حمل و نقل ریلی

مسئله گروه بندی و ایگن ها

Railroad Blocking Problem

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بهار 1394
Railroad Blocking Problem:

- Introduction
- Significance
- Terminology
- Description
- Example
- Mathematical model
- References
Introduction

Railroad Blocking Problem (RBP)

- Socio-economic data, interview samples
  - Traffic OD Demand Estimation
    - Traffic OD Demand Matrix
      - Service Network Design
        - Blocking Plan
        - Line Plan
          - Route and Frequency Settings
            - Train Scheduling
              - Train Timetables
                - Locomotive, Car and Crew Scheduling

- Infrastructure Resources (yards and terminals)

- Resources and Policies

Yard and Terminal Management

Train Dispatching Empty Car Distribution
Railroad Planning and Operations

OD Demand --> Routes --> Blocks --> Trains

- Railroad planning and scheduling problems are very large-scale and very difficult discrete optimization problems.

- In large U.S. Networks, there are teams of 10-20 highly experienced personnel for solving each problem.
Introduction

Railroad Planning and Operations

OD Demand $\rightarrow$ Routes $\rightarrow$ Blocks $\rightarrow$ Trains
The questions which must be answered:

- **Origin Destination (OD) Traffic Demand**
  - Commodities, commercial unit traffic groups, car equipment requirement?

- **Route Plan**
  - Single route or multiple routes for each OD pair?

- **Blocking Plan**
  - Block origin, block destination, commodities, final destinations?

- **Make-up Plan**
  - Block-to-train assignment?

- **Train Schedule**
  - Arrival and departure times, station dwell times?
  - Order of departure?
Railroad Blocking Problem (RBP)

Introduction

Another Scheme of Railroad Planning

Blocking Problem

Train Scheduling & Block Assignment

Locomotive Sched.

Crew Scheduling

Train Dispatching

Planning

Real-Time Scheduling

Ahuja, 2007
Railroad Blocking Problem (RBP)

Introduction

Hierarchical planning in demand-driven railways

- **Strategic Level**
  - High-Level Train Routing
  - Blocking
  - Train Formation

- **Tactical Level**
  - Train Scheduling

- **Operational Level**
  - Locomotives Scheduling
  - Crew Scheduling
  - Distribution of Empty Cars

Another Scheme of Railroad Planning

Yaghini, 2014
What is “Blocking problem”?  
Problem of determining how to aggregate a large number of commodities (shipments) into blocks of commodities as they travel from origins to destinations.

✓ **Blocking problem:**
Assignment of shipments to blocks
And
Routing of blocks through pre-determined paths in the network.

✓ **Train Formation (Make-up) Problem:**
✓ Assignment of blocks to specific trains.
✓ Next step after developing Blocking plan:
To determine in which trains those blocks should travel (Train Formation Problem).
Introduction

Transportation in Road System:
Each commodity is transferred by one truck.

Railroad Blocking Problem (RBP)

6 Commodities should be transferred:

Com.1  Com.2  Com.3  Com.4  Com.5  Com.6
6 Commodities should be transferred:

Commodities should be transferred from point A to point B, and then from point B to point C. Each block consists of commodities with the same origin and destination.

Transportation in Railroad System:
Commodities should be aggregated as blocks.
## Railroad Blocking Problem (RBP)

<table>
<thead>
<tr>
<th>Block 1</th>
<th>Block 2</th>
<th>Block 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Com.1</td>
<td>Com.3</td>
<td>-----</td>
</tr>
<tr>
<td>Com.2</td>
<td>Com.4</td>
<td>-----</td>
</tr>
<tr>
<td>Com.3</td>
<td>Com.5</td>
<td>-----</td>
</tr>
<tr>
<td>Com.4</td>
<td>Com.6</td>
<td>-----</td>
</tr>
</tbody>
</table>

How to aggregate?
Goal of Blocking plan: to minimize the costs.

Two distinct costs: distance-traveled costs, handling costs.

Distance-traveled costs: cost arising from various blocks moving through railway network.

Handling costs: related to intermediate reclassification of shipments at classification yards.

Hump yards have lower handling costs.

Flat yards have higher handling costs.
Significance

✓ An efficient blocking plan can reduce total operating costs in railroad operations.

Classifications at yards are labor and capital-intensive, consisting of 10% of railroad total operating cost on average.

✓ The blocking plan has ripple effects on subsequent plans, including train scheduling, crew and power assignment that are developed based on given blocking plans.

✓ A good blocking plan has the potential to improve railroad service levels. Through reductions in number of classifications, a good blocking plan can decrease the potential delays occurring in classifications yards, thereby enhancing service quality and, in turn, improving the ability of the railroad to complete with other freight transportation modes, such as trucking and airlines.
Difficulty of the Problem

- Mathematically, the railroad blocking problem is a **multicommodity-flow**, **network-design**, and **routing** problem.

- Network-design problems are from **NP-Hard** problems.

- Problems with only **a few** hundred network design variables can be solved to **optimality**.

- Railroads **want a near-optimal** and implementable solution within a few hours of computational time.

- Real-life blocking problems often contain **over a million** design variables \((F_{ij})\) and hundreds of billions of flow variables \((f_{ij}^k)\).
Significance

Railroad Blocking Problem (RBP)

Figure 3.2: Physical rail network of links and nodes
Significance

Railroad Blocking Problem (RBP)

Figure 3.3: Locations of terminals in the rail network
Significance

Railroad Blocking Problem (RBP)

Figure 4.1: Solution for RBP for rail system of Figures 3.2 and 3.3
**Block:**
A Block is completely specified by its **origin and destination**.
Cars using the block will be **sorted at the block's origin** and then **not sorted again until** reaching the block's destination.
Destination of a block is not necessarily equal to destination(s) of its cars.

**Blocking:**
Classification, Blocking, or Handling is the **process of sorting** cars into different blocks.

**Terminal:**
A **node** of the rail network at which **classification** may be performed.
OD pair:
A pair of Origin- Destination, which is the same for group of cars, put in a block.

Priority Class:
Number of intermediate classifications that are permitted.
If no intermediate classifications are permitted, then the commodity must be blocked for the destination terminal directly at the origin terminal.

Commodity (Shipment):
a subgroup of an OD pair demand which has the same priority class.

Routing for a commodity:
Consists of a sequence of terminals, starting with the commodity's origin and ending with the commodity's destination, that a commodity may visit.

A Train:
consists of one or more blocks, in addition to the locomotives.
Terminology

Classification yard (Station Grade 1):

A railway yard used to **separate, sort and group** cars according to their final destination(s), and also allows the inspection of trains.

**Classification Tracks**

**Arrival Tracks**

**Departure Tracks**
There are 2 types of classification yards: hump yards and flat yards.

Hump yards are characterized by a “hump” or hill, upon which the cars are pushed by an engine and moved down by gravity.

At the top of the hill, cars are automatically decoupled and switched to the proper destination track, onto which, via gravity, they roll down and are now grouped with other cars heading on the same destination track.

Hump yards are the most cost-effective and with the largest capacity.

In flat yards, the cars are moved onto the designated tracks by a locomotive, rather than via gravity assist.
Classification yard

The commodities are reclassified in “classification tracks”
Description

Railroad Blocking Problem (RBP)

Classification yard

Hump

Classification tracks
Railroad Blocking Problem (RBP)

Description

Classification yard

Hump

Classification tracks
This terminal is as “origin” of the blocks assigned to Train 1 & Train 2.
This terminal is as “origin” of the blocks assigned to Train 1 & Train 2.
This terminal is as “origin” of the blocks assigned to Train 1 & Train 2
Classification yard

- Number of available classification tracks are not always enough
- Classification is time-consuming and costly
- So, we should optimize (Minimize) number of classifications

From Origin to Destination...

- Once shipments have left their origin and are in their way to their final destination, they can pass through numerous classification yards.
- In each of these classification yards, shipments may or may not be reclassified again, as befitting the specific circumstances.
- Every time a shipment is classified, the railway incurs additional costs due to human labor, the use of yard resources, time delays, etc.
In order to **avoid extra costs** (handling costs), commodities that share a final destination (or commodities that have the possibility of traveling together for a portion of their journeys even though they may be destined to different final destinations) are grouped together to create a block.

A block is now paired with a **new origin-destination** set of yards, which may or may not correspond with the origin and destinations of any of the shipments.

A train can carry 1 or more blocks.

Block A with origin i and destination j. k is a terminal among i and j.

**Question:** Can the train carrying block A be stopped in Terminal k?

**Answer:** Yes, But block A must not be reclassified.
Railroad Blocking Problem (RBP)

**Description**

- **Origins**
- **Destinations**
- **Sorting Stations**
- **Blocking Arcs**
Description

Railroad Blocking Problem (RBP)

A commodity

Origins

Sorting Stations

Destinations

Note: Commodities with the same color, have the same destination
**Description**

**Railroad Blocking Problem (RBP)**

**Blocking Problem:** Designing the sorting network and route all commodities in it to minimize the weighted sum of travel times and sorting costs.

**Blocking Plan:** determines how to aggregate a large number of commodities into blocks of commodities as they travel from origins to destinations.

- **Blocking Problem:** developing a plan that describes:
  - which blocks should be assembled at each classification yard?
  - which shipments should be assigned to those blocks?
The shipments can pass through a number of classification yards without being reclassified, only getting classified again when they reach destination of block.

Once a block reaches its destination, it is disassembled and the shipments that are not still at their own final destination are assembled into new blocks and continue on their way to their own final destinations.

Once shipments are grouped together in a block, they get assigned to trains consisting of multiple blocks that share relevant portions of their routes.
Description

✅ **Blocking Problem**: developing a plan that describes:

- which blocks should be assembled at each classification yard?
- which shipments should be assigned to those blocks?
Railroad Blocking Problem (RBP)

Block Definition
- From “A”
- To “C”

Block Definition
- From “A”
- To “B”
Physical rail network: the **real** network, consisting of railroad terminals and tracks.

The blocking network: a **virtual** network that is overlaid on the physical network.

The blocks are **virtual arcs** which a commodity may take to have uninterrupted service between two terminals that are **not necessarily connected** by a physical link.
RBP:

- **Given:**
  - A set of commodities (shipments) with different origins/destinations

- **Determine:**
  - Design the blocking network and route all commodities over blocking network

- **Objective Function:**
  - Minimize the weighted sum of cost of arc travellings and node handlings
Description

Railroad Blocking Problem (RBP)

RBP:

- **Constraints:**

  - **Blocking capacities of nodes:**
    Each block built at any node *needs separate tracks.*
    However, because the number of tracks at any node is limited, we can build only a specified number of blocks (blocking capacity of that node).

  - **Shipment capacities of nodes:**
    Each node of the network has a limited capacity for the number of cars that can pass through it. Sending more cars than the capacity of the nodes can handle creates *congestion* and may ultimately lead to the complete *breakdown* of operations.

  - **Flow capacities of blocks:**
    Each block built in the network may have a specified capacity in terms of the number of cars that can flow on.
    However, each block should carry at least a specified number of cars.
Example 1

Railroad Blocking Problem (RBP)

<table>
<thead>
<tr>
<th>origin</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>100</td>
<td>100</td>
<td>500</td>
</tr>
<tr>
<td>b</td>
<td>150</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td></td>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>

Candidate blocks

Blocking Plan 1

Dab+Dac+Dad

Dac+Dad
+Dbc+Dbd

Dad+Dbd
+Dcd

Dad

Dab+Dac
Dac+Dbc+Dbd
Dbd+Dcd

Physical network

Blocking network

Blocking Plan 1

Blocking Plan 2

Station
Block
Example 2

Railroad Blocking Problem (RBP)

✅ Commodities (origin-destination pairs of terminals):
A → B with 100 cars
A → C with 80 cars
A → D with 90 cars

<table>
<thead>
<tr>
<th>Terminals</th>
<th>Shipment capacity</th>
<th>Blocking capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal A</td>
<td>270 cars</td>
<td>2 blocks</td>
</tr>
<tr>
<td>Terminal B</td>
<td>90 cars</td>
<td>1 block</td>
</tr>
<tr>
<td>Terminal C</td>
<td>90 cars</td>
<td>1 block</td>
</tr>
</tbody>
</table>

Shipment capacity constraints: upper bounds on the flow through each node.
Blocking capacity constraints: limits on the out-degree of each node.
Example 2

Railroad Blocking Problem (RBP)

Plan 1

✓ Short blocking strategy is used.
✓ At terminal A, all three commodities are sorted to move to terminal B.
✓ At terminal B, commodity A→B (100 cars) has reached its destination and leaves the system by separating them using classification operation.
✓ Commodities A→C (80 cars) and A→D (90 cars) are blocked by blocking operation to be moved to terminal C.
✓ At terminal C, commodity A→C has reached its destination and leaves the system by another classification operation.
✓ commodity A→D is blocked to move to terminal D.
✓ Using this blocking plan:
  100 cars for commodity A→B use 1 block (A, B)
  80 cars for commodity A→C use 2 blocks (A, B) and (B, C)
  90 cars for commodity A→D use 3 blocks (A, B), (B, C) and (C, D).

✓ Block (A,B) including: A→B, A→C and A→D [270 car classification in terminal A]
✓ Block (B,C) including: A→C and A→D [170 car classification in terminal B]
✓ Block (C,D) including: A→D [90 car classification in terminal C]
✓ Totally, **530** car classification operations.

Plan 1 is infeasible (Shipment capacity in Terminal B)
Example 2

Railroad Blocking Problem (RBP)

Plan 2

- Providing a direct block from terminal A to terminal D
- Cars which travel in block (A,D) still move along physical track through terminals B and C
- the 90 cars of Commodity A→D now require only one block, (A, D).
- Totally, **350** car classification operations.
- Plan 2 is feasible
Example 2

Railroad Blocking Problem (RBP)

Plan 3

- Block (A,B)
- Block (A,C)
- Block (C,D)

✓ Totally, 360 car classification operations.
✓ Plan 3 is feasible

Plan 4

- Block (A,B)
- Block (A,C)
- Block (A,D)

✓ Totally, 270 car classification operations.
✓ Plan 4 is infeasible

Plan 5

- Block (A,B)
- Block (A,C)
- Block (B,D)

✓ Totally, 360 car classification operations.
✓ Plan 5 is feasible
**Example 2**

**Railroad Blocking Problem (RBP)**

**Physical Network:**

- A → B → C → D

**Blocking Network:**

- A → B → C → D

**Plan 1:**

- A → B → C → D (530)

**Plan 2:**

- A → B → C → D (350)  ✔  Optimal Solution

**Plan 3:**

- A → B → C → D (360)

**Plan 4:**

- A → B → C → D (270)

**Plan 5:**

- A → B → C → D (360)
To solve RBP, we must decide **which blocks to include** in the blocking plan and which blocks to use to deliver each commodity

**Decision Variables**

- **Blocking decisions:**
  What is the blocking network?
  (i.e., how many blocks are made, and what is the origin-destination of each block?)

- **Shipment-block sequencing decisions:**
  How is each origin-destination shipment routed over the blocking network?
“Node-Arc Formulation”

Parameters:

\( G = (N, A) \) is the graph with terminal set \( N \) and potential blocks set \( A \).

\( K \) is the set of all commodities \( k \) designated by an origin-destination pair of nodes.

\( v_k \) is the volume of commodity \( k \).

\( \text{orig}(k) \) is the origin terminal for commodity \( k \).

\( \text{dest}(k) \) is the destination terminal for commodity \( k \).

\( \text{orig}(a) \) is the origin of potential block \( a \).

\( \text{dest}(a) \) is the destination of potential block \( a \).

\( u_a \) is the capacity of potential block \( a \).

\( c_a \) is the per unit cost of flow on arc \( a \) (assumed equal for all commodities).

\( B(i) \) is the number of blocks which may be originated at terminal \( i \).

\( V(i) \) is the volume which may be classified at terminal \( i \).

Variables:

\( x^k_a \) 1 if commodity \( k \) is flowing on block \( a \), 0 otherwise.

\( y_a \) 1 if block \( a \) is included in the blocking network, 0 otherwise.

Mathematical Model

Objective Function:

The objective is to minimize the sum of the costs of delivering each commodity using the blocking network formed by blocks for which \( y_a = 1 \).

\[
\text{Min } Z = \sum_{k \in K} \sum_{a \in A} c_a \cdot v_k \cdot x_k^a
\]

- \( c_a \cdot v_k \cdot x_k^a \) represents the per unit cost of flow on block \( a \), volume of commodity \( k \), and 1 if commodity \( k \) is flowing on block \( a \), 0 otherwise

Blocking Network:
Mathematical Model

Constraints:

For each terminal, balance equations for the flow of each commodity:

\[
\sum_{a \in A \atop \text{orig}(a) = i} x^k_a - \sum_{a \in A \atop \text{dest}(a) = i} x^k_a = \begin{cases} 
1 & \text{orig}(a) = i, \\
-1 & \text{dest}(a) = i, \\
0 & \text{otherwise}, 
\end{cases} 
\forall i \in N, \ k \in K,
\]

1 if commodity k is flowing on block a, 0 otherwise.
Mathematical Model

Railroad Blocking Problem (RBP)

Constraints:

For each potential block:
1) flow on blocks which are not built, must be prevented.
2) upper bound $u_a$ on flow for blocks -which are built- is enforced.

$$\sum_{k \in K} \nu^k x^k \leq u_a y_a, \quad \forall a \in A,$$

- volume of commodity $k$
- capacity of potential block $a$
- 1 if block $a$ is included in the blocking network, 0 otherwise
Mathematical Model

Railroad Blocking Problem (RBP)

Constraints:

enforcing terminal limit $B(i)$ for sum of the blocks which leave the terminal.

$$\sum_{a \in A \text{ and } \text{orig}(a) = i} y_a \leq B(i), \quad \forall i \in N,$$

1 if block $a$ is included in the blocking network, 0 otherwise.

Blocking capacity in terminal $i$ (Maximum number of blocks which may be originated at terminal $i$).
Mathematical Model

**Railroad Blocking Problem (RBP)**

**Constraints:**

modelling the volume of cars, which may be classified at each terminal

\[ \sum_{k \in K} \sum_{a \in A} v_k x^k_a \leq V(i), \quad \forall i \in N, \]

- \( v_k \) volume of commodity \( k \)
- \( x^k_a \)\( \ x^k_a = 1 \) if commodity \( k \) is flowing on block \( a \), 0 otherwise
- \( V(i) \) Shipment capacity (Maximum volume of commodities which may be classified at terminal \( i \))
Mathematical Model

Railroad Blocking Problem (RBP)

Constraints:

\[ y_a \in \{0, 1\}, \quad \forall a \in A, \]
\[ x^k_a \in \{0, 1\}, \quad \forall a \in A, \forall k \in K. \]
Mathematical Model

**Railroad Blocking Problem (RBP)**

\[
\text{Min } Z = \sum_{k \in K} \sum_{a \in A} c_{a} \nu_{k} x_{a}^{k},
\]

Subject to:

\[
\sum_{a \in A \atop \text{orig}(a) = i} x_{a}^{k} - \sum_{a \in A \atop \text{dest}(a) = i} x_{a}^{k} = \begin{cases} 
1 & \text{orig}(a) = i, \\
-1 & \text{dest}(a) = i, \\
0 & \text{otherwise}, 
\end{cases} \quad \forall i \in N, k \in K,
\]

\[
\sum_{k \in K} \nu_{k} x_{a}^{k} \leq u_{a} y_{a}, \quad \forall a \in A,
\]

\[
\sum_{a \in A \atop \text{orig}(a) = i} y_{a} \leq B(i), \quad \forall i \in N,
\]

\[
\sum_{k \in K} \sum_{a \in A \atop \text{orig}(a) = i} \nu_{k} x_{a}^{k} \leq V(i), \quad \forall i \in N,
\]

\[
y_{a} \in \{0, 1\}, \quad \forall a \in A,
\]

\[
x_{a}^{k} \in \{0, 1\}, \quad \forall a \in A, \forall k \in K.
\]
Mathematical Model (2)  

Railroad Blocking Problem (RBP)

A path-based NDP (Network Design Problem) formulation of the railroad blocking problem:

\[
(P) \quad \min \sum_{k \in \mathcal{K}} \sum_{q \in \mathcal{G}(k)} PC^k_q v^k f_q^k, \tag{1}
\]

s.t.

\[
\sum_{q \in \mathcal{G}(k)} \delta^q_a f_q^k \leq y_a, \quad \forall k \in \mathcal{K}, \forall a \in \mathcal{A}, \tag{2}
\]

\[
\sum_{q \in \mathcal{G}(k)} f_q^k = 1, \quad \forall k \in \mathcal{K}, \tag{3}
\]

\[
\sum_{a \in \mathcal{A}} \xi^a_i y_a \leq B(i), \quad \forall i \in \mathcal{N}, \tag{4}
\]

\[
\sum_{k \in \mathcal{K}} \sum_{q \in \mathcal{G}(k)} \sum_{a \in \mathcal{A}} v^k \delta^q_a \xi^a_i f_q^k \leq V(i), \quad \forall i \in \mathcal{N}, \tag{5}
\]

\[
f_q^k \geq 0, \quad \forall q \in \mathcal{G}(k), \forall k \in \mathcal{K}, \tag{6}
\]

\[
y_a \in \{0, 1\}, \quad \forall a \in \mathcal{A}, \tag{7}
\]

where \(PC^k_q = \sum_{a \in \mathcal{A}} C^a_q \delta^q_a\).

References:


Railroad Blocking Problem (RBP)