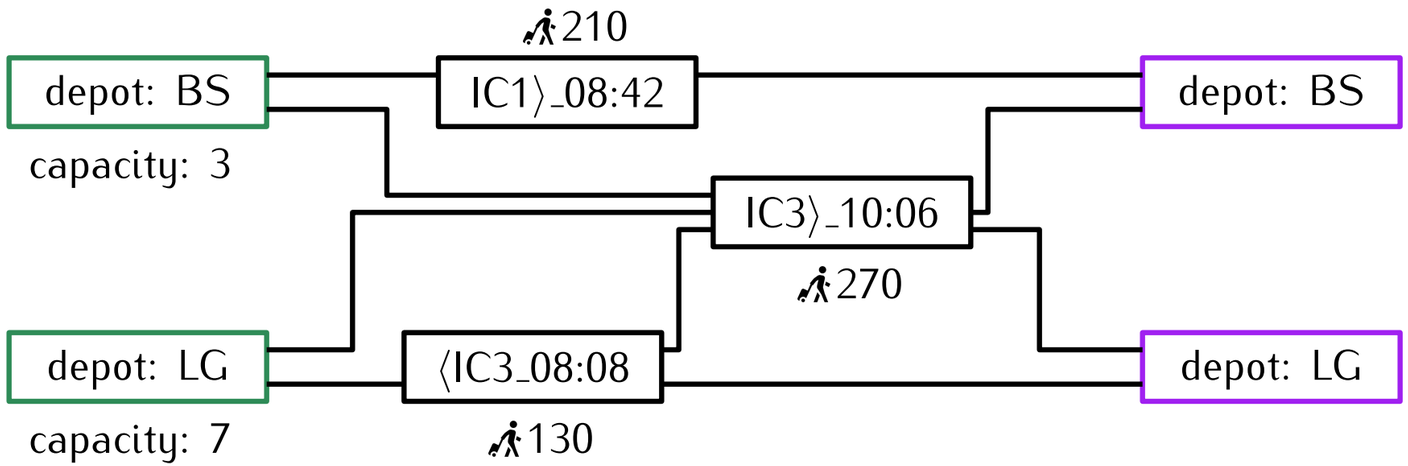
Collaboration SBB - ETH

RSSched

Rolling Stock Scheduling with Maintenance Regulations



by Leon Sering

Rolling Stock Scheduling

What does **rolling stock** mean?

rolling stock: "Vehicles that drive on rails."

for the project:

vehicle: multiple wagen that can drive by itself but are never uncoupled (smallest unit)

formation: one or more vehicles that are coupled and form a train

type: vehicle can be of different types, only vehicles of the same type can form a formation

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schedule: collection of **tours**, one for each vehicle

tour: sequence of **activities** covering one day

- **start:** spawning at a depot in the morning
- **service trip:** brings customers from a to b
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- **maintenance:** maintenance check after given distance
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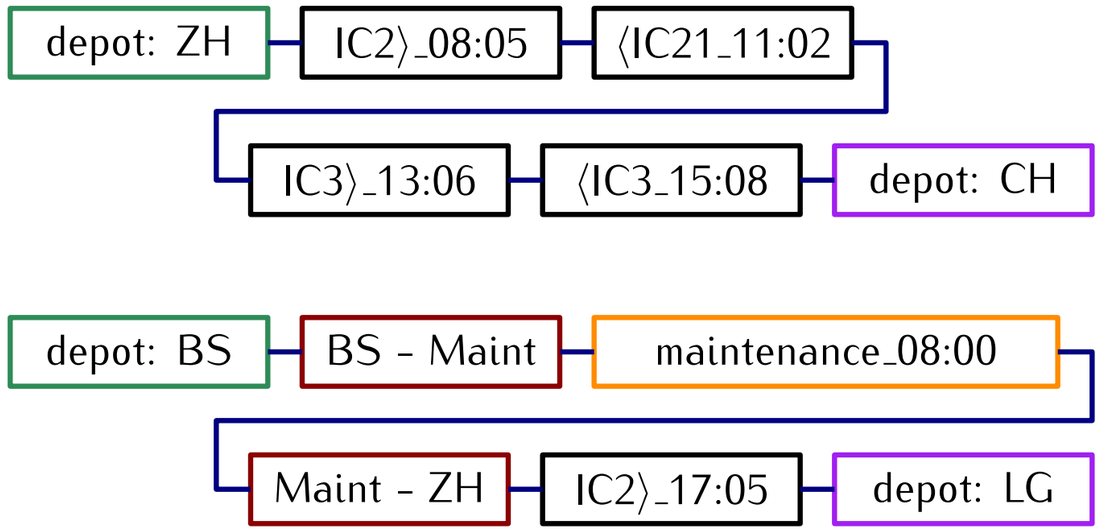

Phase 1
Basic Scheduling

Phase 1 - Task

input:

- **locations** (finite set L)
- **depots:** location, capacity
- **routes** origin, destination, distance, duration
- **service trips** route, departure time, passenger demand
- **dead head trips:**
  - distance matrix $\mathbb{R}_{\geq 0}^{L \times L}$
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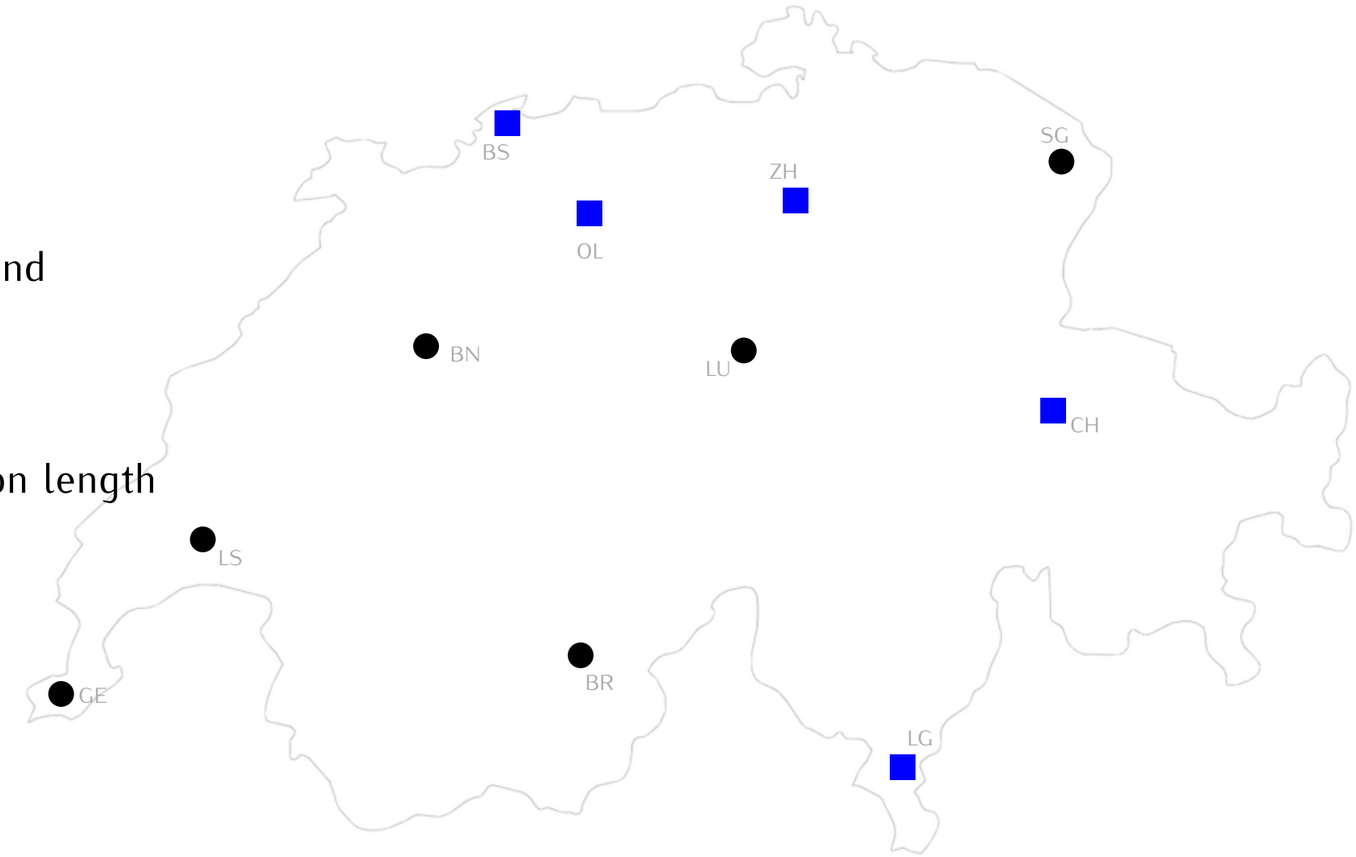

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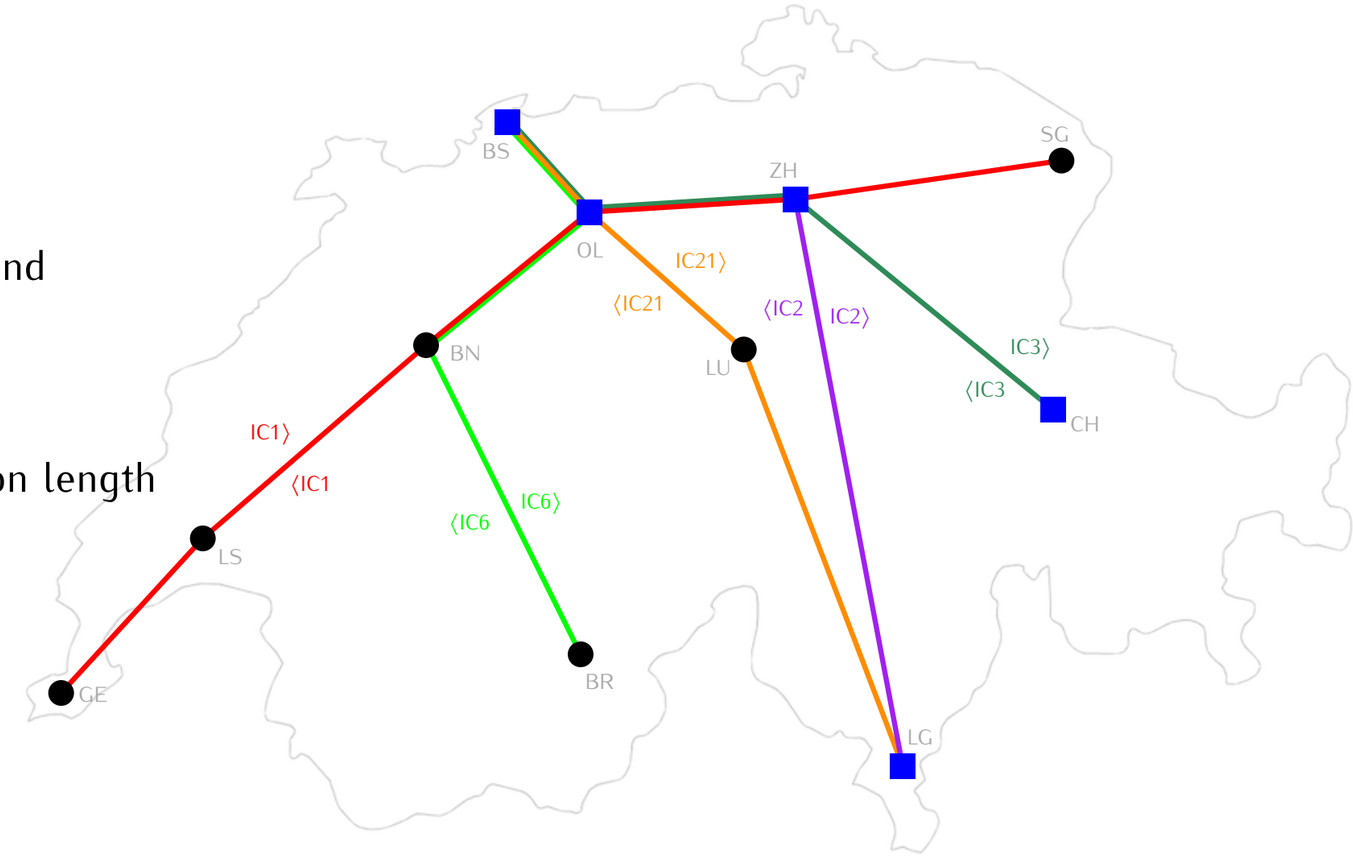

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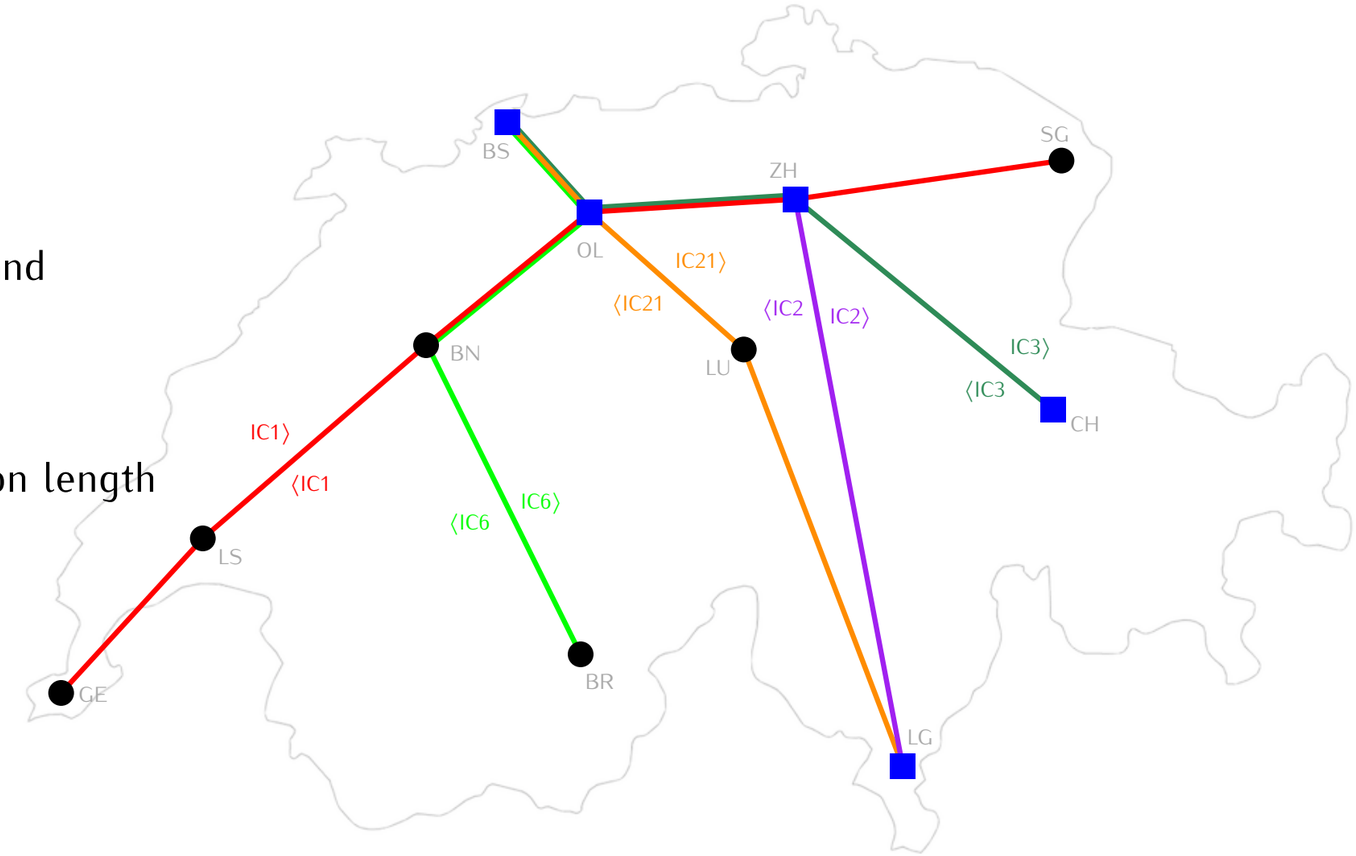

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IC1⟩_07:42	⟨IC1_07:07		⟨IC21_09:02
⋮	⋮		⋮
IC1⟩_20:42	⟨IC1_21:07	...	⟨IC21_22:02

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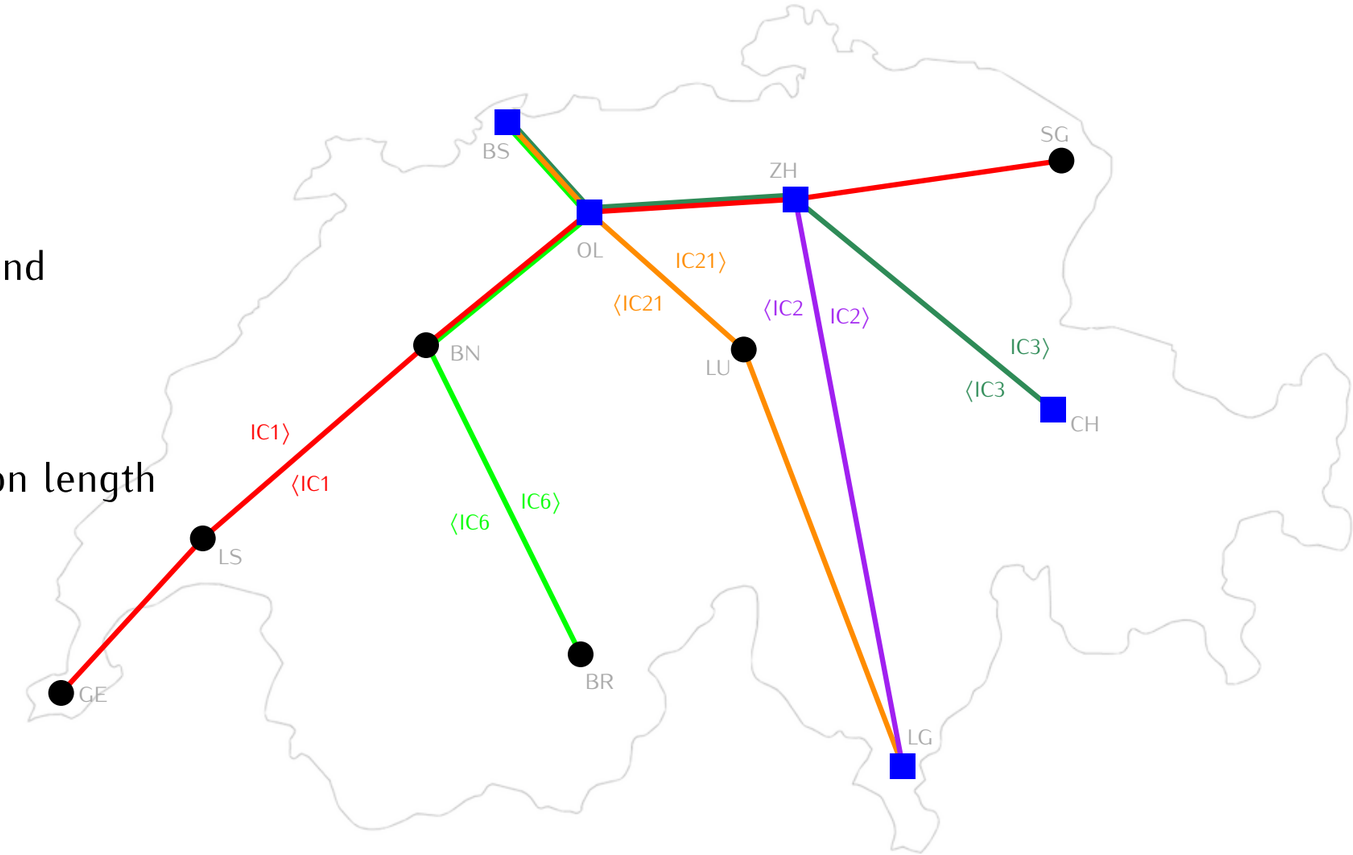

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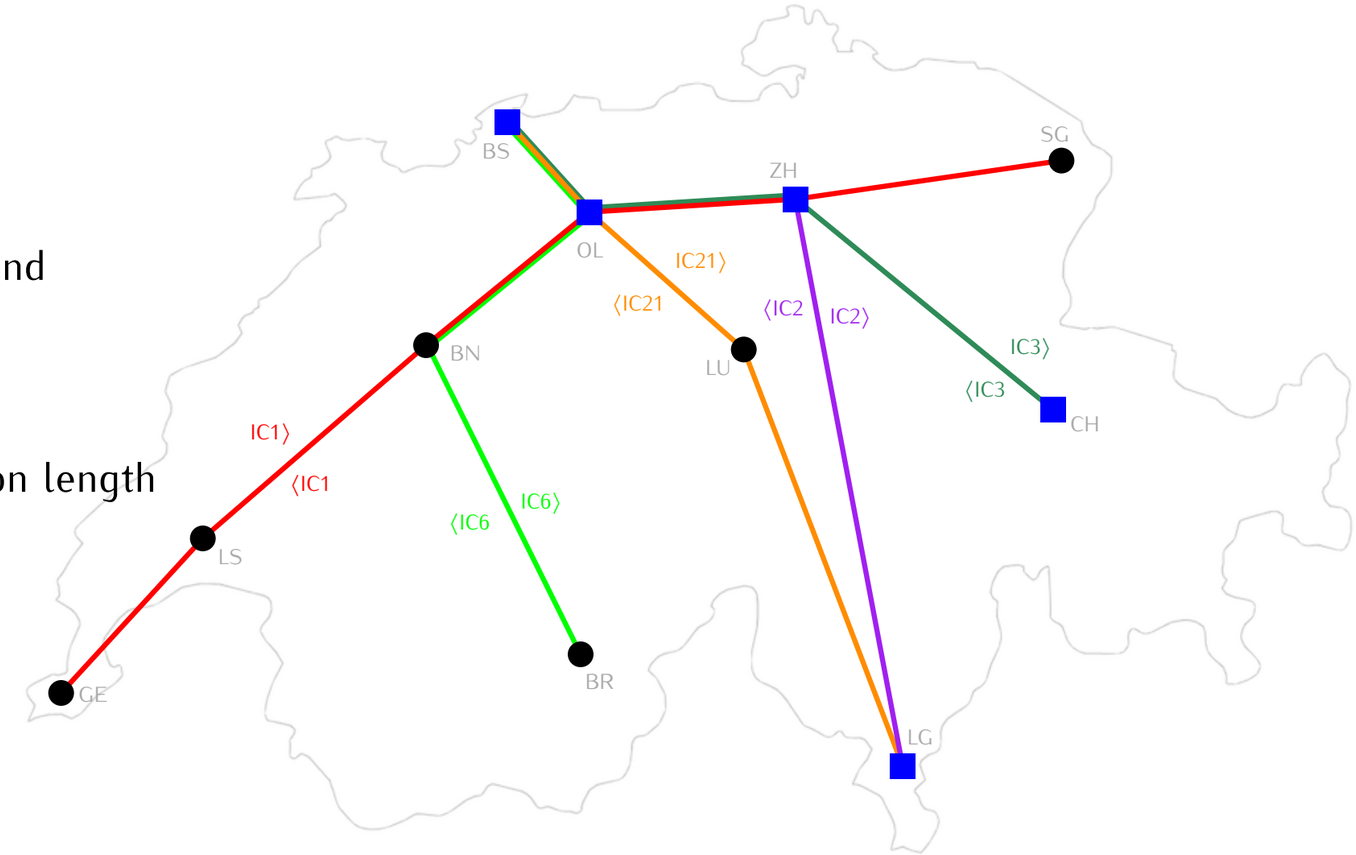

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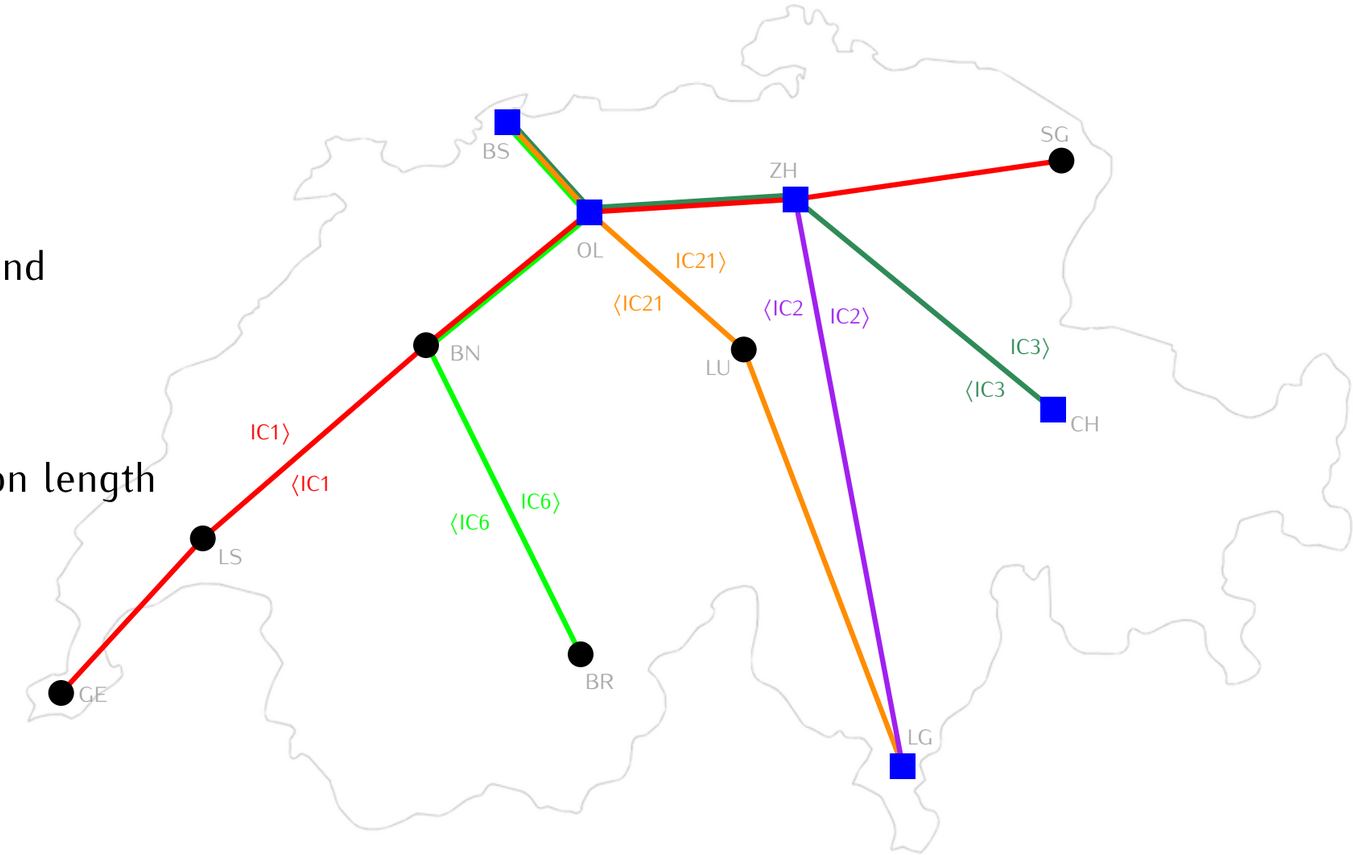

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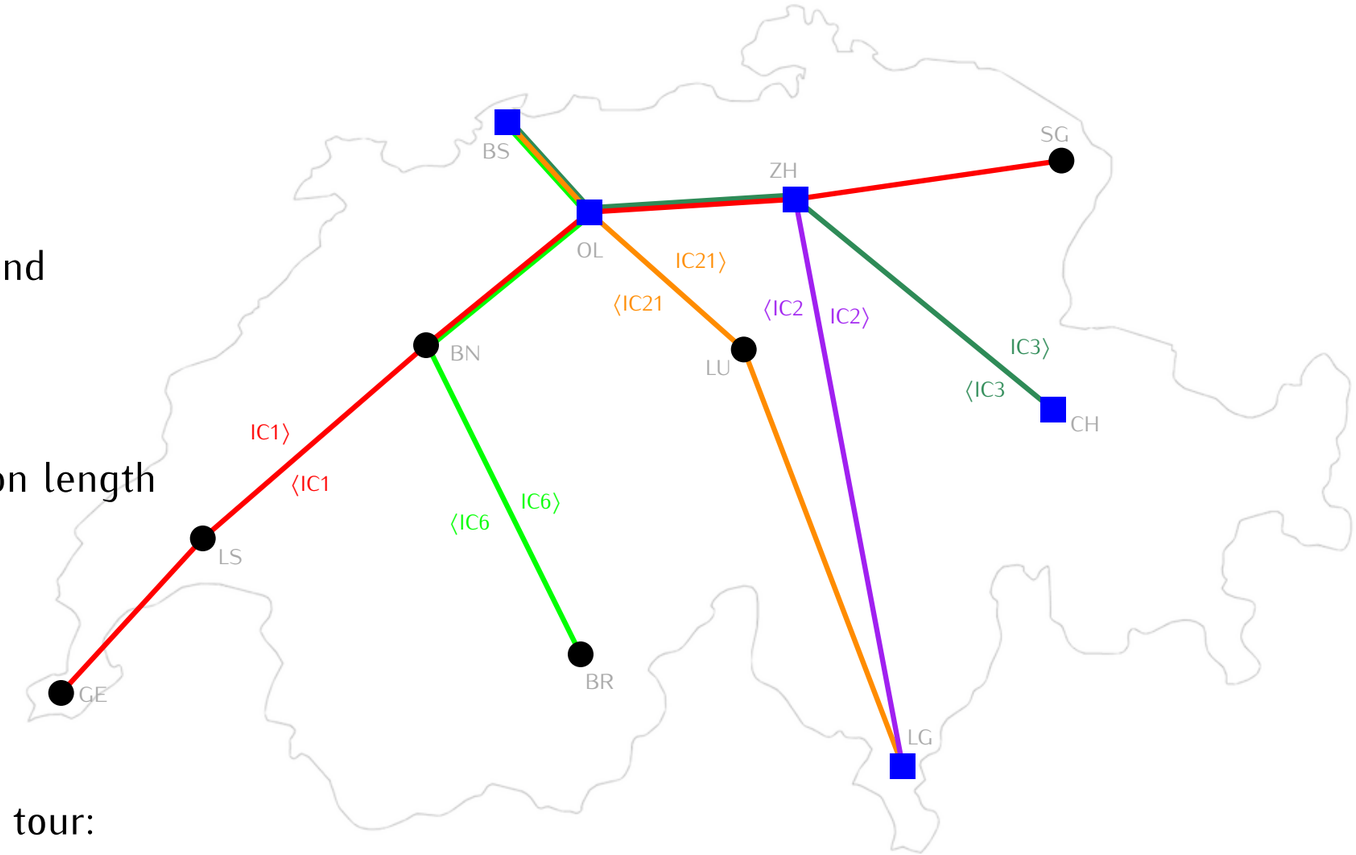

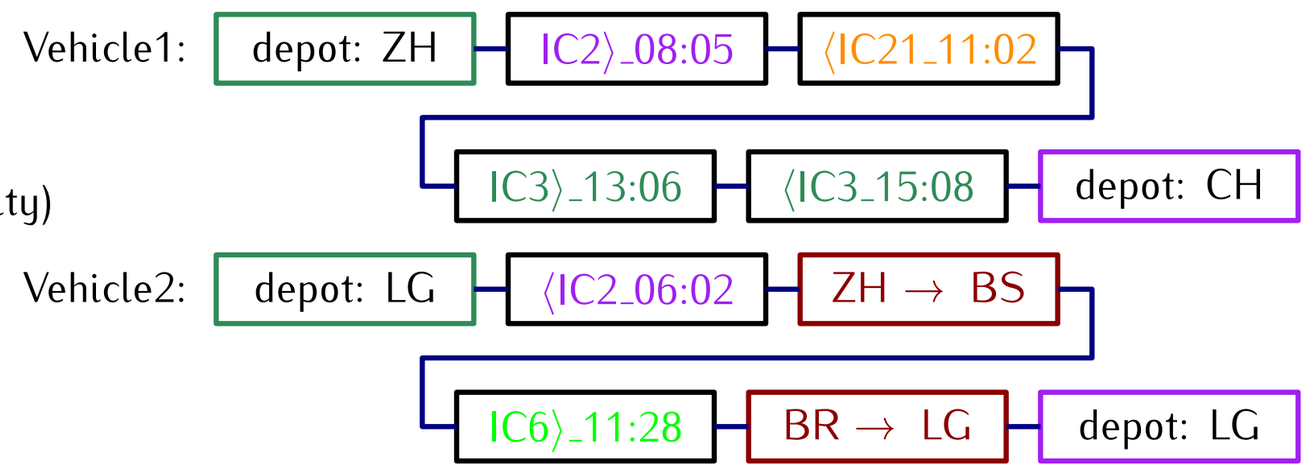

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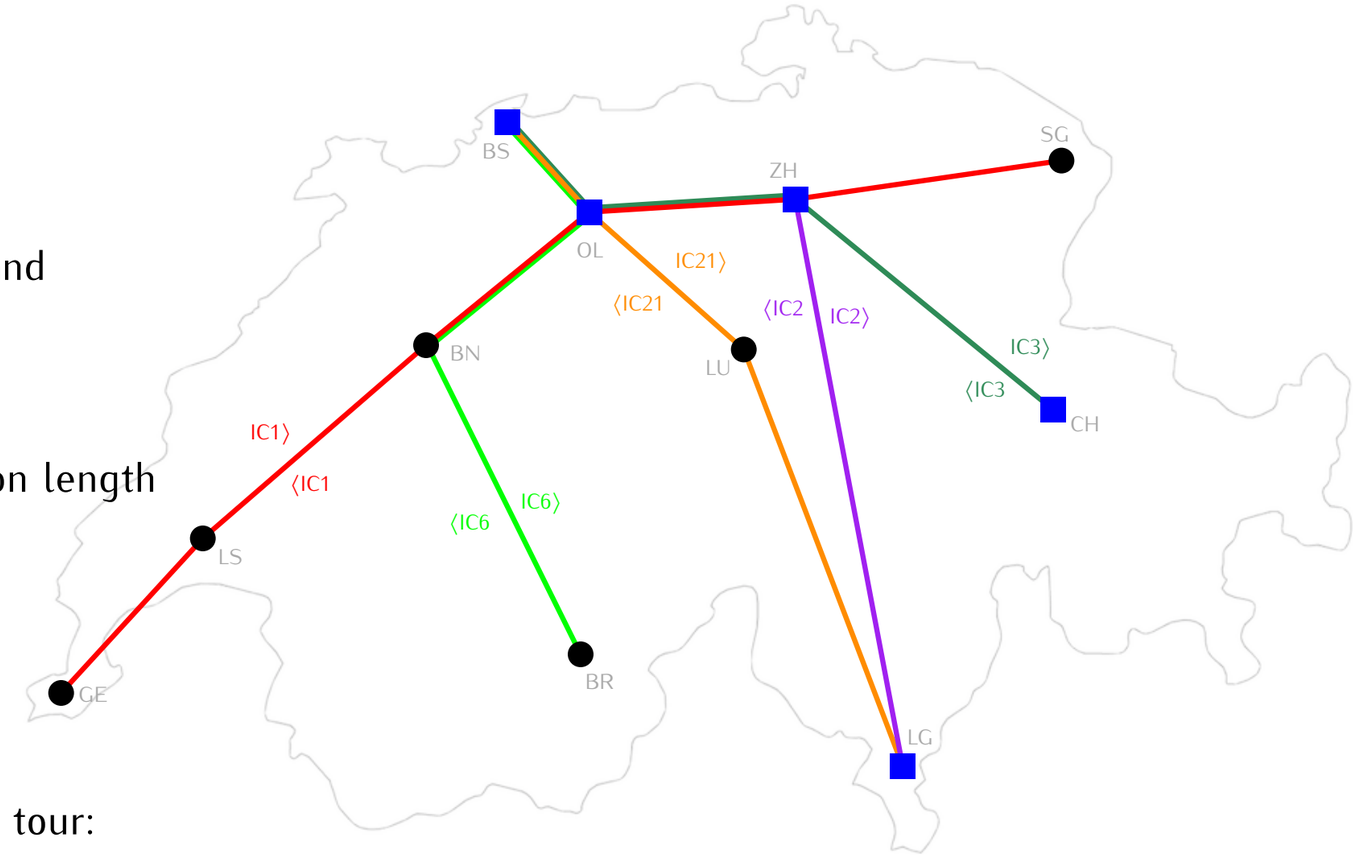
hierachical objective: (to be minimized from top to bottom)

1. # unserved passengers
2. # number of vehicles
3. total distance traveled



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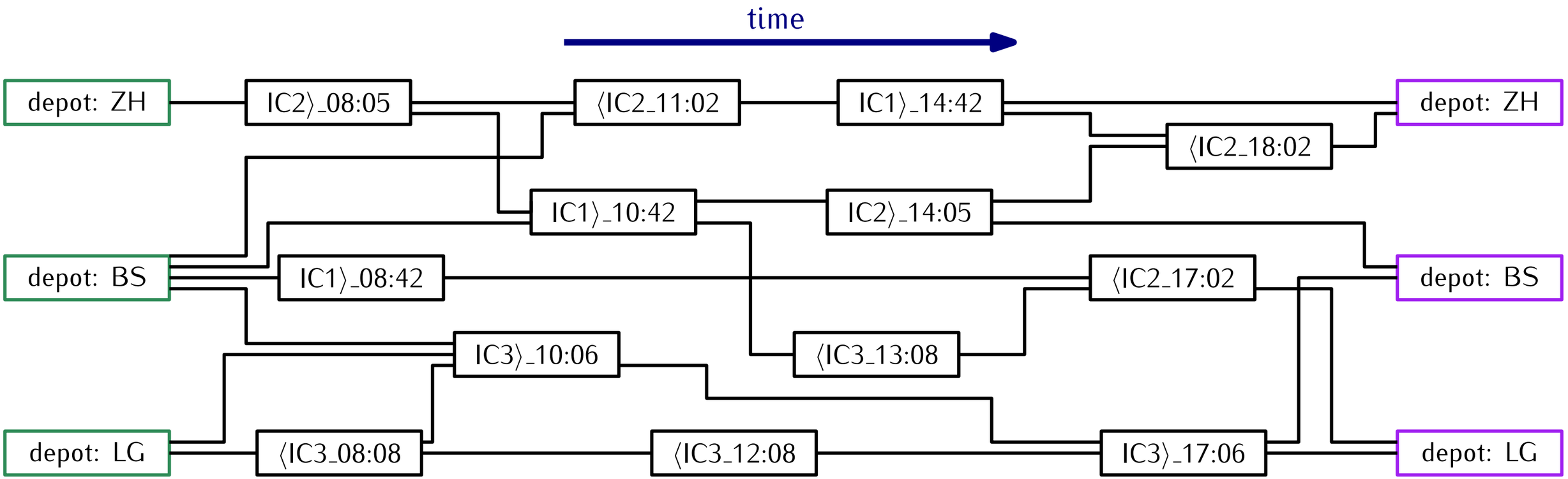

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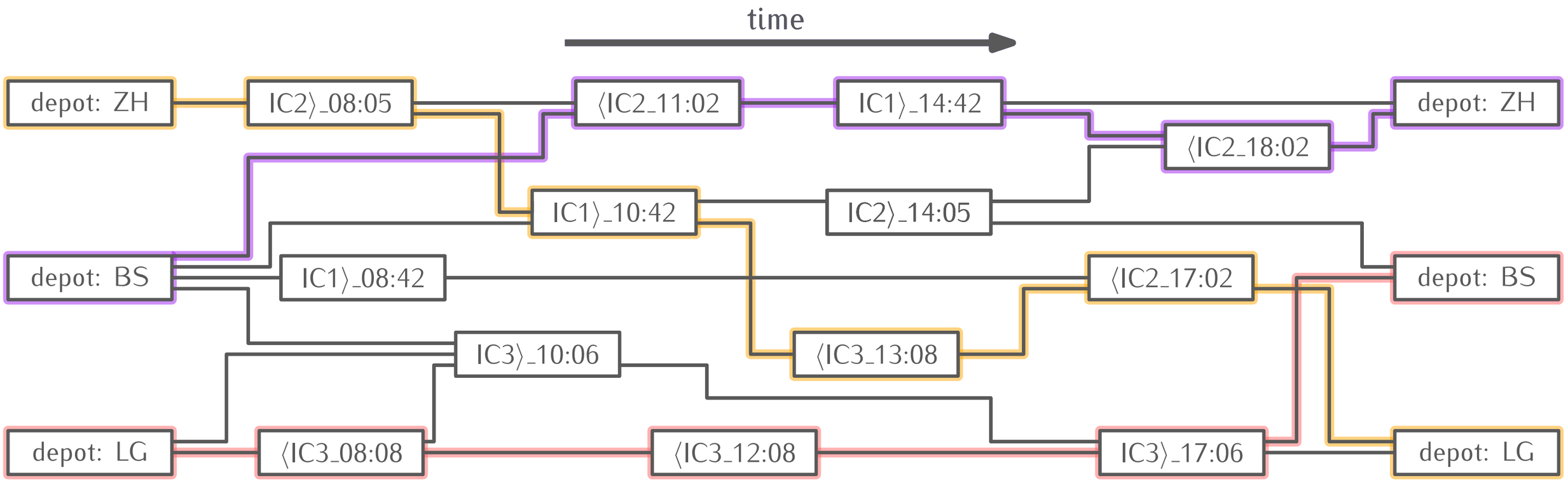

Phase 1 - Algorithm

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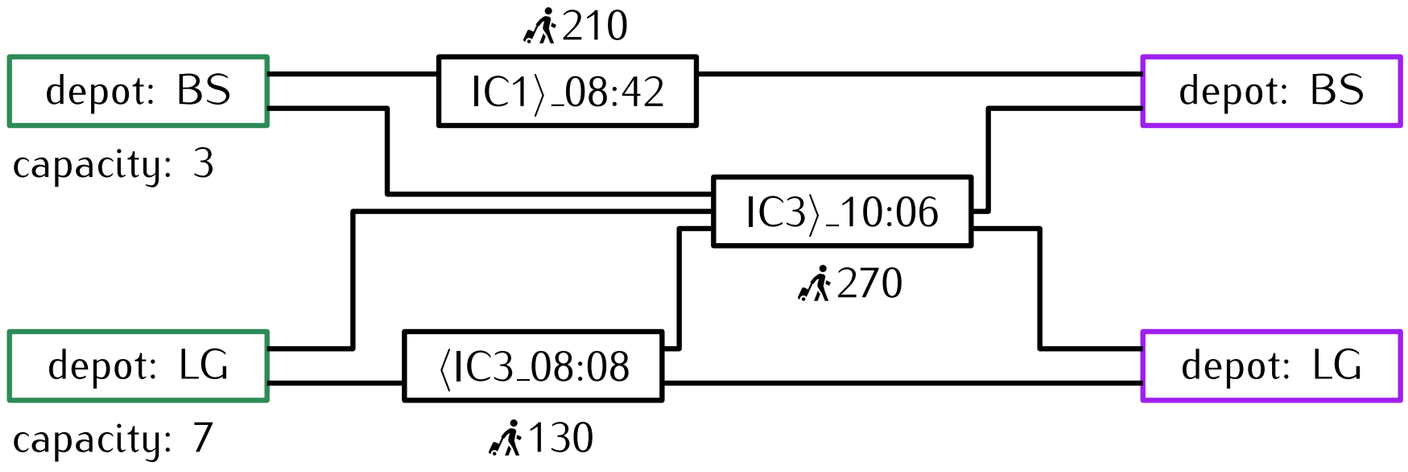

train info:

- passenger capacity per train: 200
- maximal vehicle in formation: 5

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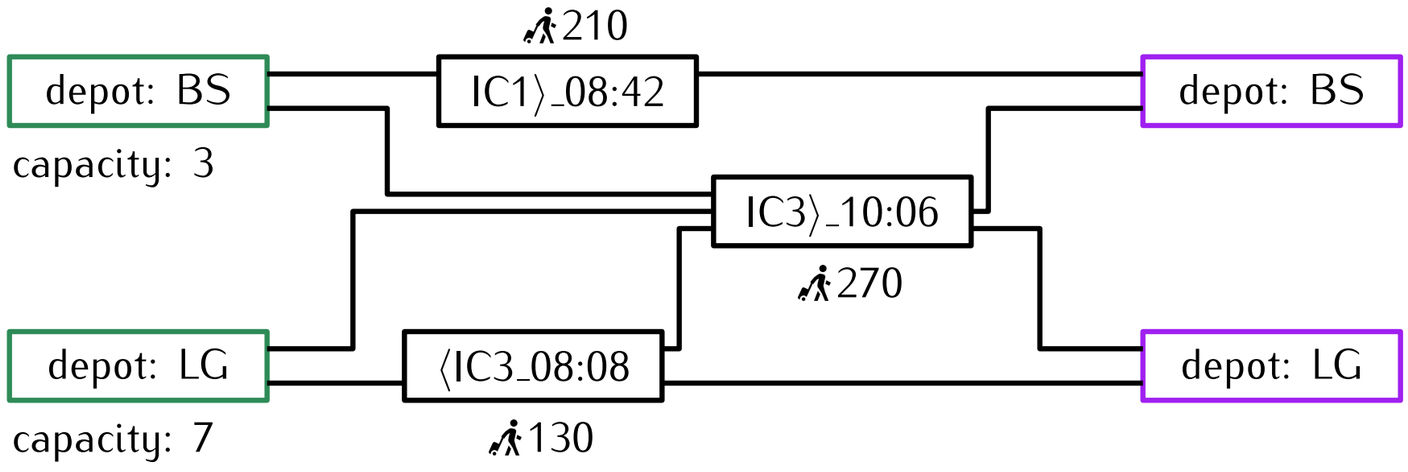

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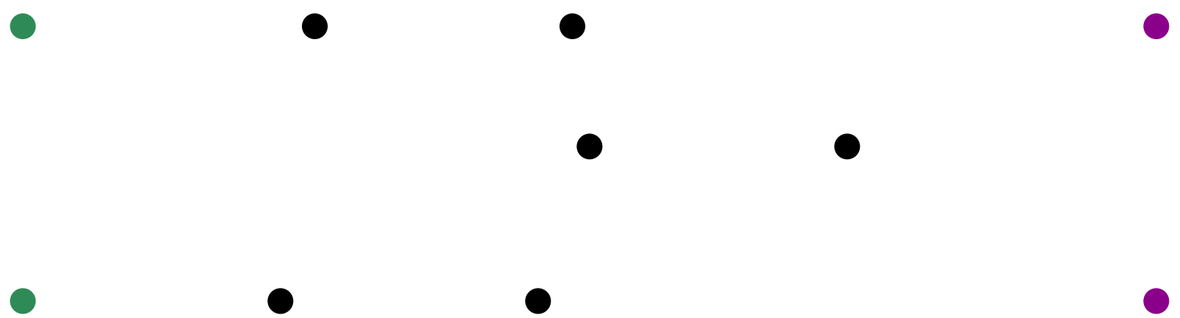

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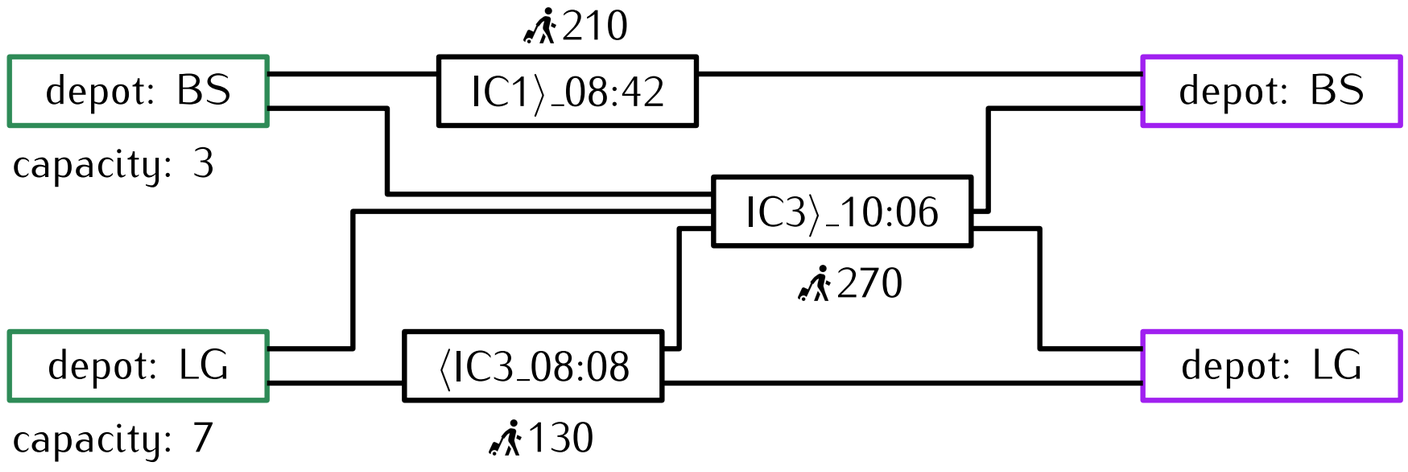

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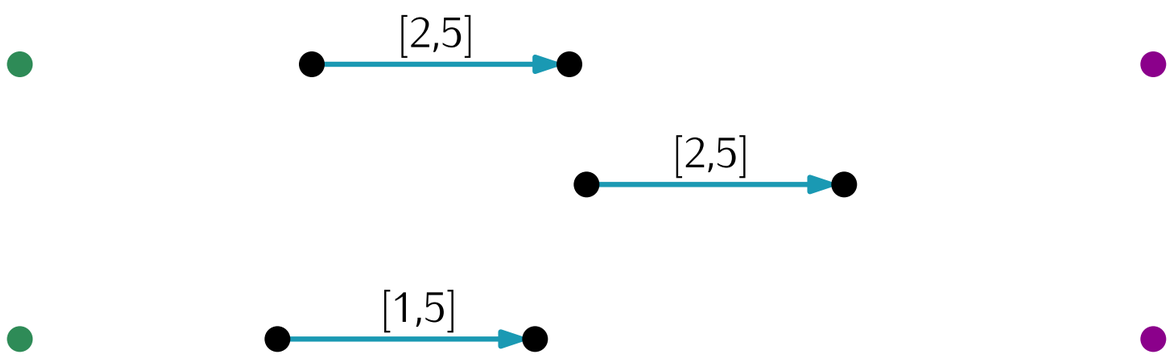

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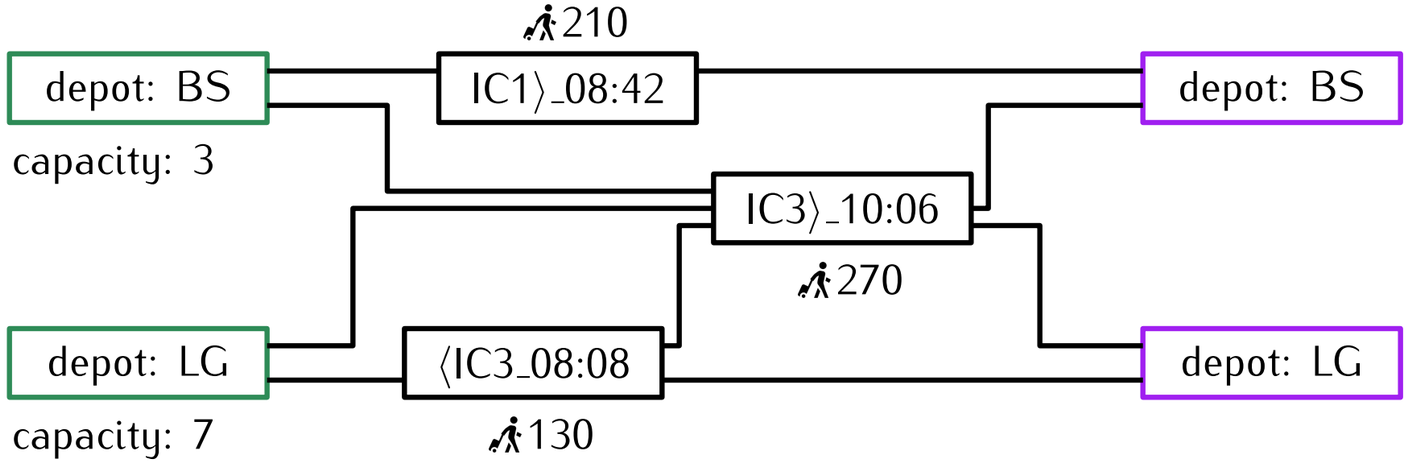

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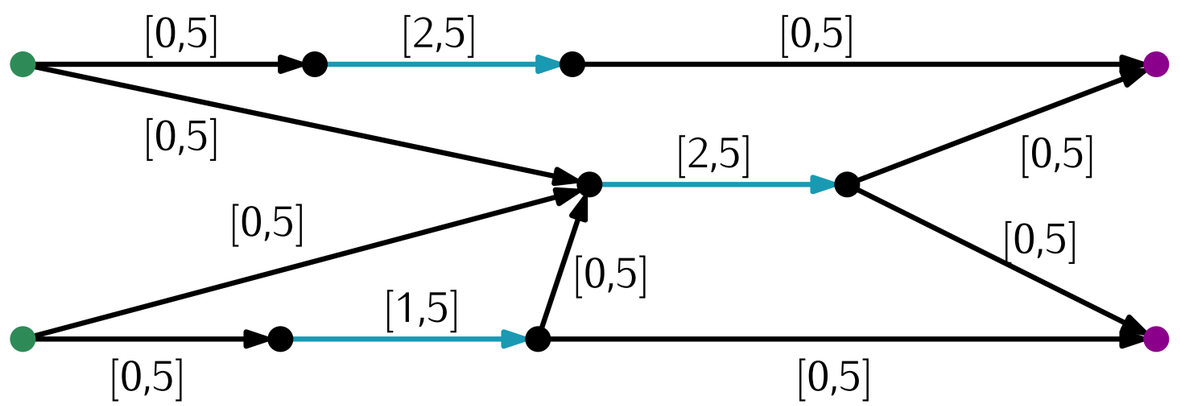

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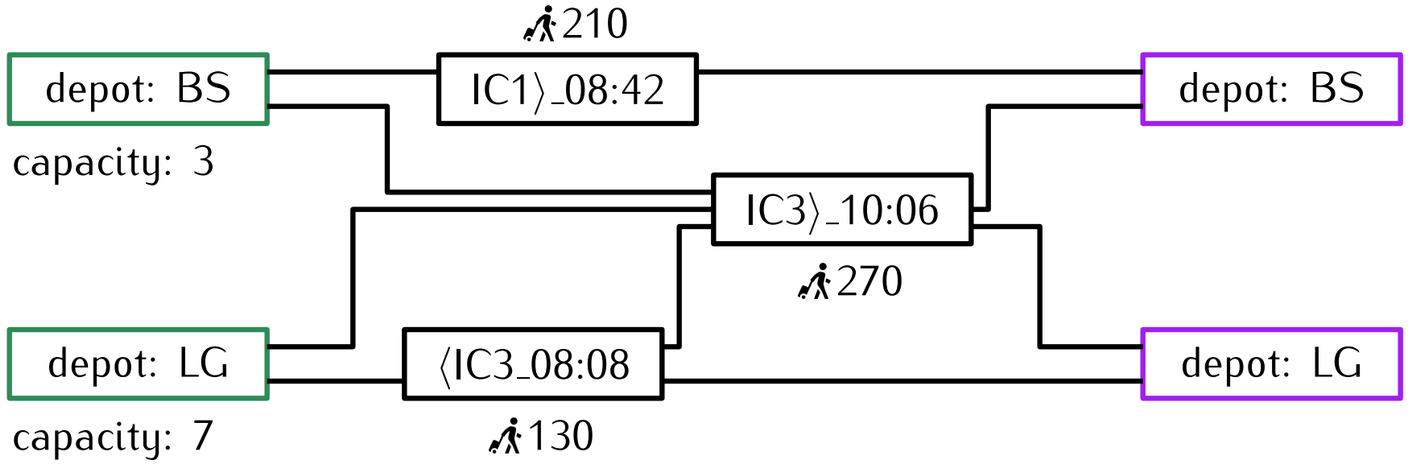

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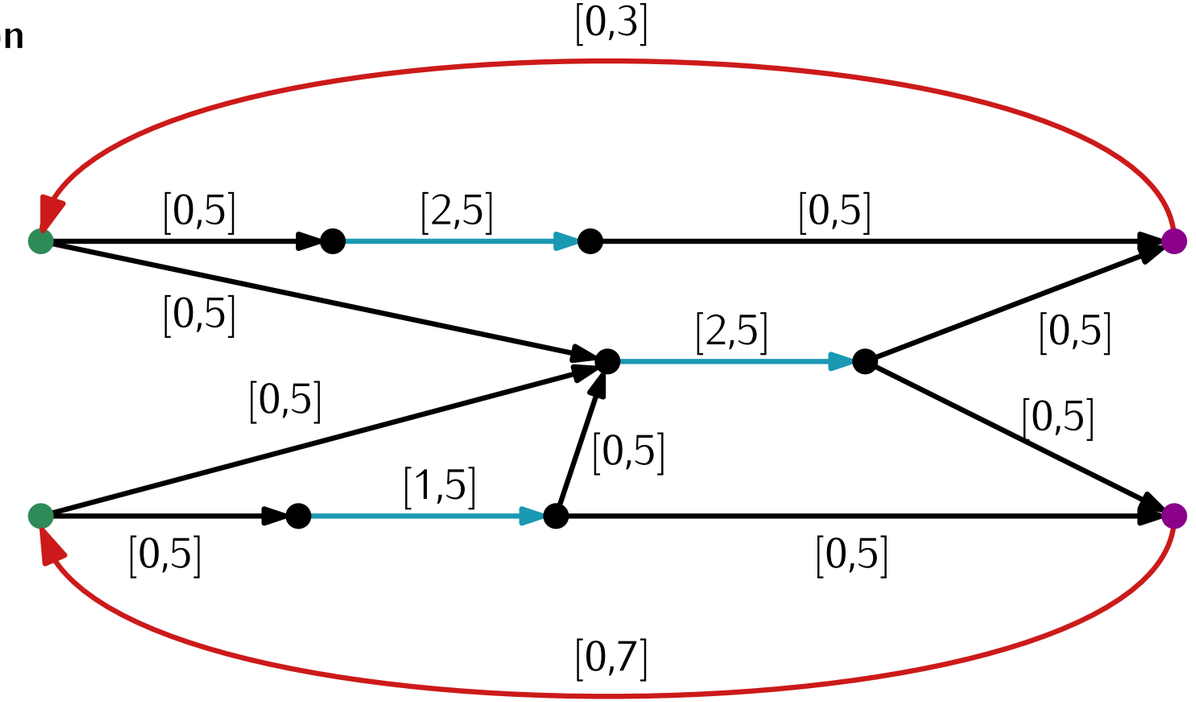

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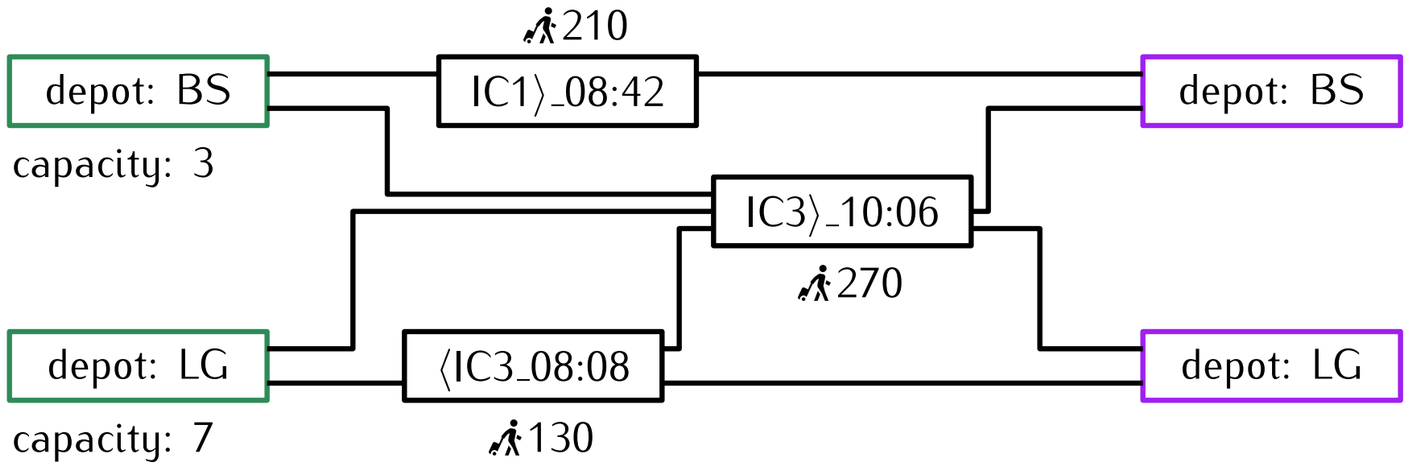

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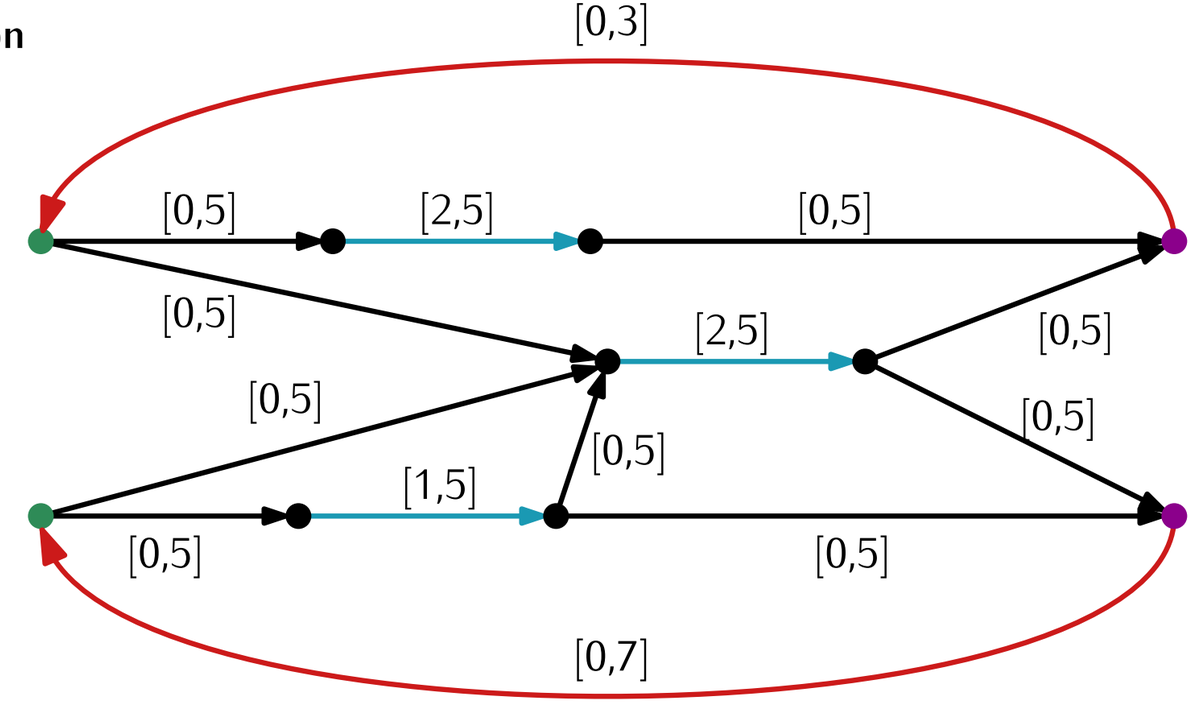

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Phase 1 - Algorithm

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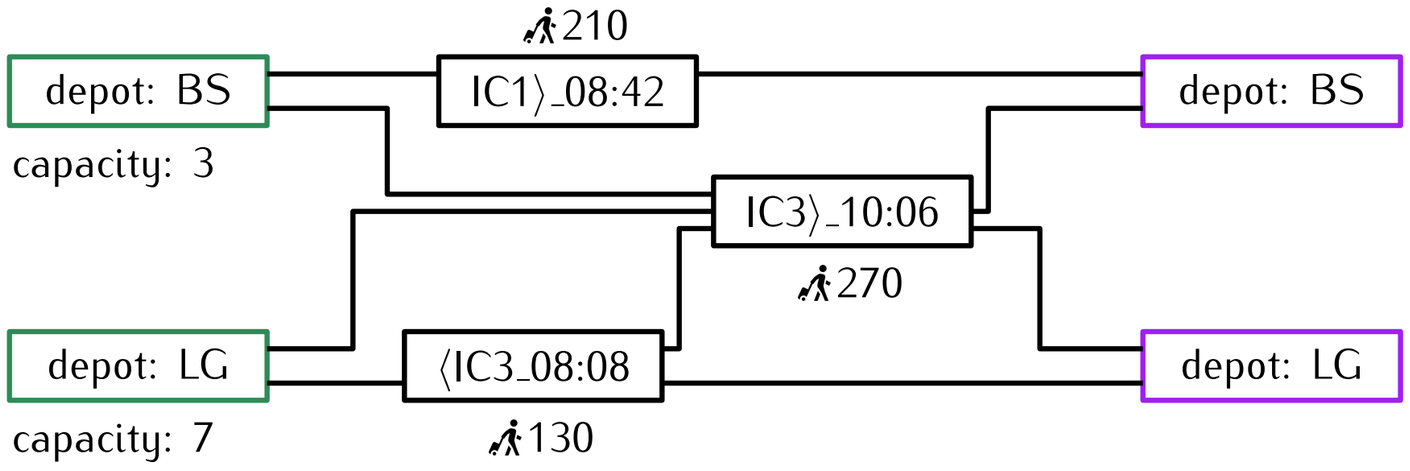

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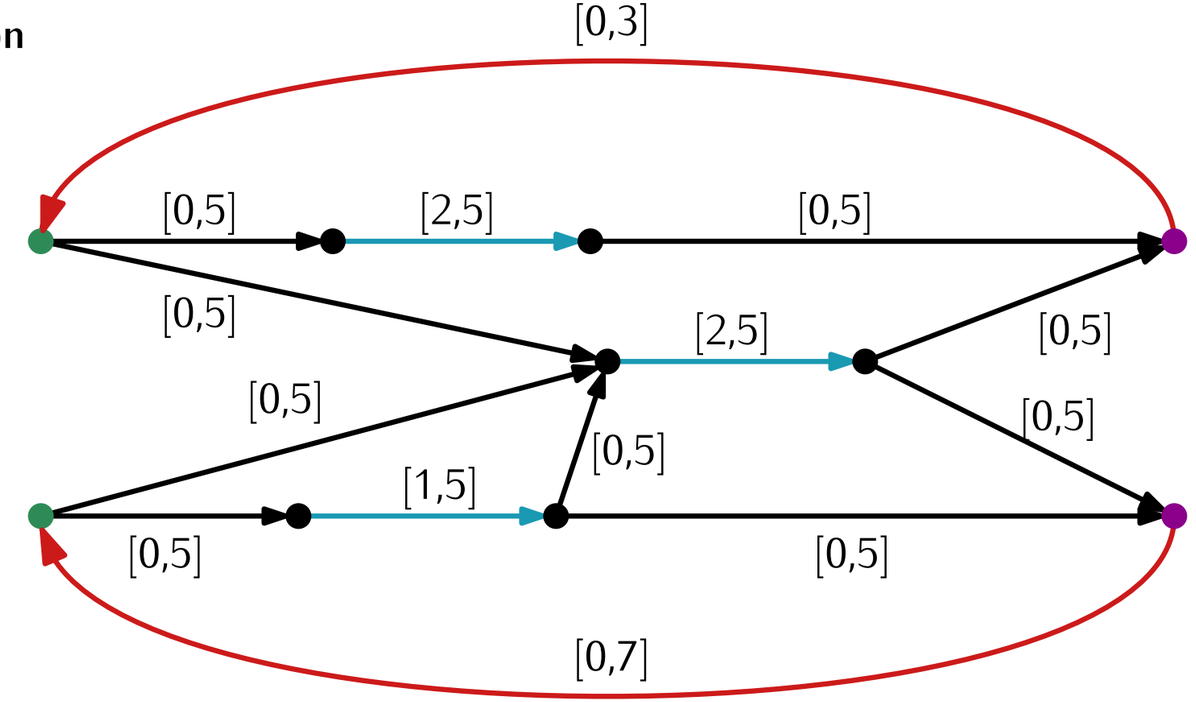

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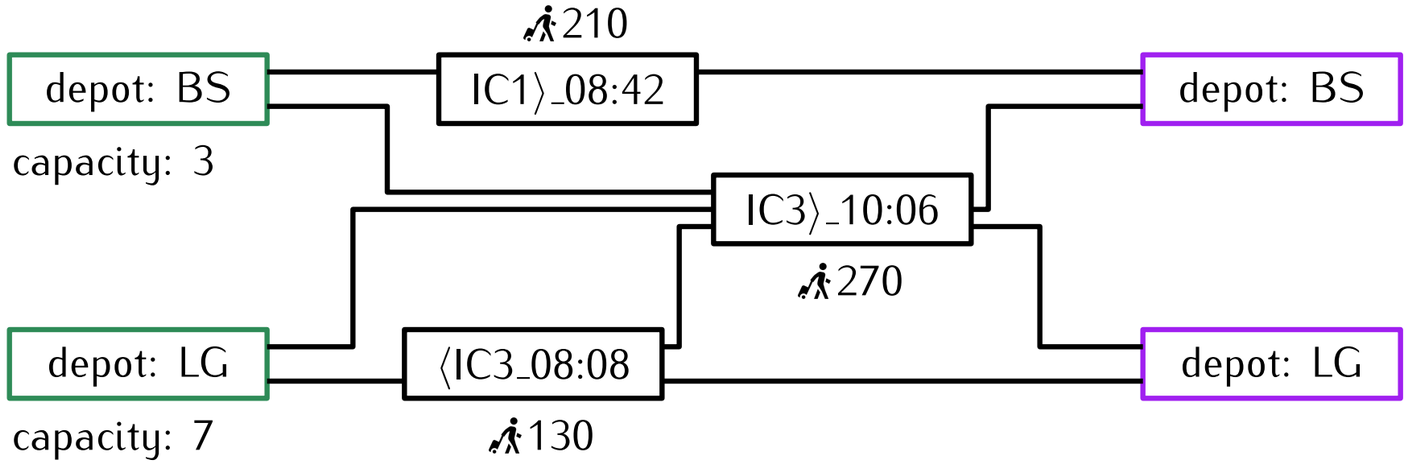

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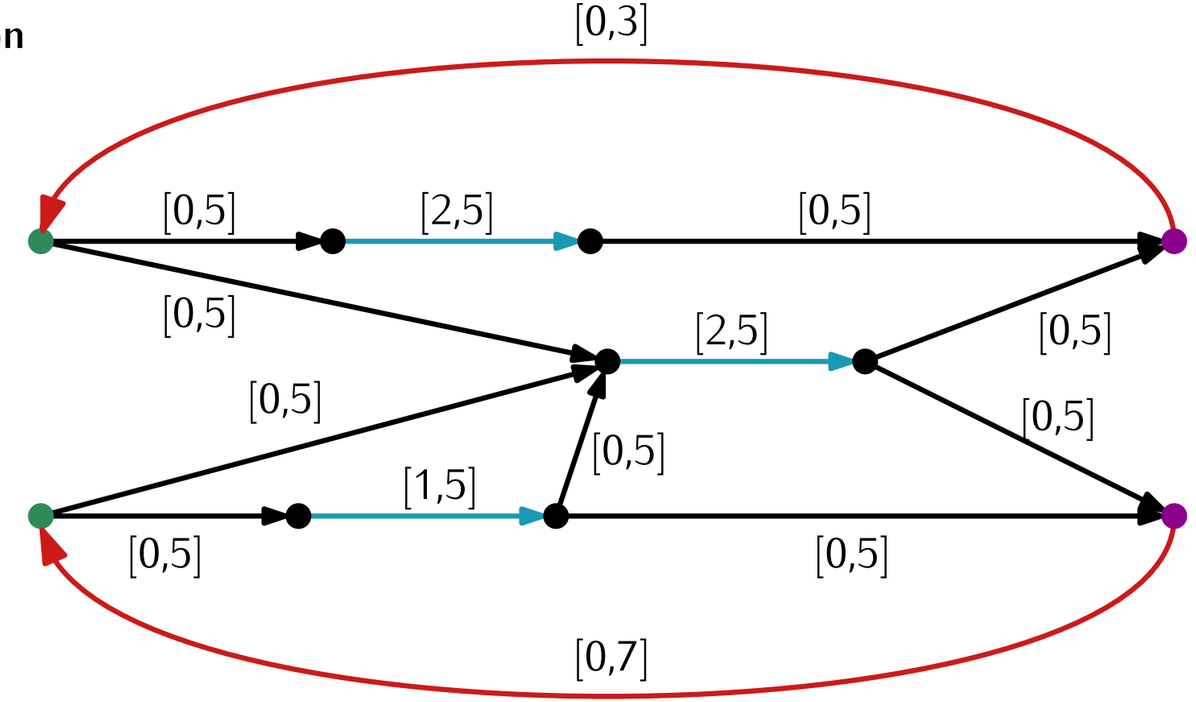

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running time

- 1200 service trips
- 120 vehicle ⇒ **0.5 seconds**
- Lenovo X1 Yoga

Phase 2
Model Extensions

Phase 2 - New Aspects

seated / standing passengers

- assumption: passengers travelling < 15 minutes can stand (no seat needed)

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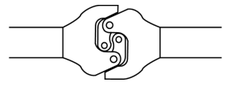
strengthen / weaken train formation during a trip

- split service trips into segments
- within a segment: no coupling allowed
- between segments: vehicles can be (de-)coupled



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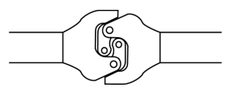

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- vehicles can be towed unused on a service trips (saves staff cost)

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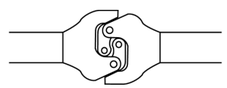

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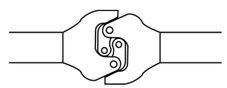

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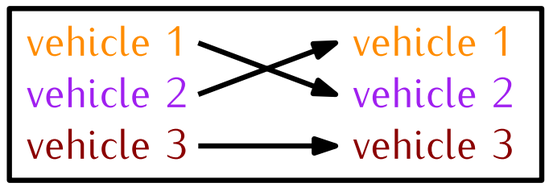
maintenance

- maintenance stations with multiple maintenance slots
- maintenance slots can be used by each type
- vehicles must go to maintenance every 15 000 km ($\sim$ every 20 days)
- schedule is a single day repeated each day
- $\rightarrow$ map vehicles arriving at a depot in the evening to vehicles departure early in the morning (on the next day)



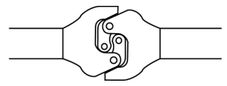
Phase 2 - New Aspects

seated / standing passengers

- assumption: passengers travelling < 15 minutes can stand (no seat needed)

strengthen / weaken train formation during a trip

- split service trips into segments
- within a segment: no coupling allowed
- between segments: vehicles can be (de-)coupled



"hitch-hiking"

- vehicles can be towed unused on a service trips (saves staff cost)

vehicle types

- only vehicles of the same type can be coupled
- service trips are served by exactly one type

maintenance

- maintenance stations with multiple maintenance slots
- maintenance slots can be used by each type
- vehicles must go to maintenance every 15 000 km ($\sim$ every 20 days)
- schedule is a single day repeated each day
- $\rightarrow$ map vehicles arriving at a depot in the evening to vehicles departure early in the morning (on the next day)

old hierachical objective:

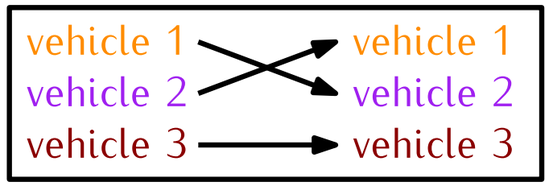
1. # unserved passengers
2. # number of vehicles
3. total distance traveled

new hierachical objective:

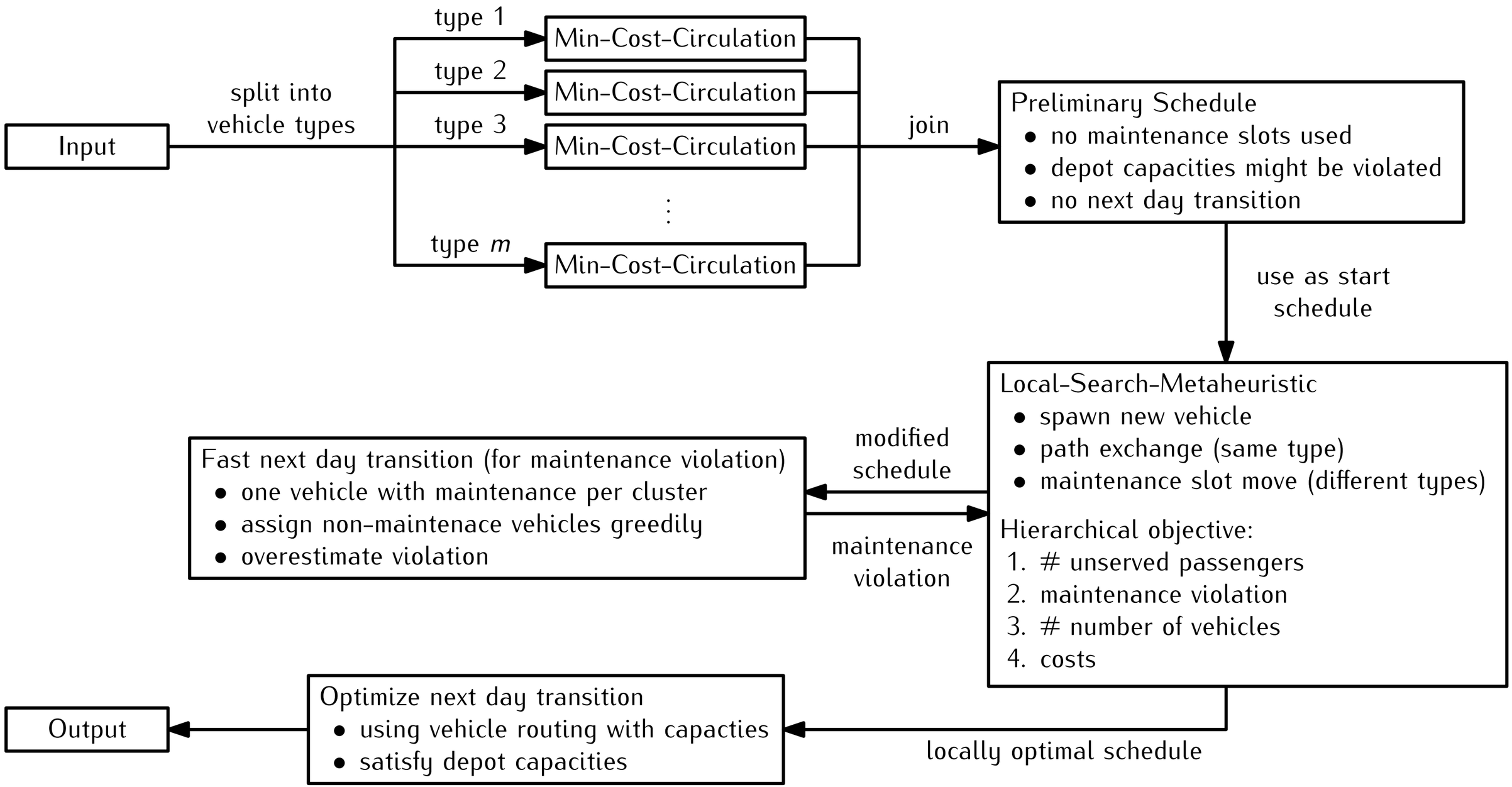
1. # unserved passengers
2. maintenance violation
3. # number of vehicles
4. costs

costs are a linear combination of

- total service trip duration
- total dead head trip duration
- mainteance duration
- idle duration
- staff cost (each train formation pays this only once)



Phase 2 - Algorithm Overview



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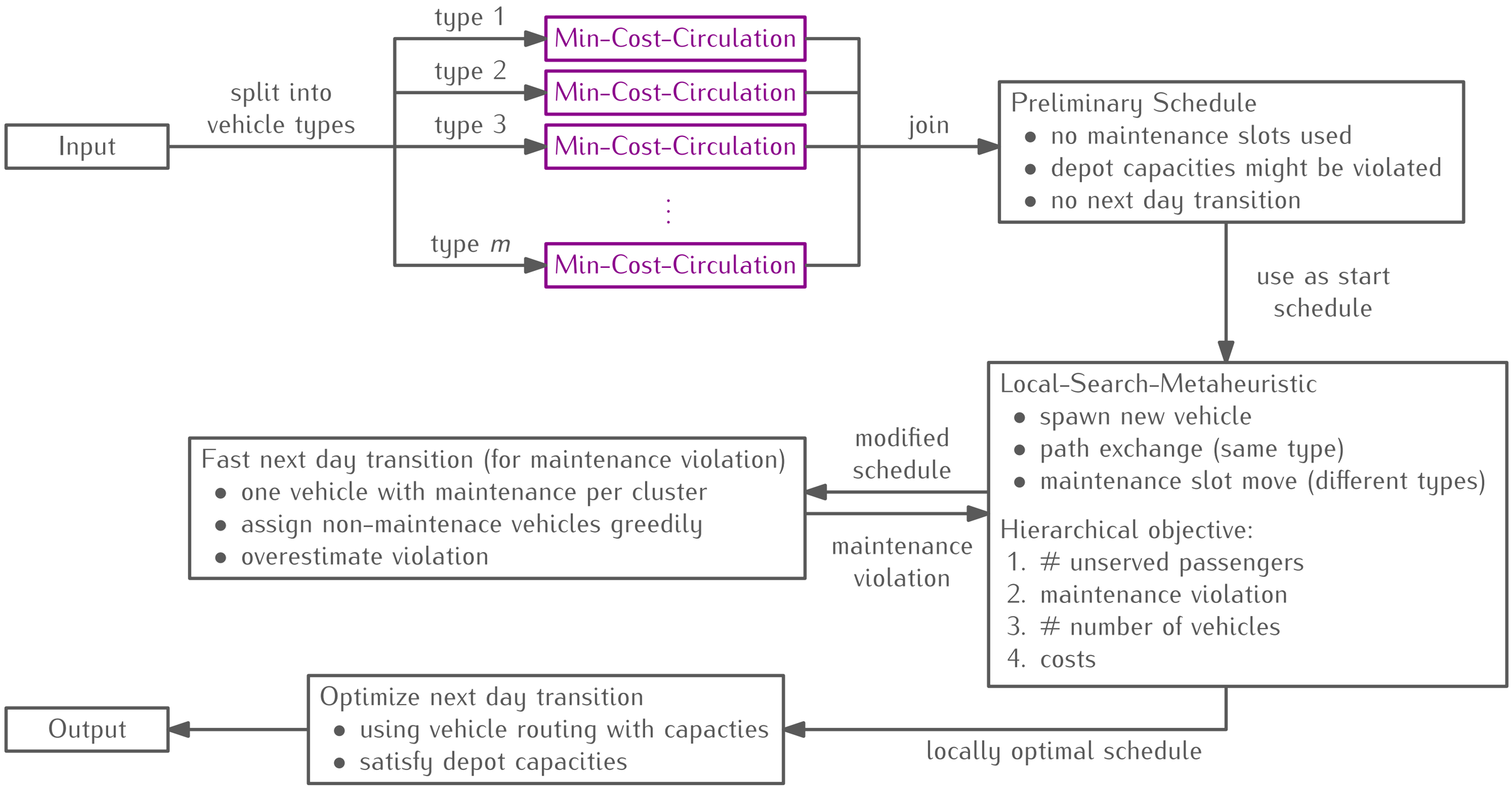
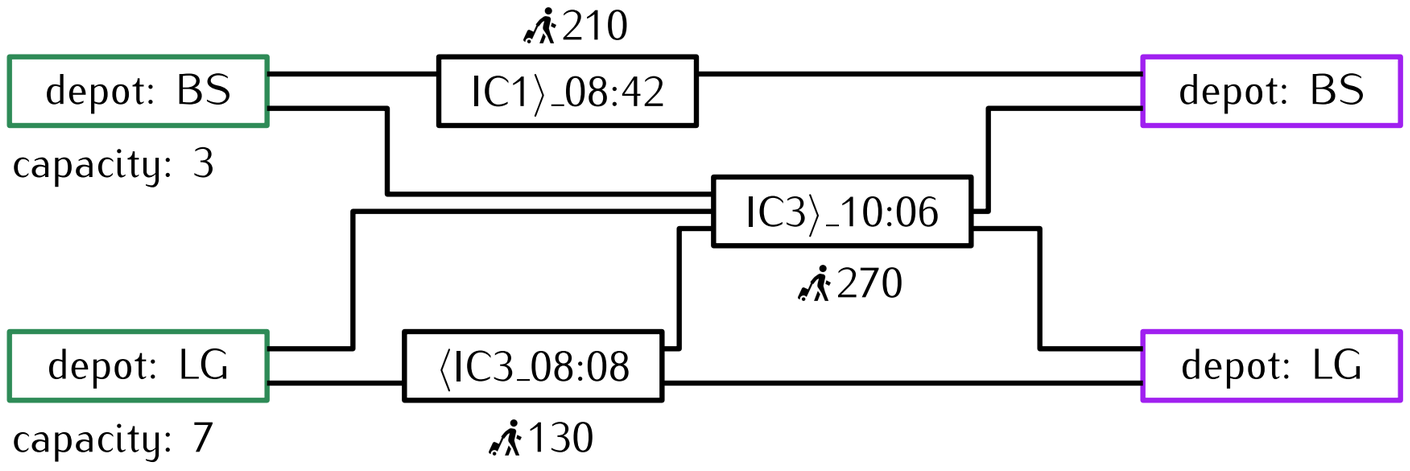


Min-Cost-Circulation

Model



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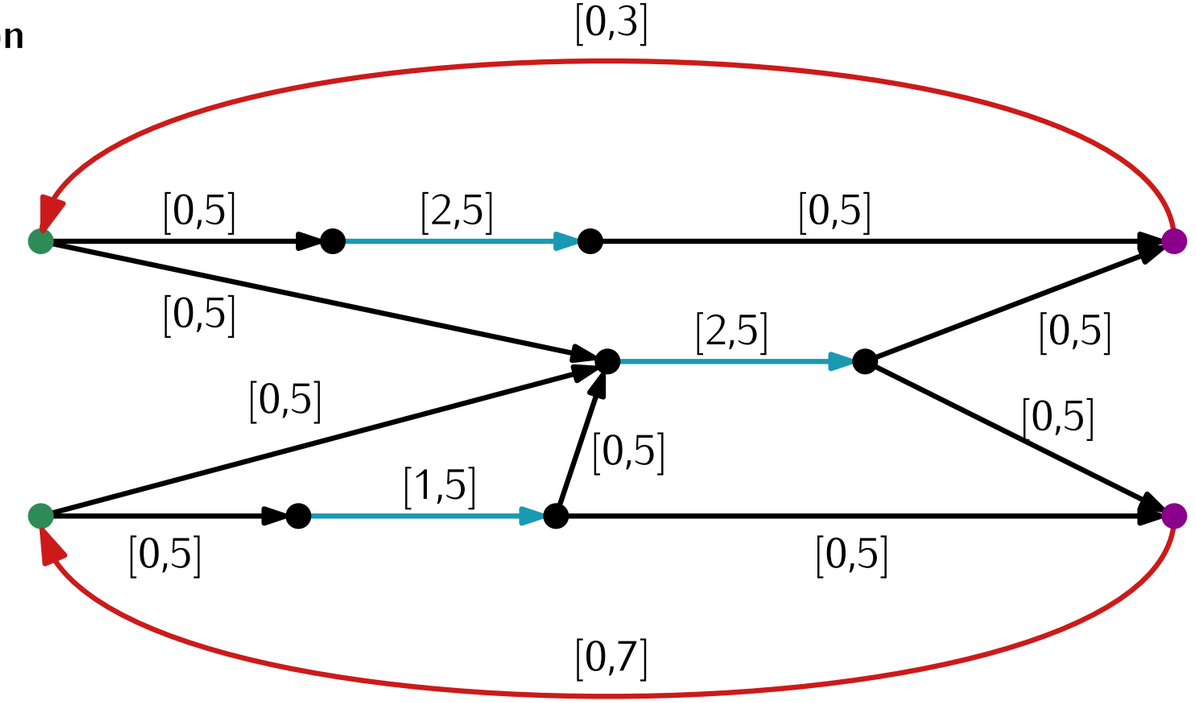
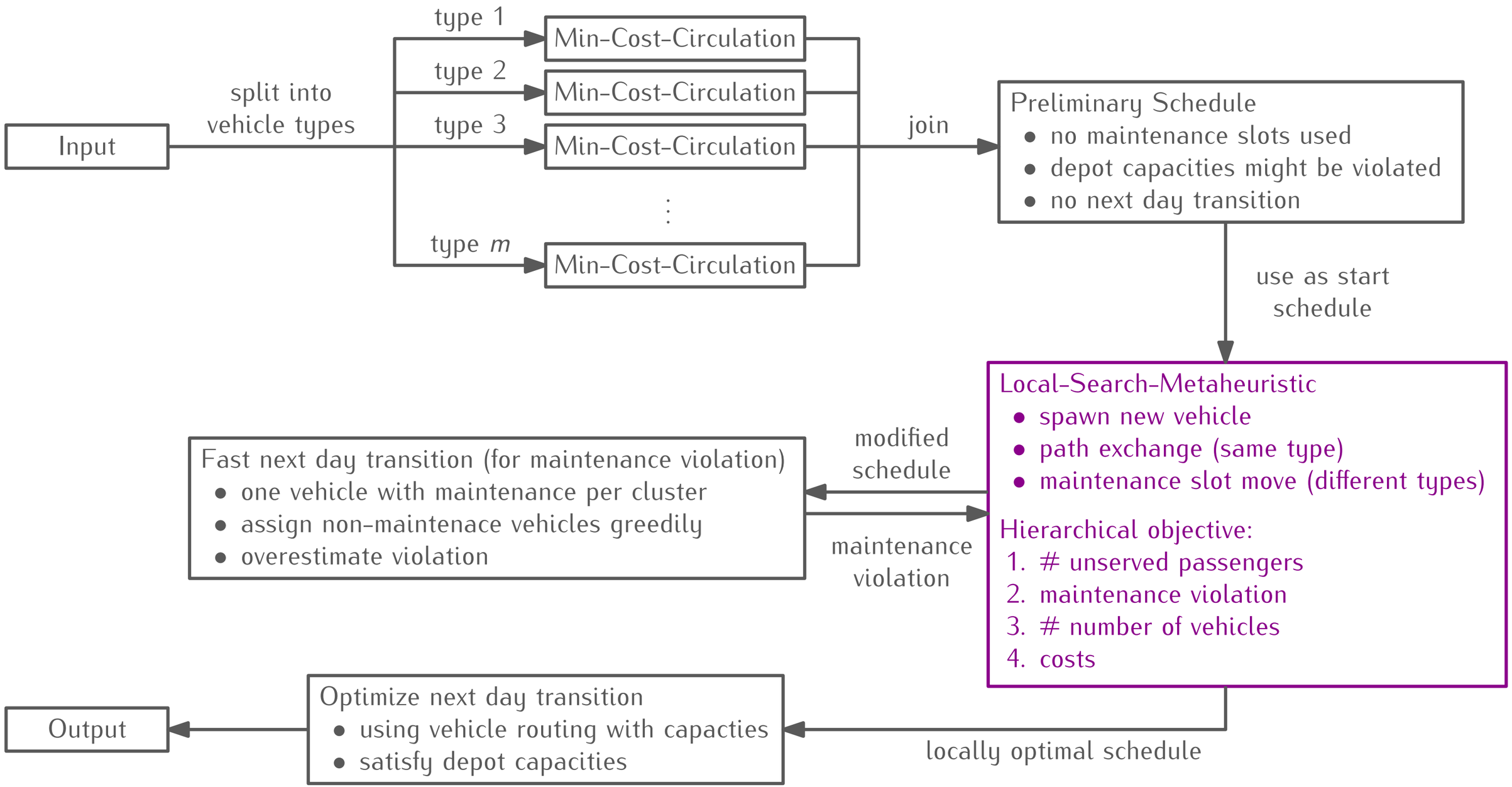


~~**costs:**~~
~~1. forward arcs: distance traveled~~
~~2. depot arcs: sum of all distances~~

costs:
1. forward arcs: new costs
2. depot arcs: sum of all costs

Phase 2 - Algorithm Overview



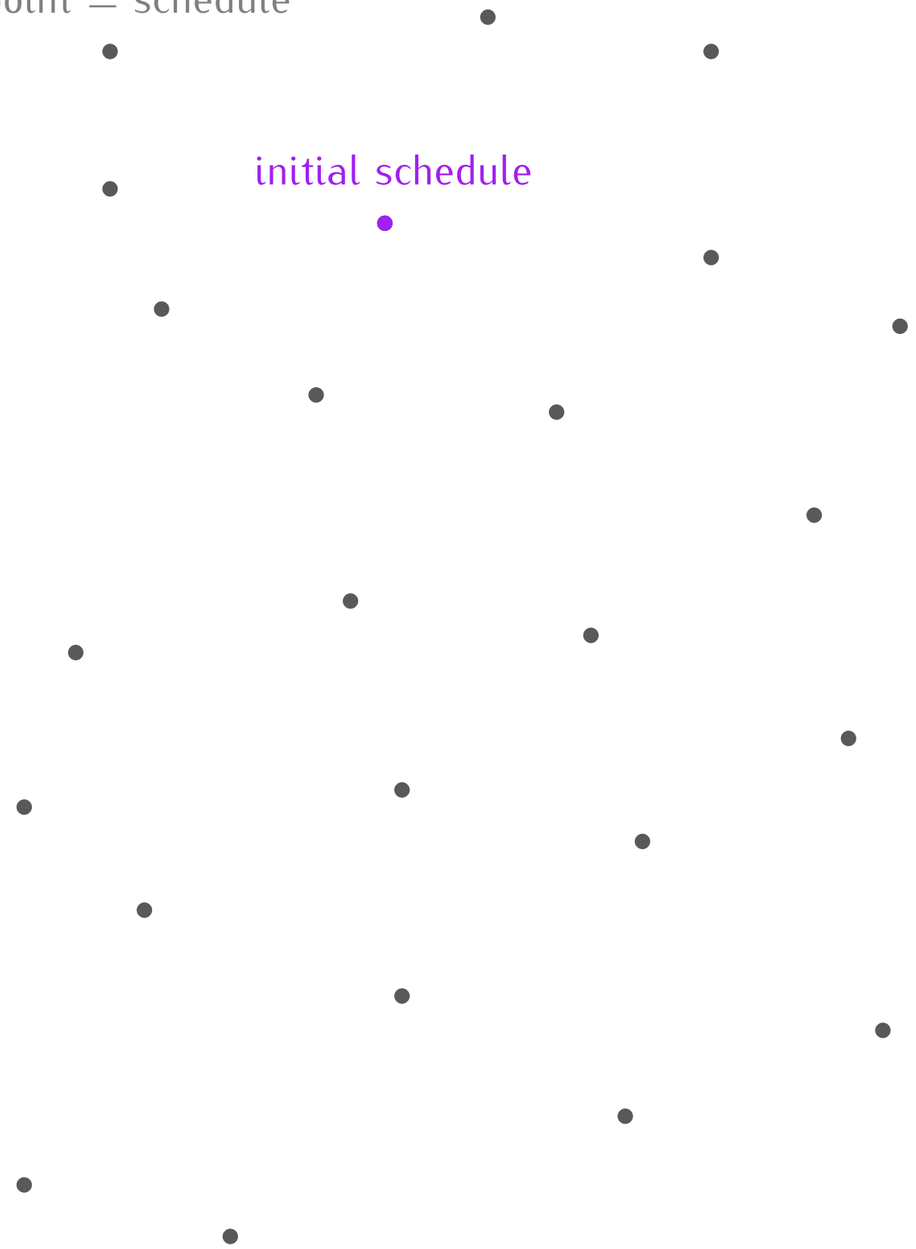
Local Search

point = schedule

Local Search

point = schedule

initial schedule



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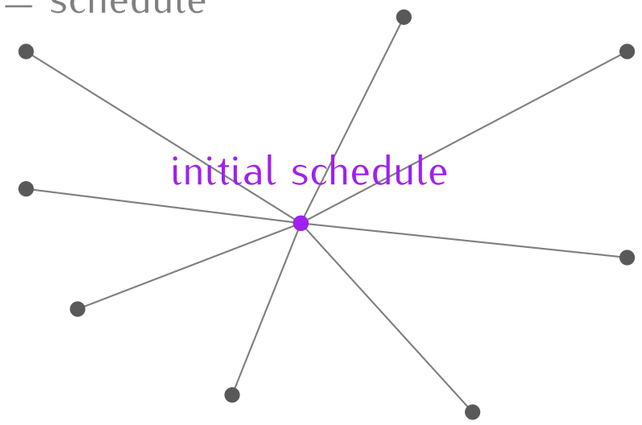
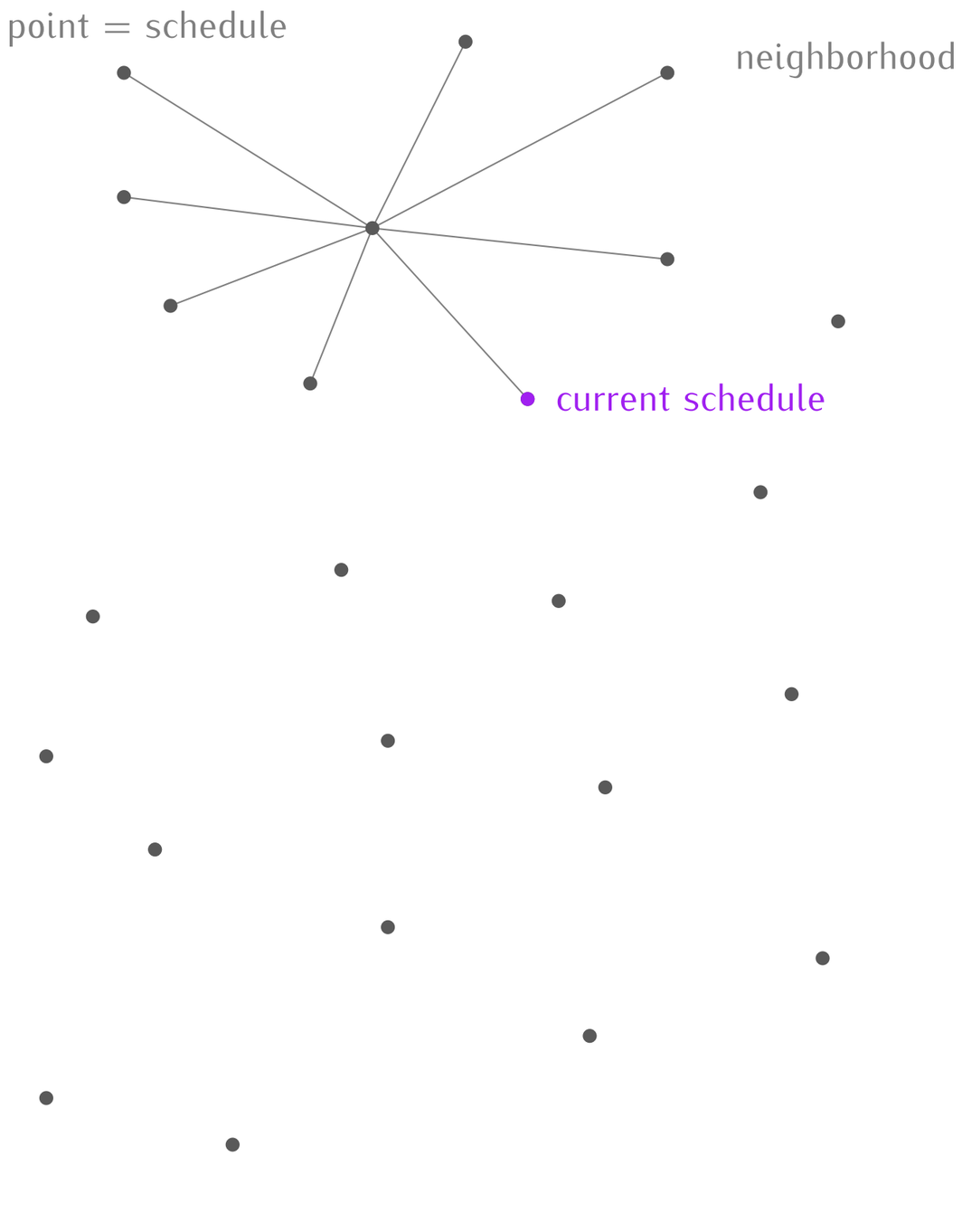


neighborhood

Local Search



Local Search

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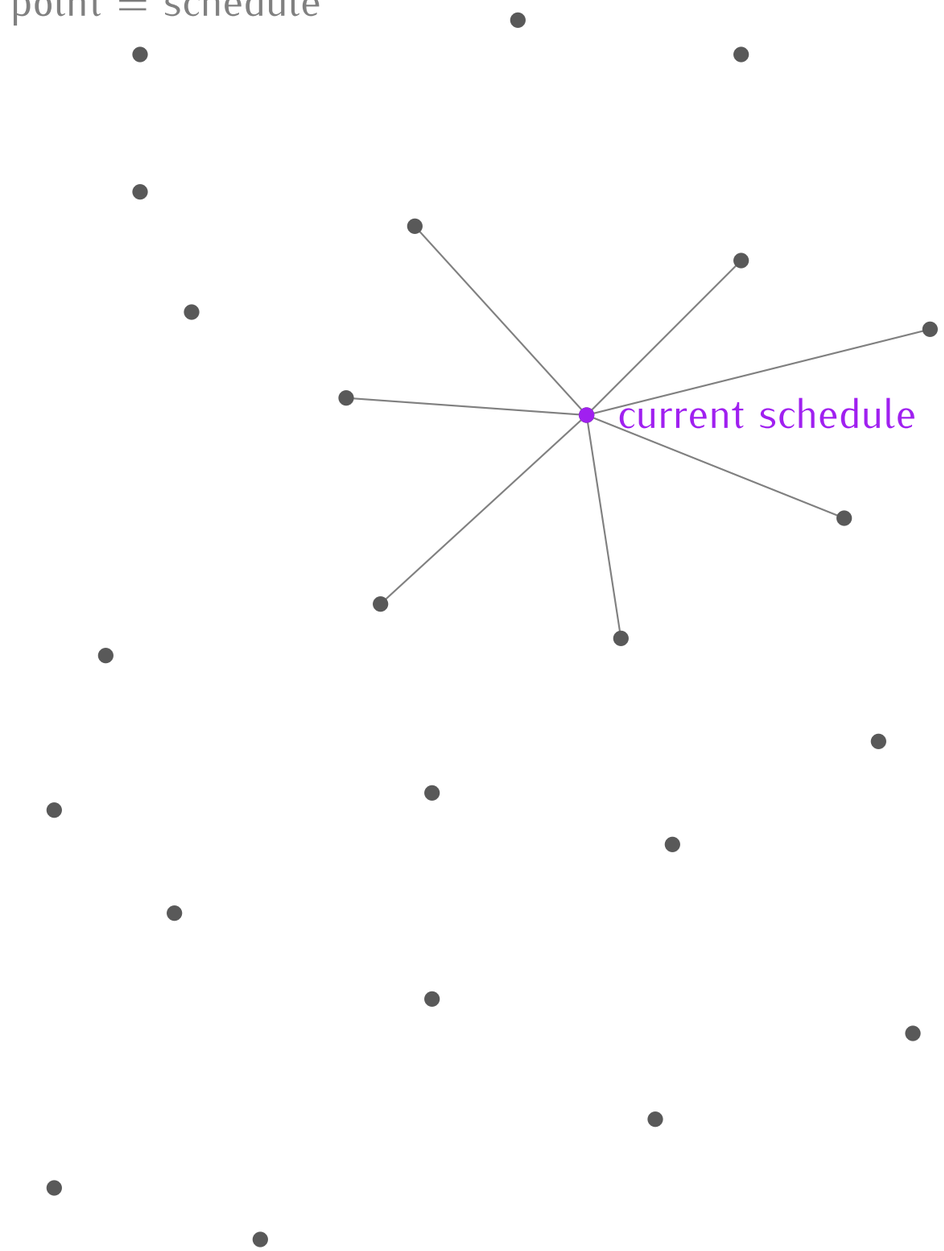

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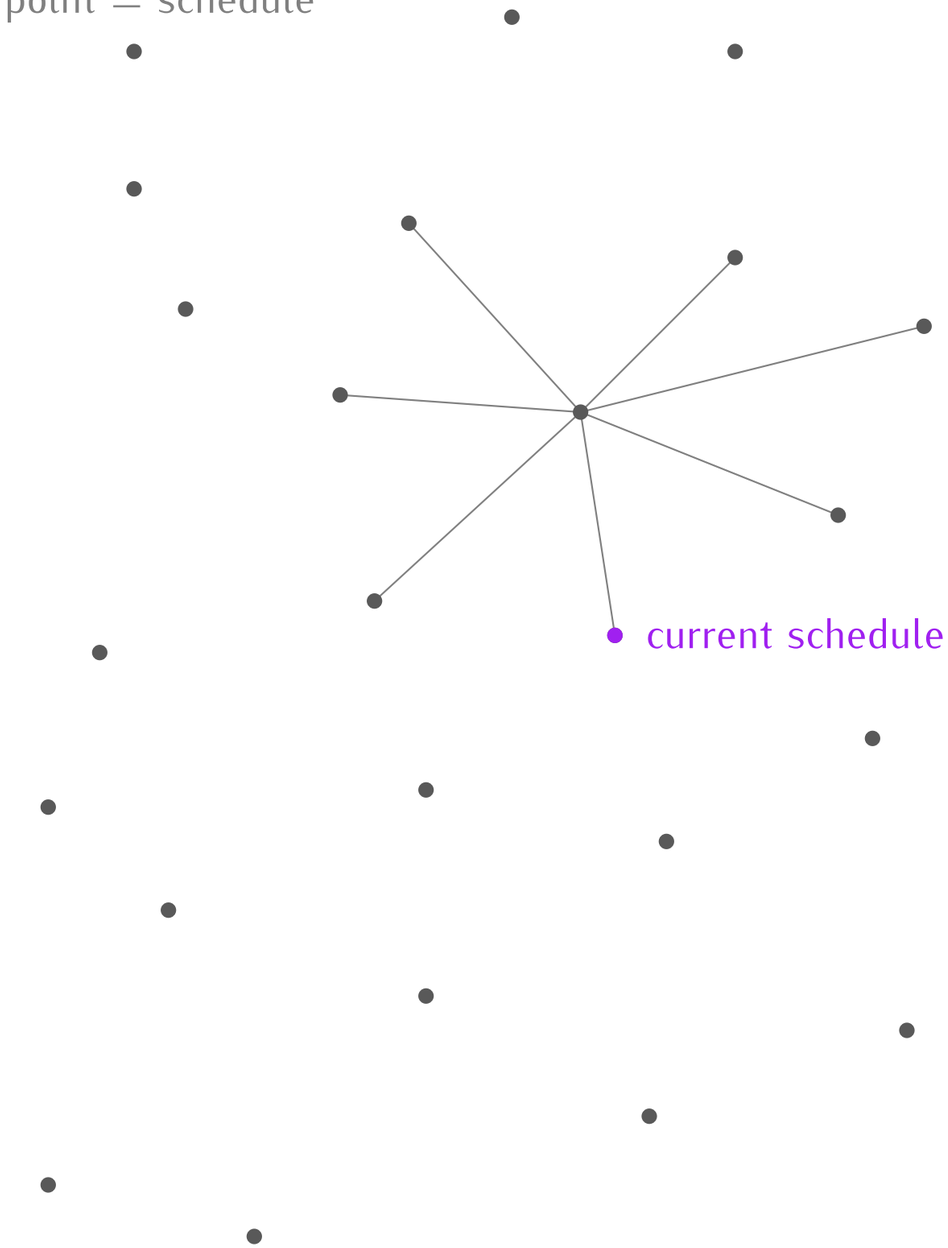

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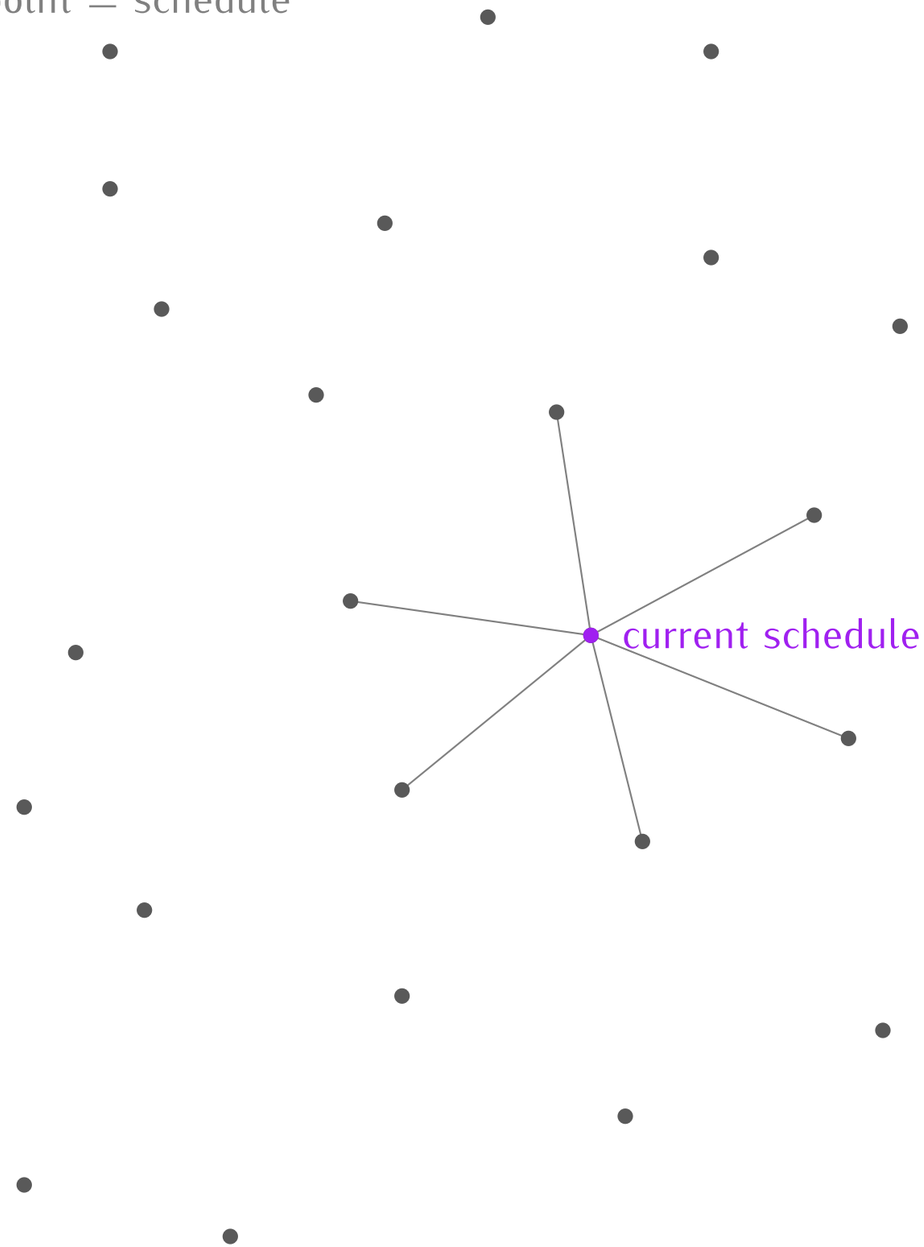

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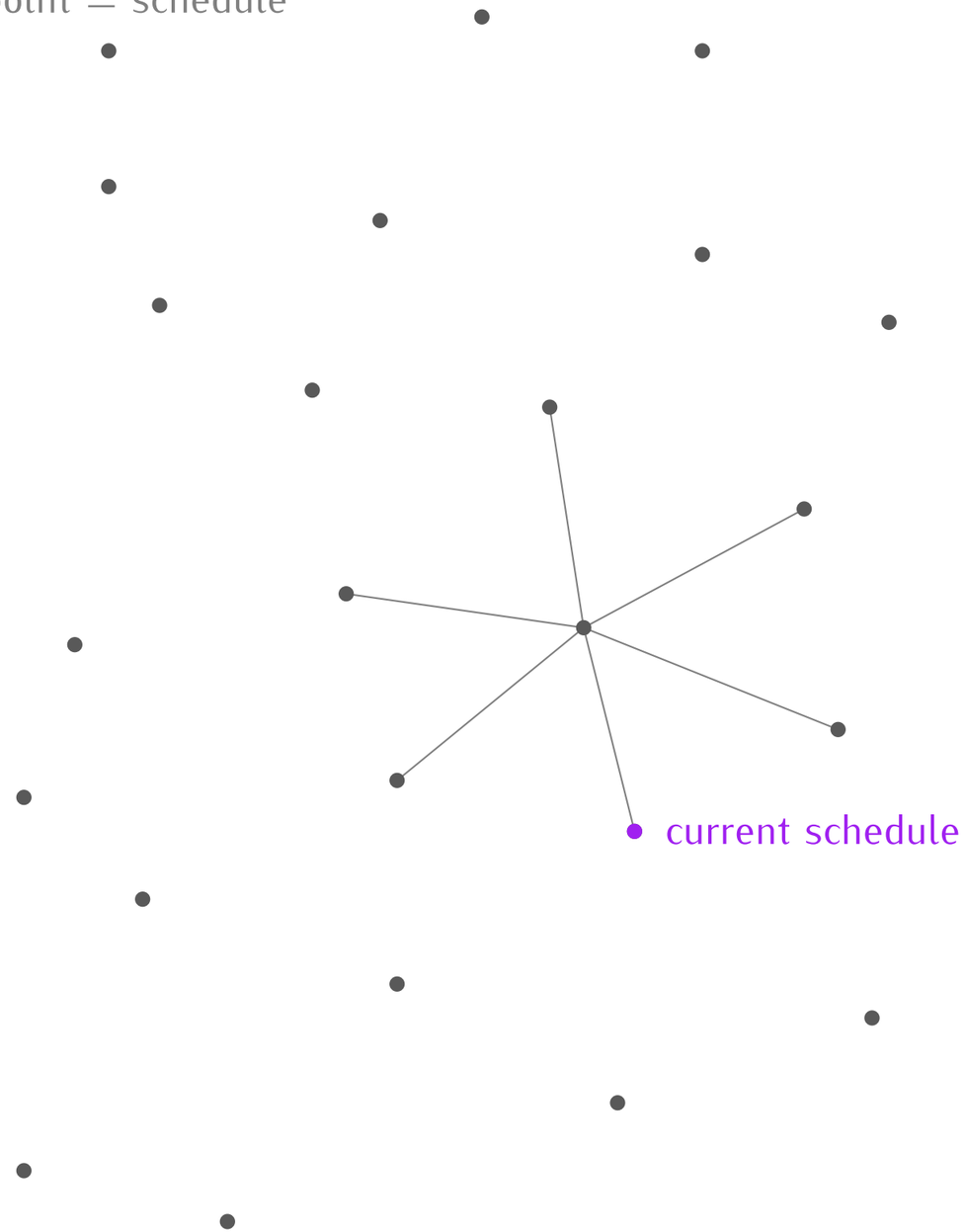
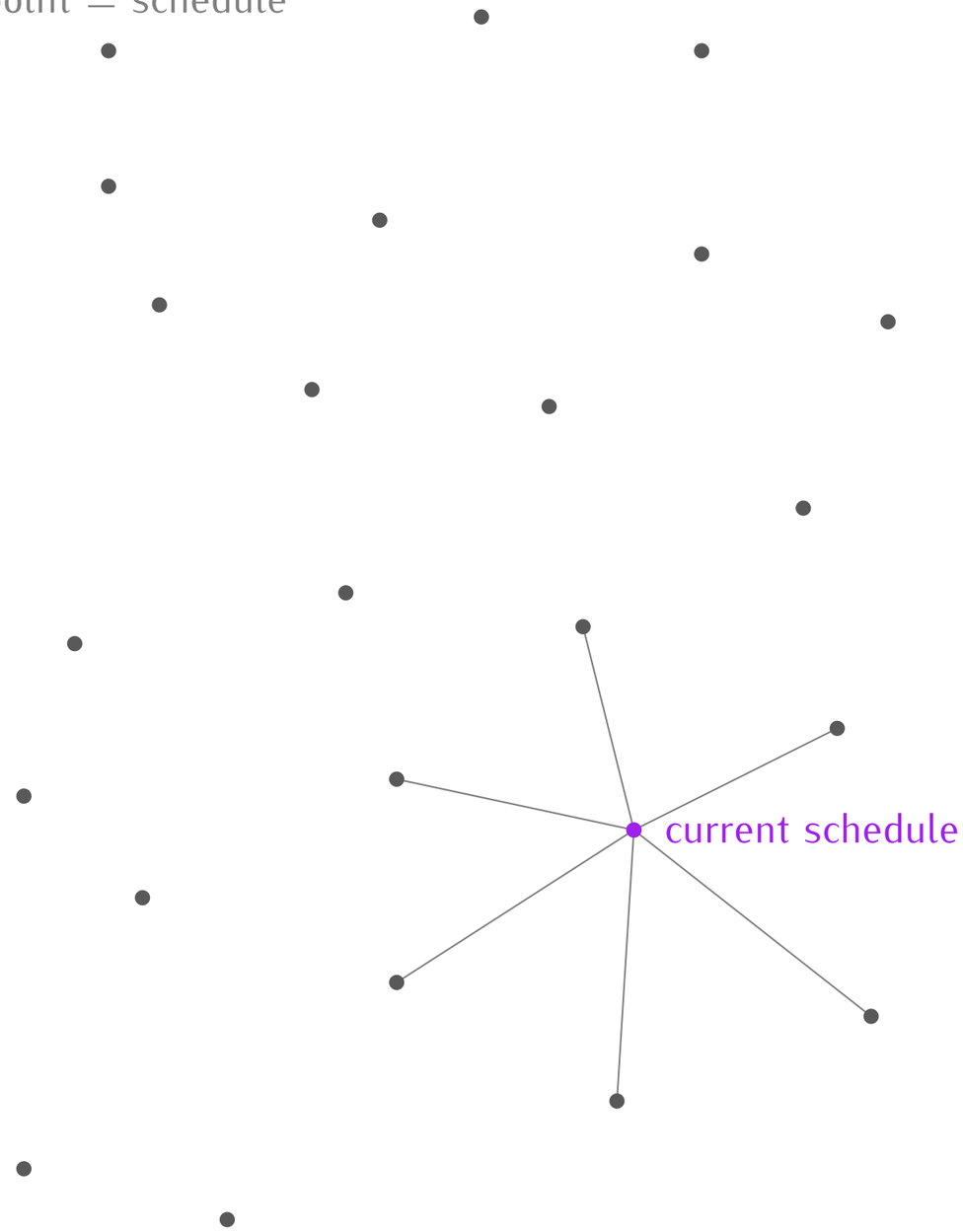


Local Search

point = schedule



Local Search

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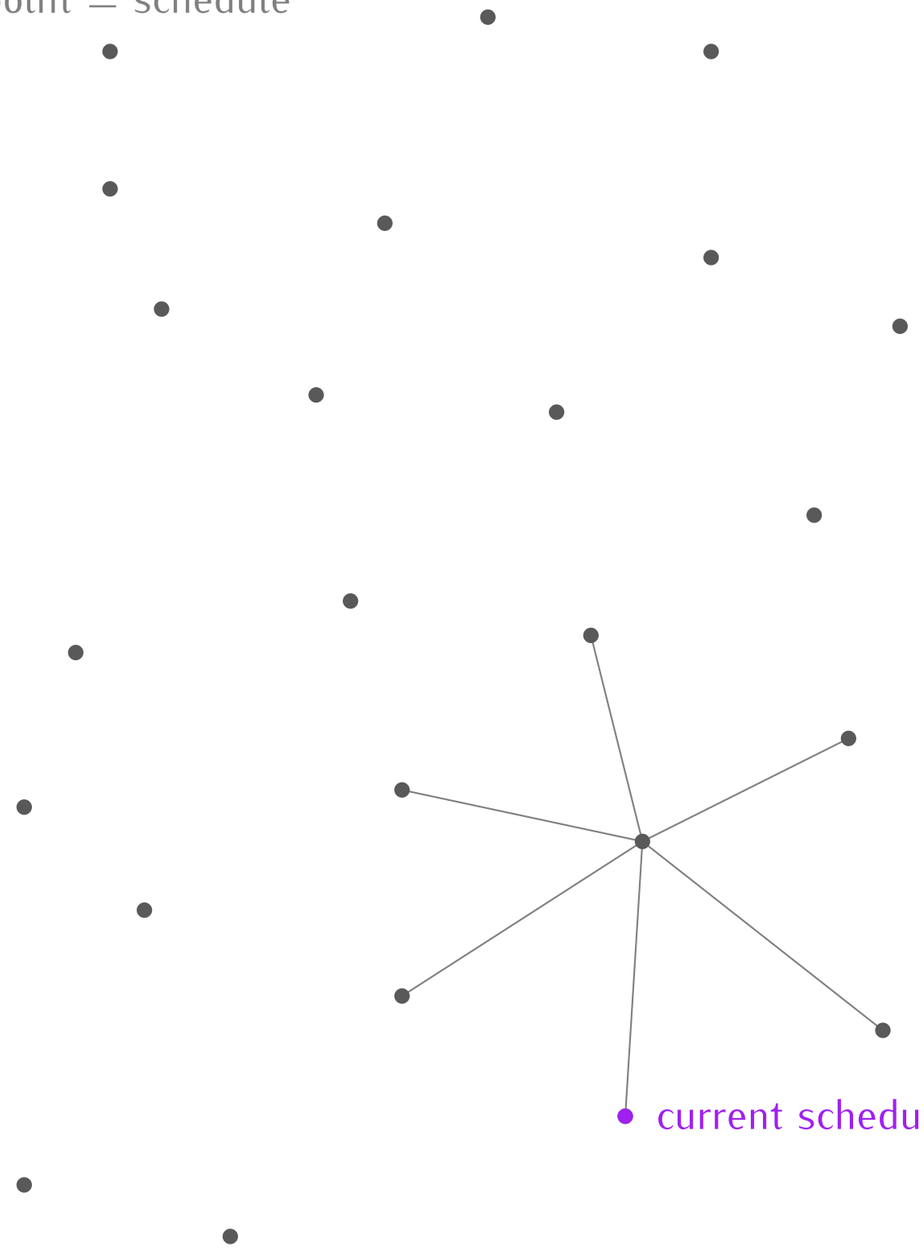
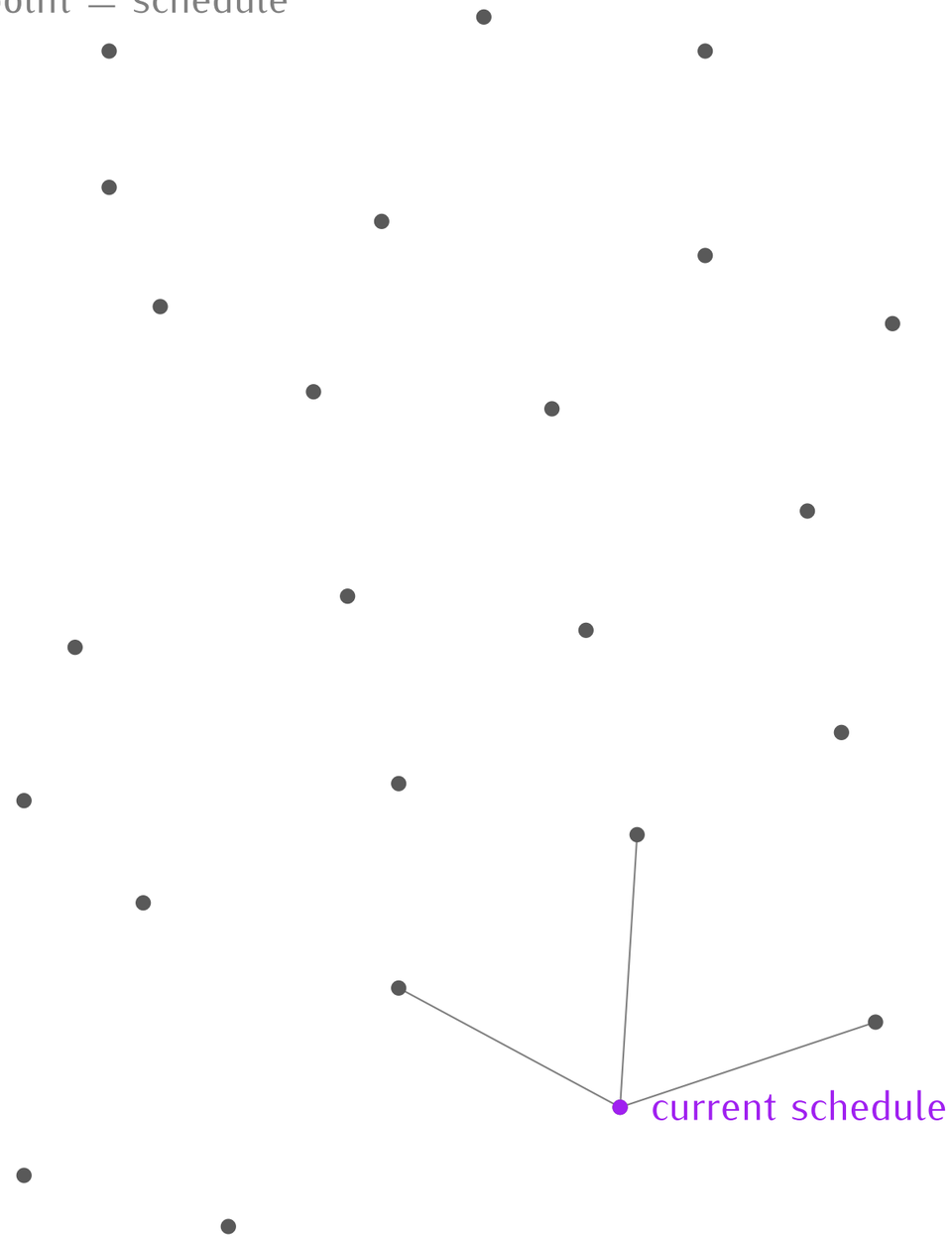


current schedule

Local Search

point = schedule



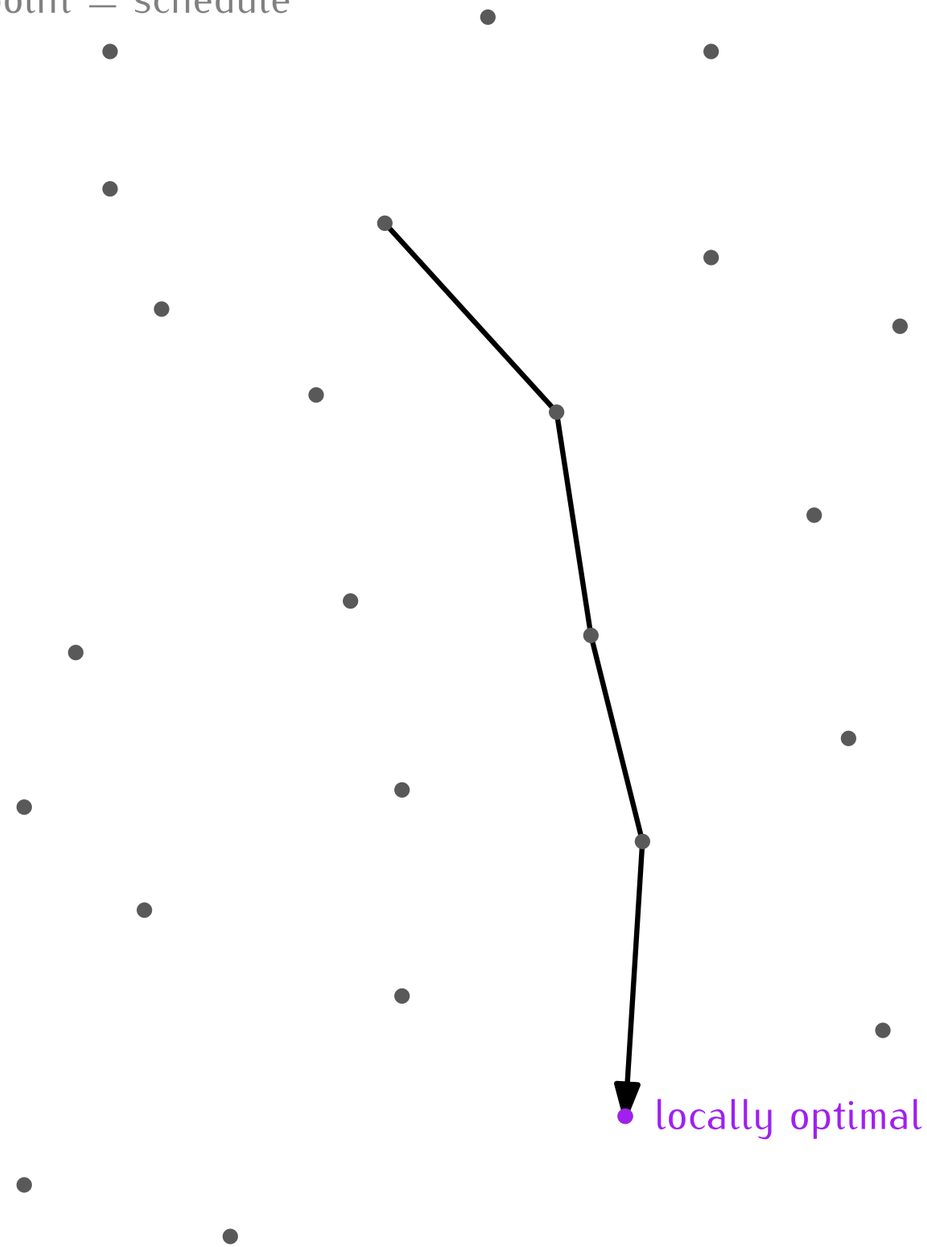
Local Search

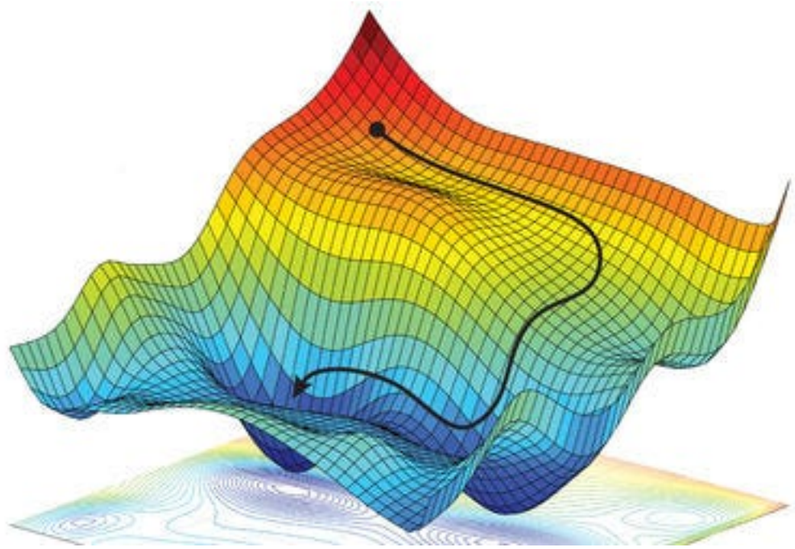
point = schedule

- locally optimal schedule

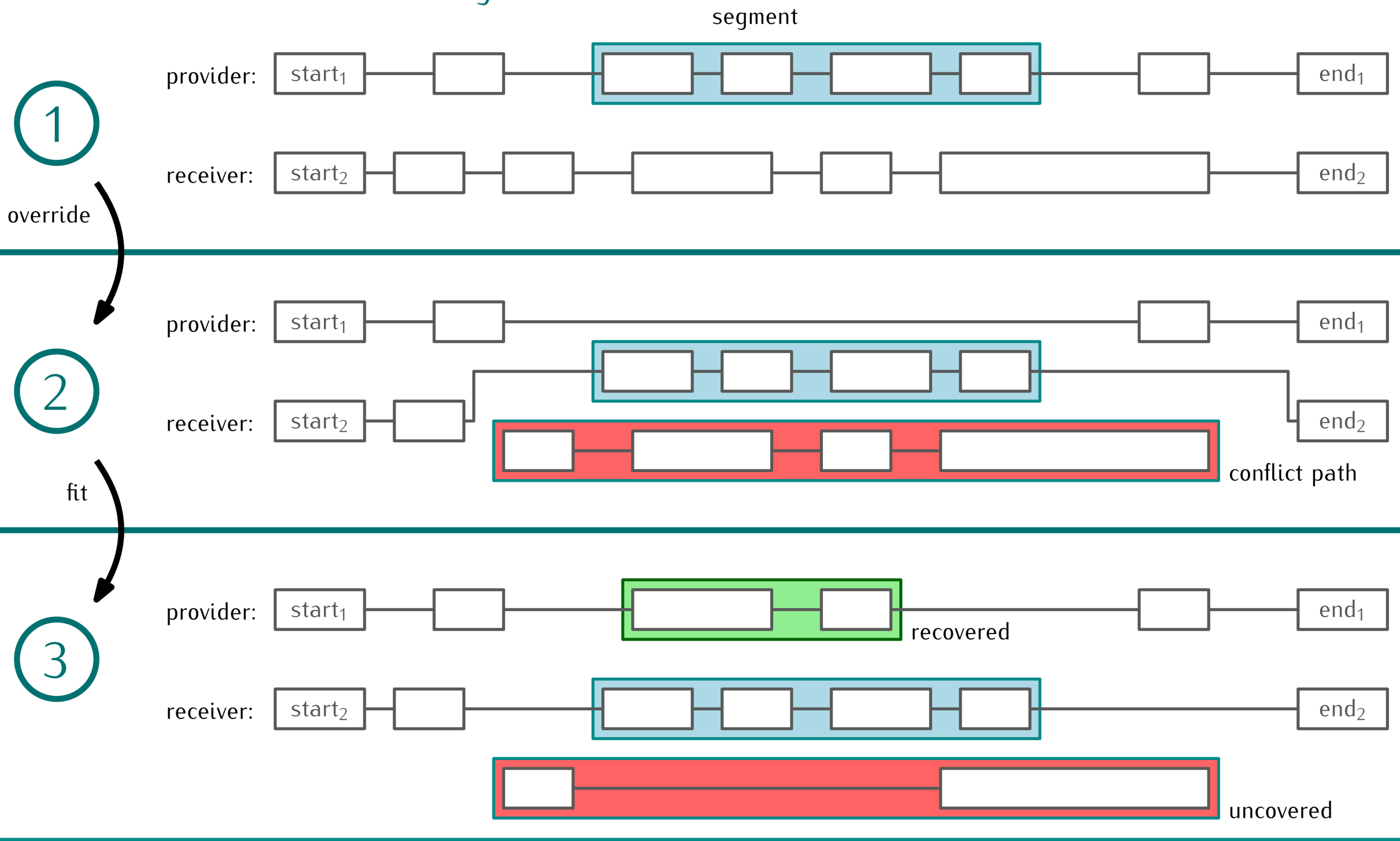
Local Search

point = schedule



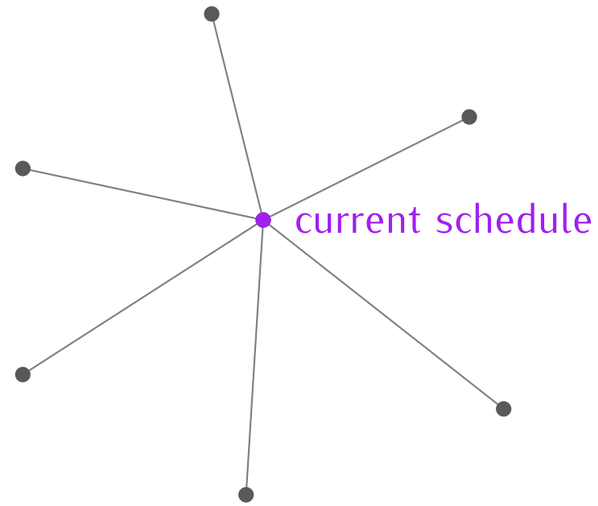


Local Modification: Path Exchange



Neighborhood

given the current schedule, consider the following modificaitons:



for each vehicle as **provider**:

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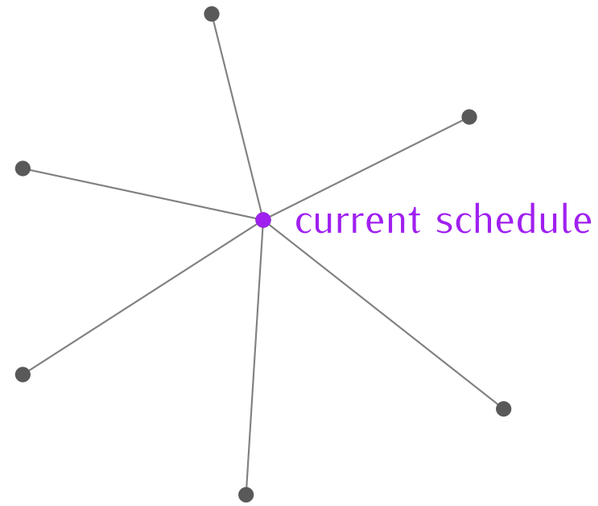

for each vehicle as **provider**:

dead-head trips slower than service trips

for each segment of provider's tour that can be removed

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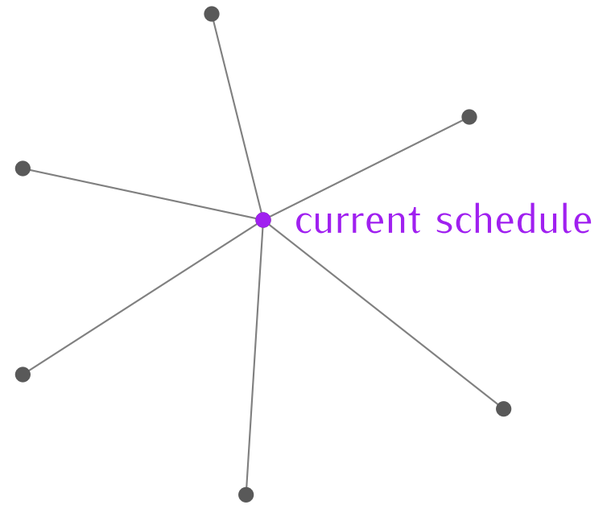

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for each vehicle of the same type (that is not the provider) as **receiver**:

(if segment is mainteance slot also different types are allwed)

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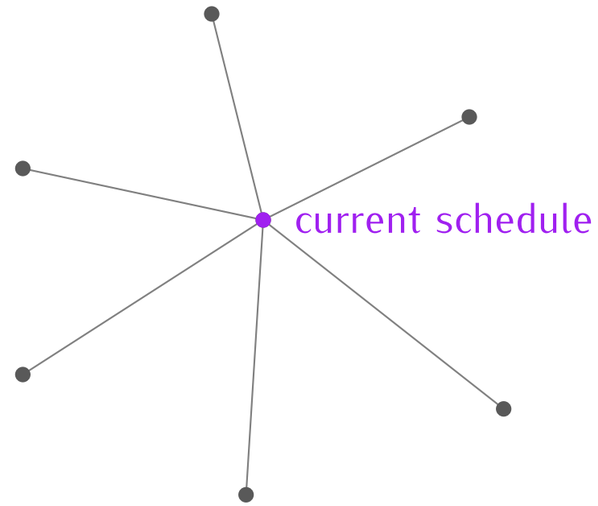

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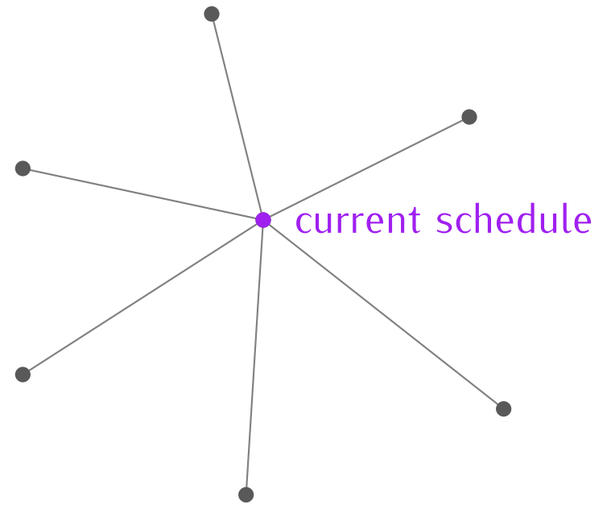
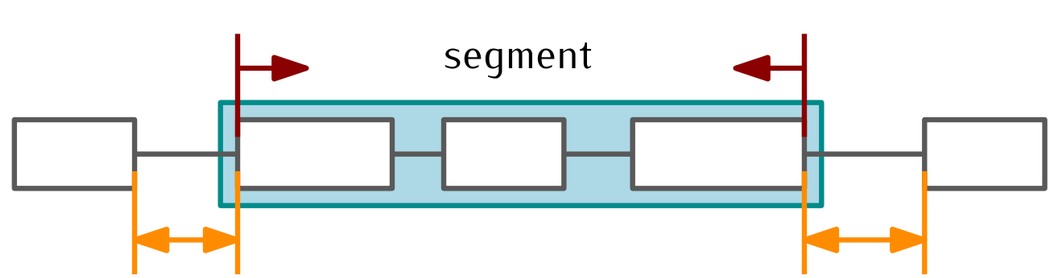


for each vehicle as **provider**:

dead-head trips slower than service trips

for each segment of provider's tour that can be removed

- restrict length: start of first node to end of last node
- restrict overhead time before and after



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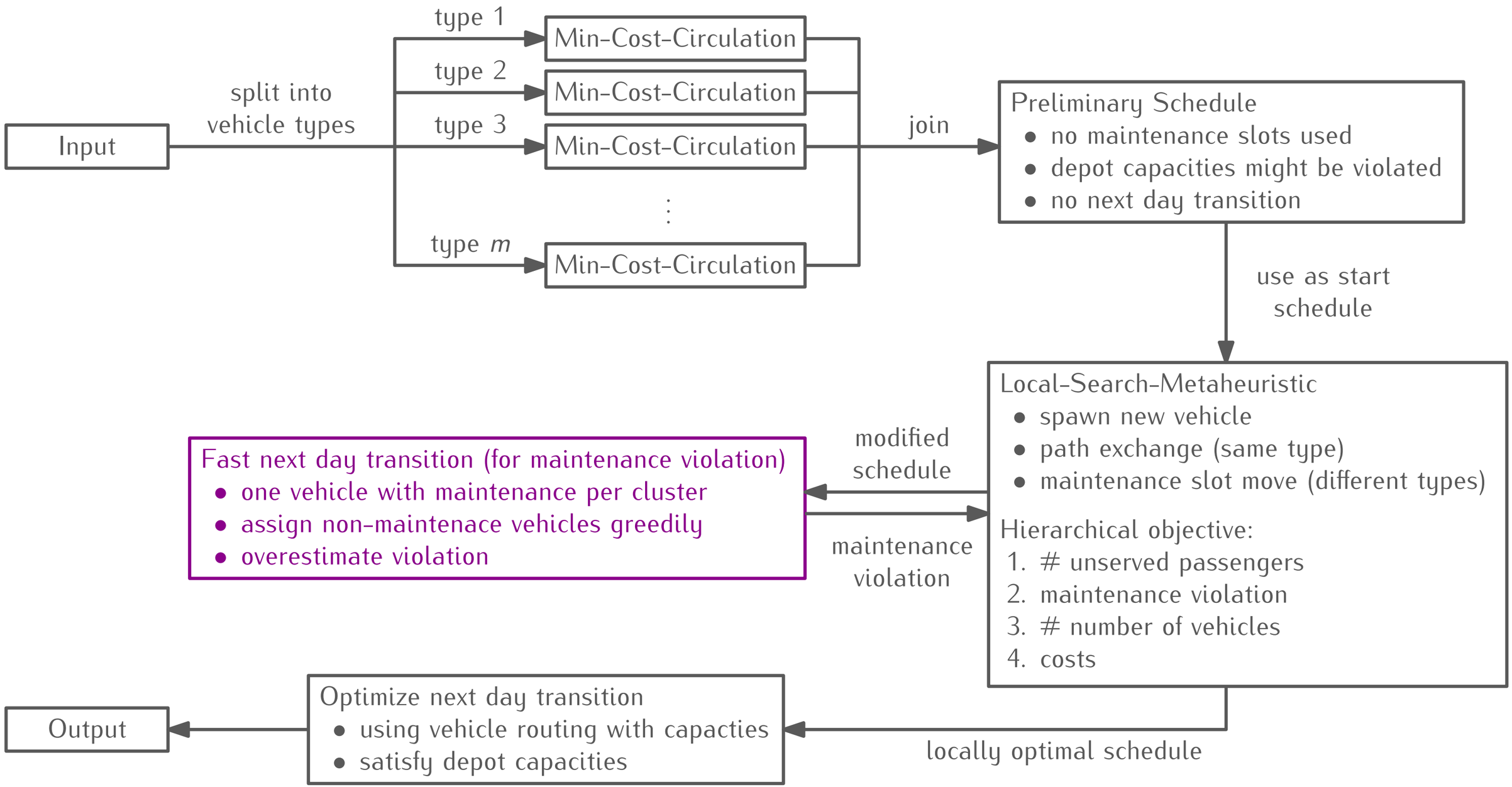
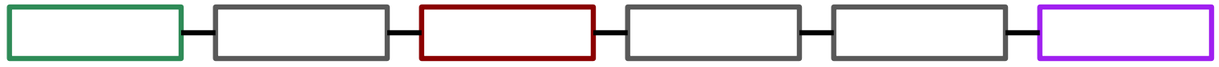
Phase 2 - Algorithm Overview



Next Day Transition (for maintenance regulations)

Vehicle	Schedule	Distance
A		5 000 km
B		7 000 km
C		2 000 km
D		5 000 km
E		3 000 km

Next Day Transition (for maintenance regulations)

maintenance all 15 000 km

Vehicle	Schedule	Distance		Maintenance Counter
A		5 000 km		= 5 000 km
B		7 000 km		= 7 000 km
C		2 000 km	- 15 000 km	= - 13 000 km
D		5 000 km		= 5 000 km
E		3 000 km	- 15 000 km	= - 12 000 km

Next Day Transition (for maintenance regulations)

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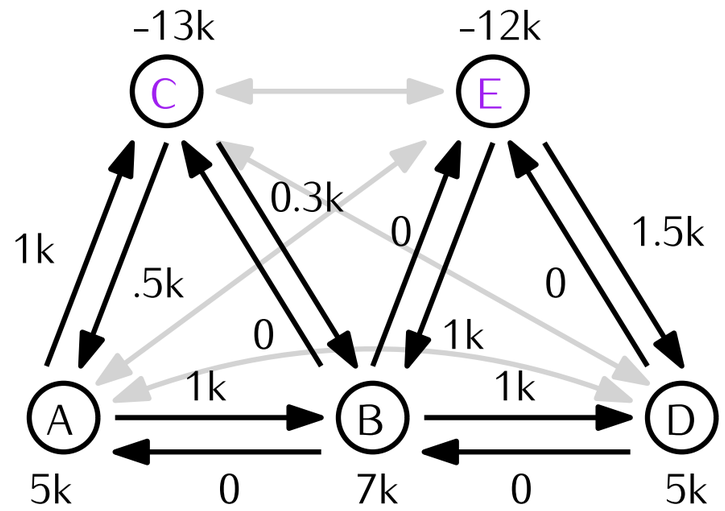
Model

- consider types individually
- fully connected directed graph
  - one node per vehicle labeled with maintenance counter
  - arcs (v_1, v_2) are labelled with dead-head-distance between end depot of v_1 to start depot of v_2



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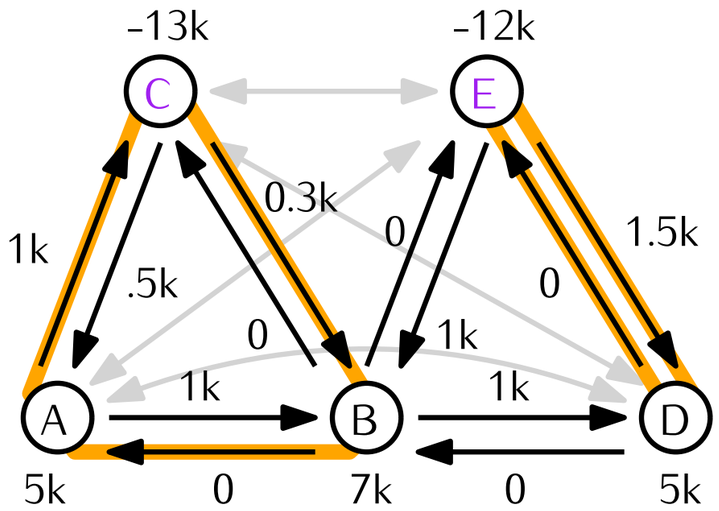
Next Day Transition

- a set of disjoint cycles
- all nodes are covered



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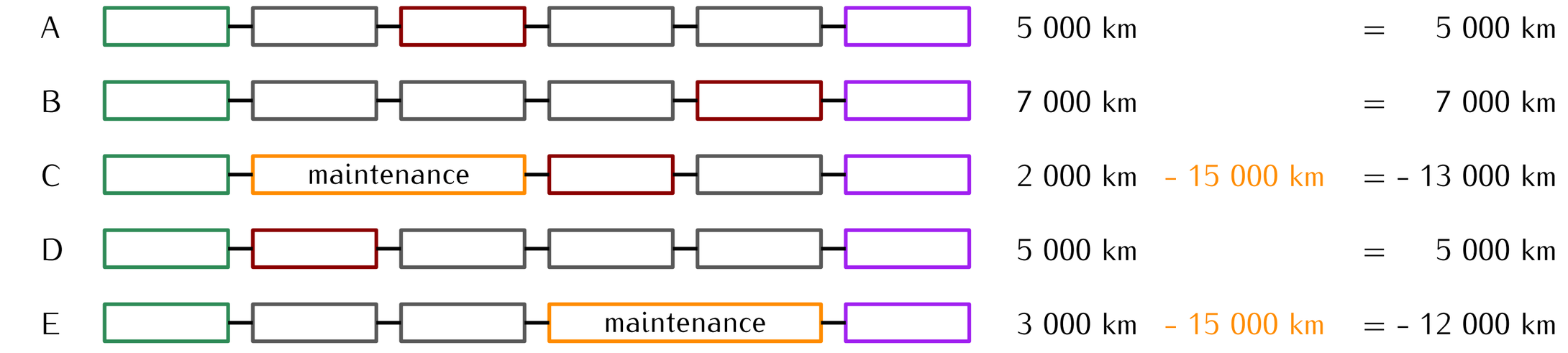

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Next Day Transition

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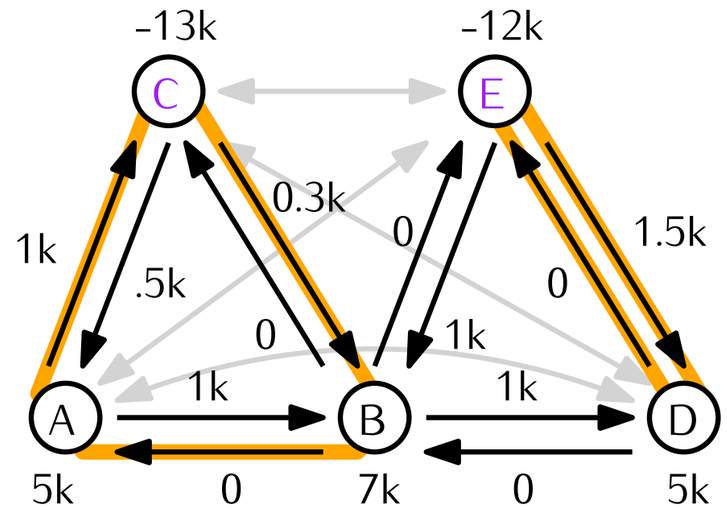
Objective:

- minimize maintenance violation: $\max_{C \in \mathcal{C}} (\max \{ d(C), 0 \})$

  where $d(C)$ = sum over all node and arc labels of cycle C



Fast next day transition

Algorithm

1. put all maintenance vehicles in a cycle (and sort them)
2. for each non-maintenance vehicle (in decreasing order):
   (a) put vehicle into the first fitting cycle (or the last if none are fitting)
   (b) resort cycles

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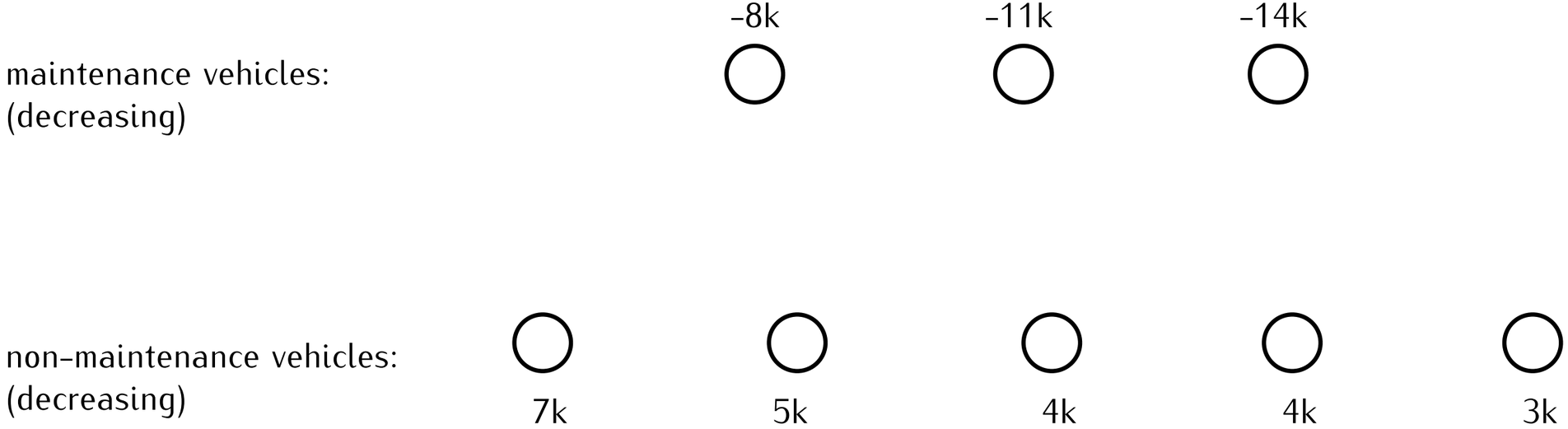

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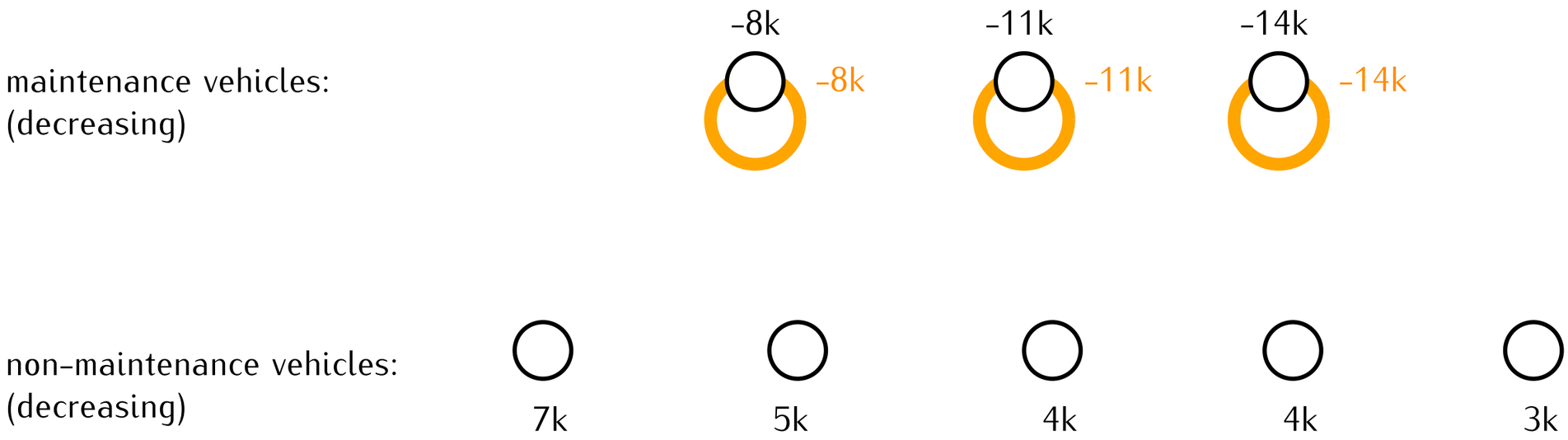

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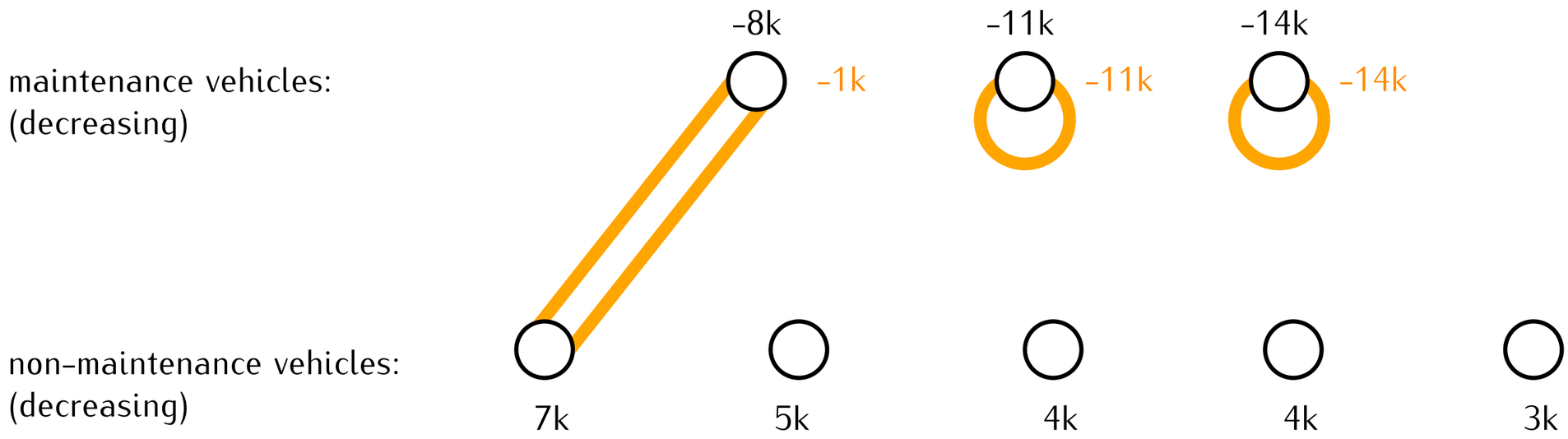

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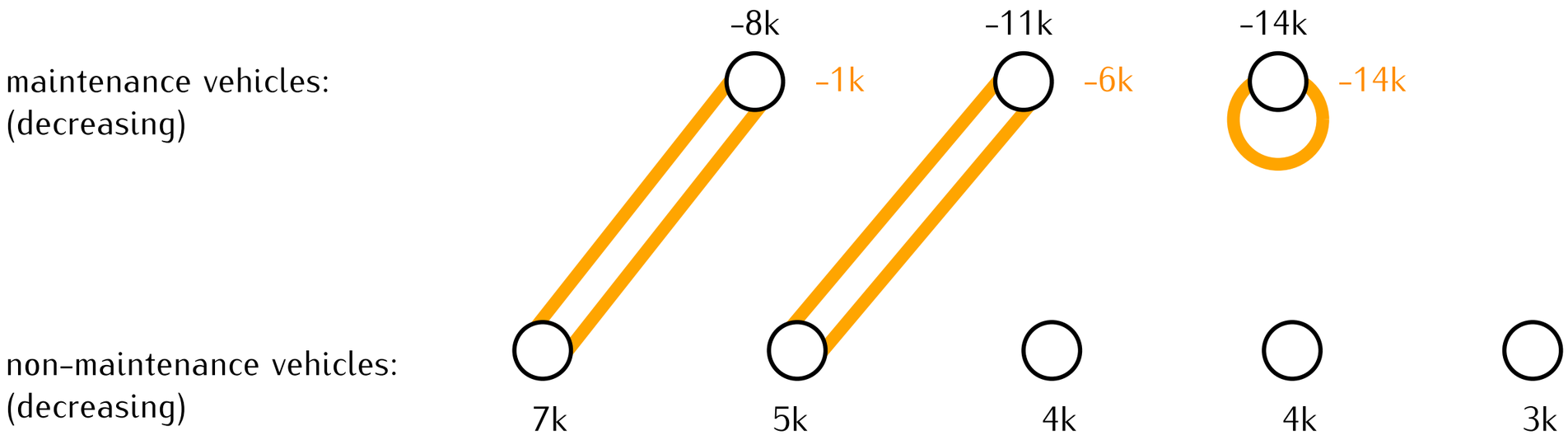

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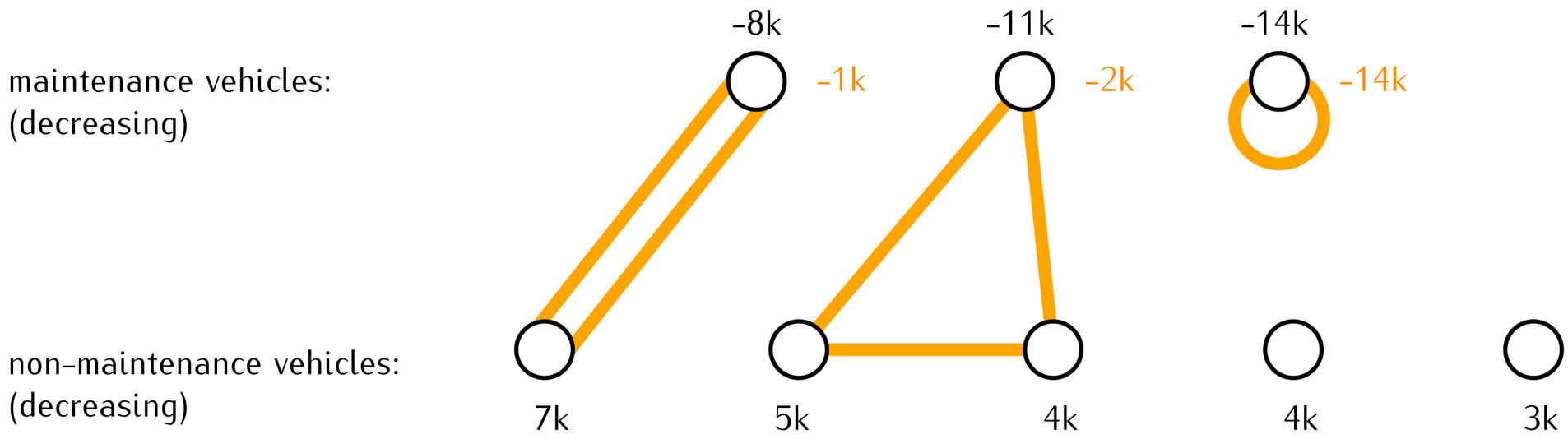

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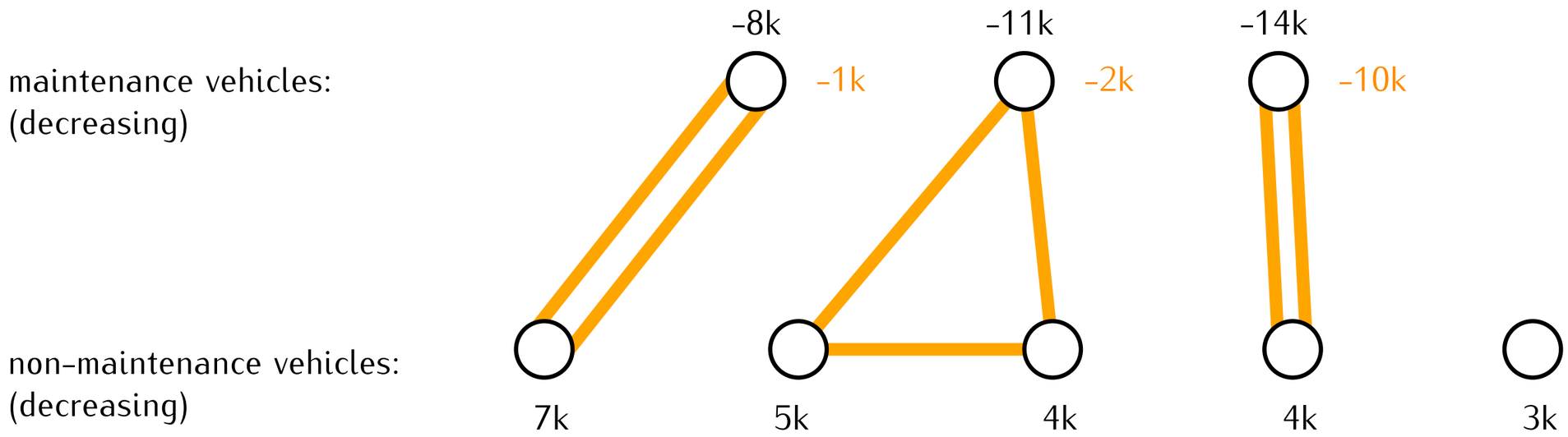

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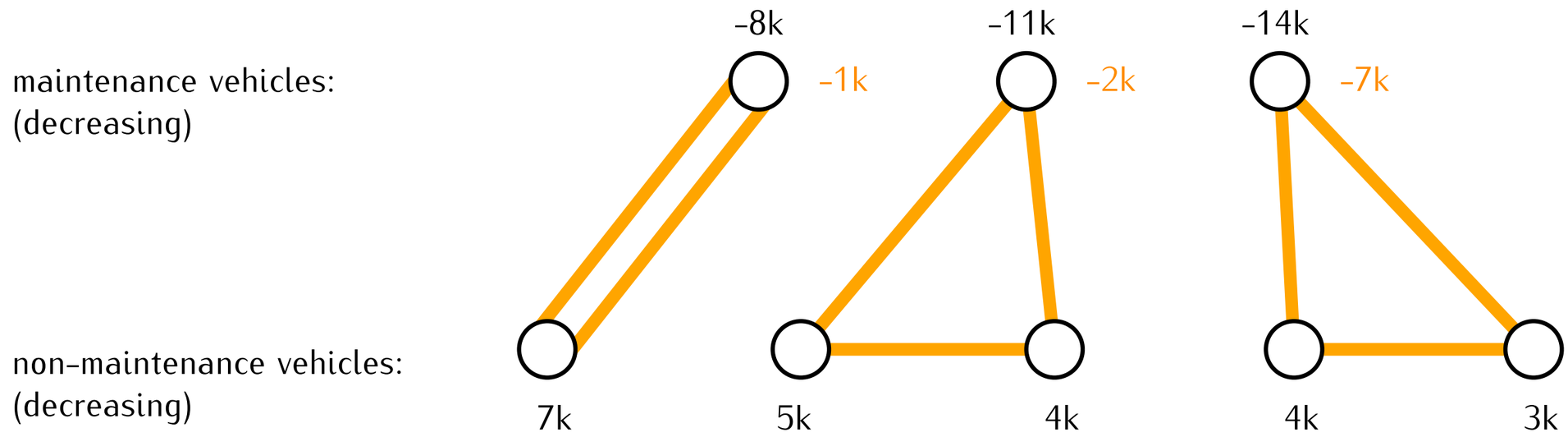

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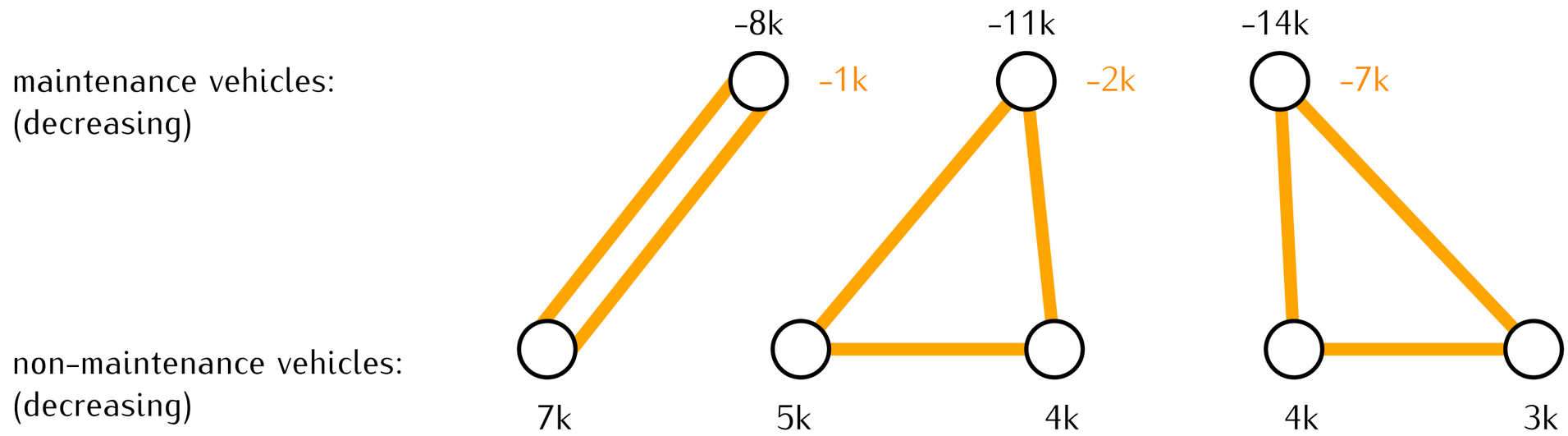
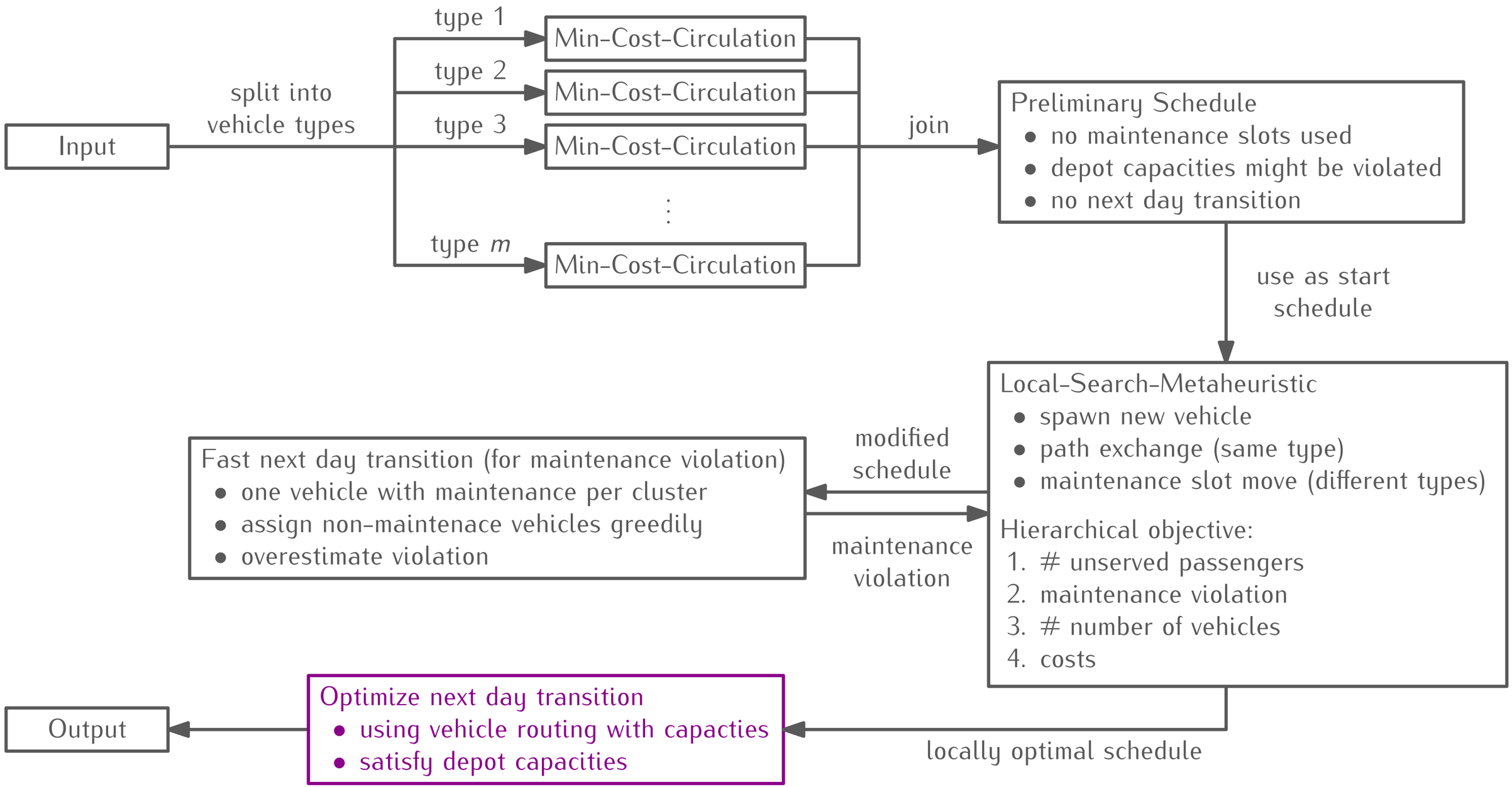


(dead-head trips between the depots are ignored for the slides)

Phase 2 - Algorithm Overview



Optimize Next Day Transition

Local Search (again):

- still: only one maintenance vehicle per cycle
- ignore dead-head-trips between depots
- store partition instead of cycles
- cycles are computed afterwards for each component

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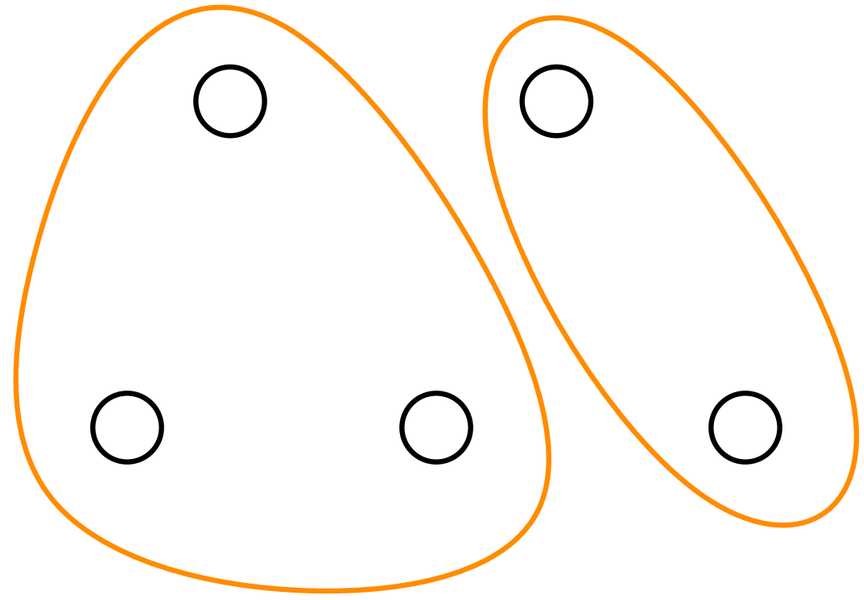
Partition Swap:



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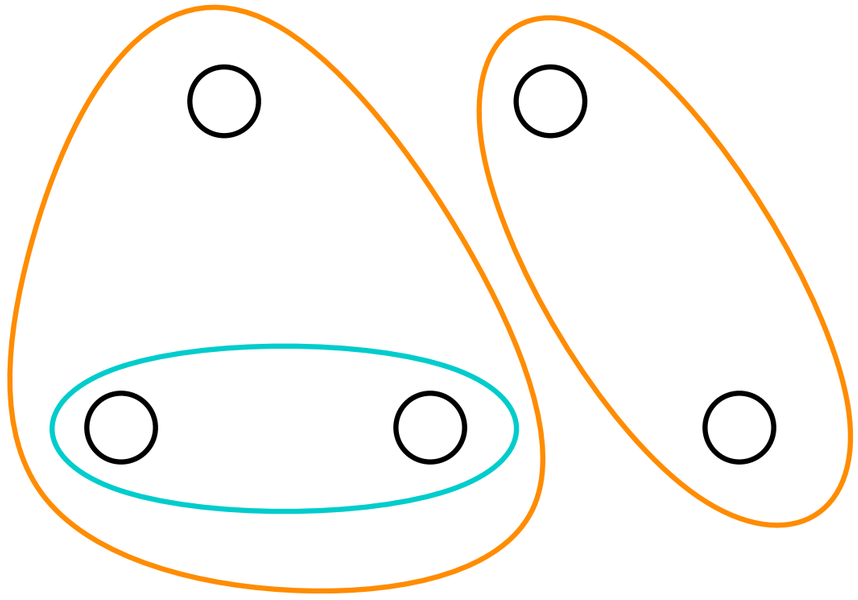
- cycles are computed afterwards for each component

Partition Swap:

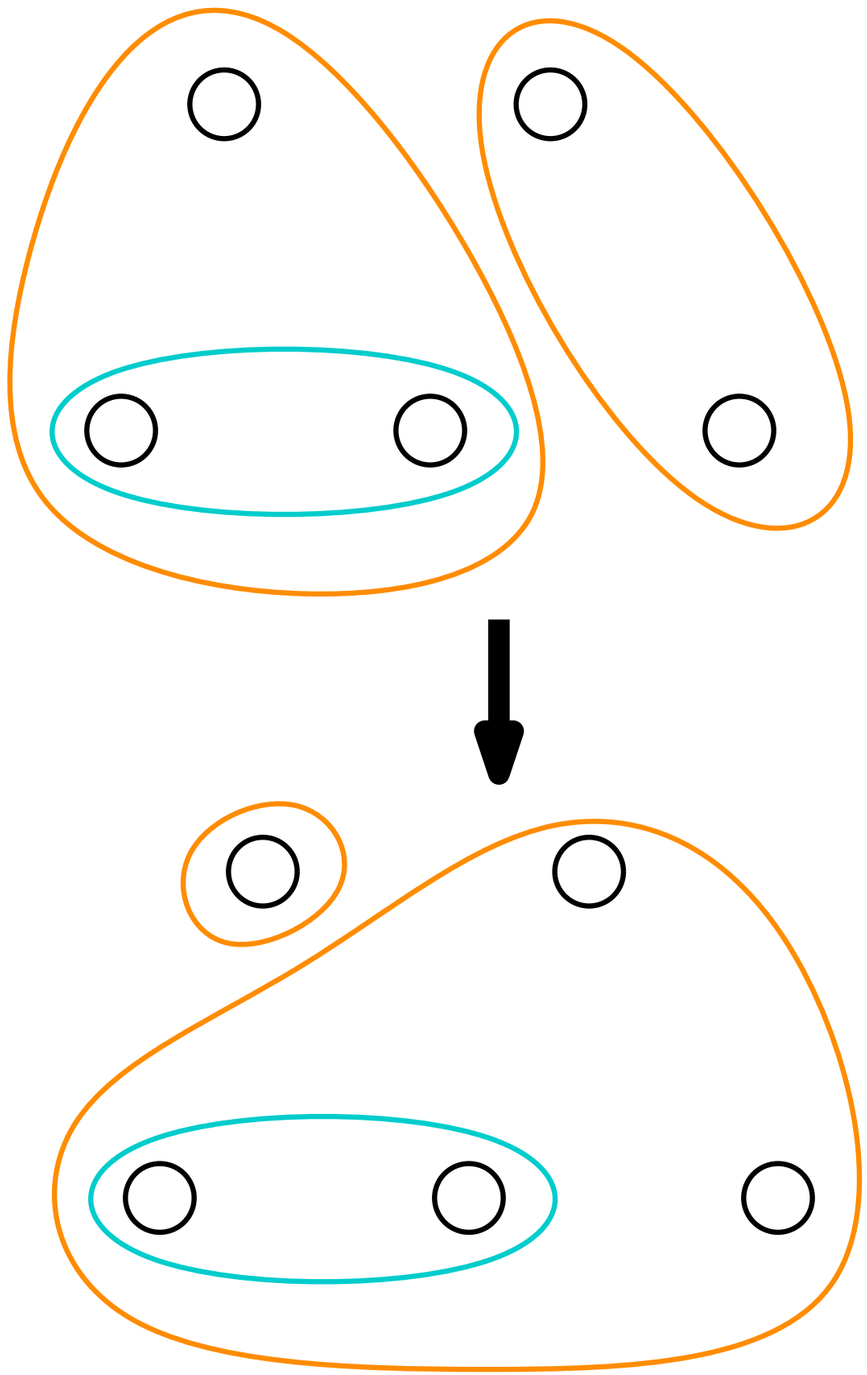


Optimize Next Day Transition

Local Search (again):

- still: only one maintenance vehicle per cycle
- ignore dead-head-trips between depots
- store partition instead of cycles
- cycles are computed afterwards for each component

Partition Swap:



Optimize Next Day Transition

Local Search (again):

- still: only one maintenance vehicle per cycle
- ignore dead-head-trips between depots
- store partition instead of cycles
- cycles are computed afterwards for each component

Neighborhood:

for each component as **provider**:

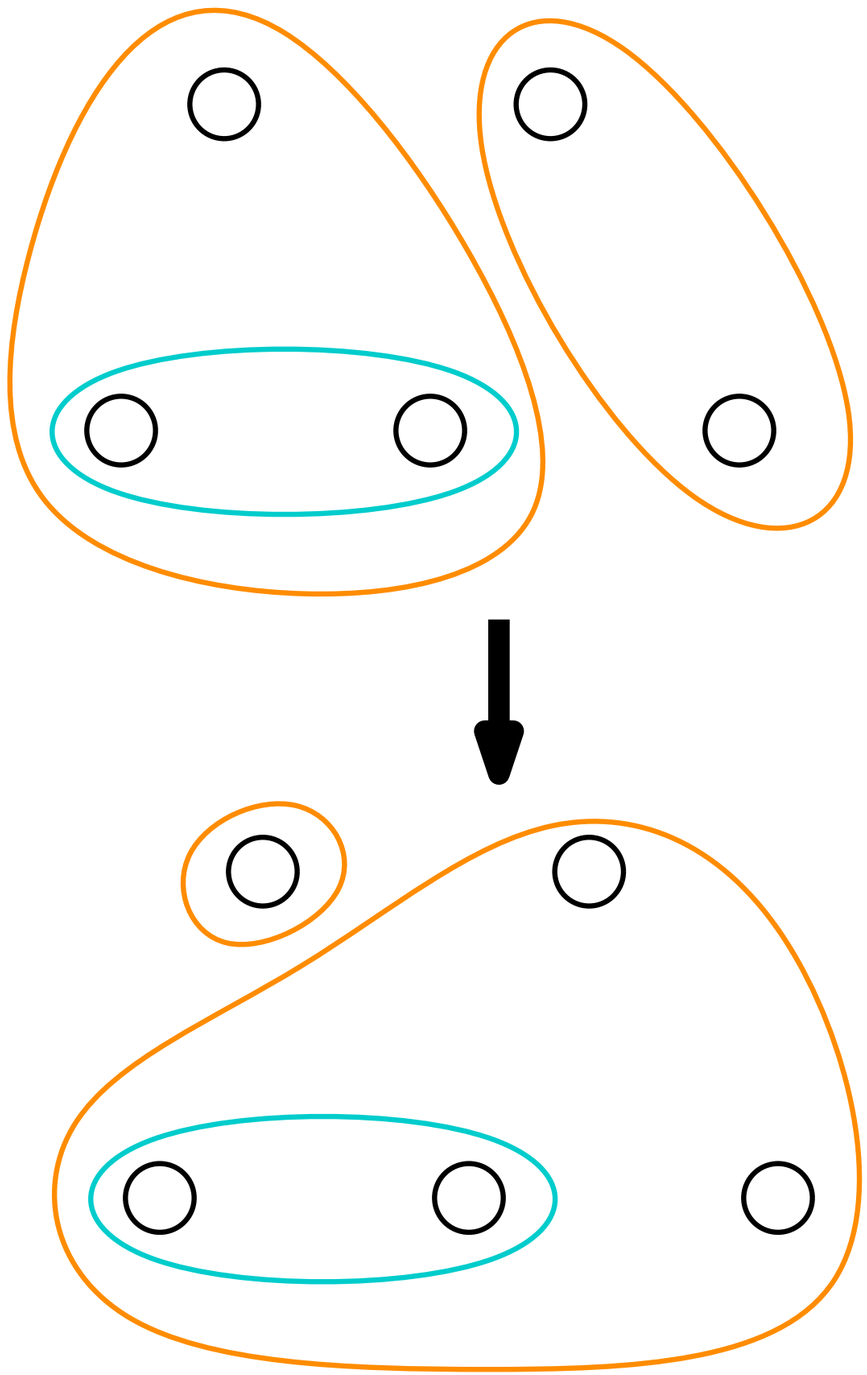
  for each other component as **receiver**:

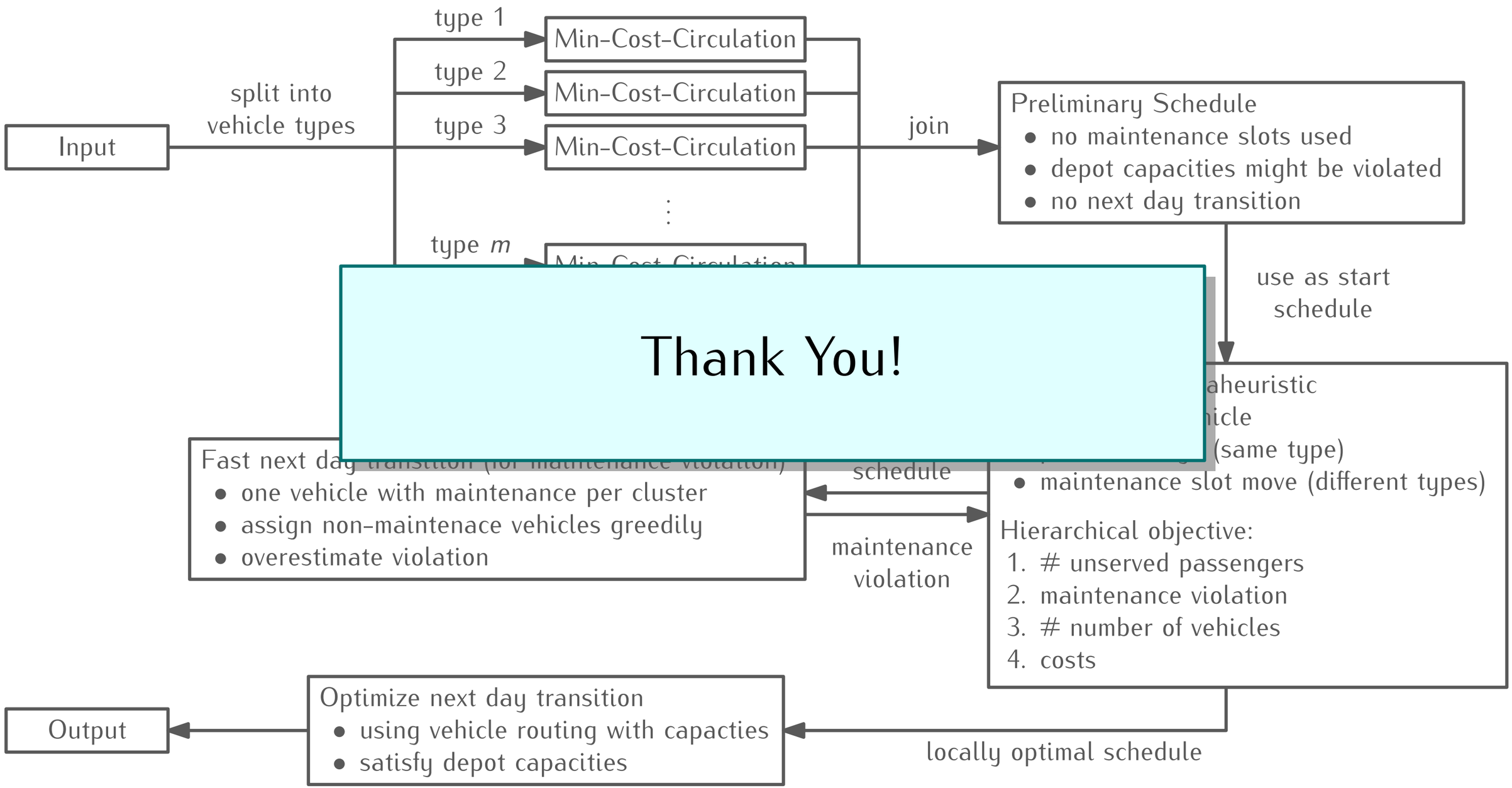
    for each subset of provier's vehicles

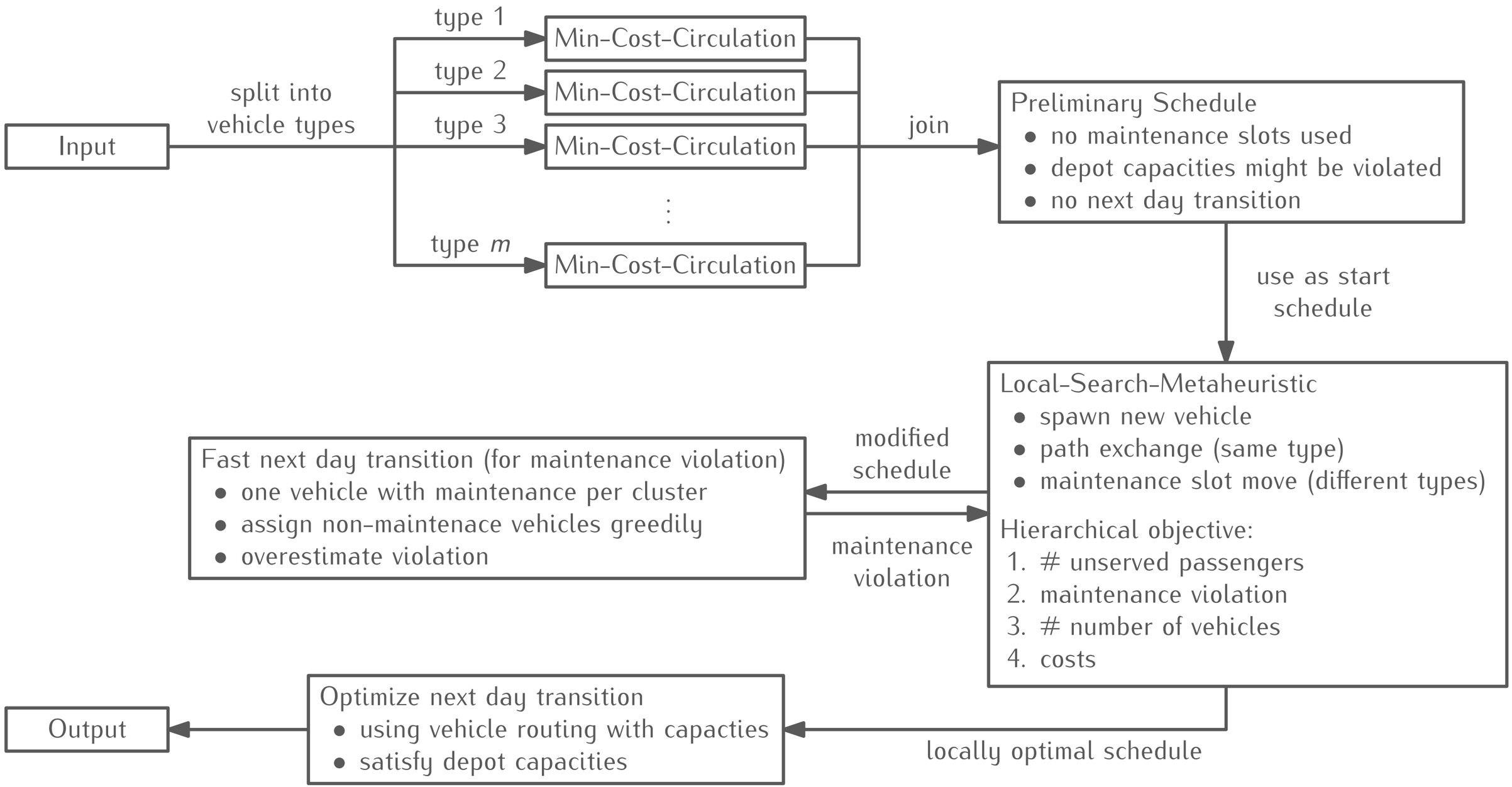
      PartitionSwap(subset, provider, receiver)

      recompute cycles for provider and receiver

Partition Swap:




Input
split into vehicle types
type 1
type 2
type 3
type m
Min-Cost-Circulation
Min-Cost-Circulation
Min-Cost-Circulation
join
Preliminary Schedule
• no maintenance slots used
• depot capacities might be violated
• no next day transition
use as start schedule
Thank You!
aheuristic
icle
(same type)
• maintenance slot move (different types)
Hierarchical objective:
1. # unserved passengers
2. maintenance violation
3. # number of vehicles
4. costs
schedule
maintenance violation
Fast next day transition (for maintenance violation)
• one vehicle with maintenance per cluster
• assign non-maintenace vehicles greedily
• overestimate violation
locally optimal schedule
Optimize next day transition
• using vehicle routing with capacties
• satisfy depot capacities
Output


Input
split into vehicle types
type 1
type 2
type 3
type m
Min-Cost-Circulation
Min-Cost-Circulation
Min-Cost-Circulation
Min-Cost-Circulation
join
Preliminary Schedule
• no maintenance slots used
• depot capacities might be violated
• no next day transition
use as start schedule
Local-Search-Metaheuristic
• spawn new vehicle
• path exchange (same type)
• maintenance slot move (different types)
Hierarchical objective:
1. # unserved passengers
2. maintenance violation
3. # number of vehicles
4. costs
modified schedule
maintenance violation
Fast next day transition (for maintenance violation)
• one vehicle with maintenance per cluster
• assign non-maintenace vehicles greedily
• overestimate violation
locally optimal schedule
Optimize next day transition
• using vehicle routing with capacties
• satisfy depot capacities
Output