دانشگاه صنعتی اصفهان
دانشکده مهندسی حمل و نقل

حمل و نقل ریلی

مسئله گروه بندی واگن ها

Railroad Blocking Problem

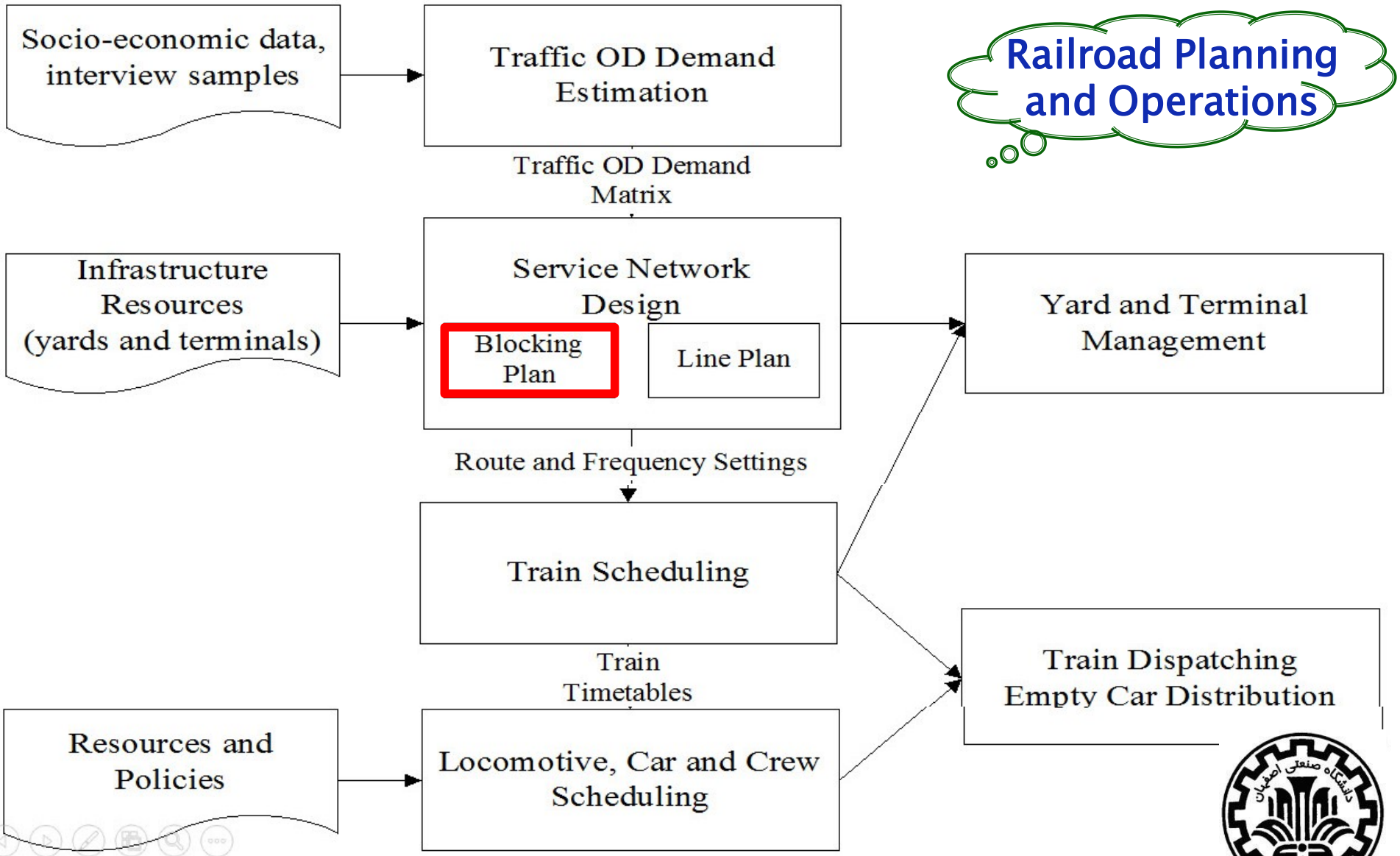
مدرس: محمد تمنایی

بهار ۱۳۹۴

Railroad Blocking Problem:

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

Railroad Blocking Problem (RBP)



Railroad Blocking Problem (RBP)

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.

Railroad Blocking Problem (RBP)

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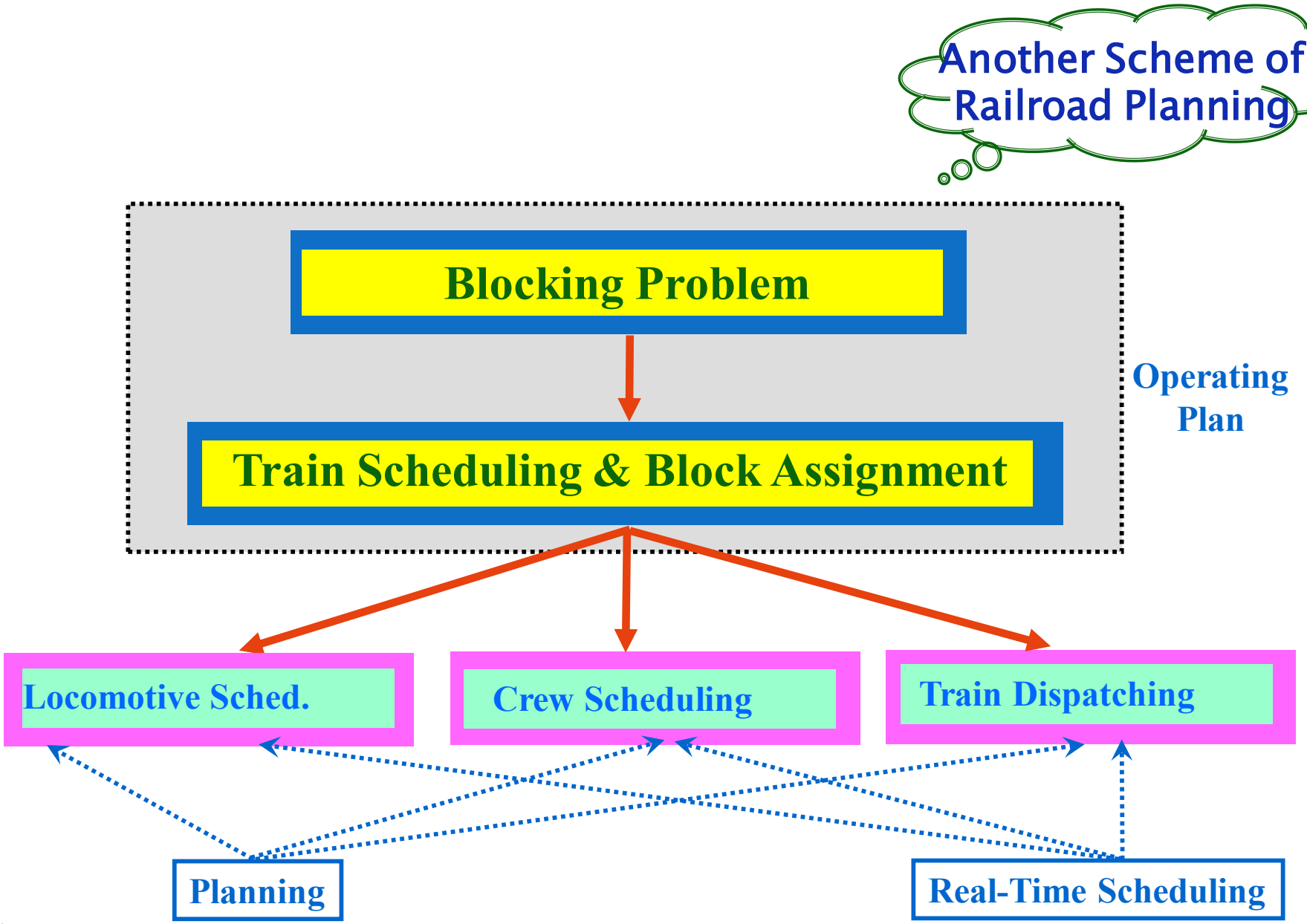
Railroad Blocking Problem (RBP)

OD Demand --> Routes --> Blocks --> 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?

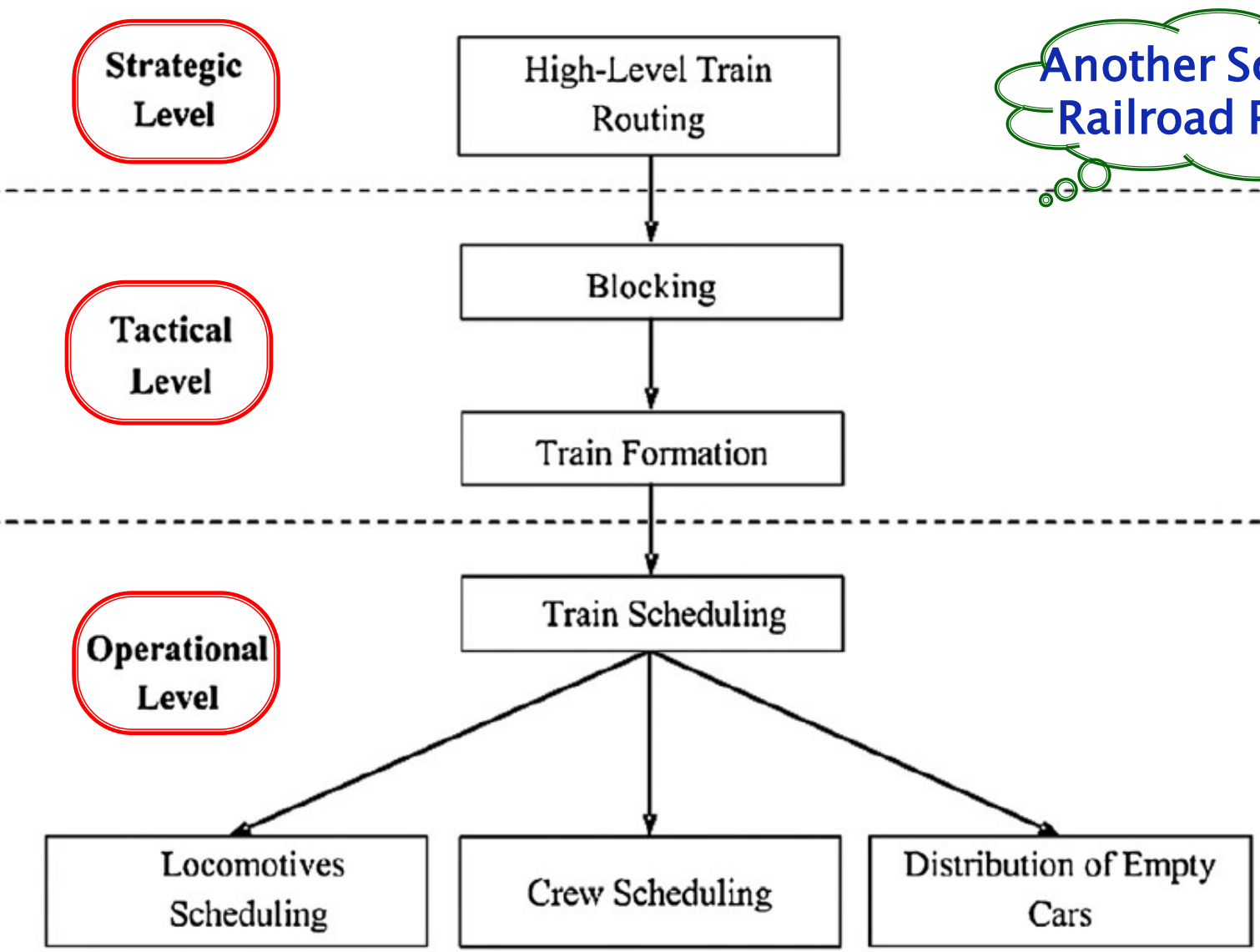
Railroad Blocking Problem (RBP)



Ahuja, 2007

Railroad Blocking Problem (RBP)

Hierarchical planning in demand-driven railways



Railroad Blocking Problem (RBP)

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.

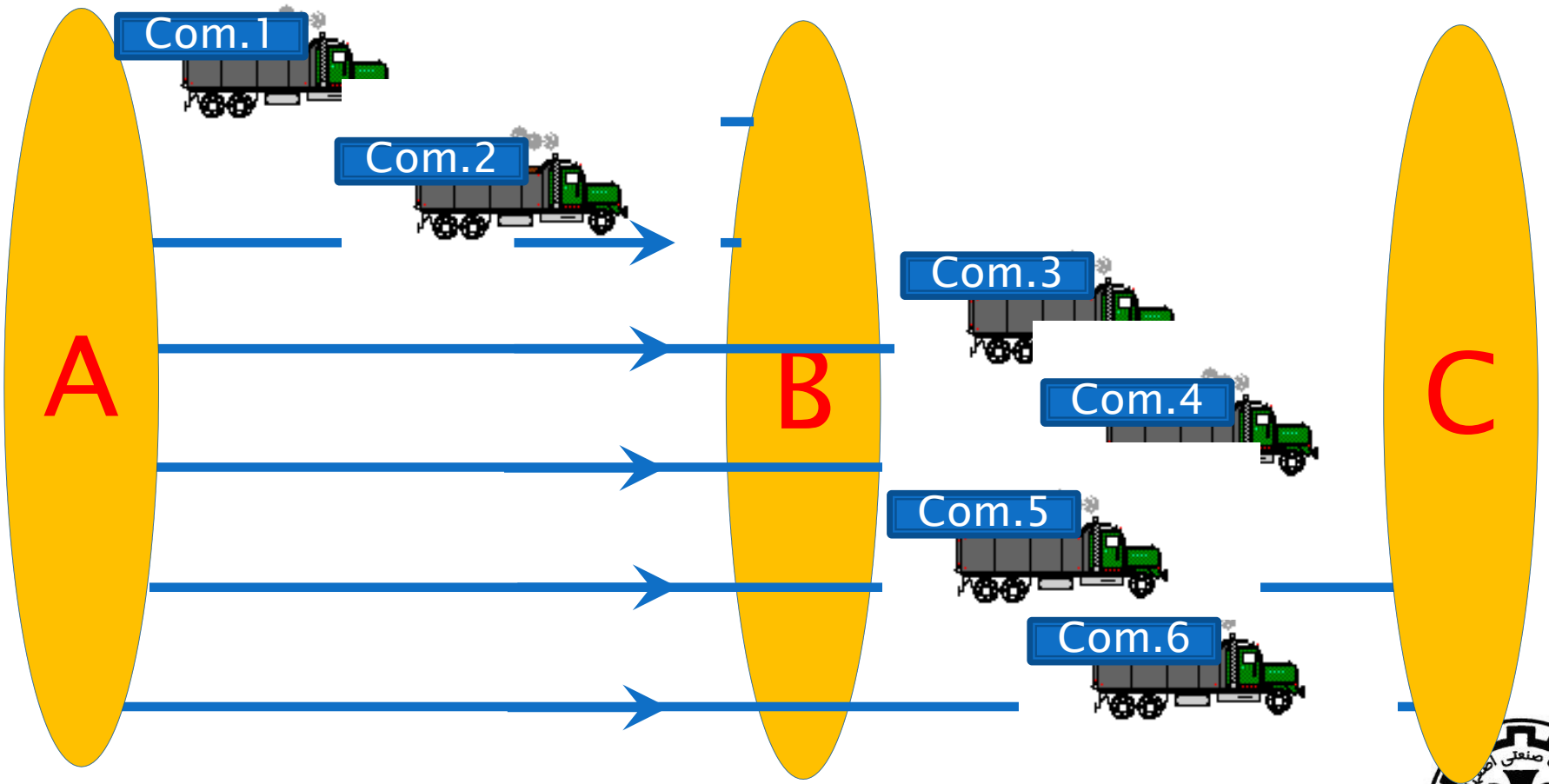
- ✓ **Train Formation (Make-up) Problem:**
- ✓ Assignment of blocks to specific trains.
- ✓ Next step after developing Blocking plan:

To determine in which trains those blocks should travel (Train Formation Problem).

Railroad Blocking Problem (RBP)

6 Commodities should be transferred:

Com.1 Com.3 Com.5
Com.2 Com.4 Com.6

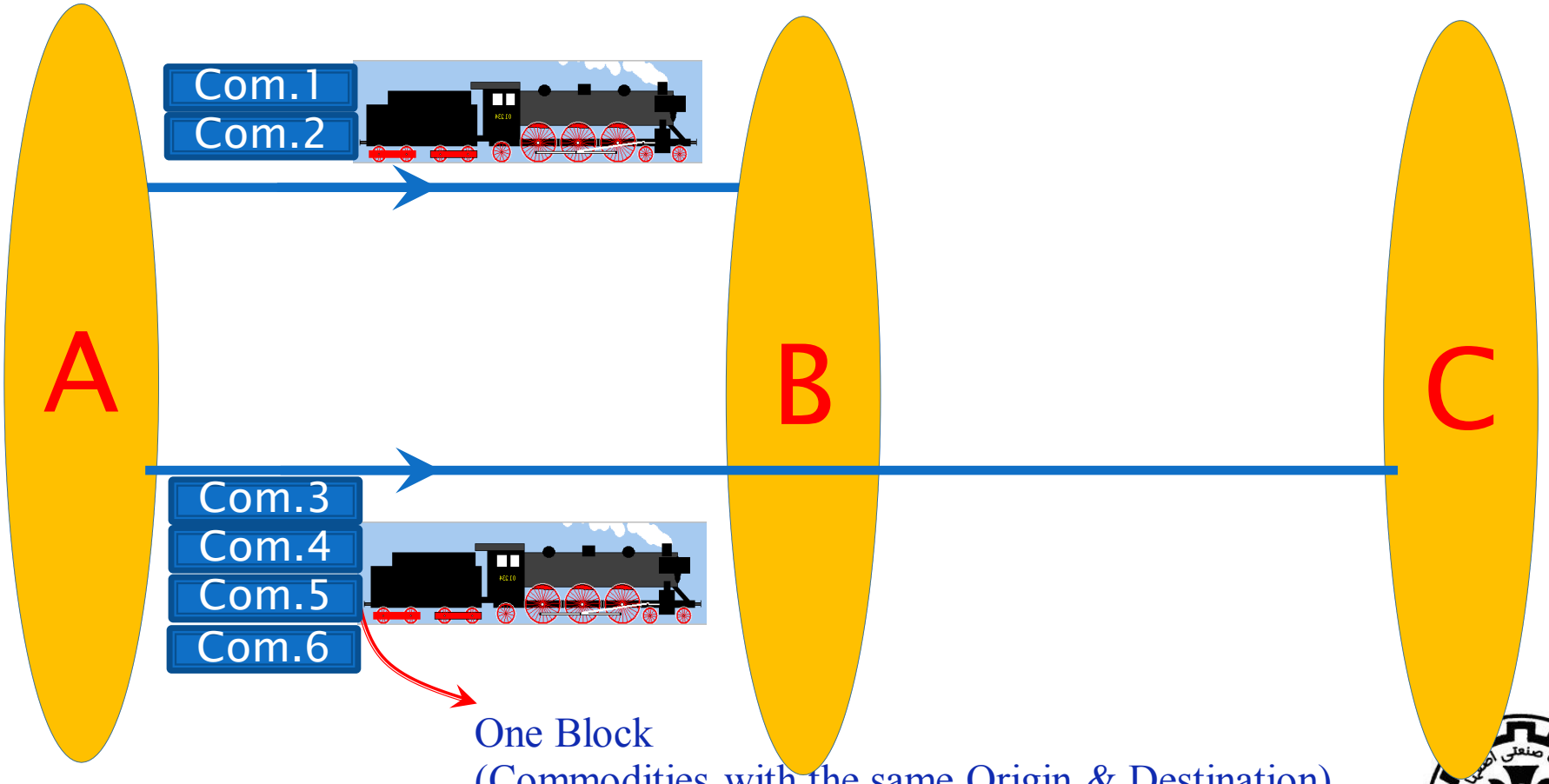


Transportation in Road System:
Each commodity is transferred by one truck.

Railroad Blocking Problem (RBP)

6 Commodities should be transferred:

Com.1 Com.3 Com.5
Com.2 Com.4 Com.6



One Block
(Commodities with the same Origin & Destination)

Transportation in Railroad System:
Commodities should be aggregated as blocks.

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Railroad Blocking Problem (RBP)

Com.1
Com.2
Com.3
Com.4
Com.5
Com.6

How to aggregate ?

Block 1	Block 2	Block 3
Com.1 Com.2	Com.3 Com.4 Com.5 Com.6	-----
Com.1 Com.2 Com.3	Com.4 Com.5 Com.6	-----
Com.1 Com.2	Com.3 Com.4	Com.5 Com.6

Railroad Blocking Problem (RBP)

- ✓ **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.

Railroad Blocking Problem (RBP)

- ✓ 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** occuring 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.

Railroad Blocking Problem (RBP)

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.

$$Minimize\ z(f, y) = \sum_{k \in K} \sum_{(i,j) \in A} c_{ij}^{k} f_{ij}^{k} + \sum_{(i,j) \in A} F_{ij}\, y_{ij}$$

- ✓ 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}).

Railroad Blocking Problem (RBP)

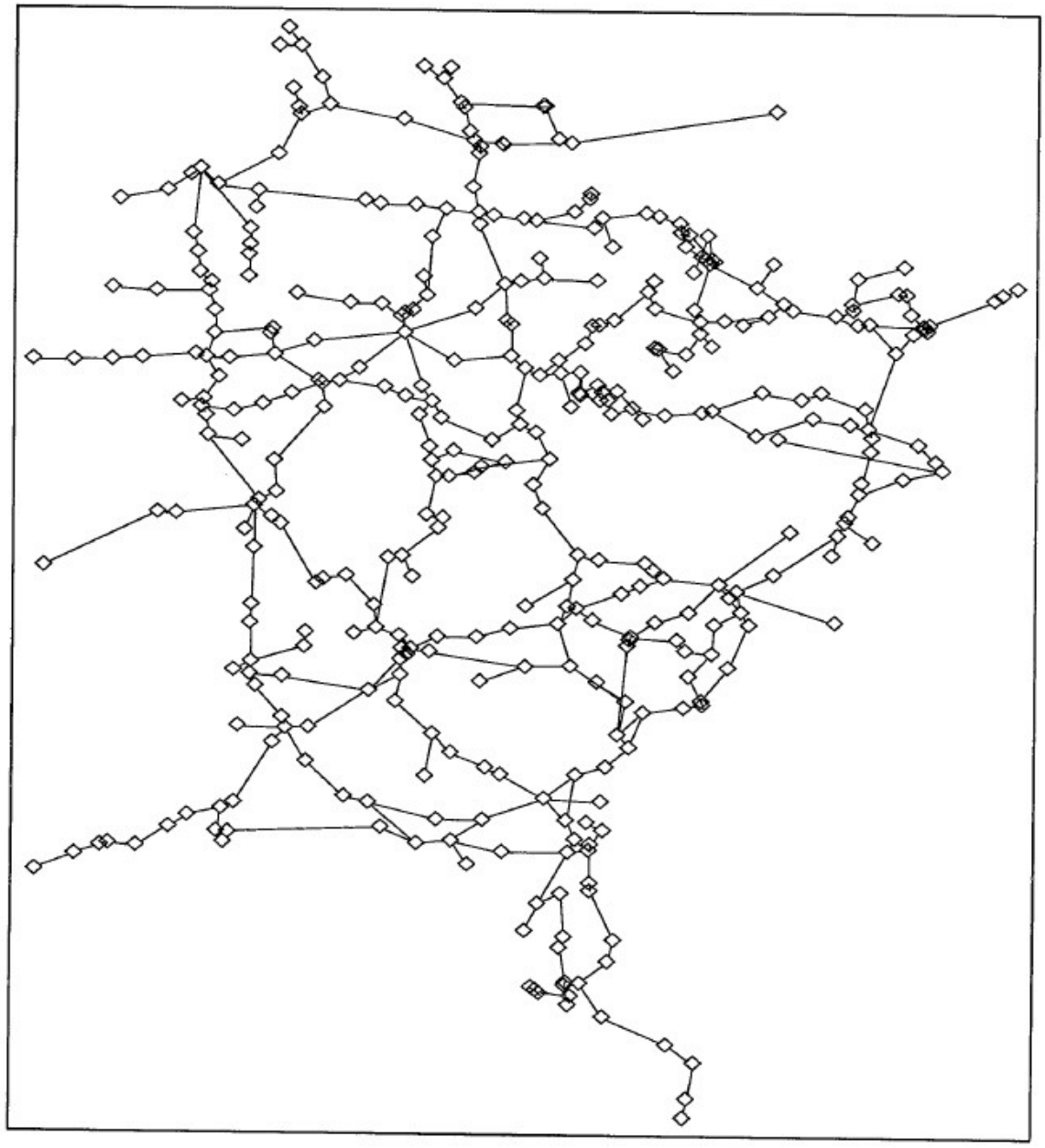


Figure 3.2: Physical rail network of links and nodes

Railroad Blocking Problem (RBP)

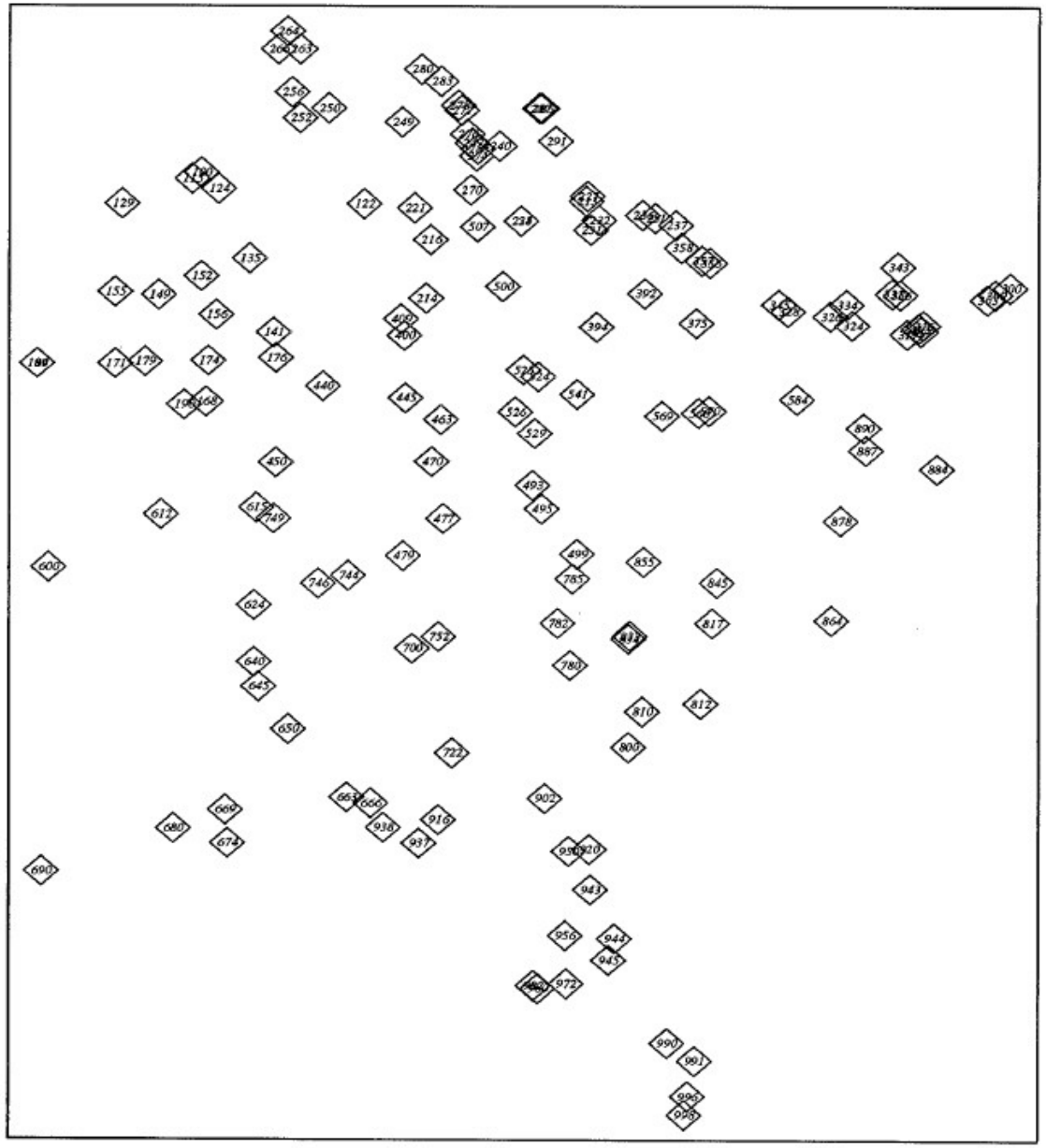


Figure 3.3: Locations of terminals in the rail network

Railroad Blocking Problem (RBP)

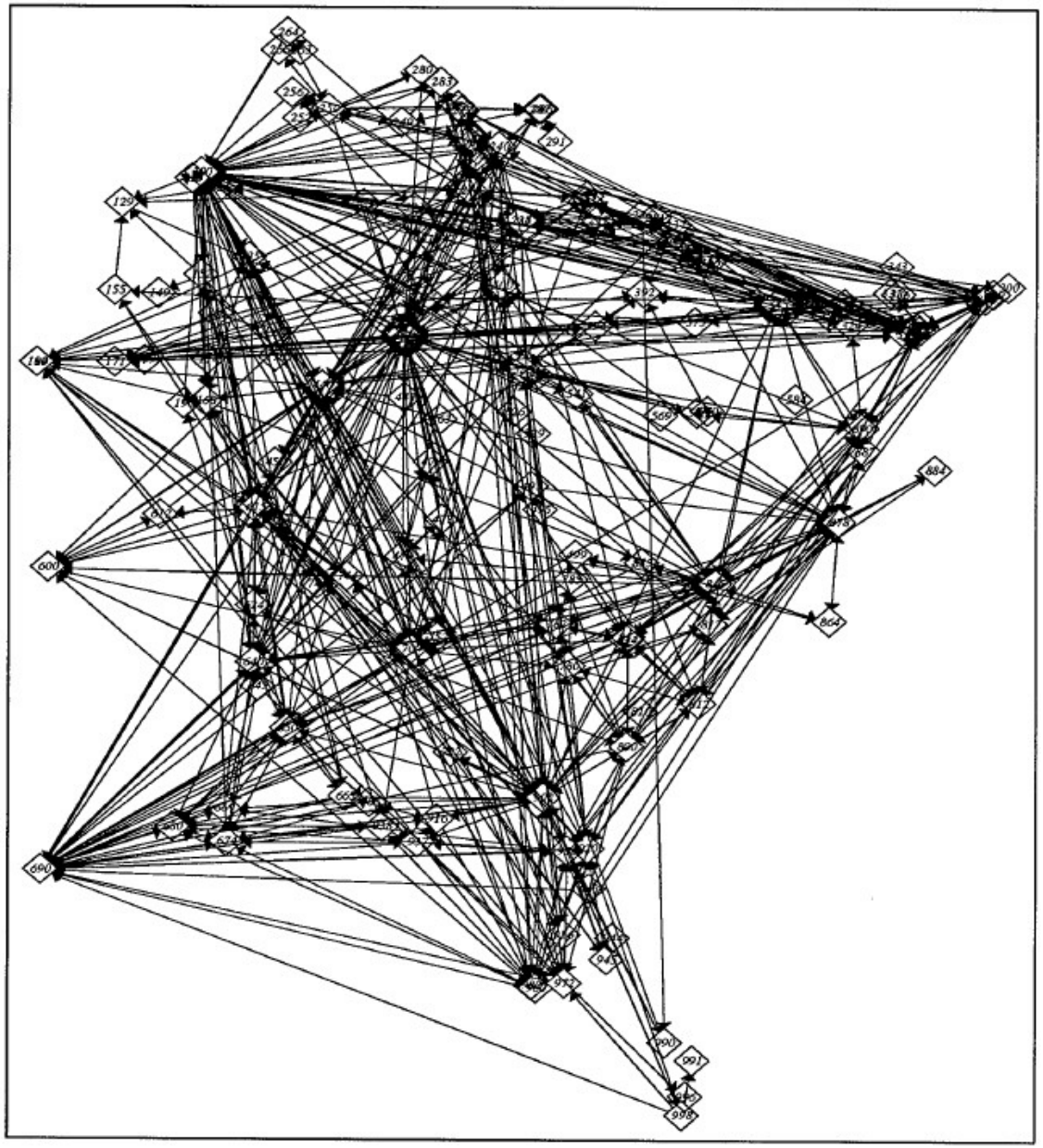


Figure 4.1: Solution for RBP for rail system of Figures 3.2 and 3.3

Railroad Blocking Problem (RBP)

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.

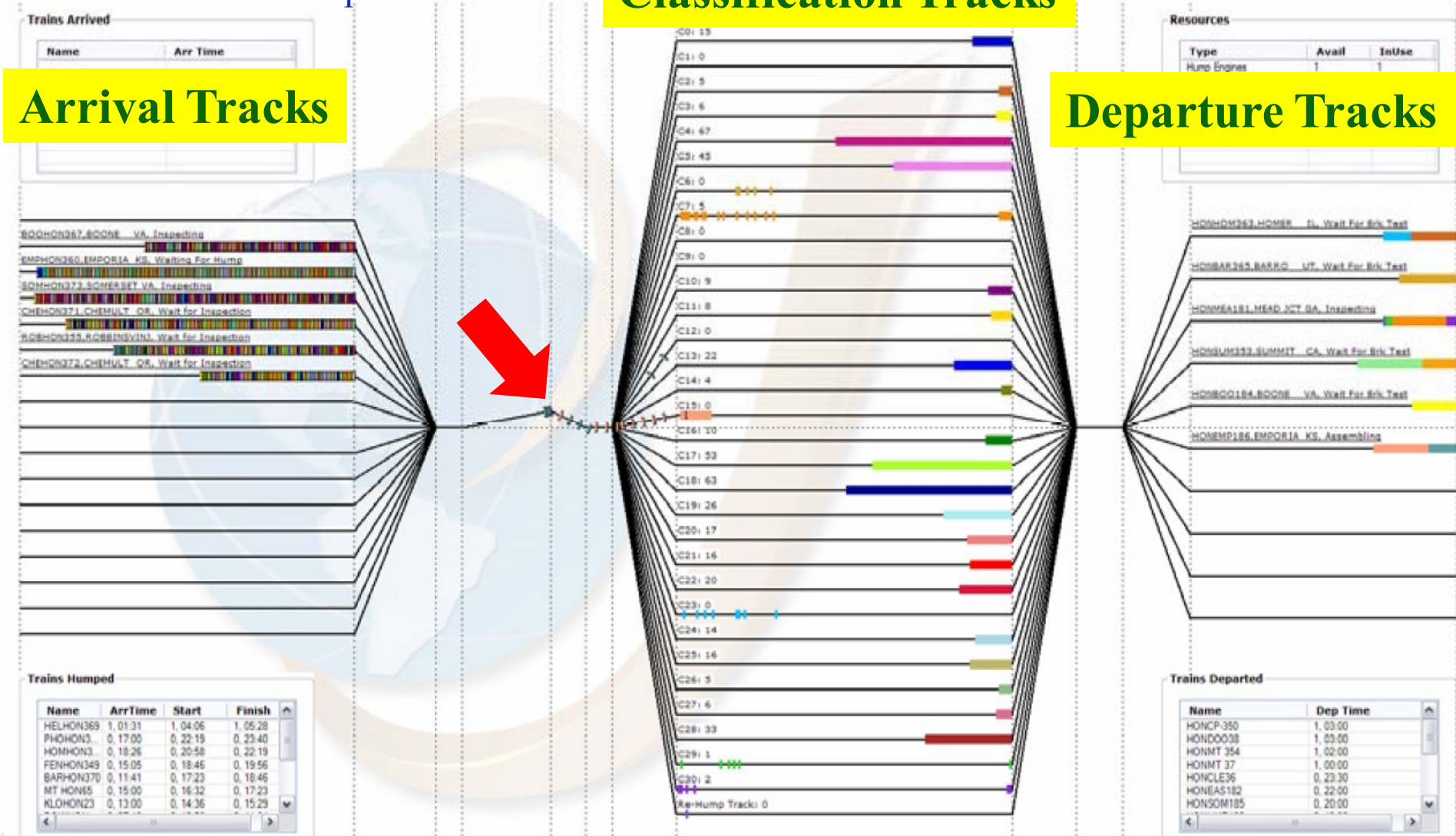
A Train:

consists of **one or more blocks**, in addition to the **locomotives**.

Railroad Blocking Problem (RBP)

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.

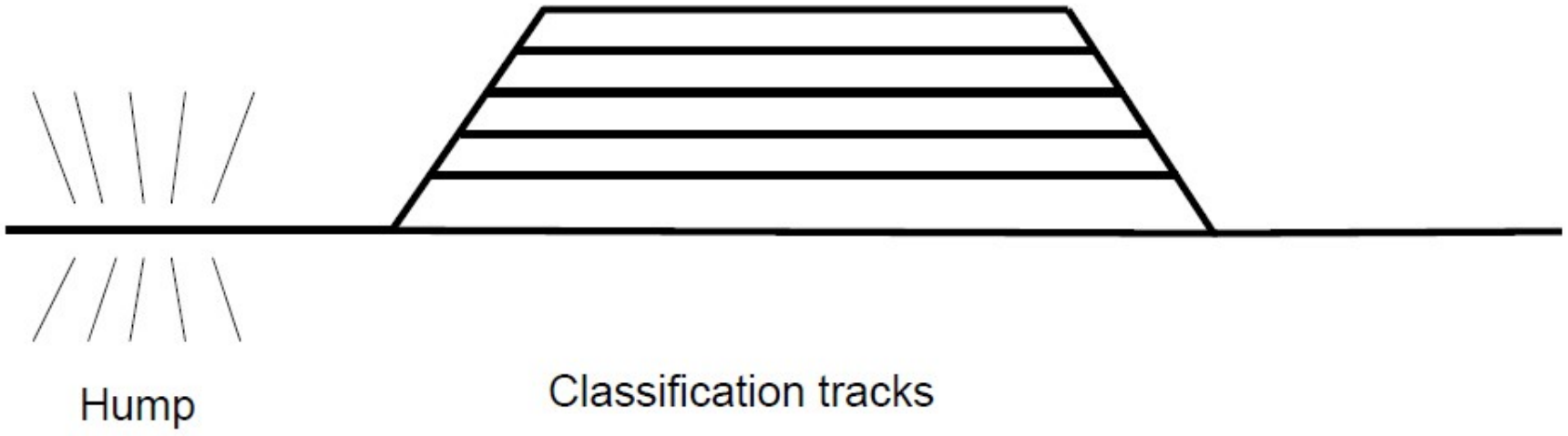


Classification yard (Station Grade 1):

- ✓ **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.

Railroad Blocking Problem (RBP)

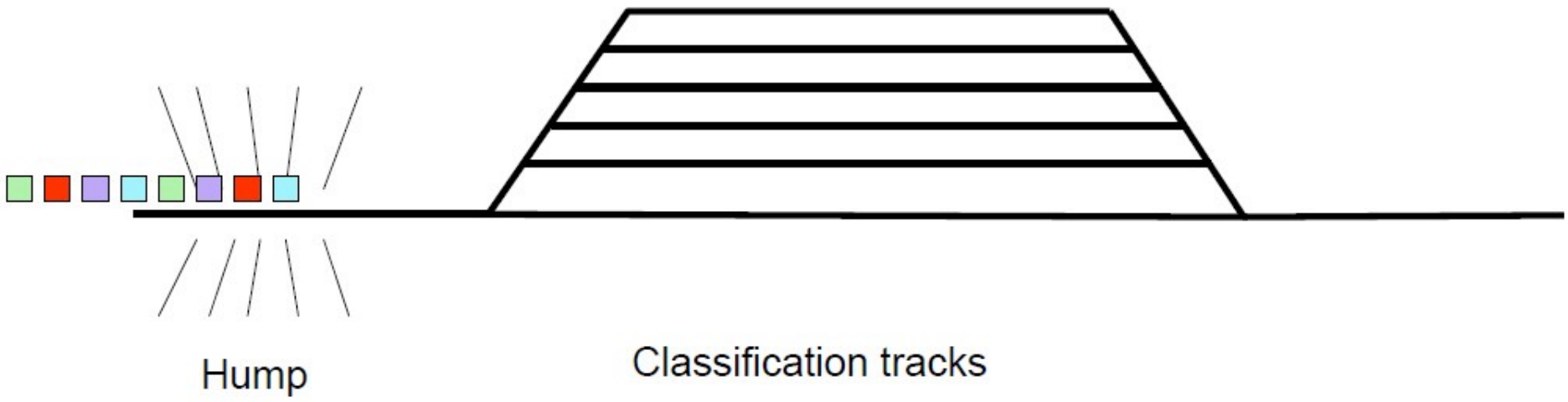
Classification yard



The commodities are reclassified in “classification tracks”

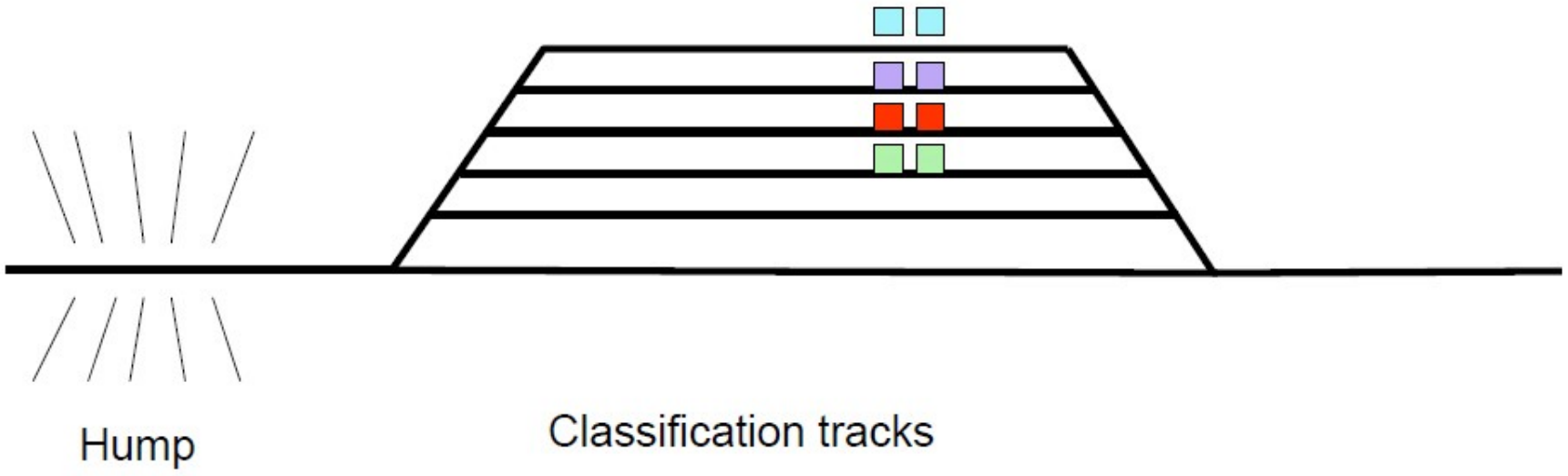
Railroad Blocking Problem (RBP)

Classification yard



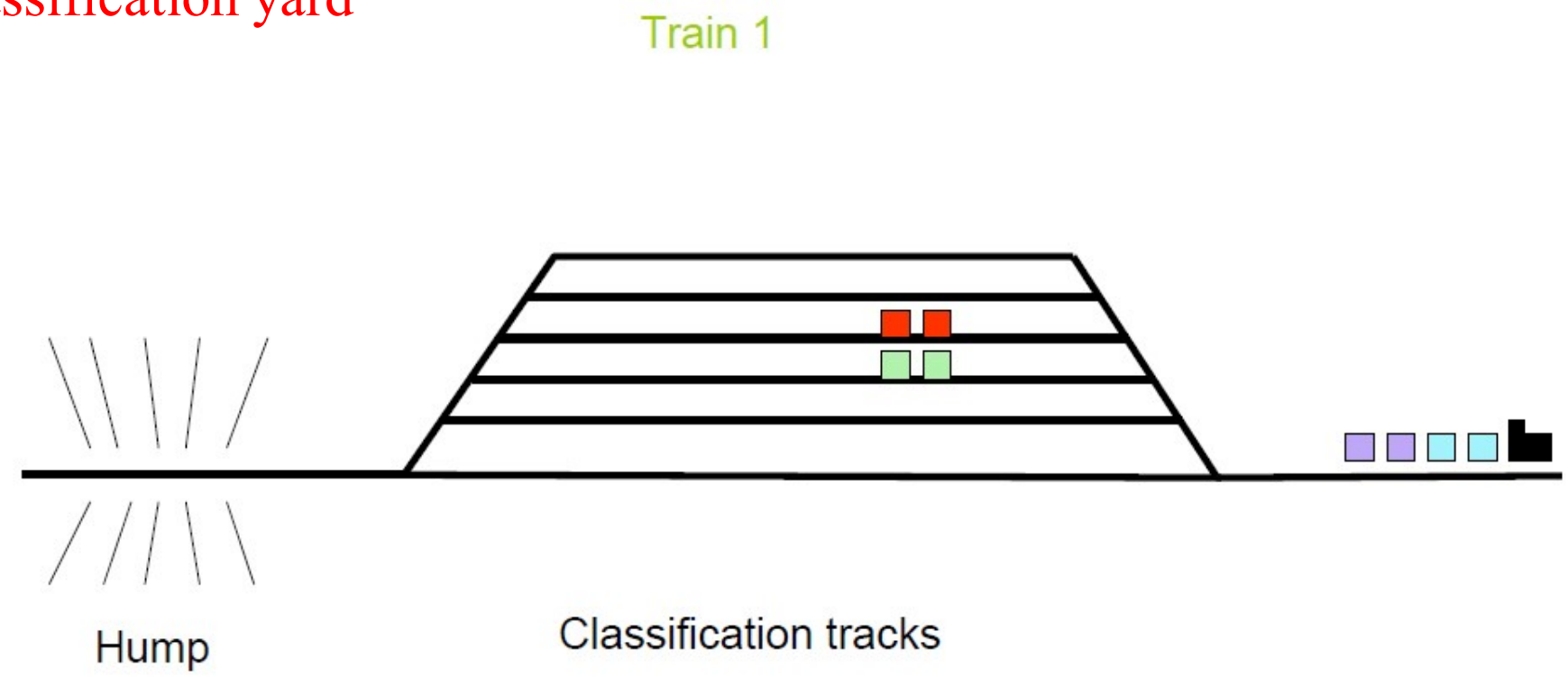
Railroad Blocking Problem (RBP)

Classification yard



Railroad Blocking Problem (RBP)

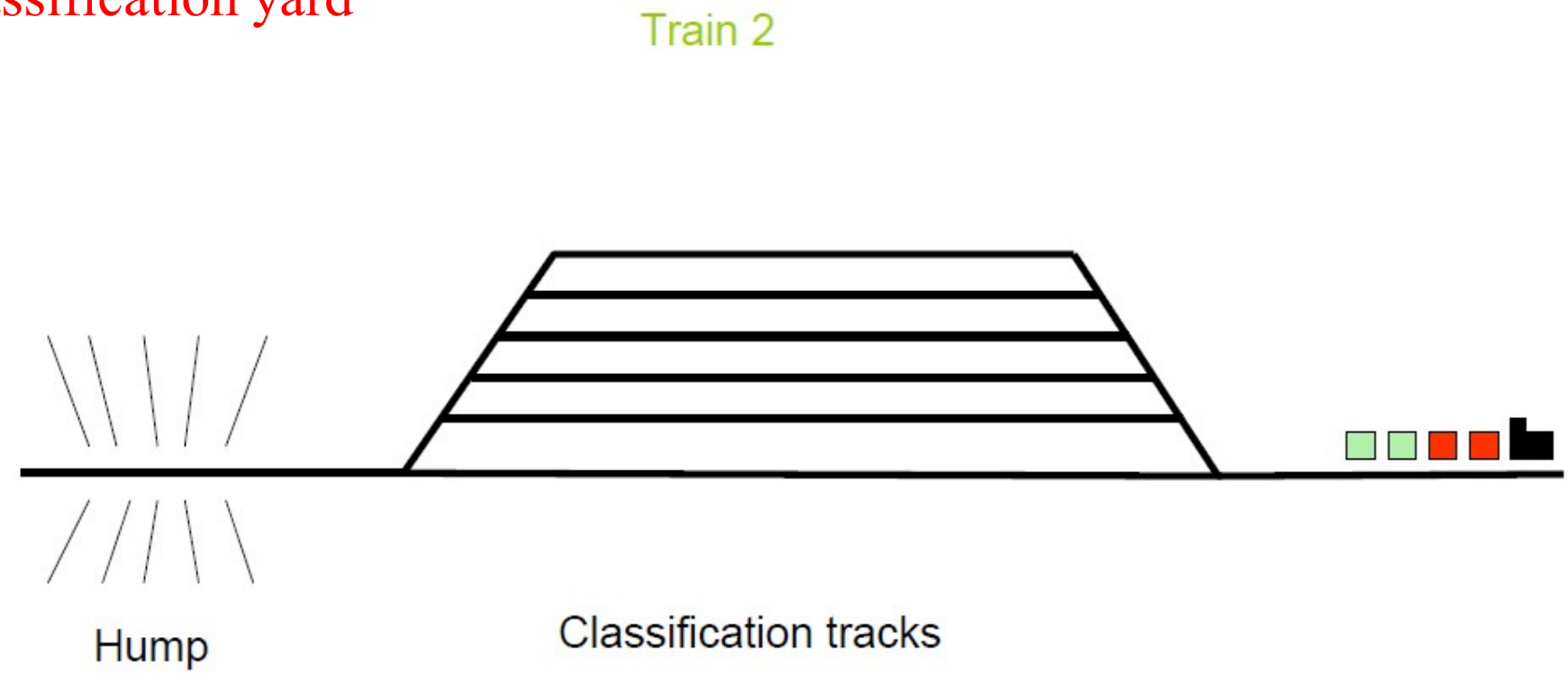
Classification yard



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

Railroad Blocking Problem (RBP)

Classification yard



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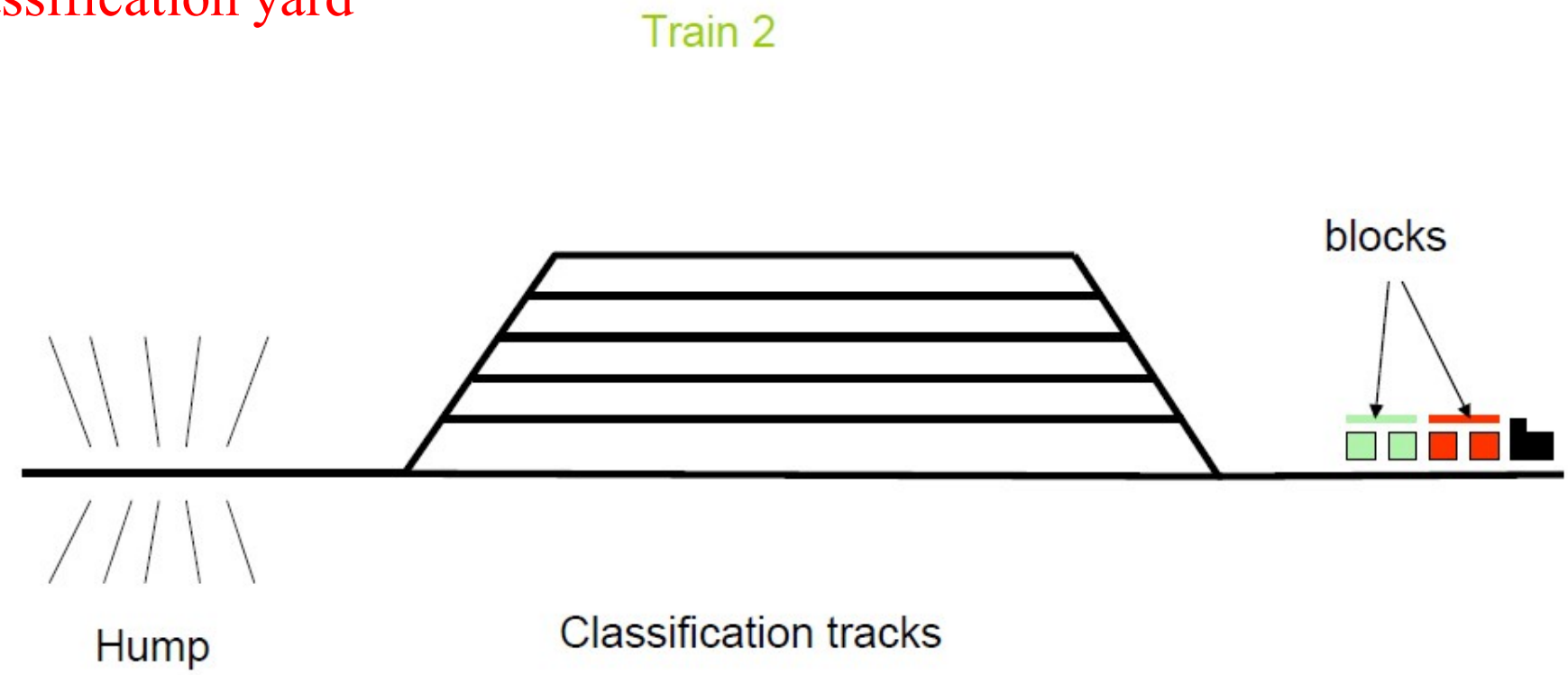
Railroad Blocking Problem (RBP)

Classification yard



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

Railroad Blocking Problem (RBP)

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.

Railroad Blocking Problem (RBP)

- ✓ 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.

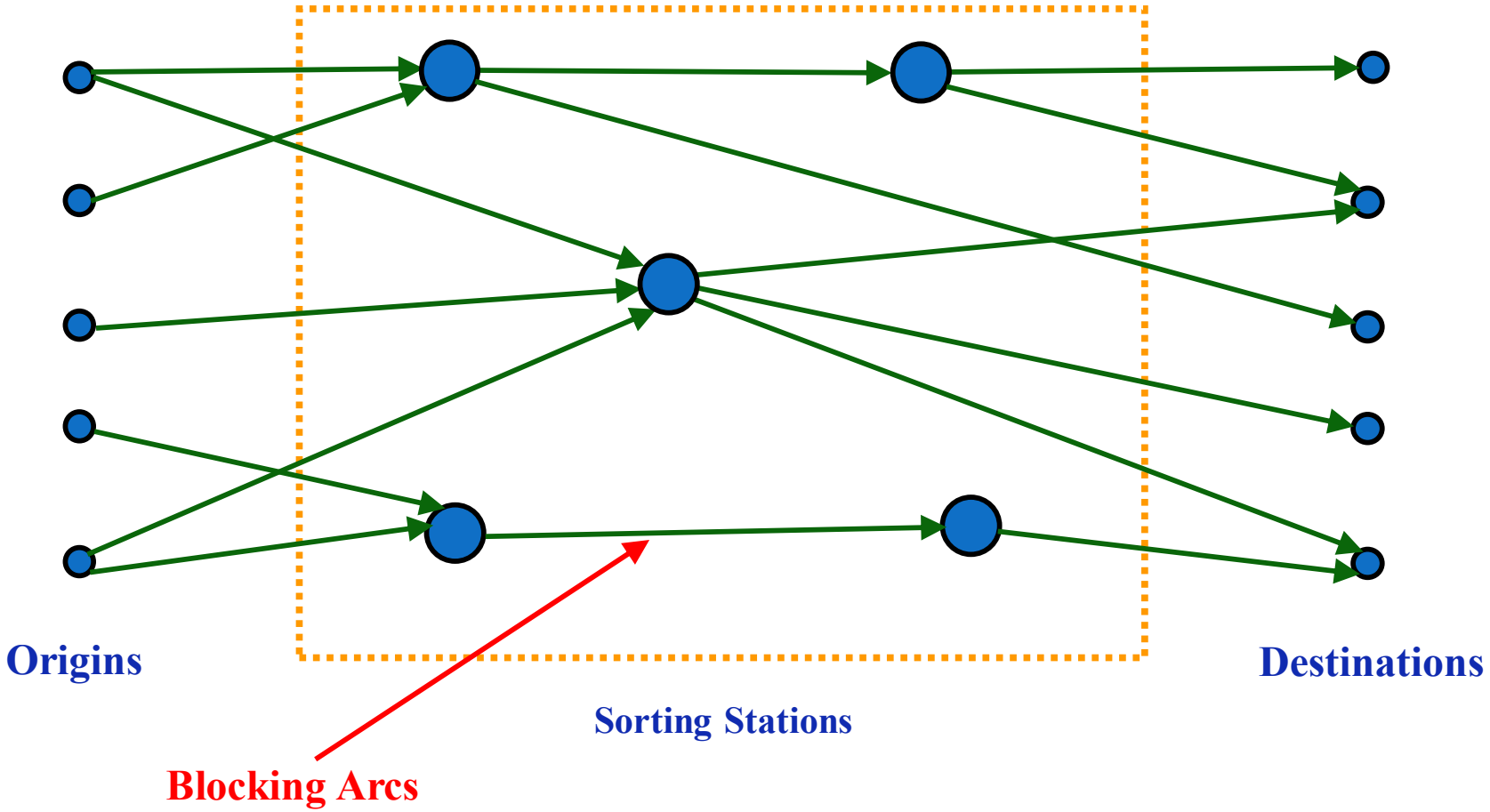
- ✓ A train can carry 1 or more blocks.
- ✓ Block A with origin i and destination j. k is a terminal among i and j.

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

Answer: Yes, But block A must not be reclassified.

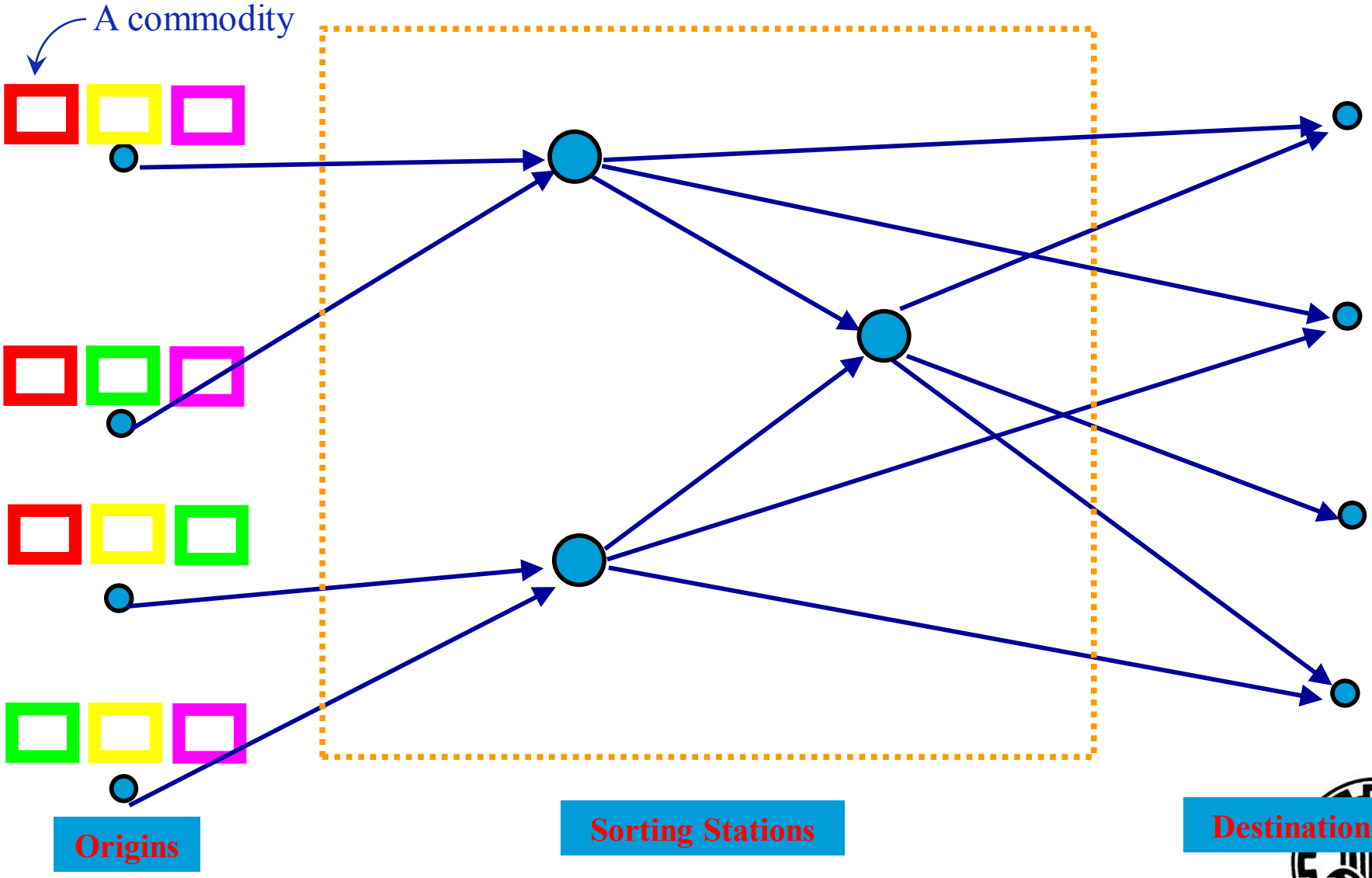
Description

Railroad Blocking Problem (RBP)



Description

Railroad Blocking Problem (RBP)



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

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

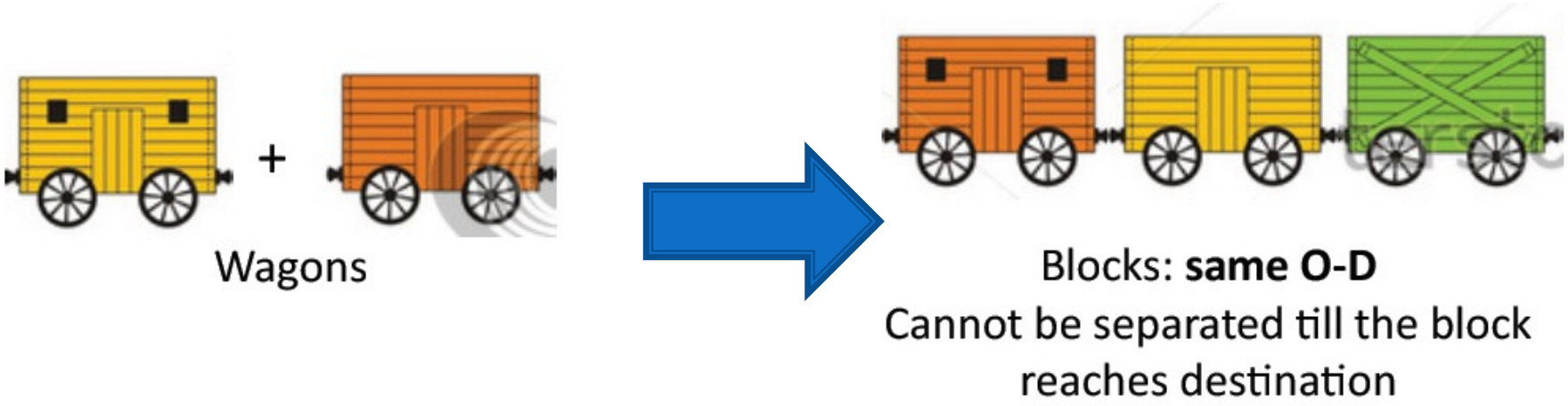
Blocking Plan: determines how to aggregate a large number of commodities into blocks of commodities as they travel from origins to destinations.

- ✓ **Blocking Problem:** developing a plan that describes:

  - which blocks should be assembled at each classification yard?
  - which shipments should be assigned to those blocks?

Railroad Blocking Problem (RBP)

- ✓ The shipments can pass through a number of classification yards without being reclassified, **only getting classified again** when they **reach destination of block**.



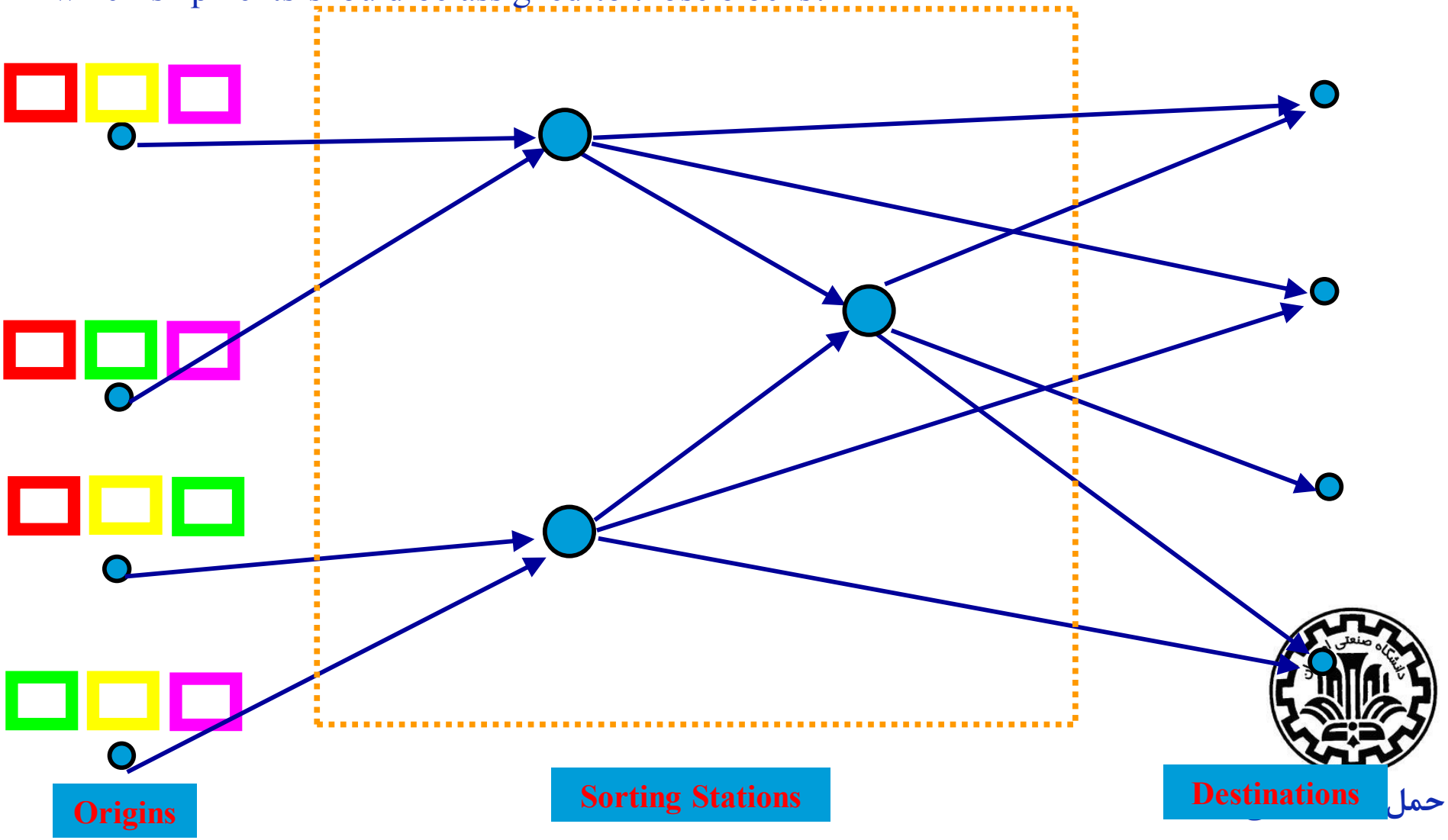
- ✓ Once a block reaches its destination, it is **disassembled** and the shipments that **are not still** at their own final destination are assembled into **new blocks and continue** on their way to their own final destinations

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

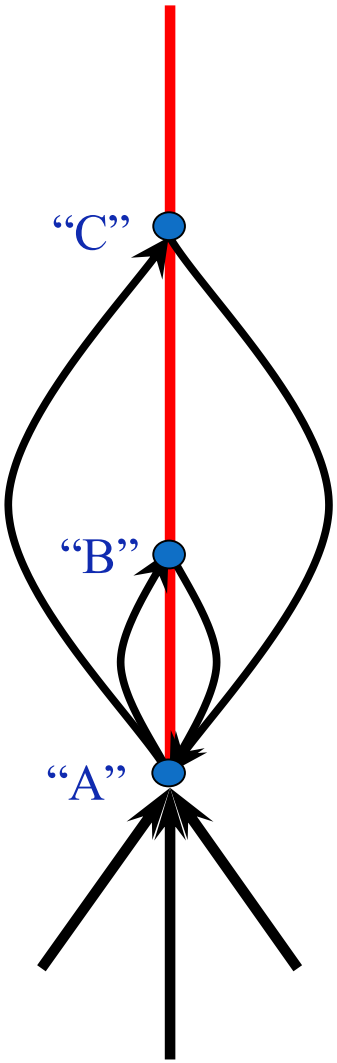
Description

Railroad Blocking Problem (RBP)

- ✓ **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)

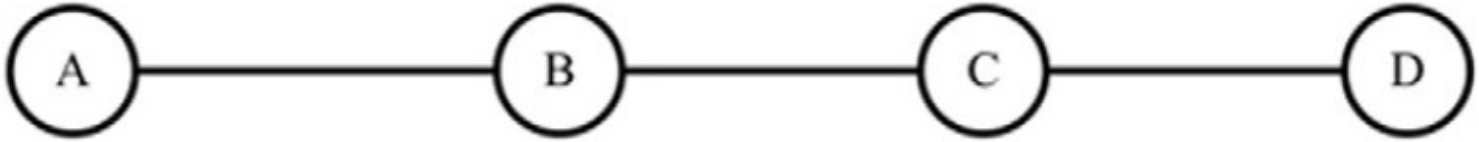


Block Definition
- From “A”
- To “C”

Block Definition
- From “A”
- To “B”

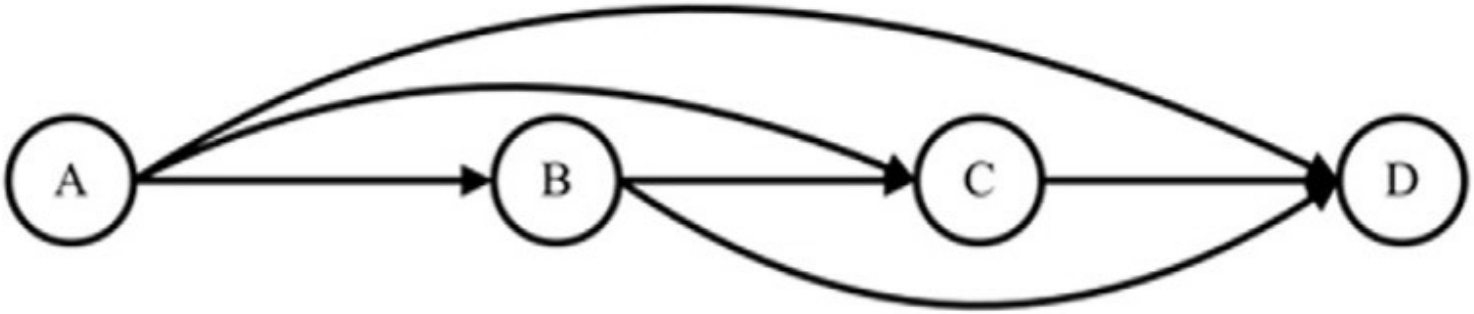
Railroad Blocking Problem (RBP)

Physical Network:



✓ Physical rail network: the **real** network, consisting of railroad terminals and tracks.

Blocking Network:



✓ 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

Railroad Blocking Problem (RBP)

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

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.

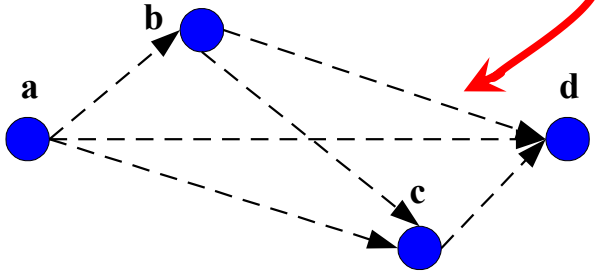
Example 1

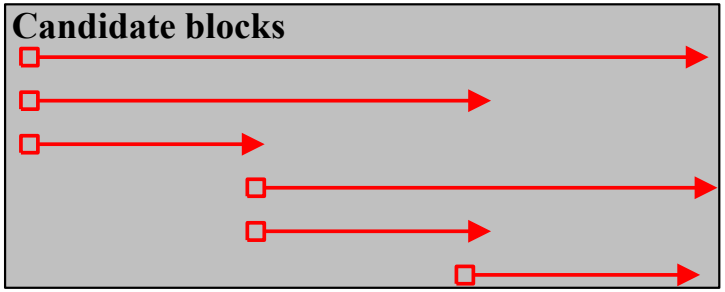
Railroad Blocking Problem (RBP)

origin \ destination	b	c	d
a	100	100	500
b		150	200
c			50

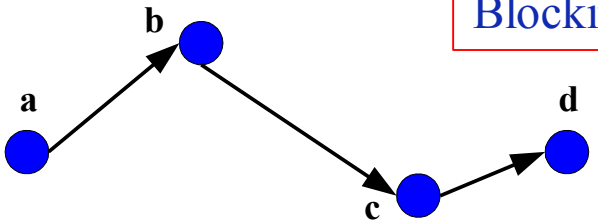
Physical network

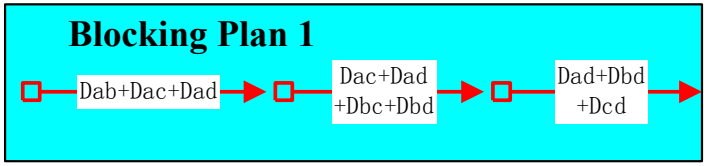
Blocking network



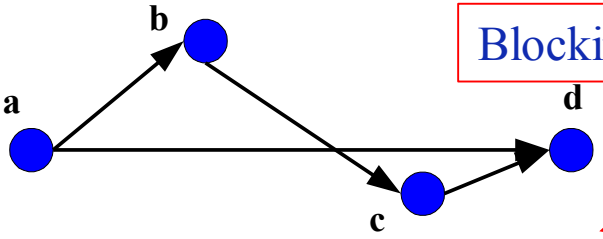


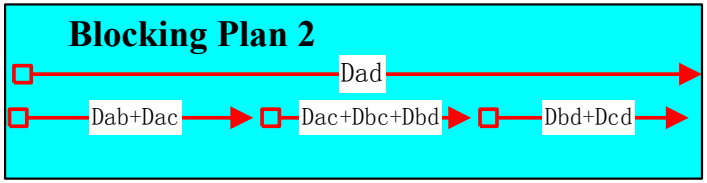
Blocking Plan 1





Blocking Plan 2





Station

Block

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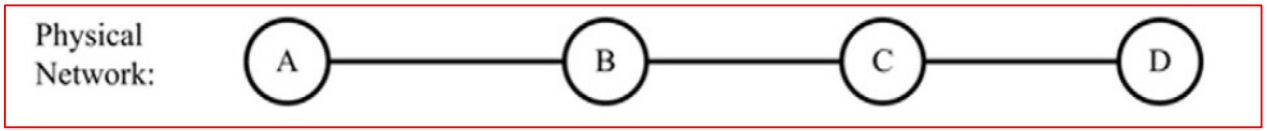
Example 2

Railroad Blocking Problem (RBP)



✓ commodities (origin-destination pairs of terminals):

A → B with 100 cars

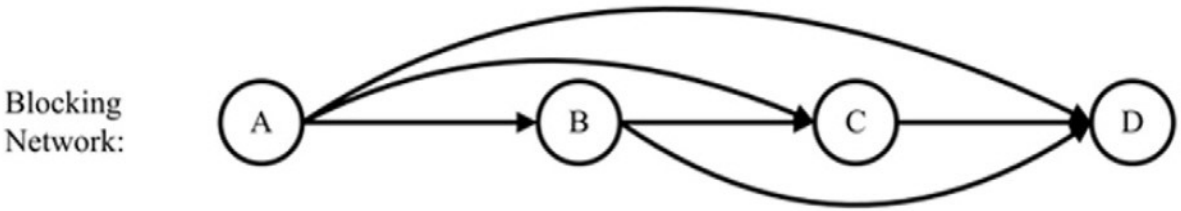
A → C with 80 cars

A → D with 90 cars

Terminals	Shipment capacity	Blocking capacity
Terminal A	270 cars	2 blocks
Terminal B	90 cars	1 block
Terminal C	90 cars	1 block

Shipment capacity constraints: upper bounds on the flow through each node.

Blocking capacity constraints: limits on the out-degree of each node.



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Example 2 — Railroad Blocking Problem (RBP)

Plan 1

A→ B with 100 cars
A→ C with 80 cars
A→ D with 90 cars

- ✓ 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).

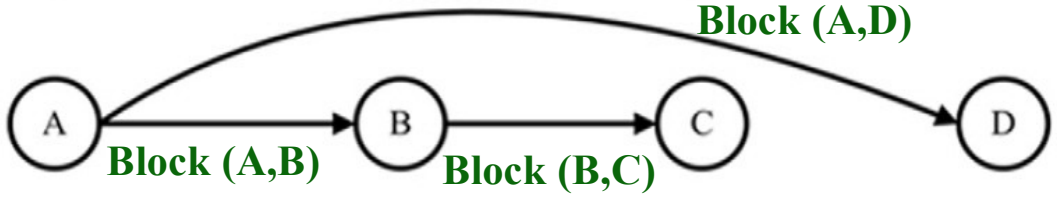
- ✓ Block (A,B) including: A→B, A→C and A→D [270 car classification in terminal A]
- ✓ Block (B,C) including: A→C and A→D [170 car classification in terminal B]
- ✓ Block (C,D) including: A→D [90 car classification in terminal C]
- ✓ Totally, **530** car classification operations.

Plan 1 is infeasible (Shipment capacity in Terminal B)

Example 2

Railroad Blocking Problem (RBP)

Plan 2



A→ B with 100 cars
A→C with 80 cars
A→D with 90 cars

- ✓ 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

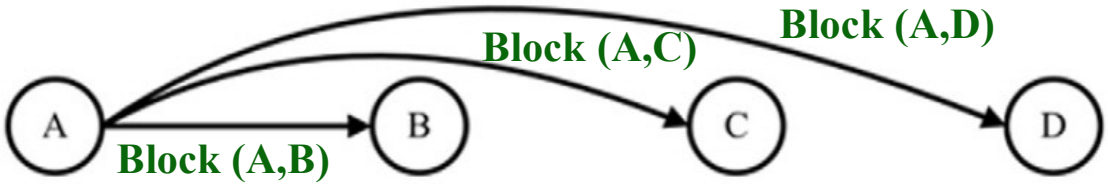
Railroad Blocking Problem (RBP)

A→ B with 100 cars
A→C with 80 cars
A→D with 90 cars

Plan 3

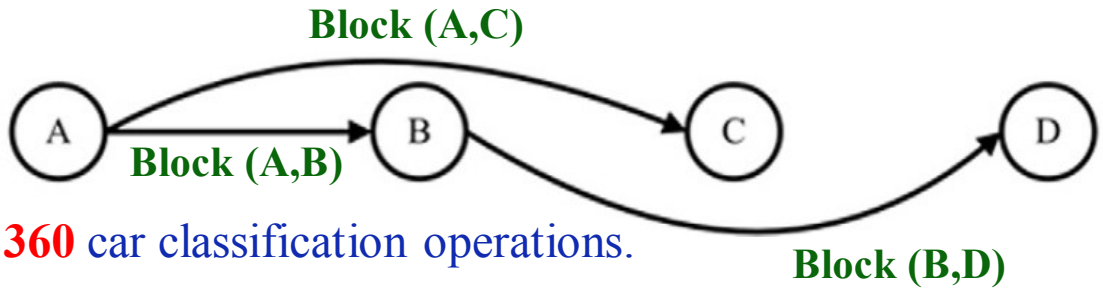
- ✓ Totally, **360** car classification operations.
- ✓ Plan 3 is feasible

Plan 4



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

Plan 5

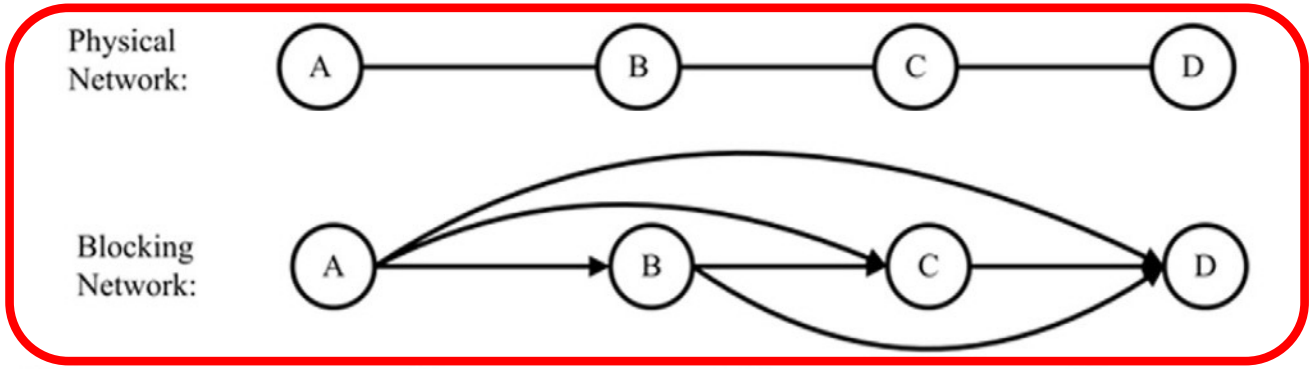


- ✓ Totally, **360** car classification operations.
- ✓ Plan 5 is feasible

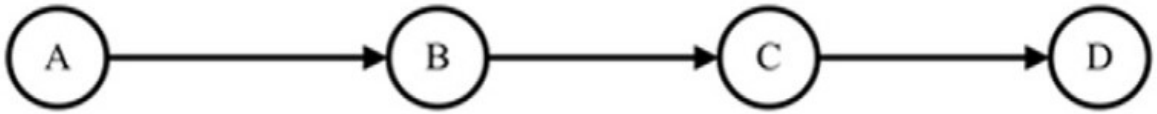
حمل و نقل ریلی

Example 2

Railroad Blocking Problem (RBP)



Plan 1:



~~530~~

Plan 2:

350

✓ Optimal Solution

Plan 3:

360

Plan 4:

~~270~~

Plan 5:

360

حمل و نقل ریلی

Railroad Blocking Problem (RBP)

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?

Railroad Blocking Problem (RBP)

"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.
υ_k is the volume of commodity k.
orig(k) is the origin terminal for commodity k.
dest(k) is the destination terminal for commodity k.
orig(a) is the origin of potential block a.
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_a^k 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.

Ref.: Harry N. Newton, 1996 "network design under budget constraints with application to the railroad blocking problem", PhD Thesis, Auburn University.

Railroad Blocking Problem (RBP)

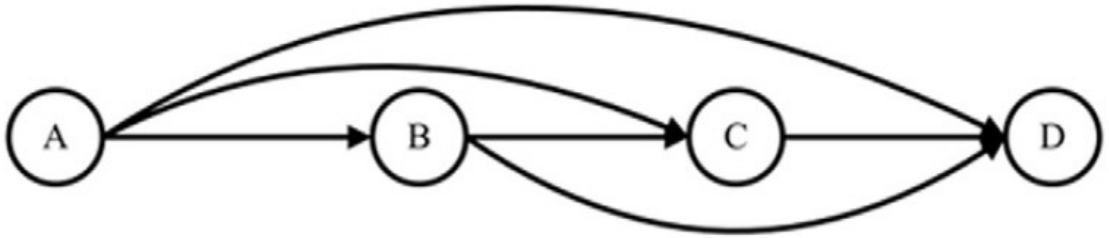
Objective Function:

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

$$\text{Min } Z = \sum_{k \in K} \sum_{a \in A} c_a . \upsilon_k . x_a^k$$

- c_a: the per unit cost of flow on block a
- υ_k: volume of commodity k
- x_a^k: 1 if commodity k is flowing on block a, 0 otherwise

Blocking Network:



Railroad Blocking Problem (RBP)

Constraints:

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

$$\sum_{\substack{a\in A\\ orig(a)=i}} x_a^k - \sum_{\substack{a\in A\\ dest(a)=i}} x_a^k = \begin{cases} 1 & orig(a)=i, \\ -1 & dest(a)=i, \\ 0 & otherwise, \end{cases} \quad \forall i \in N,\ k \in K,$$

terminal i

Commodity k

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

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.

$$\sum_{k \in K} v^k x_a^k \leqslant u_a y_a, \qquad \forall a \in A,$$

Block a

volume of commodity k

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

capacity of
potential block a

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

Railroad Blocking Problem (RBP)

Constraints:

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

$$\sum_{\substack{a \in A \\ orig(a)=i}} y_a \leqslant B(i), \quad \forall i \in N,$$

terminal i

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).

Railroad Blocking Problem (RBP)

Constraints:

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

$$\sum_{k \in K} \sum_{\substack{a \in A \\ orig(a)=i}} v_k x_a^k \leqslant V(i), \quad \forall i \in N,$$

terminal i

volume of commodity k

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

Shipment capacity (Maximum volume of commodities which may be classified at terminal i)

Constraints:

$$y_a \in \{0,1\}, \quad \forall a \in A,$$

$$x_a^k \in \{0,1\}, \quad \forall a \in A, \ \forall k \in K.$$

Railroad Blocking Problem (RBP)

$$Min \quad Z = \sum_{k \in K} \sum_{a \in A} c_a v_k x_a^k,$$

Subject to:

$$\sum_{\substack{a \in A \\ orig(a)=i}} x_a^k - \sum_{\substack{a \in A \\ dest(a)=i}} x_a^k = \begin{cases} 1 & orig(a) = i, \\ -1 & dest(a) = i, \\ 0 & otherwise, \end{cases} \quad \forall i \in N, \ k \in K,$$

$$\sum_{k \in K} v^k x_a^k \leqslant u_a y_a, \quad \forall a \in A,$$

$$\sum_{\substack{a \in A \\ orig(a)=i}} y_a \leqslant B(i), \quad \forall i \in N,$$

$$\sum_{k \in K} \sum_{\substack{a \in A \\ orig(a)=i}} v_k x_a^k \leqslant V(i), \quad \forall i \in N,$$

$$y_a \in \{0, 1\}, \quad \forall a \in A,$$

$$x_a^k \in \{0, 1\}, \quad \forall a \in A, \ \forall k \in K.$$

Mathematical Model (2) Railroad Blocking Problem (RBP)

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

$$(\mathscr{P}) \quad \min \sum_{k\in\mathscr{K}} \sum_{q\in\mathscr{Q}(k)} PC_q^k v^k f_q^k, \tag{1}$$

s.t.

$$\sum_{q\in\mathscr{Q}(k)} \delta_a^q f_q^k \leqslant y_a, \qquad \forall k \in \mathscr{K},\ \forall a \in \mathscr{A}, \tag{2}$$

$$\sum_{q\in\mathscr{Q}(k)} f_q^k = 1, \qquad \forall k \in \mathscr{K}, \tag{3}$$

$$\sum_{a\in\mathscr{A}} \xi_i^a y_a \leqslant B(i), \qquad \forall i \in \mathscr{N}, \tag{4}$$

$$\sum_{k\in\mathscr{K}} \sum_{q\in\mathscr{Q}(k)} \sum_{a\in\mathscr{A}} v^k \delta_a^q \xi_i^a f_q^k \leqslant V(i), \qquad \forall i \in \mathscr{N}, \tag{5}$$

$$f_q^k \geqslant 0, \qquad \forall q \in \mathscr{Q}(k),\ \forall k \in \mathscr{K}, \tag{6}$$

$$y_a \in \{0,1\}, \qquad \forall a \in \mathscr{A}, \tag{7}$$

where $PC_q^k = \Sigma_{a\in\mathscr{A}} C_a \delta_a^q$.

Ref.: C. Barnhart , H. Jin, P.H. Vance, "Railroad Blocking: A Network Design Application", operations research, vol. 48, no. 4, july–august 2000, pp. 603–614

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Railroad Blocking Problem (RBP)