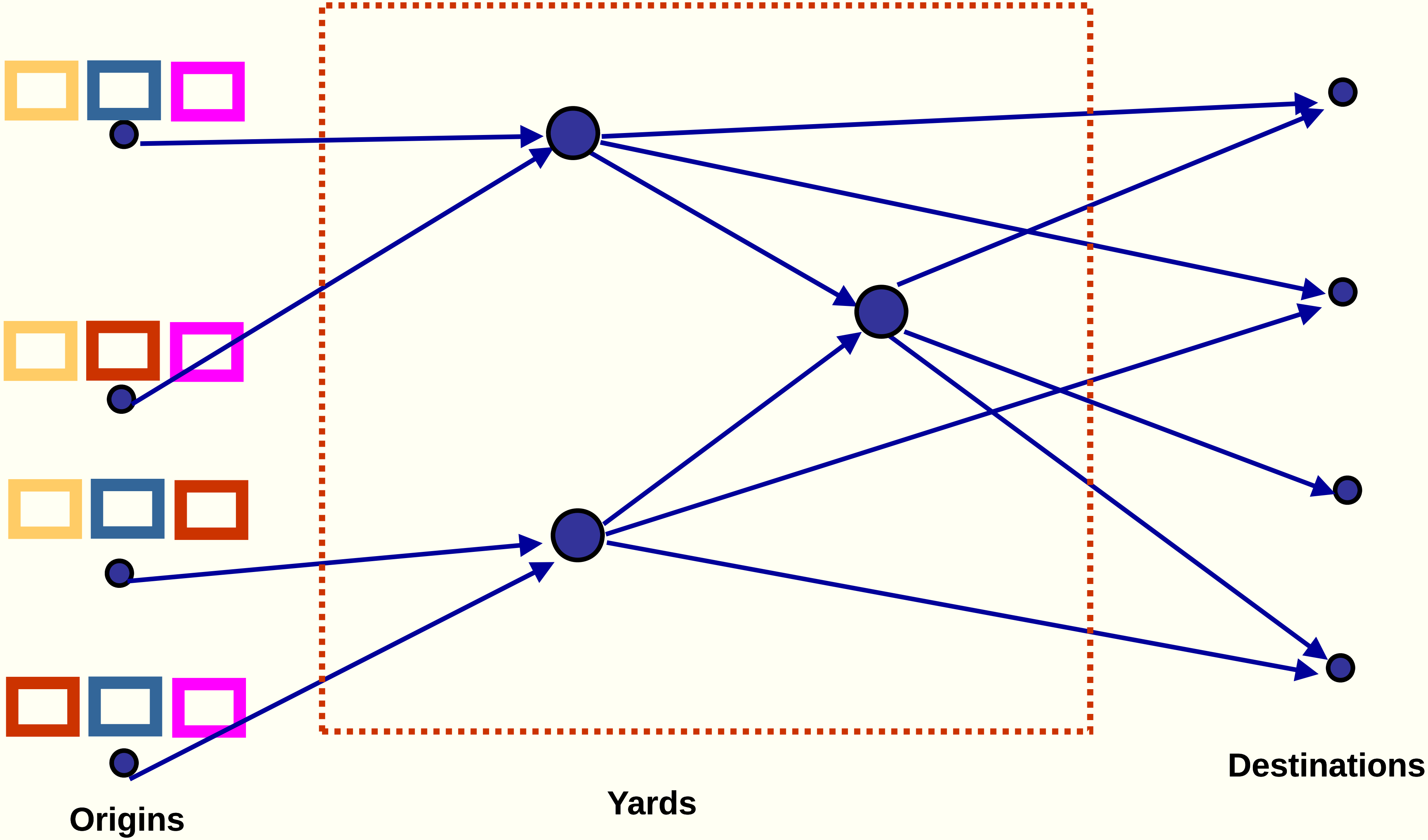
- Railroad blocking problem is essentially a consolidation problem, which is similar to that encountered in postal service design.



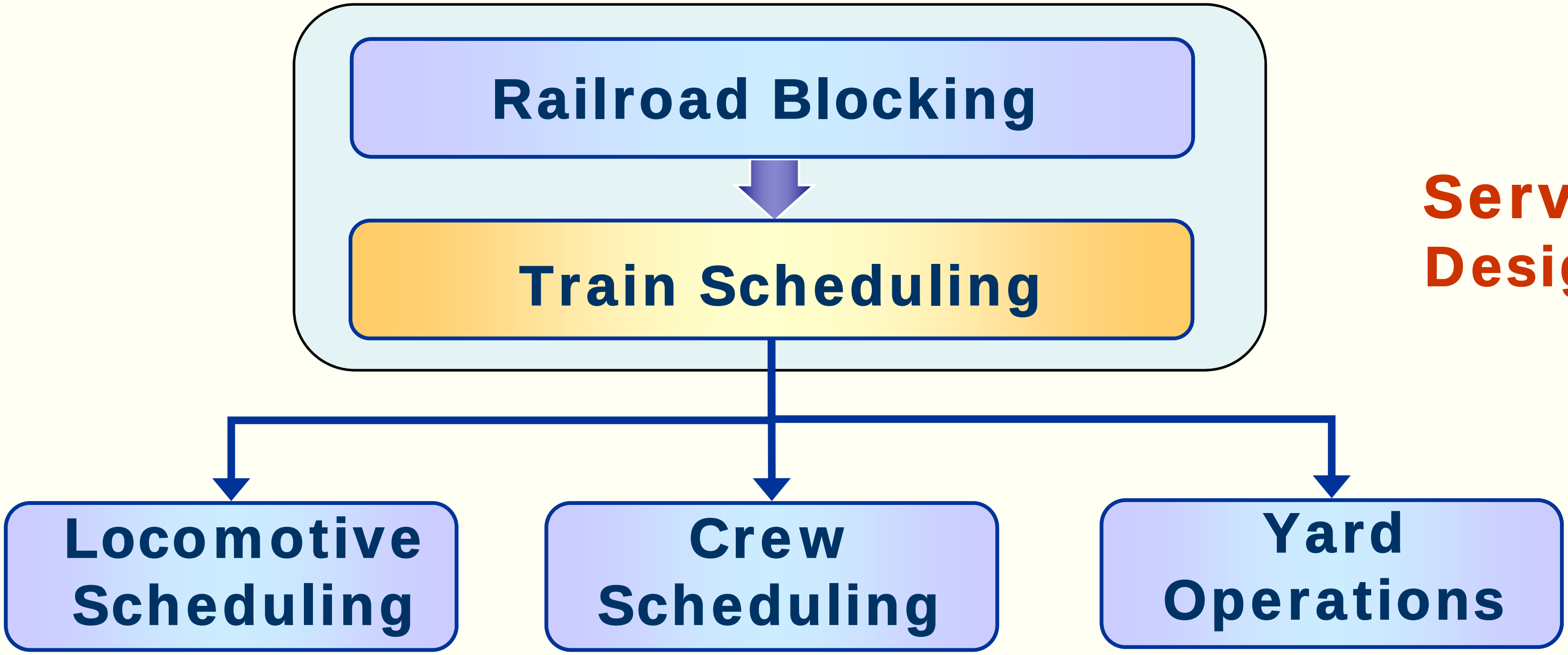


- A railroad block is like a mailbag in the postal service context.

The Railroad Blocking Problem

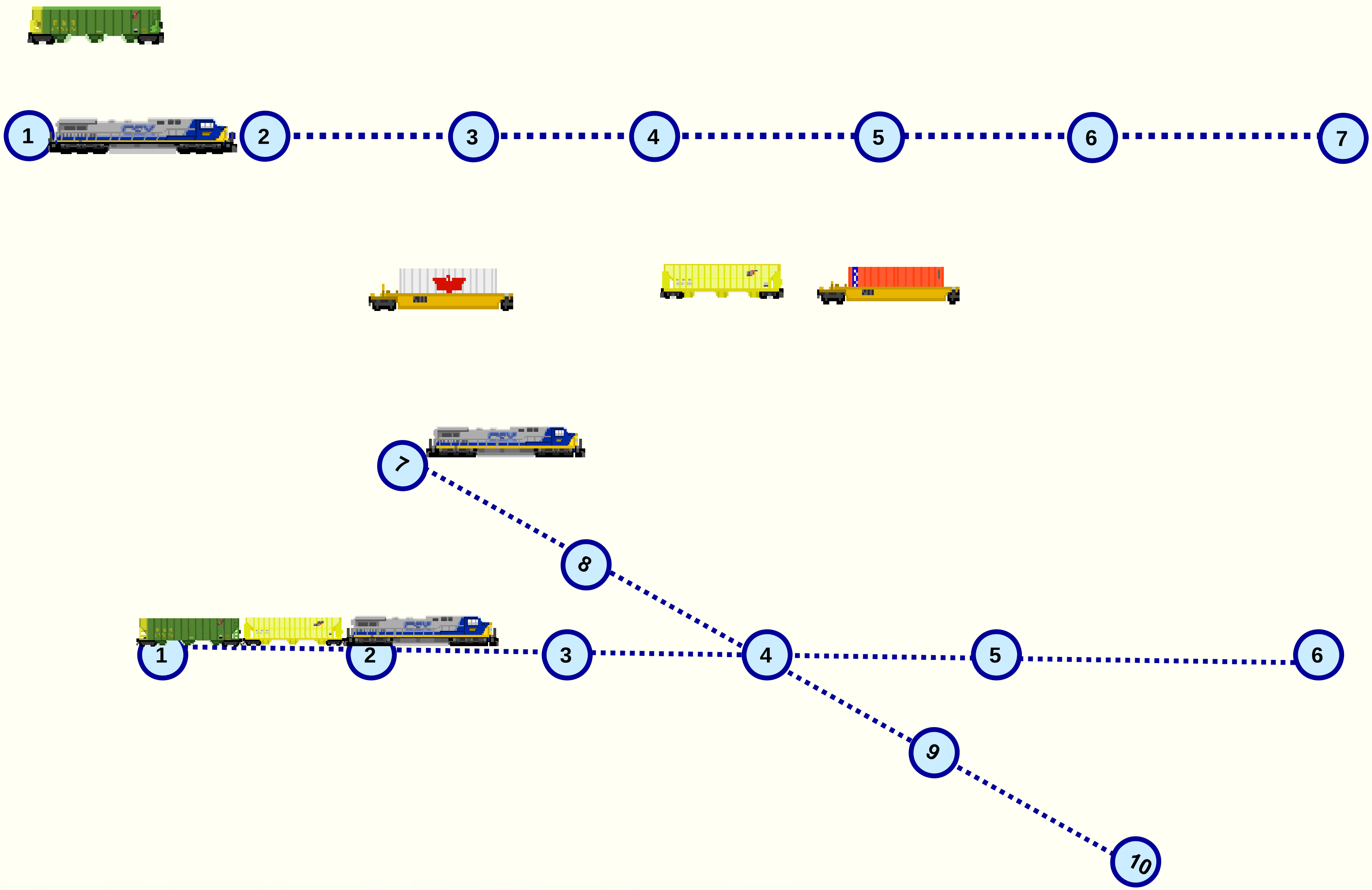


Railroad Planning Process

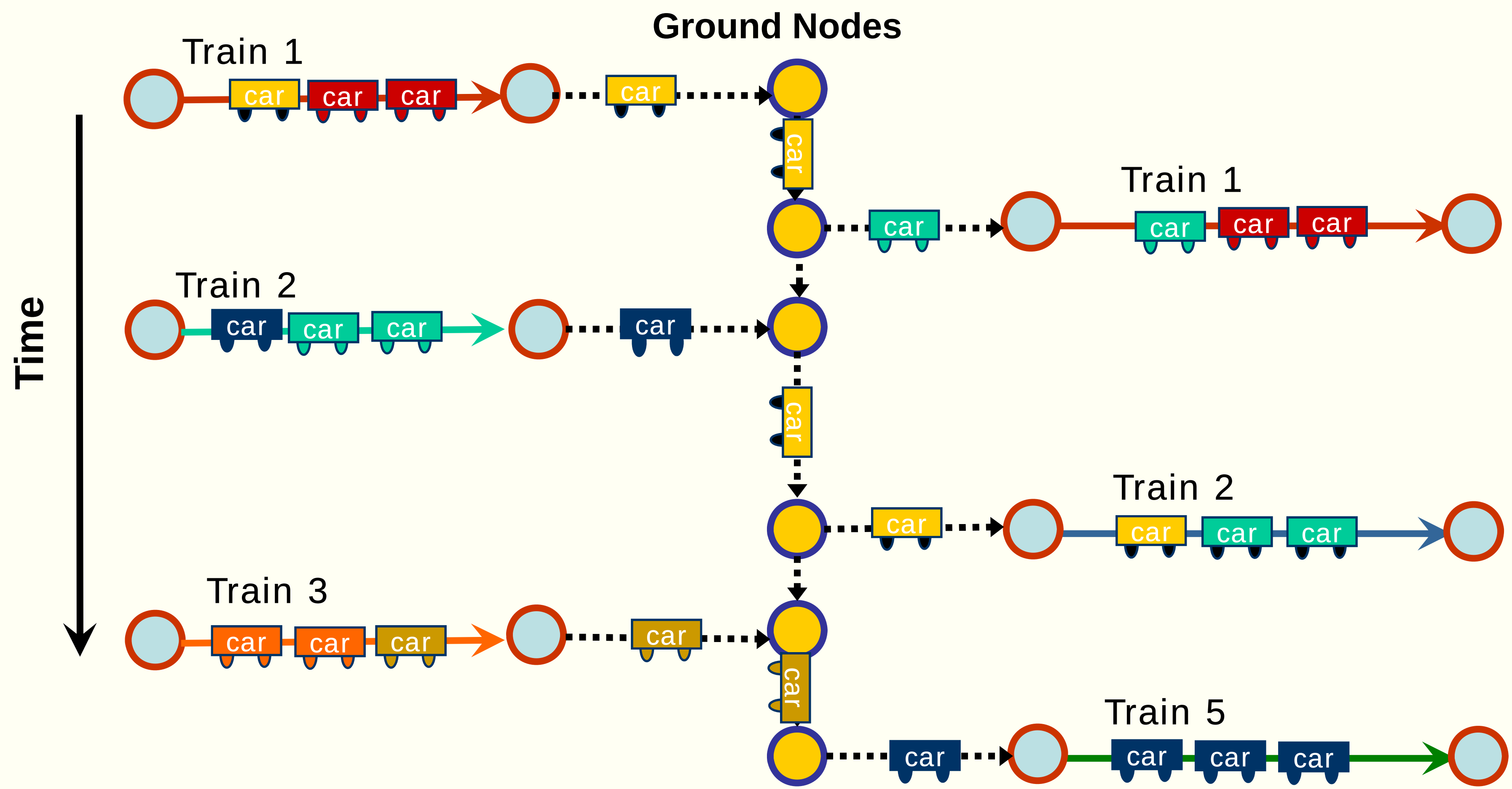


Service Design

Flow of Blocks on Trains

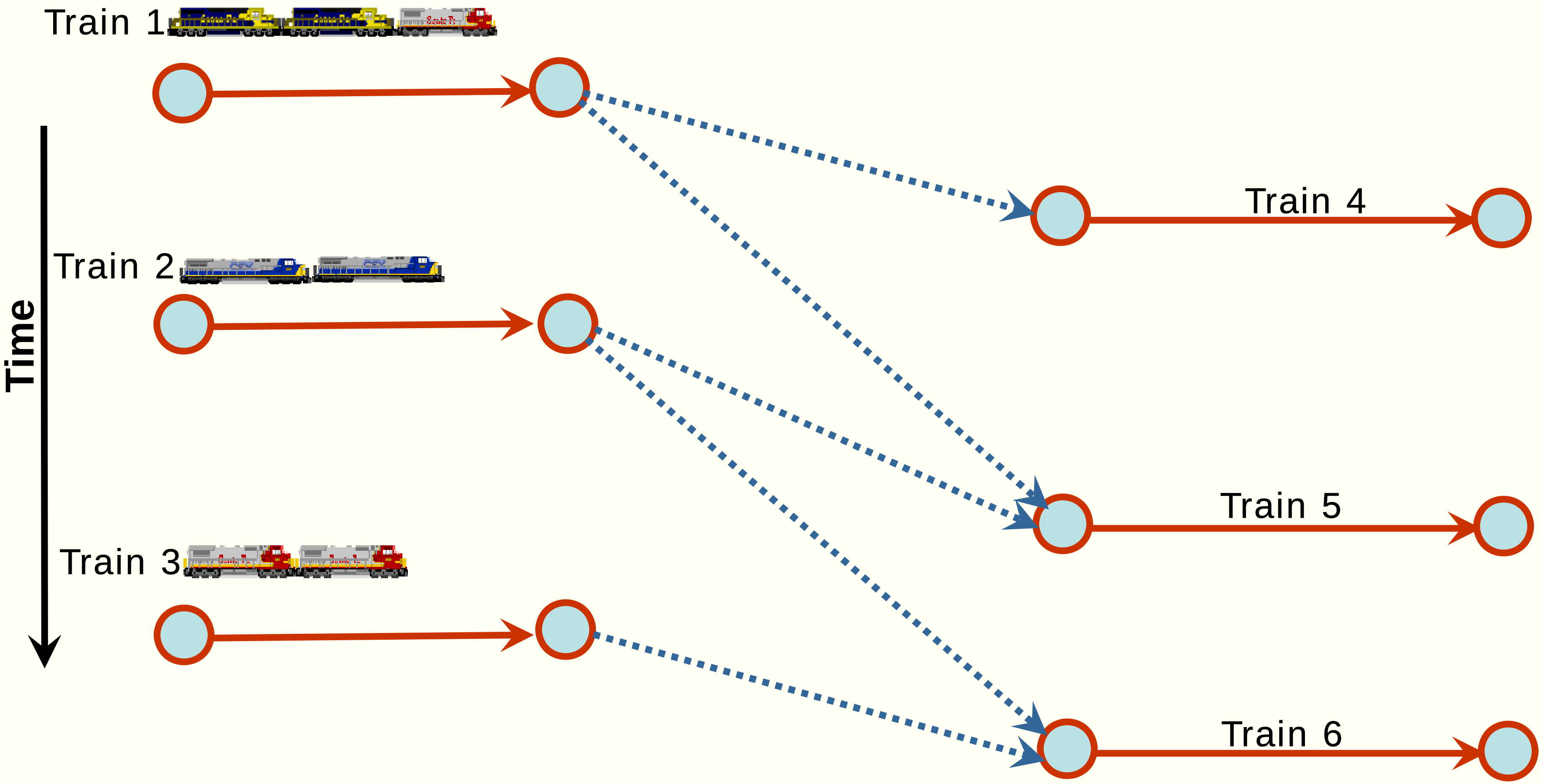


Railcar Flow Network



- We construct the weekly time-space train network and flow railcars through this network.

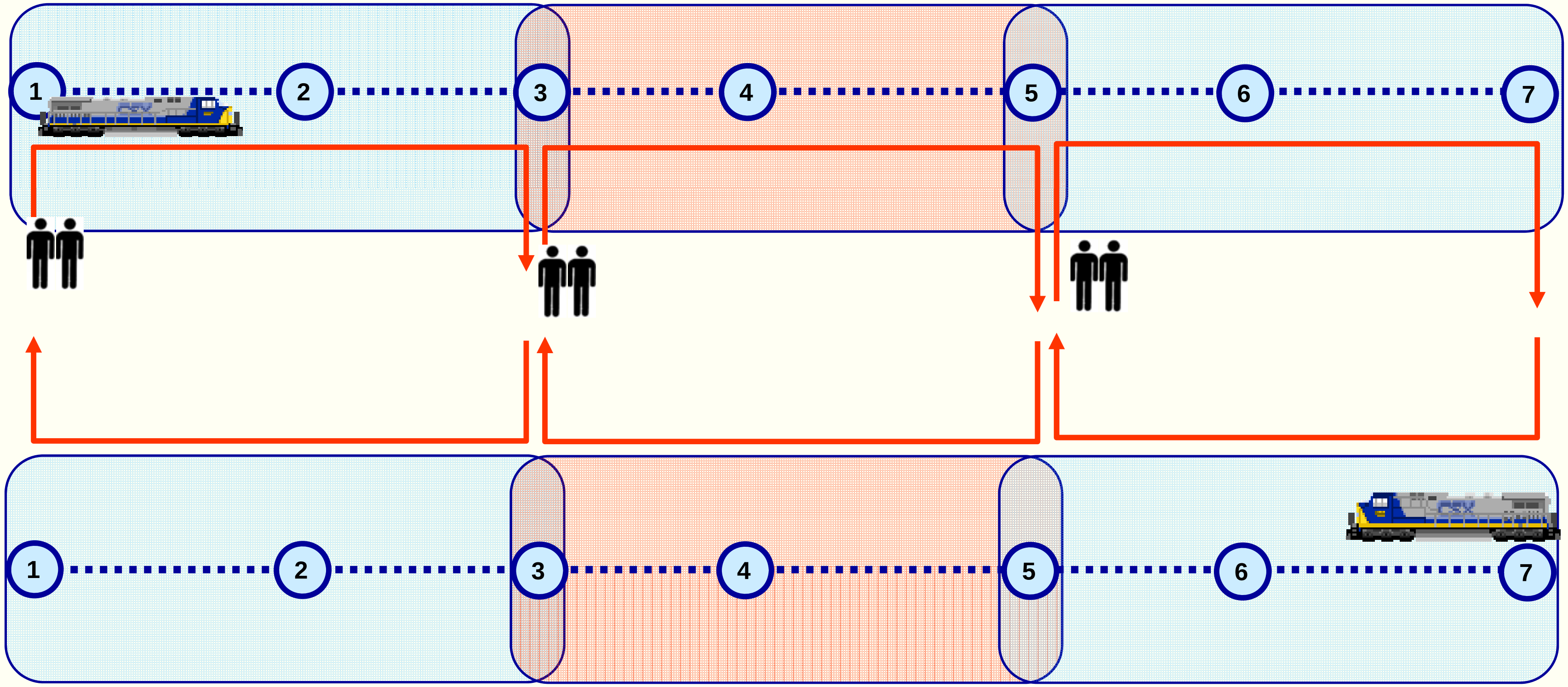
Locomotive Flow Network



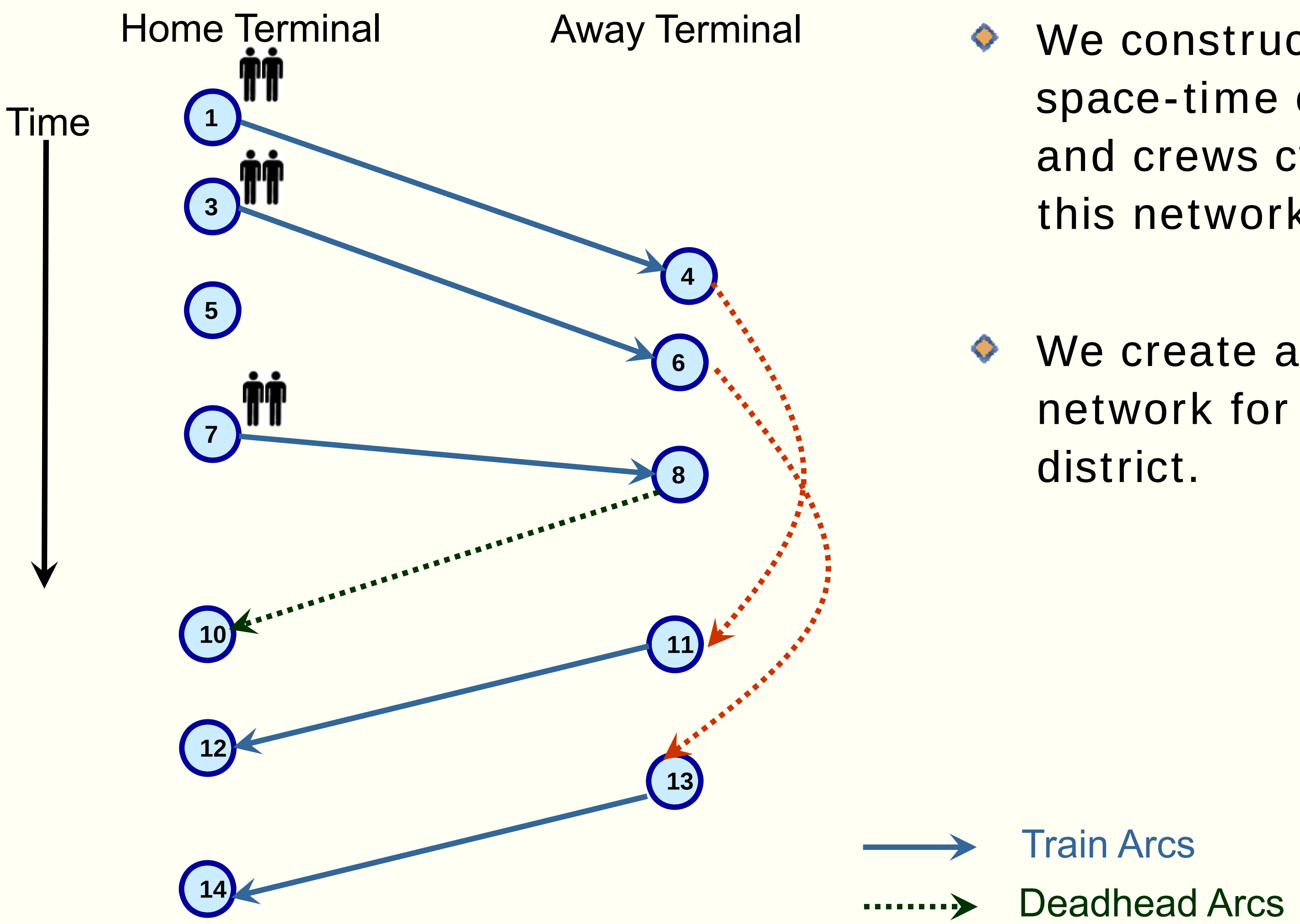
- We construct the weekly space-time train network and locomotives cycle through this network.

Crew Scheduling at US Railroads

- Each train requires a crew and changes crew at several locations as it travels from its origin to its destination.



Crew Flow Network



- We construct the weekly space-time crew network and crews cycle through this network.
- We create a separate network for each crew district.

Importance of Blocking

- Blocking determines train schedule design.

- Train schedule determines the major resource costs:
  - Car costs
  - Locomotive costs
  - Crew costs

- Solving the blocking problem to near-optimality is critical to efficiency is railroad operations.

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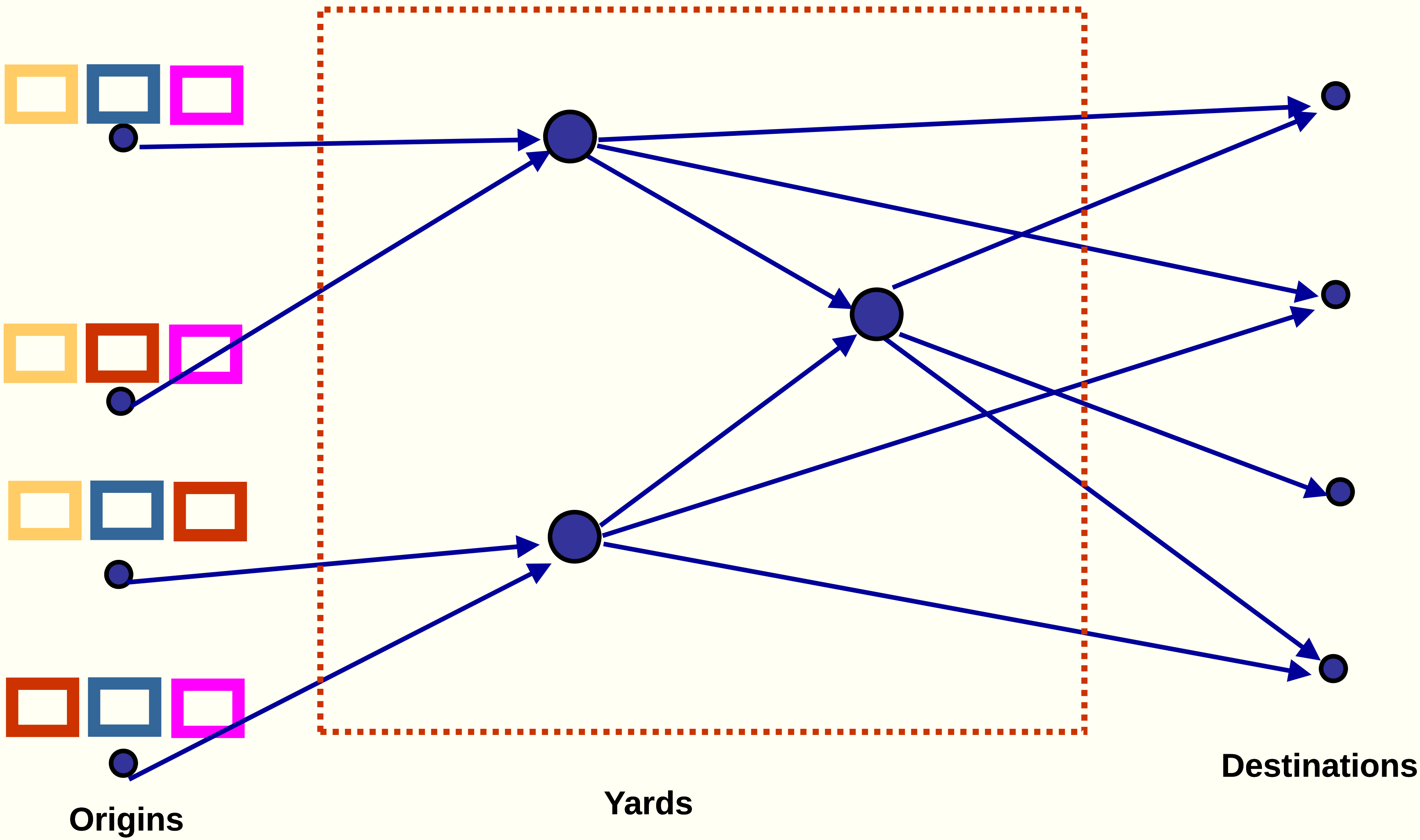
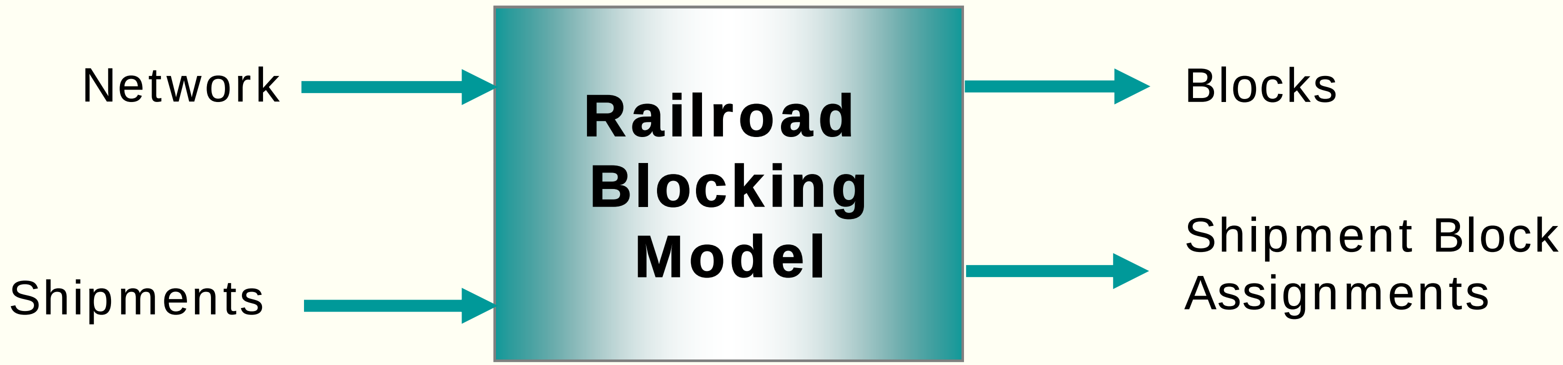
The Railroad Blocking Problem



The Railroad Blocking Model



- Constraints:
  - Maximum number of blocks that can be build at a node is limited.
  - Maximum volume of shipments passing through a node is limited.
- Objective Function:
  - Distances traveled by shipments
  - Intermediate handlings of shipments

Integer Programming Formulation

Minimize $\sum_{k\in K}\sum_{(i,j)\in A} c_{ij} \; x_{ij}^k + \sum_{i\in N}\sum_{(i,j)\in O(i)} h_i y_{ij}$

subject to:

$$\sum_{(i,j)\in O(i)} x_{ij}^k - \sum_{(j,i)\in I(i)} x_{ij}^k = \begin{cases} v_k & \text{if } i = o(k) \\ 0 & \text{if } i \neq o(k) \text{ or } d(k) \\ -v_k & \text{if } i = d(k) \end{cases} \quad \text{for all } k \in K$$

$$\sum_{k\in K} x_{ij}^k \le u_{ij} y_{ij} \quad \text{for all } (i, j) \in A$$

$$\sum_{(i,j)\in O(i)} y_{ij} \le b_i \quad \text{for all } i \in N$$

$$\sum_{k\in K}\sum_{(i,j)\in I(i)} x_{ij}^k \le d_i \quad \text{for all } i \in N$$

$y_{ij} = 0$ or 1 and $x_{ij}^k = 0$ or v_k

Blocking Problem for a US Railroad

- Multi-commodity flow network design and routing problem:
  - 3,000 nodes
  - 50,000 commodities
  - Over a million 0-1 network design variables (y_{ij})
  - Hundreds of billions of integer flow variables (x_{ij}^{k})

- Substantial amount of costs involved:
  - Cost of flow: $1,000 - $2,000 million
  - Cost of handling: $500 - $1,000 million

- Currently solved manually.

Literature Survey

- ABM (Algorithmic Blocking Model) by Carl Van Dyke [1986, 1988]
- Keaton [1989, 1992]
- Newton, Barnhart and Vance [1998]
- Barnhart and Vance [2000]
- The railroad blocking problem remained an unsolved problem until recently.

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A VLSN Search Algorithm

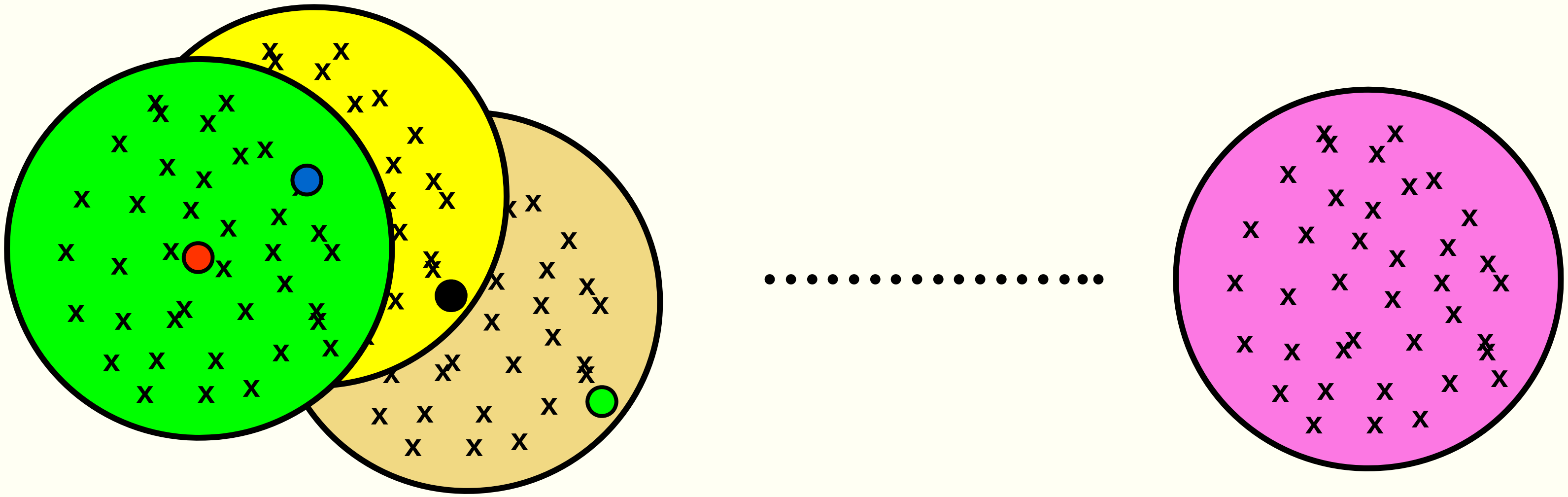
- We have developed a **Very Large-Scale Neighborhood (VLSN) Search Algorithm** to solve the blocking problem.
- Funded by National Science Foundation

Neighborhood Search Algorithms

- Start with a feasible solution x
- Define a neighborhood of x
- Identify an improved neighbor y
- Replace x by y and repeat

VLSN Search Algorithm

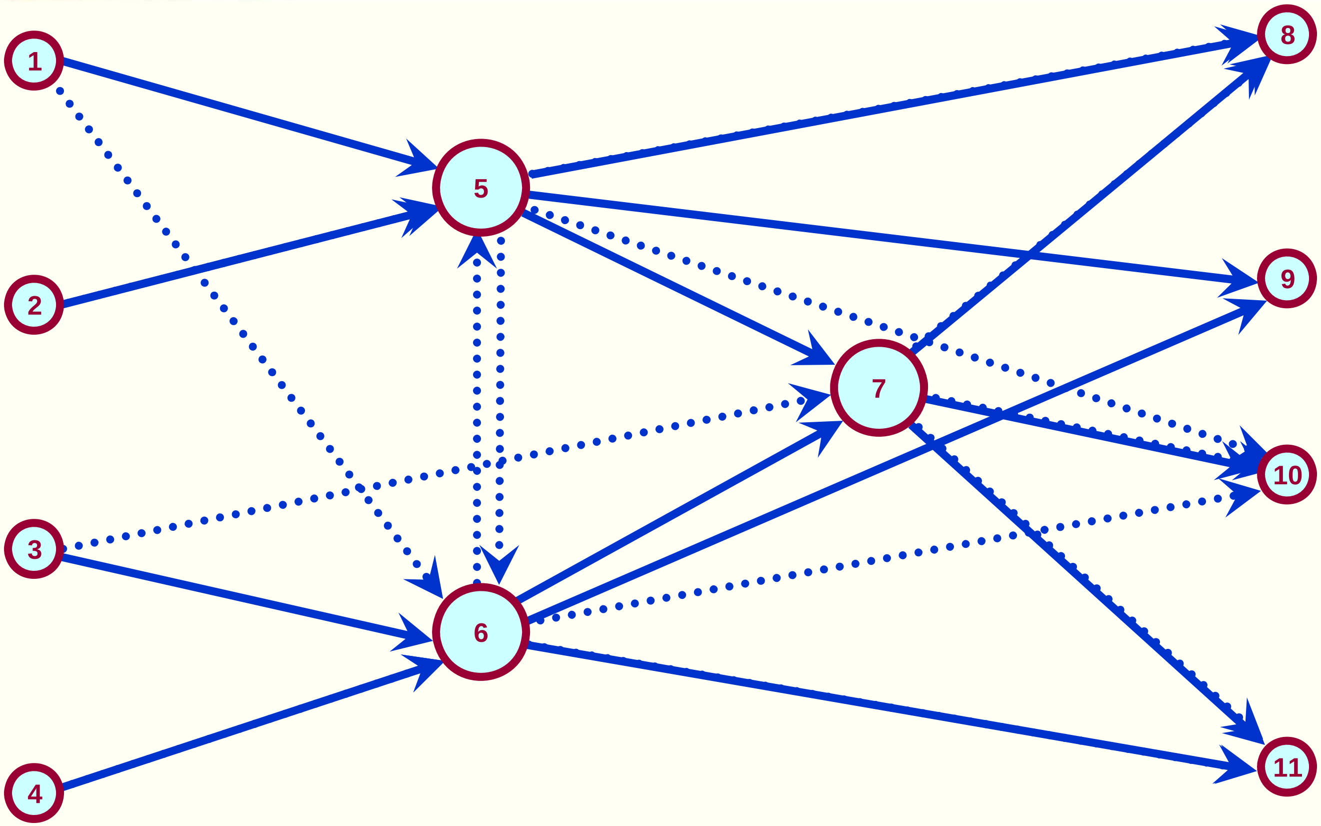
Size of the neighborhood is very-very large.



A VLSN Search Algorithm

- Basic idea:
  - Determine an initial blocking plan.
  - Use VLSN search algorithm to improve the blocking plan.
  - Keep improving the plan until it stops improving.

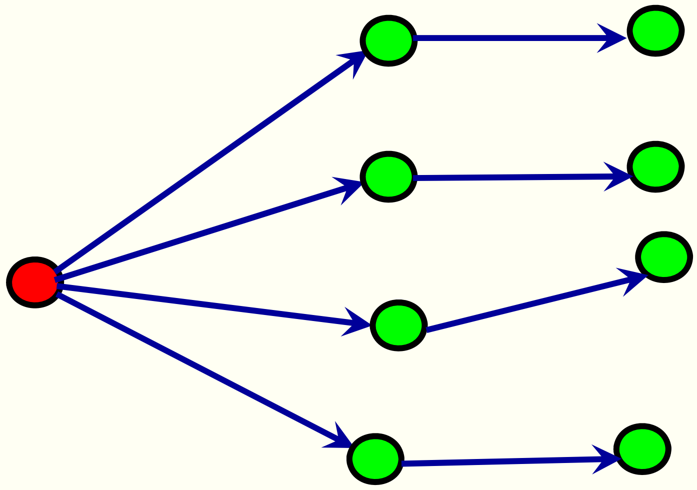
Overview of the VLSN Search Algorithm



- We reoptimize blocks at one node at a time assuming that blocks do not change at other nodes.
- We reoptimize all nodes one-by-one and keep performing passes over the nodes until the solution terminates to a local optimal solution.

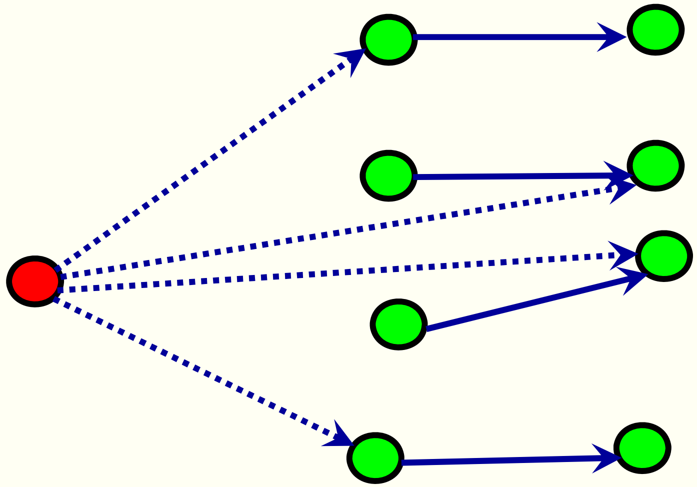
Finding Improved Neighbors

- First Step:
  - Select a node and delete all arcs incident on it
  - Reroute the traffic.



Finding Improved Neighbors (contd.)

- Second Step:
  - Build arcs one by one with the largest savings.
  - Reroute all the shipments to compute the savings of an arc.

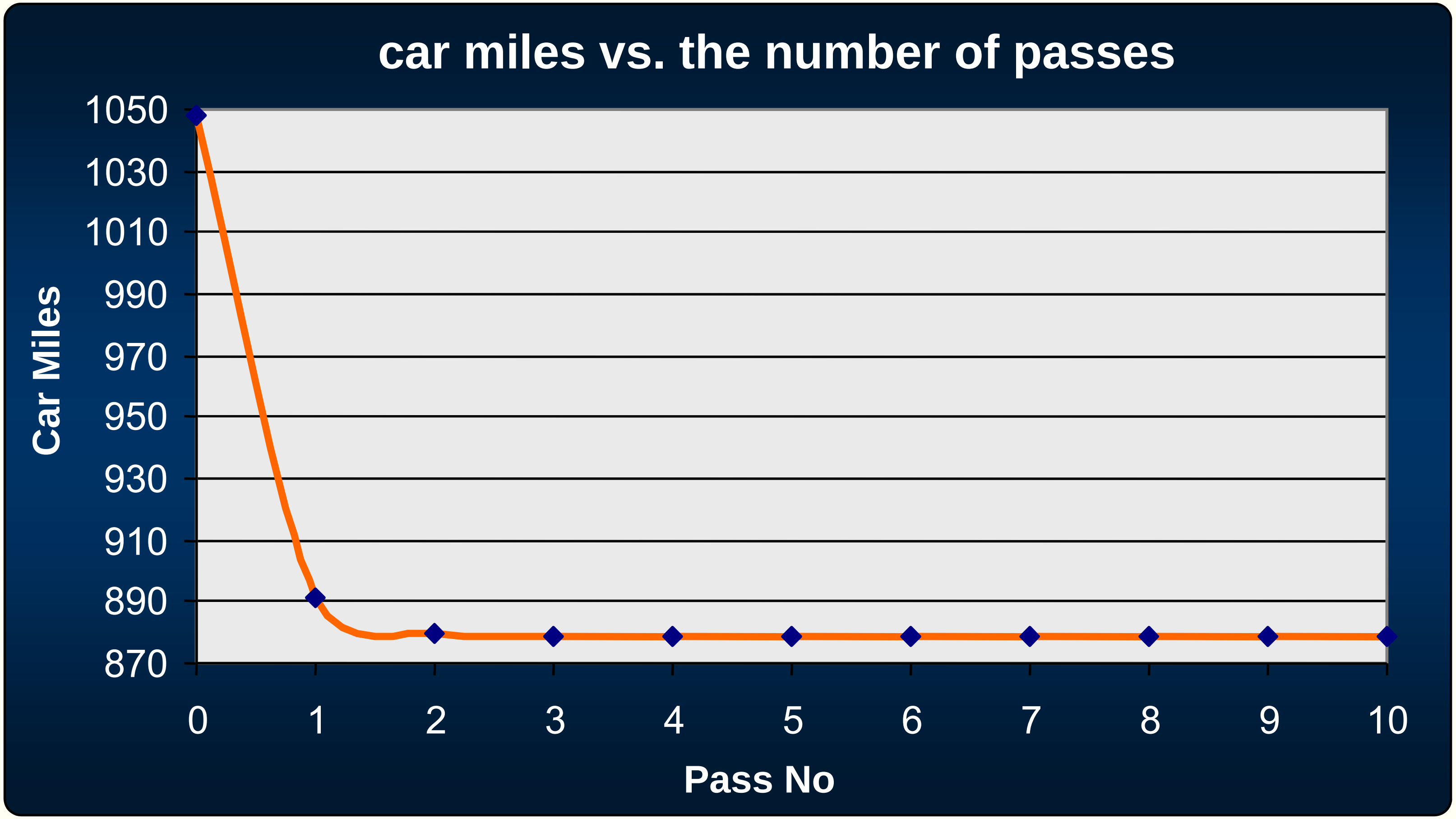


We account for rerouting of all shipments to compute potential savings.

Finding Improved Neighbors (contd.)

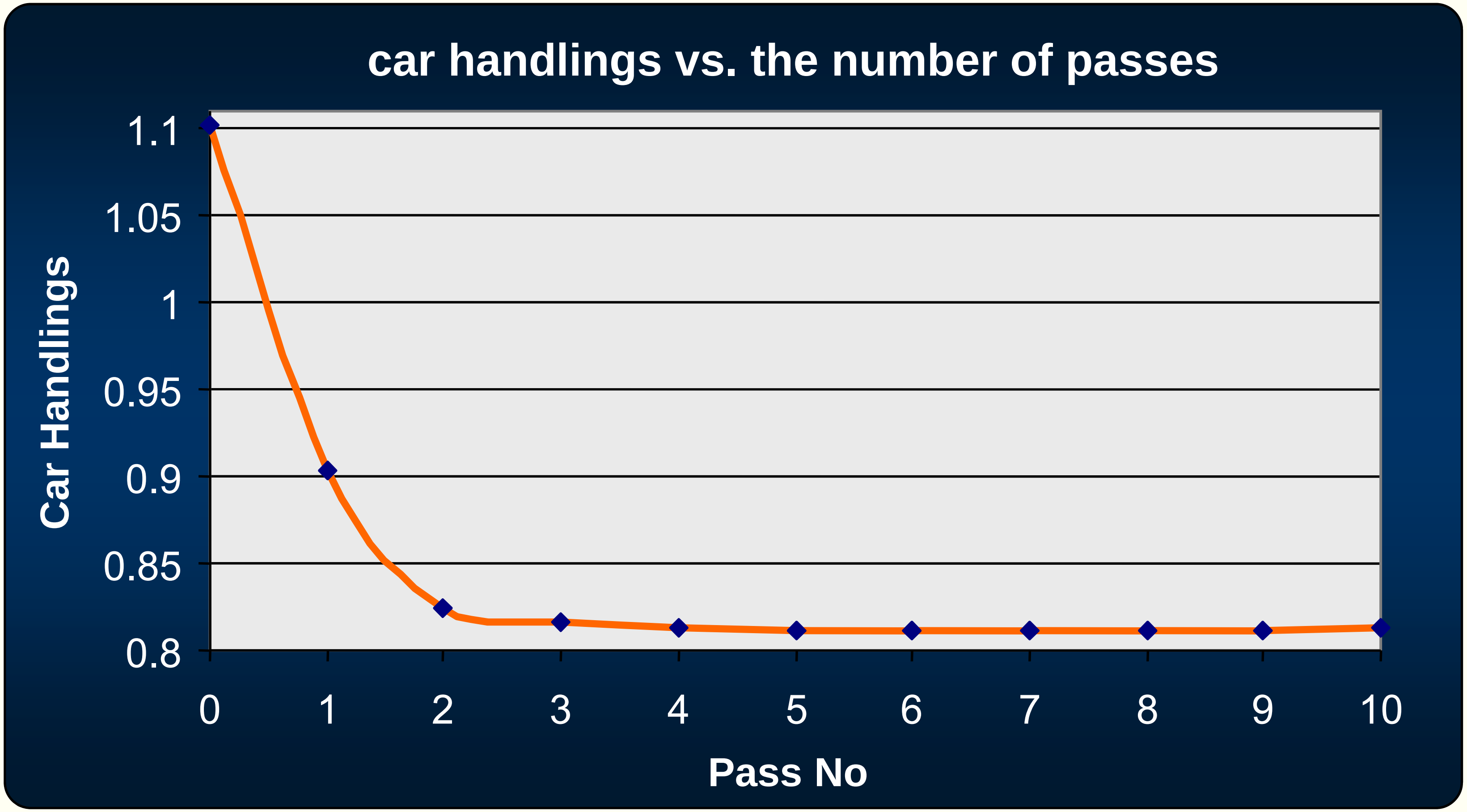
- Third Step:
  - Reoptimize all nodes one by one.
- Fourth Step:
  - Perform passes over the nodes until the solution is locally optimal.

Convergence of the Algorithm



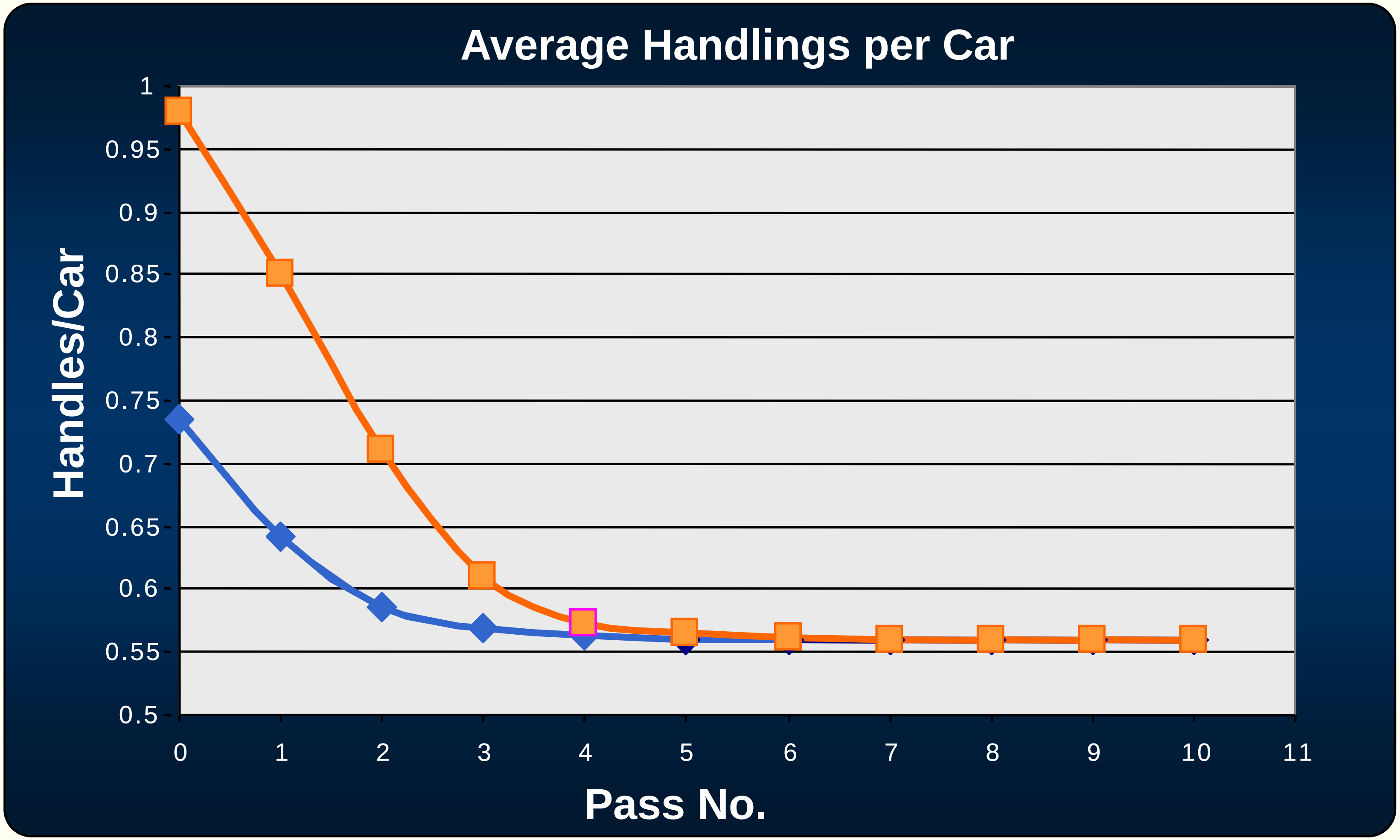
Very fast convergence for car miles.

Convergence of the Algorithm (contd.)



Very fast convergence for car handlings.

Sensitivity to the Starting Solution



Final solution is rather insensitive to the starting solution.

Critical Issue: Speed

- Typically, we reoptimize blocks at over 30,000 nodes.
- We reoptimize blocks at a node in an average of 0.1 second.
  - Good network reoptimization algorithms
  - Clever speed-up techniques
  - Sophisticated data structures
  - Efficient coding
- Total running time: 1 to 2 hours
- Highly scalable algorithms

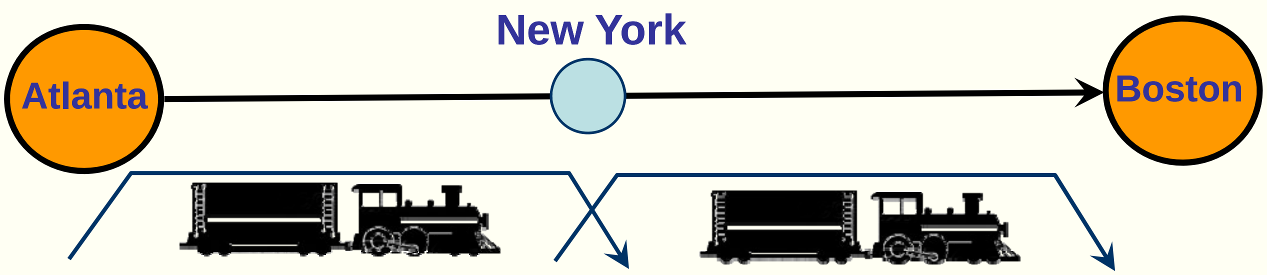
Incremental Blocking

- Given an existing blocking plan, change it by a specified amount and determine a revised blocking plan. Example:
  - Make 10 new blocks
  - Delete 10 or more existing blocks

- Motivation
  - Small changes
  - Less risk
  - More implementable

Train-Friendly Blocking

- Given a train schedule, make only those blocks that require no more than K block swaps. Example: K =1.



Additional Features

- Block restrictions
- Block preferences
- Block fixing
- Shipment-block path fixing
- Avoid low volume blocks
- Directional blocking
- Location-based block changes
- Minimize shipment reroutings

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Computational Results

- We have performed several case studies on the data provided by several US Class I railroads.

- We performed three types of computational results:
  - Clean-slate blocking
  - Incremental blocking
  - Incremental train-friendly blocking

Clean-Slate Blocking Results

	% Savings in Car Miles	% Savings in Intermediate Handlings
Railroad 1	**1.3%**	**14%**
Railroad 2	**0.6%**	**17.7%**
Railroad 3	**0.6%**	**20.5%**

- Conclusion: Significant reduction in intermediate handlings through better blocking plans.

- In reality, due to additional constraints, savings may be less but 5%-10% savings in handlings are achievable.

Incremental Blocking Results

% New Blocks	% Savings in Car Miles	% Savings in Intermediate Handlings
0.7%	0.6%	7.3%
0.9%	0.5%	7.9%
1.4%	0.5%	9.5%
1.9%	0.5%	10.5%
3.8%	0.5%	14.1%
9.5%	0.6%	19.1%

- Conclusion: Even small changes in the blocking plan can have significant impact on intermediate handlings.

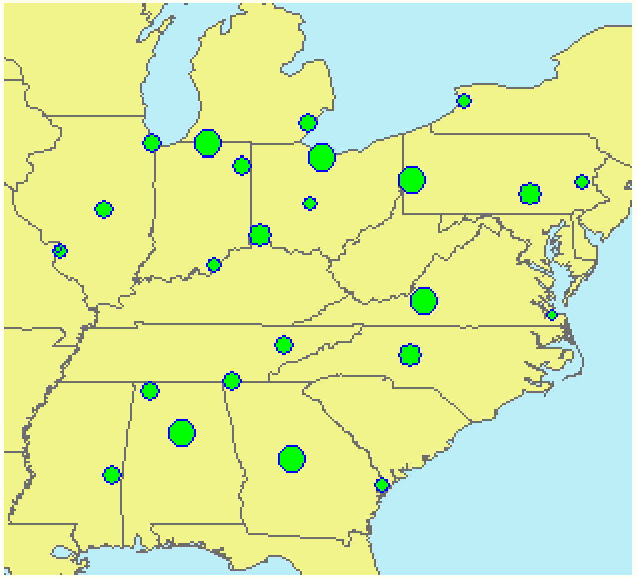
Railroad Users

- Norfolk Southern
  - Licensed and integrated with OPD.
- BNSF Railway
  - Licensed and currently being used for planning studies
- CSX Transportation
  - Used for generating their current operating plan: One Plan
- Additional Potential Clients
  - Major freight railroads in USA, Canada, Europe, and South America.

Network Optimizer (NeO) Issues

Yard locations have significant impact on blocking and train plans.

Yard locations at railroads have been determined historically.



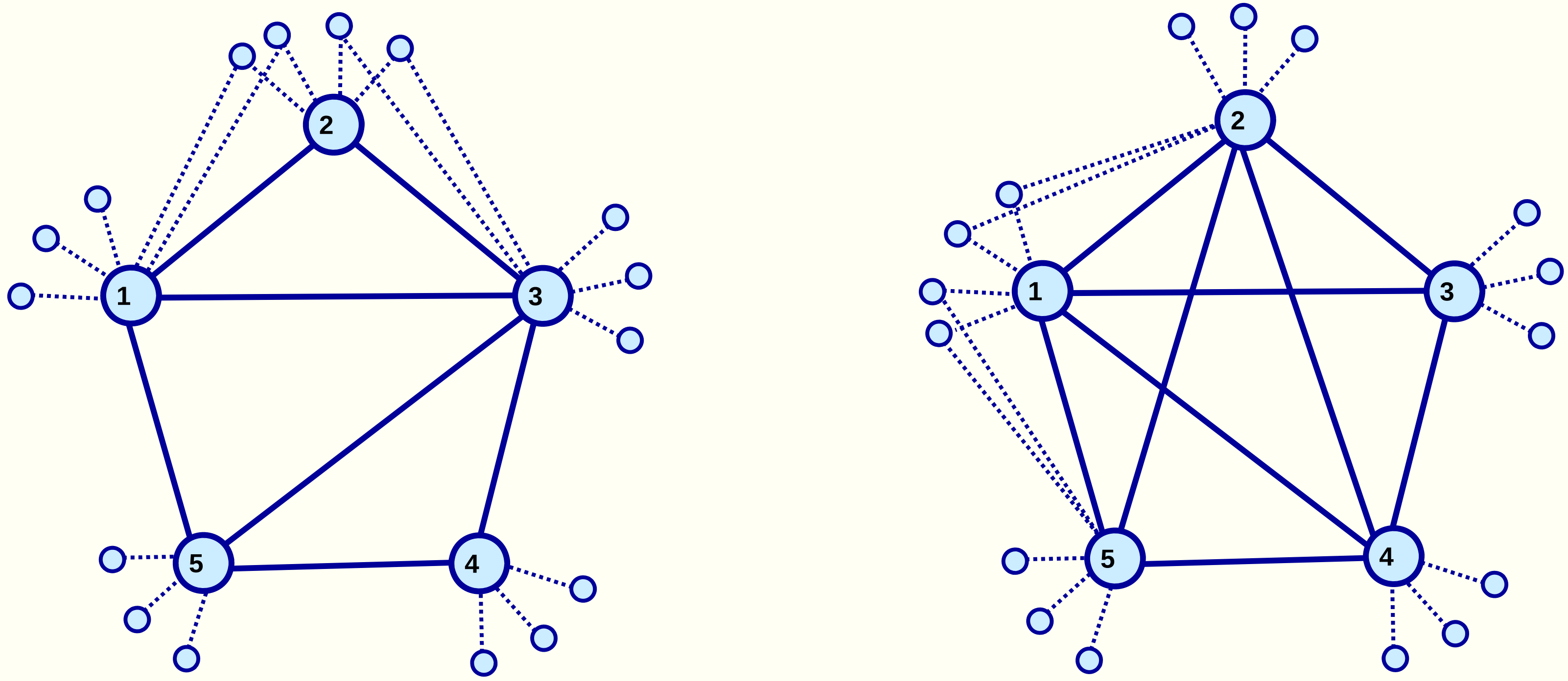
Are current yard locations optimal?

Which yard locations to add or remove?

Where to add blocking capacity?

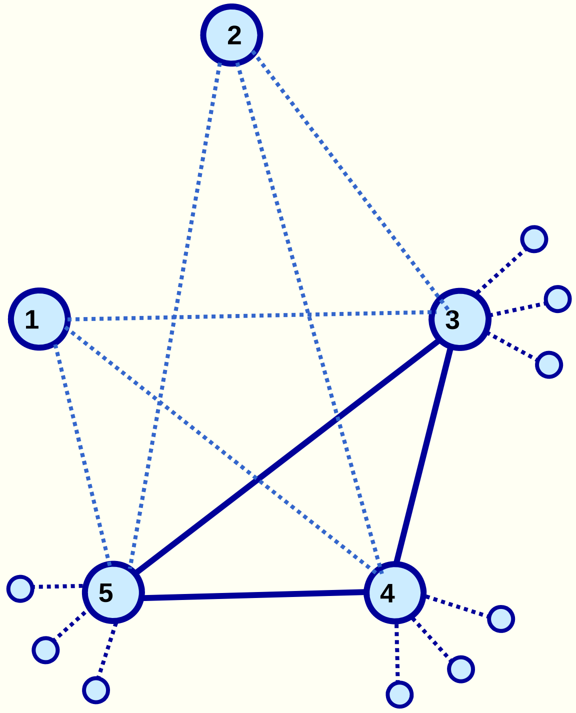
Where to add link and car handling capacity?

NeO Drop Method



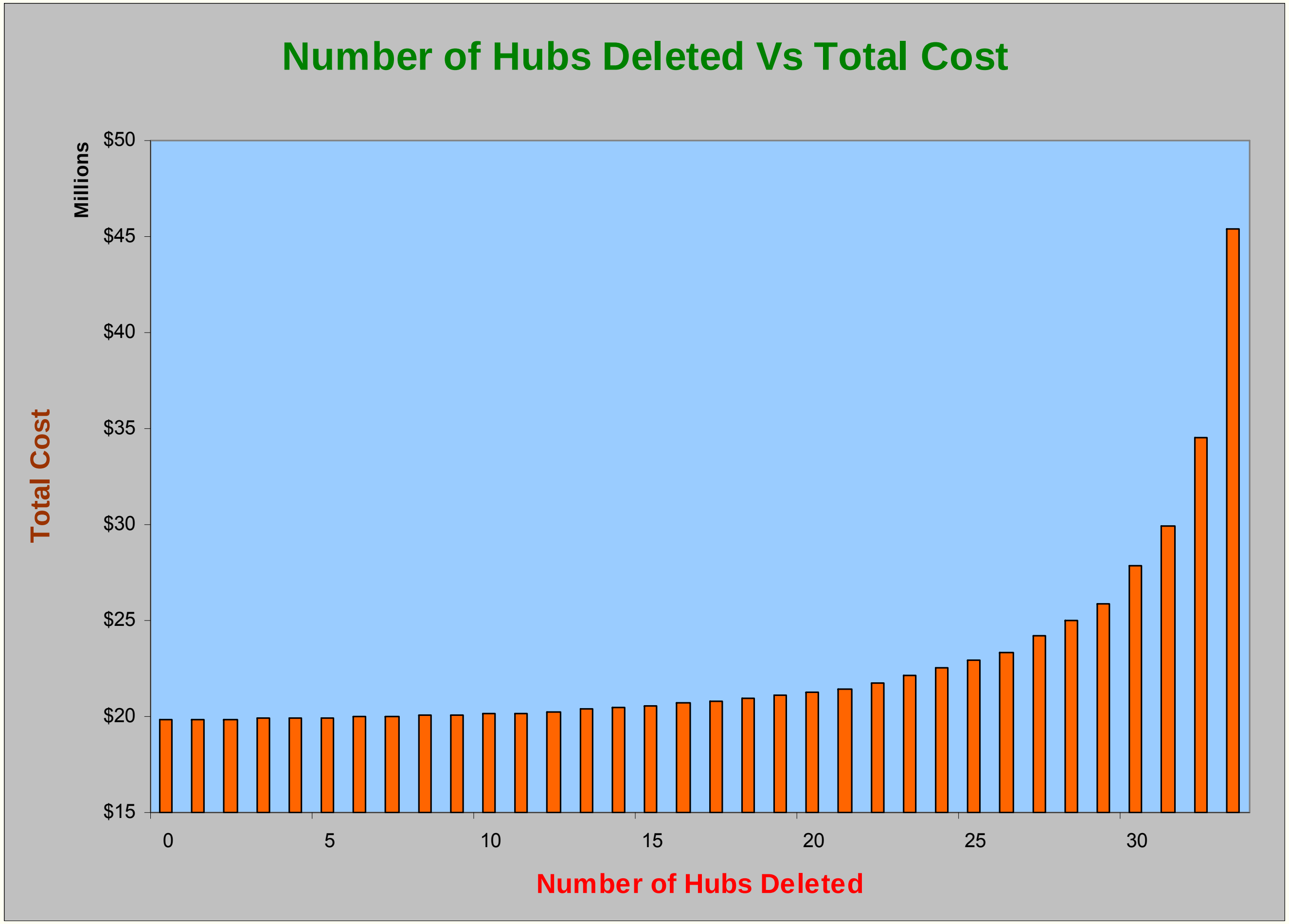
- Consider each yard for potential deletion one by one and compute the change in transportation cost by solving the blocking problem.
- Drop the yard with least impact on the cost.

NeO Swap Method



- Swap each potential yard location with the current yard location.
- Solve the blocking problem to assess the impact of this change.
- Perform the exchange if the swap is profitable.

Computational Results



- We observe that 5-10 hub yards can be downgraded without any major impact on the total cost of handlings and car miles.

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- **Innovative Railroad Blocking Optimizer (Decision Support System)**

Railroad Blocking Optimizer: Decision Support System

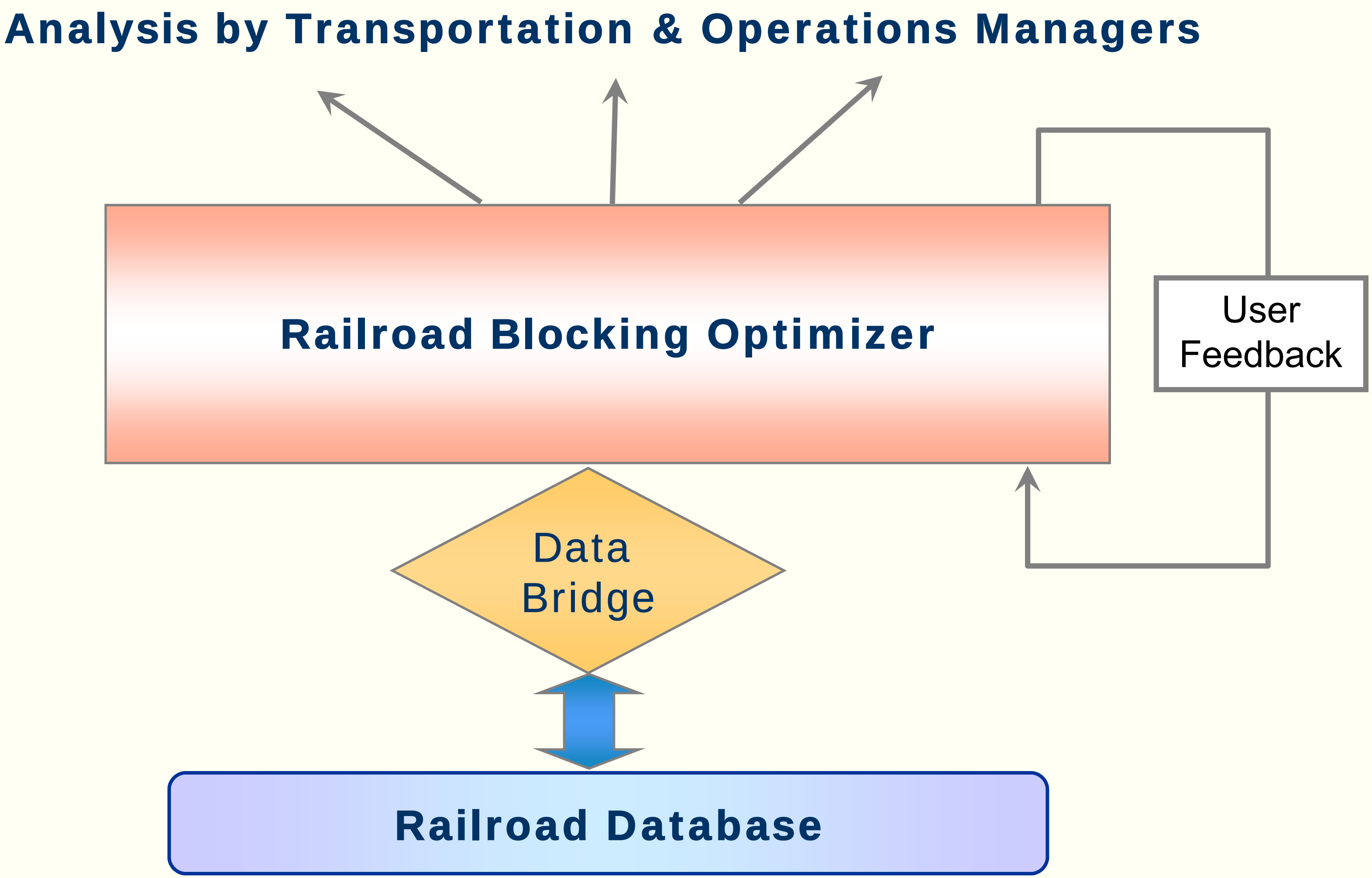
- We have packaged the railroad blocking optimizer into a web-based interactive decision support system with several new and enhanced features.

- Funded by National Science Foundation's Small Business Innovations Research (SBIR) Program (Grant: 0450504)

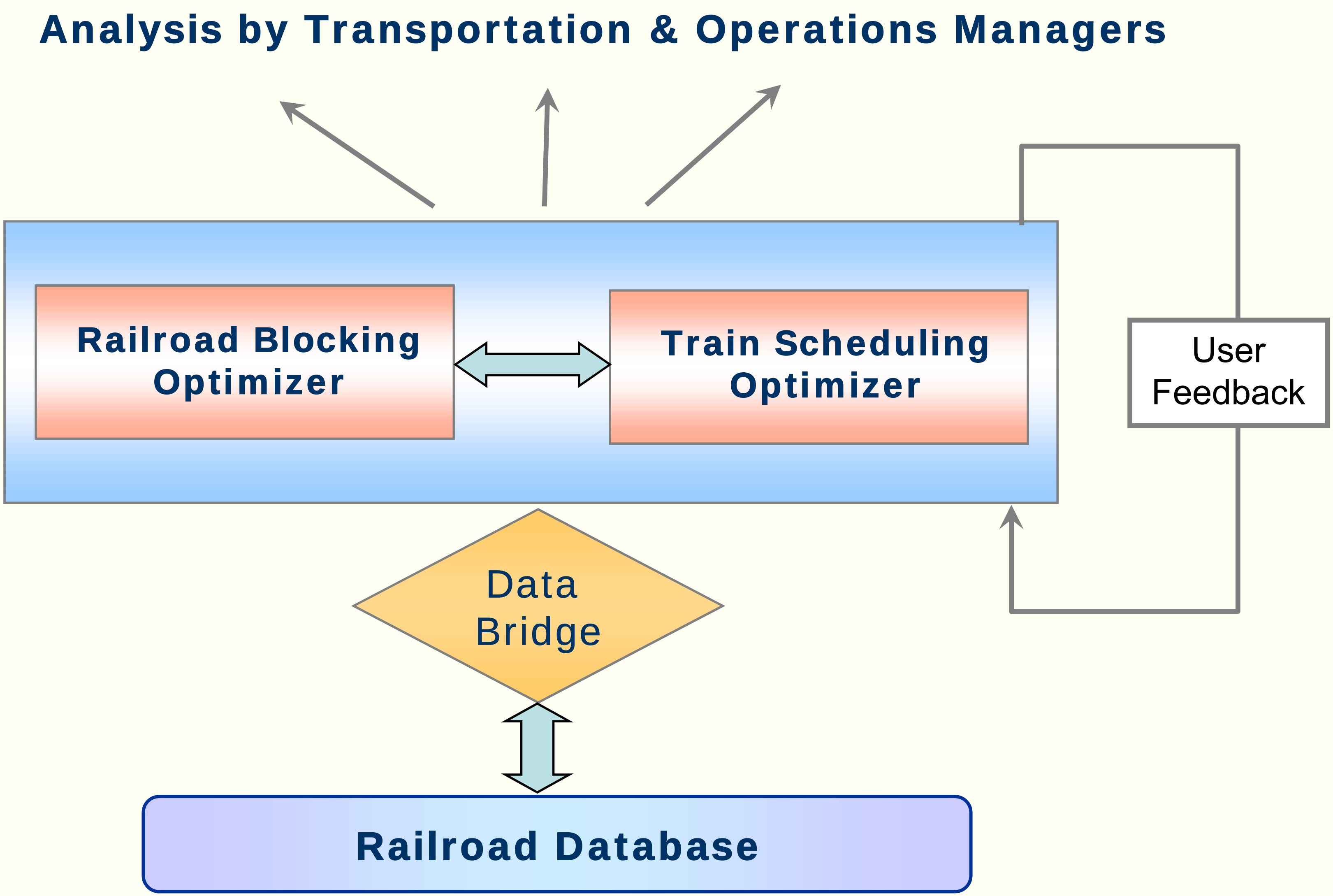
Overview of Decision Support System

- Scenario
  - Manage different scenarios
- Data
  - View and edit data
- Optimization
  - Determine the Model Plan and fine-tune it
- Analysis
  - Analyze the Model Plan and compare with Seed Plan
- Admin
  - Manage users allowed to use the system

Using Blocking Optimizer at Railroads



Service Design Suite



Impact on Railroads

- Ability to create new service designs in a two-three weeks
- Ability to incrementally change service designs in a few days
- Increase network capacity
- Improve profitability

Additional Applications of Blocking

- Airline Service Design

- Trucking Service Design

- Package Delivery Network Service Design

- Ship Network Service Design

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OPTIMIZATION IN ACTION