Optimization Software

Introduction to Rich Vehicle Routing Problem Solvers

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Course organisation

- Labs in CREMI : 5×4 hours $+$ 2×2 hours
- 1 lab (today) : Introduction
- 2 labs (in October) : Presentation of two solvers (OR-Tools and LocalSolver)
- 3 labs (in November-December) : Working on your projects
- 1 lab (8 December) : You present your results
- Evaluation : 100% for the project
- Course web-page :

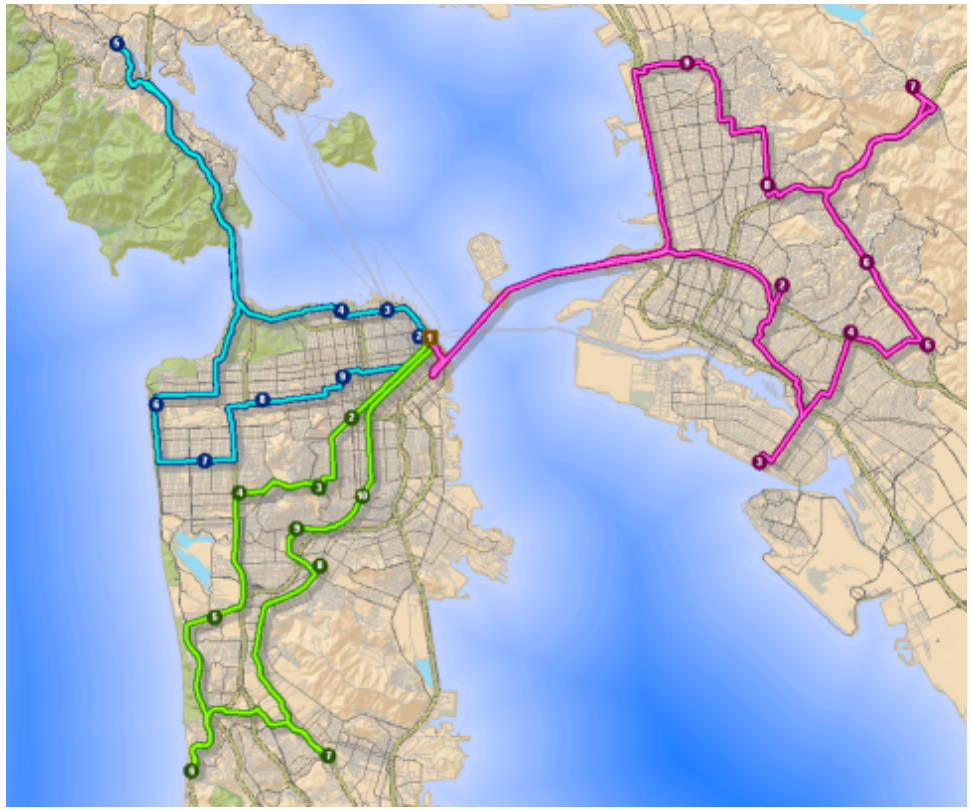
www.math.u-bordeaux.fr/~sadykov/teaching/vrp/

Contents

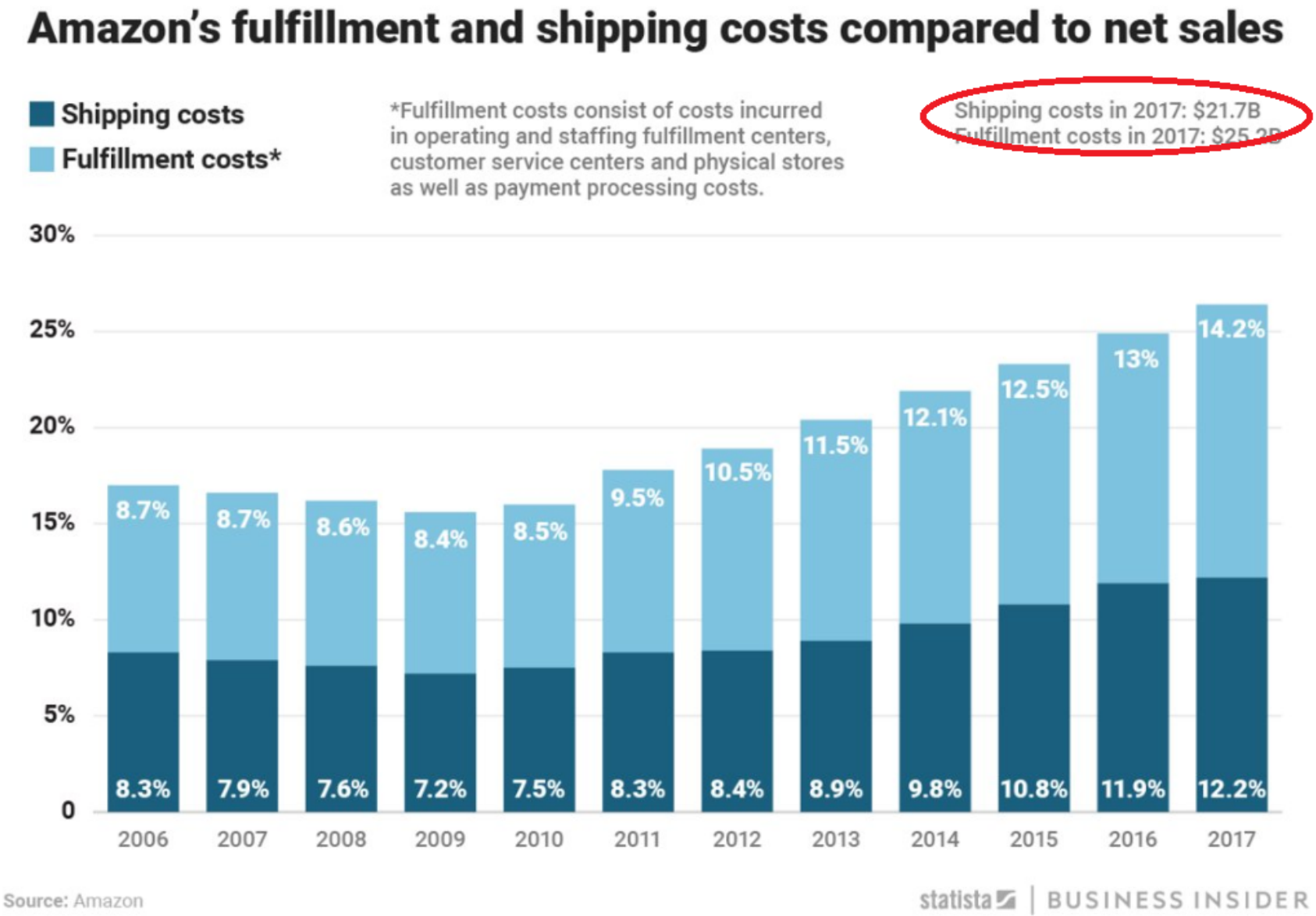
Vehicle Routing Problem (VRP)

One of the most widely studied in Combinatorial Optimization :

- +6,000 works published only in 2019 (Google Scholar), mostly heuristics
- Direct application in the real systems that distribute goods and provide services



Shipping costs (depot–customer) in Amazon



Update: shipping costs in 2019: $37.9B (12.5% of net sales)

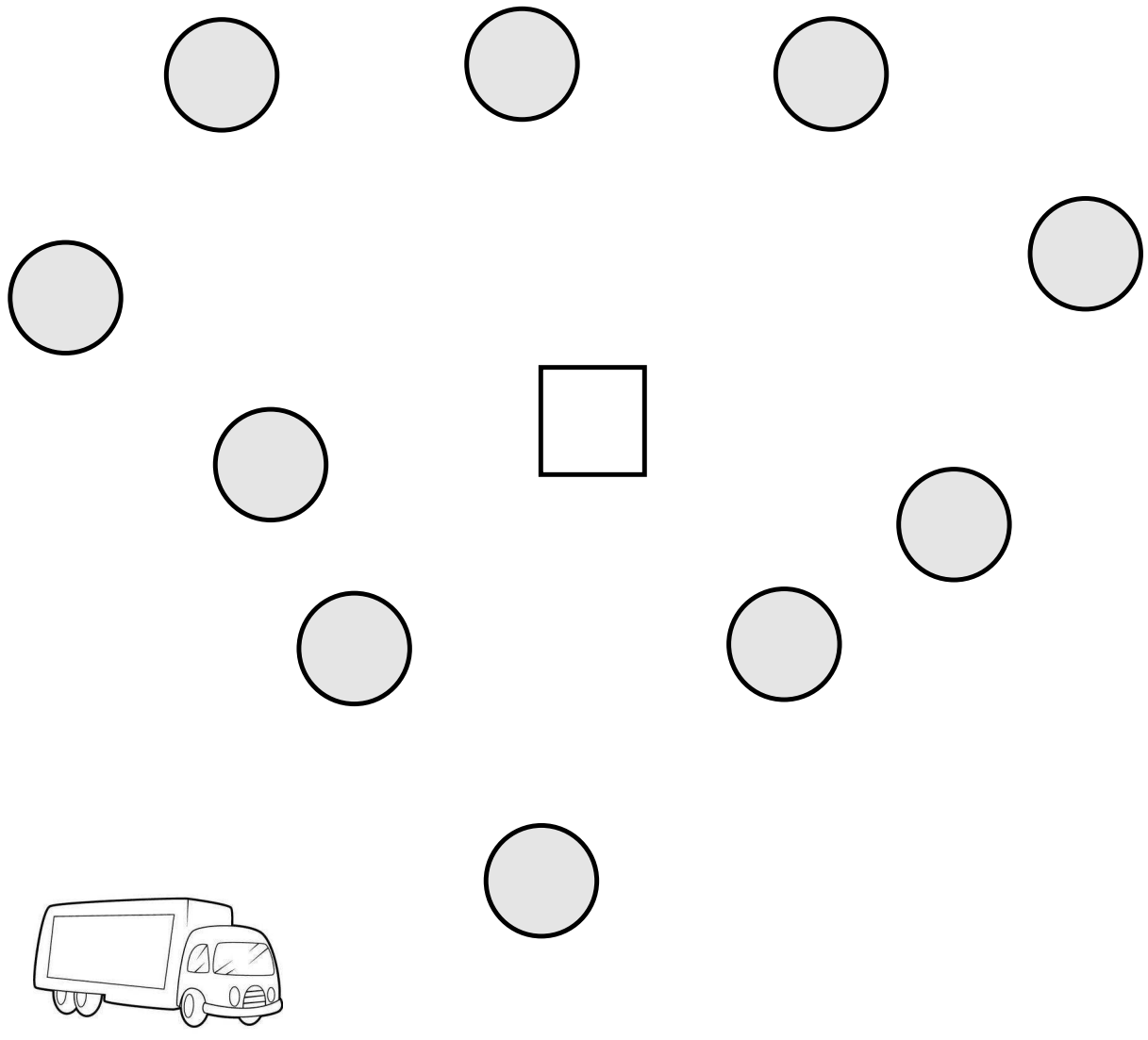
Vehicle Routing Problem (VRP)

Reflecting the variety of real transportation systems, VRP literature is spread into hundreds of variants. For example, there are variants that consider :

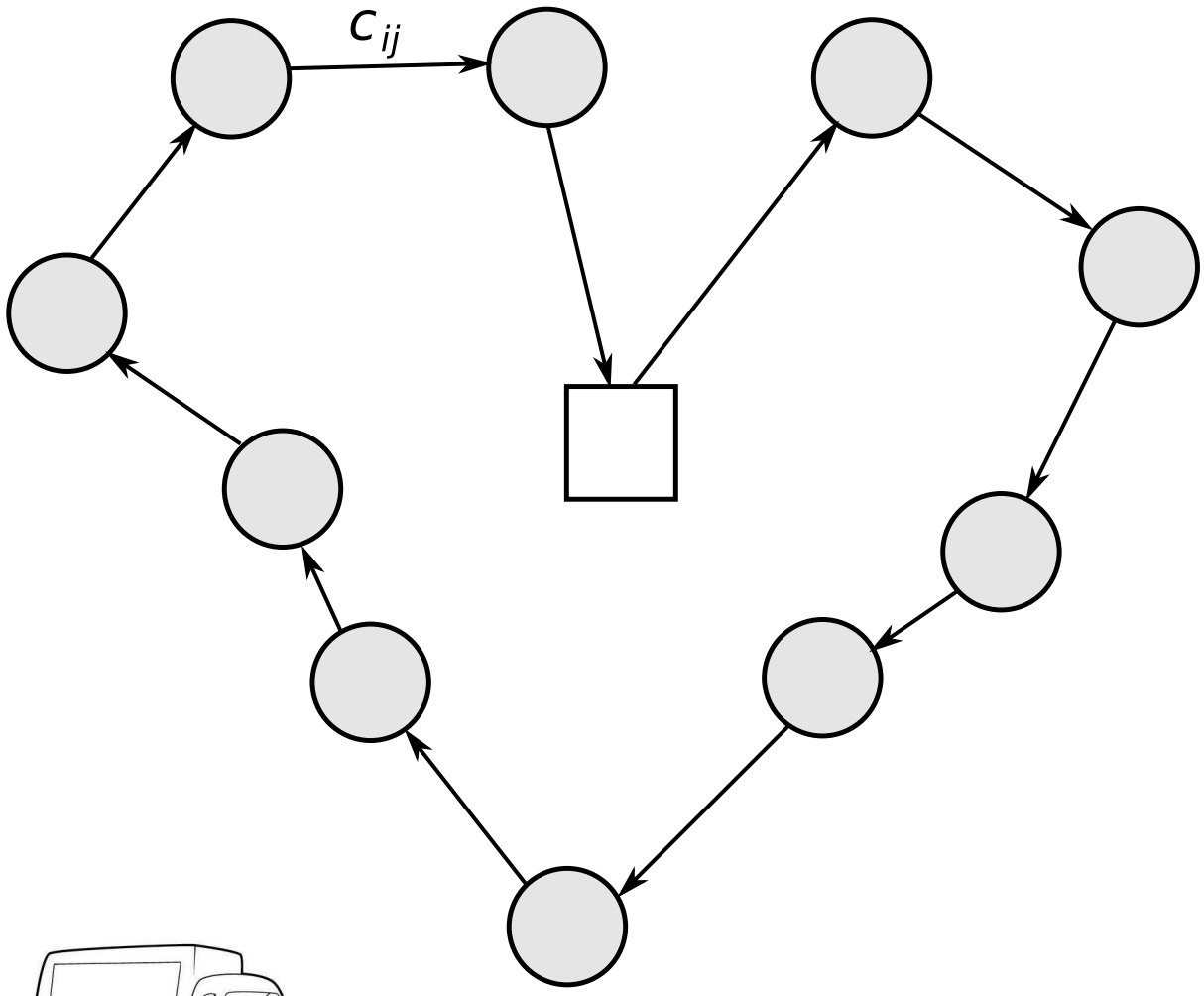
- Vehicle capacities,
- Time windows,
- Heterogeneous fleets,
- Multiple depots, periods, echelons,
- Split delivery, pickup and delivery, backhauling,
- Arc routing (Ex : garbage collection),
- Electric vehicle routing, drone routing,
- etc, etc.

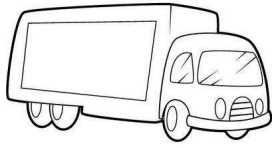
"Rich VRPs" combine several variants.

Traveling Salesman Problem (TSP) (I)



Traveling Salesman Problem (TSP) (I)

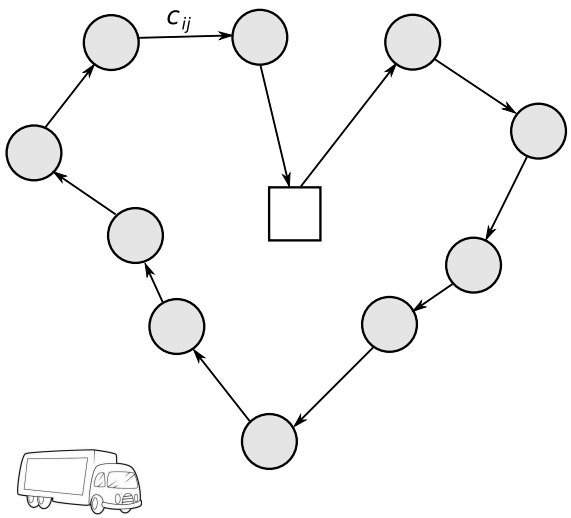




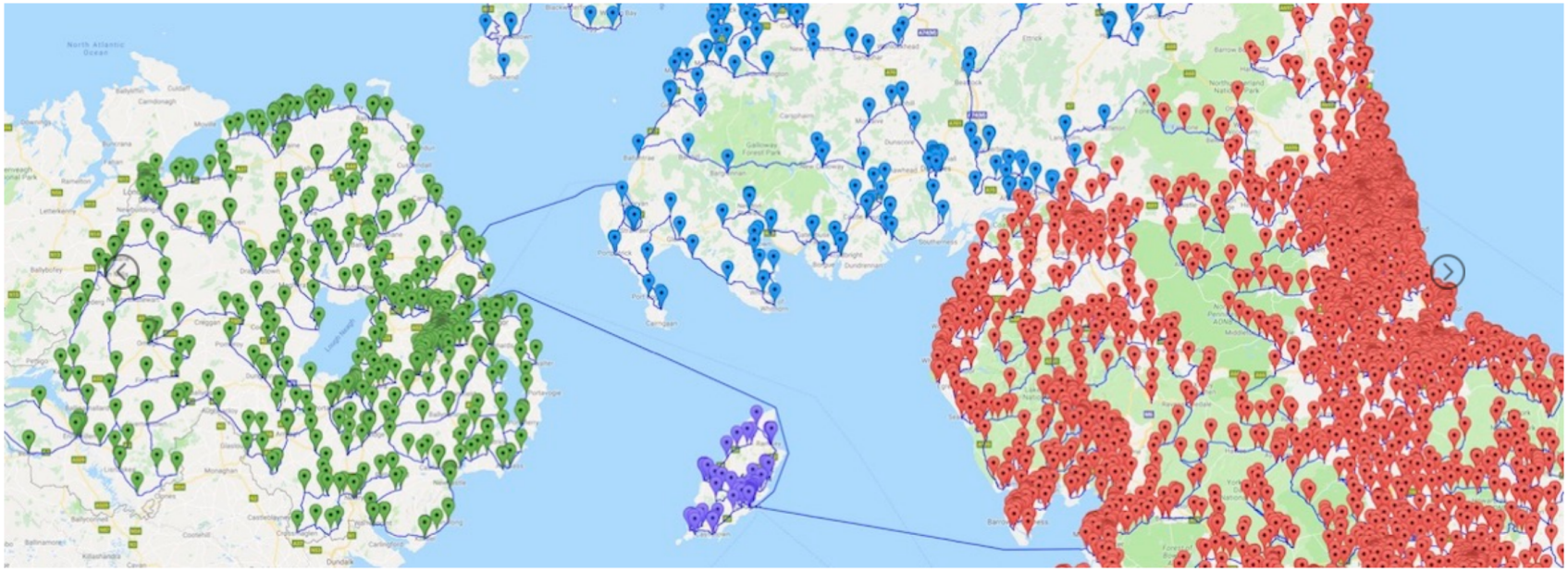
Traveling Salesman Problem (TSP) (II)

Simplest routing problem : single vehicle, no constraints to the route

- TSP model applies only to simple and small delivery systems



Traveling Salesman Problem (TSP) (III)



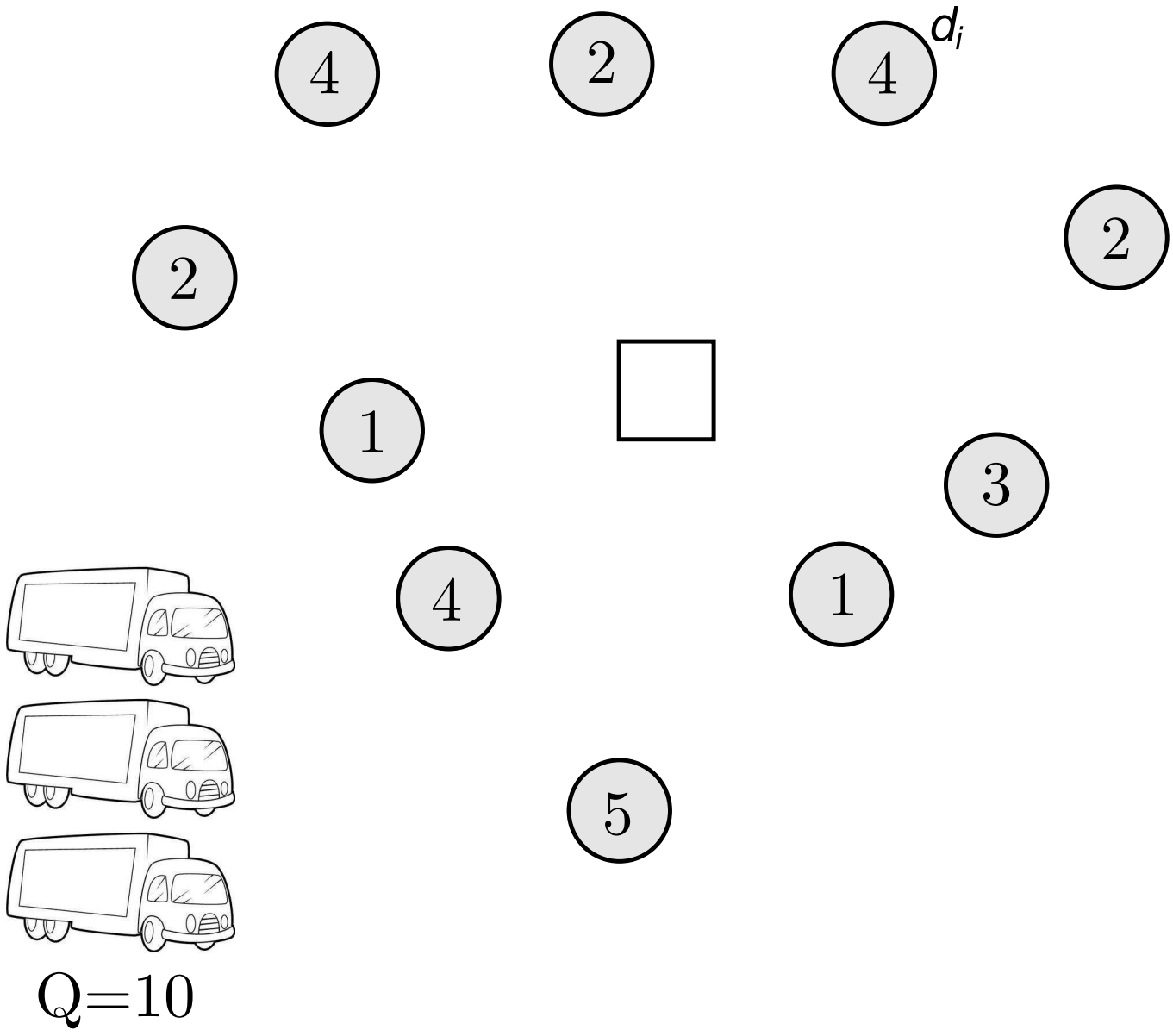
The smallest walk visiting 49.687 pubs in Great Britain is 63.739.687 meters.

Solution time : 250 years (14 months wall clock time)

Finding optimal solutions with 100 points takes on average 0.22 secondes

Source : http ://www.math.uwaterloo.ca/tsp/uk

Capacitated Vehicle Routing Problem (CVRP)



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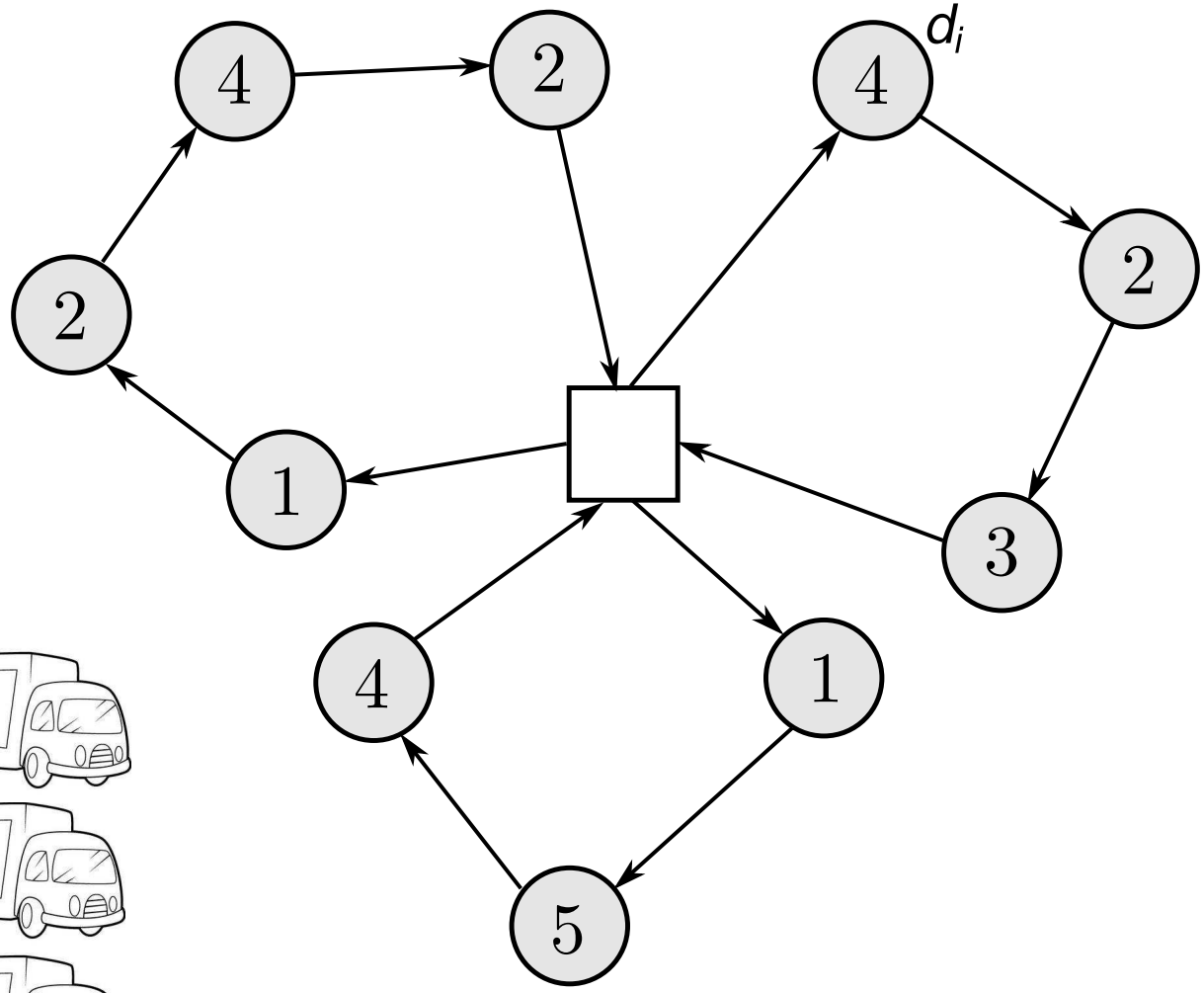
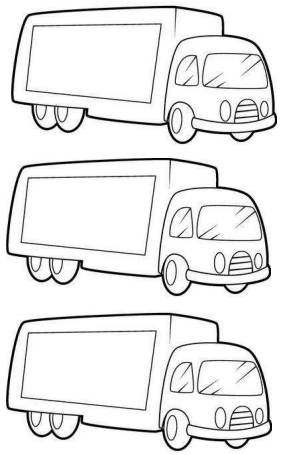




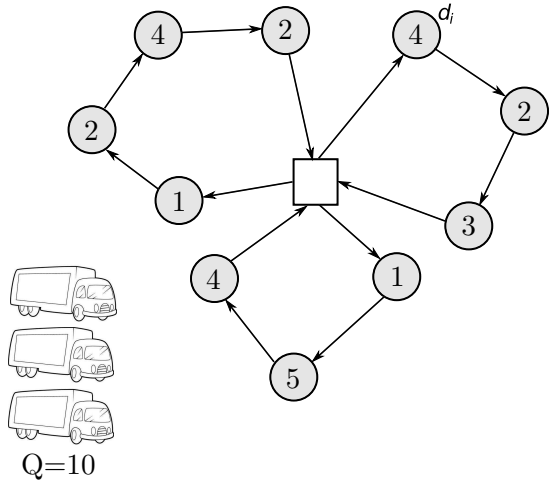
Q=10

Capacitated Vehicle Routing Problem (CVRP)

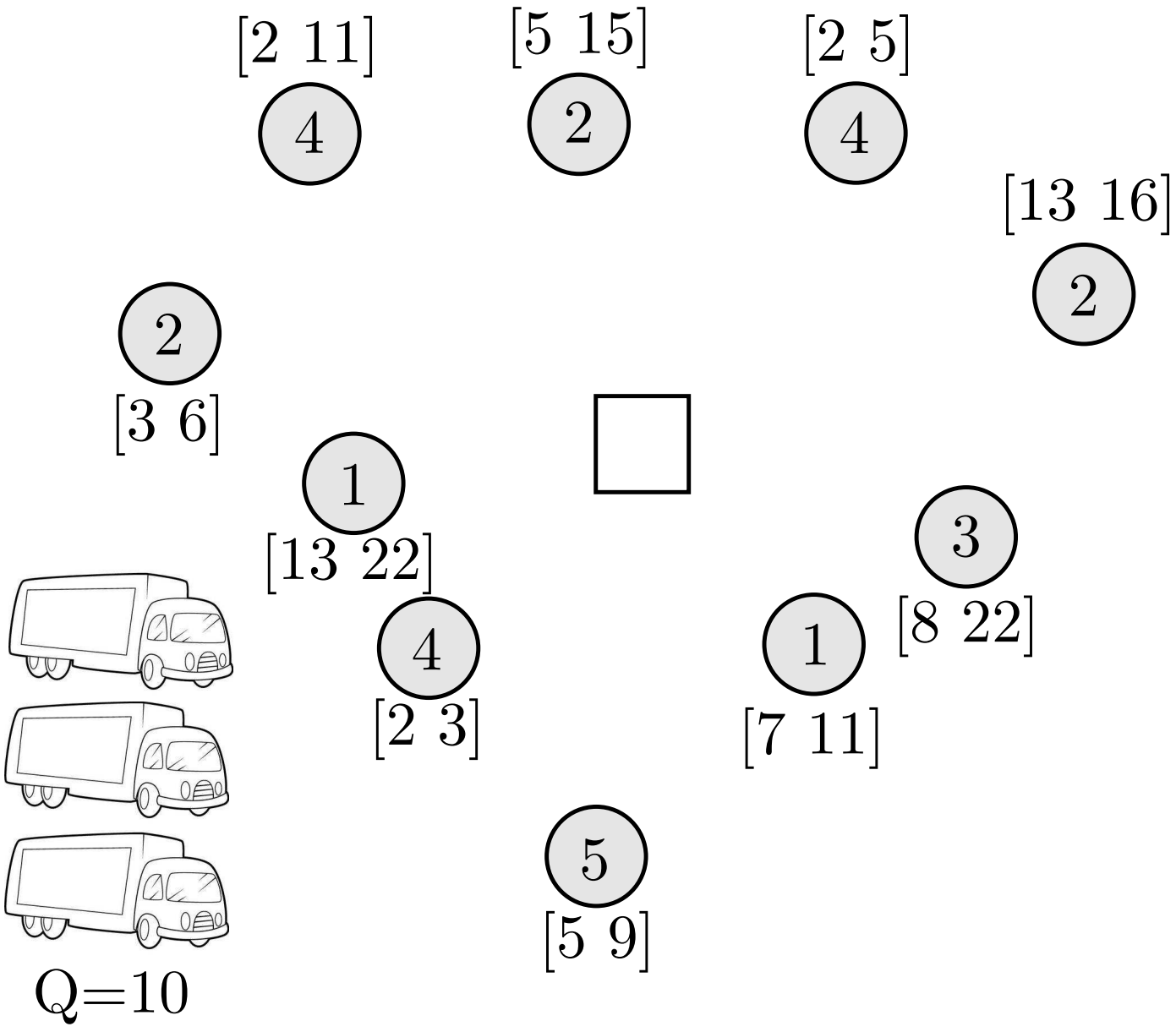
Introduced in 1959

Instance : $n + 1$ points (depot + n customers), cost c_{ij} for traveling from i to j, customer demands d_i, K identical vehicle with capacity Q.

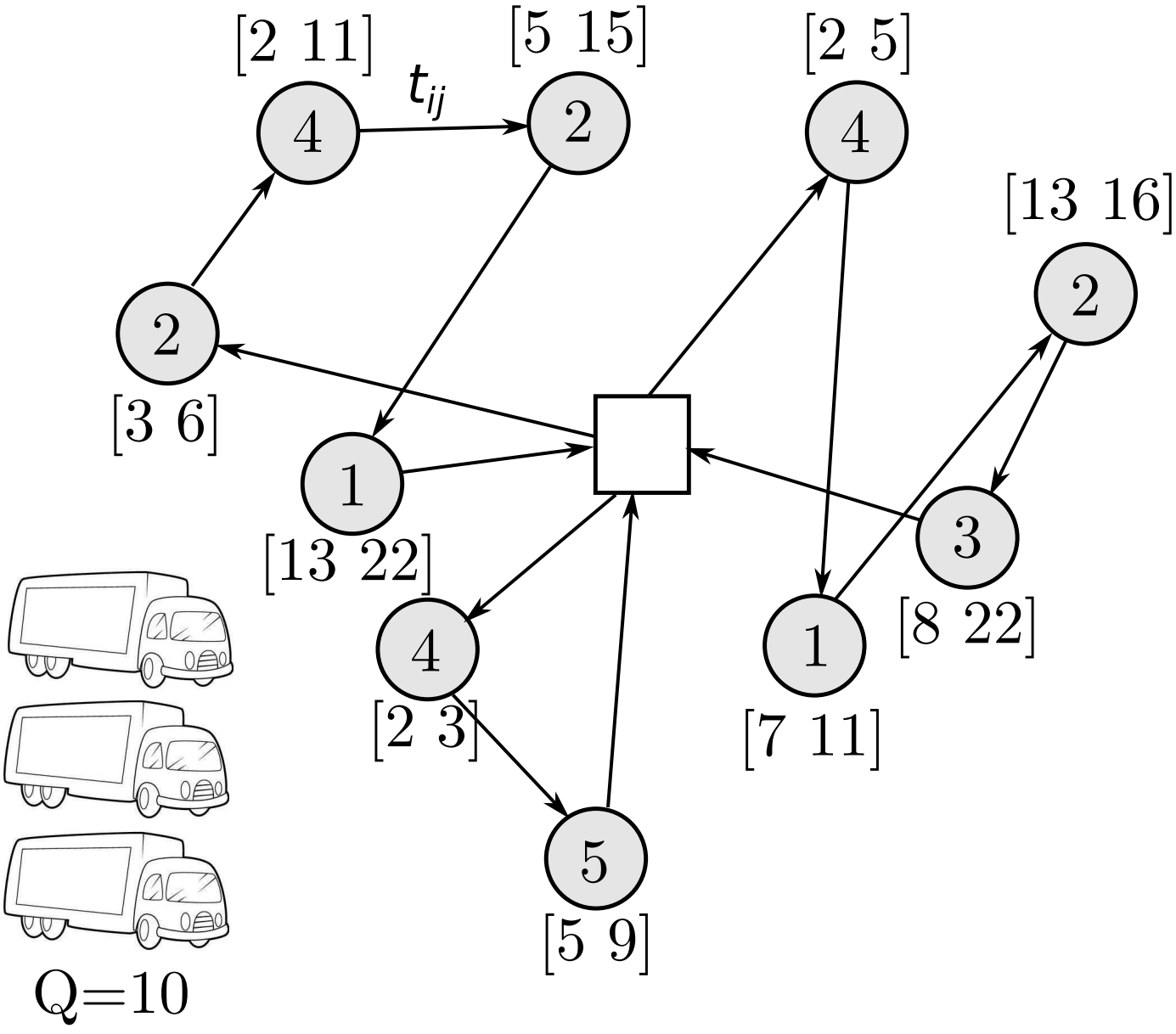
Solution : K routes starting and ending at the depot, visiting all customers, respecting the vehicle capacities and minimizing total cost.



VRP with Time Windows (VRPTW)



VRP with Time Windows (VRPTW)



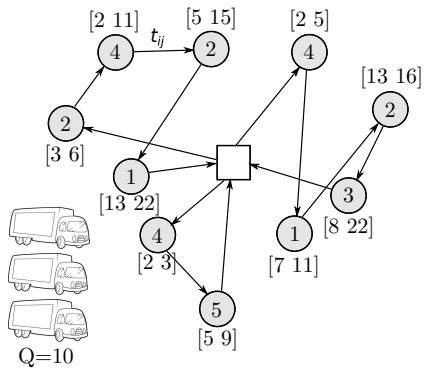
VRP with Time Windows (VRPTW)

Introduces a time dimension :

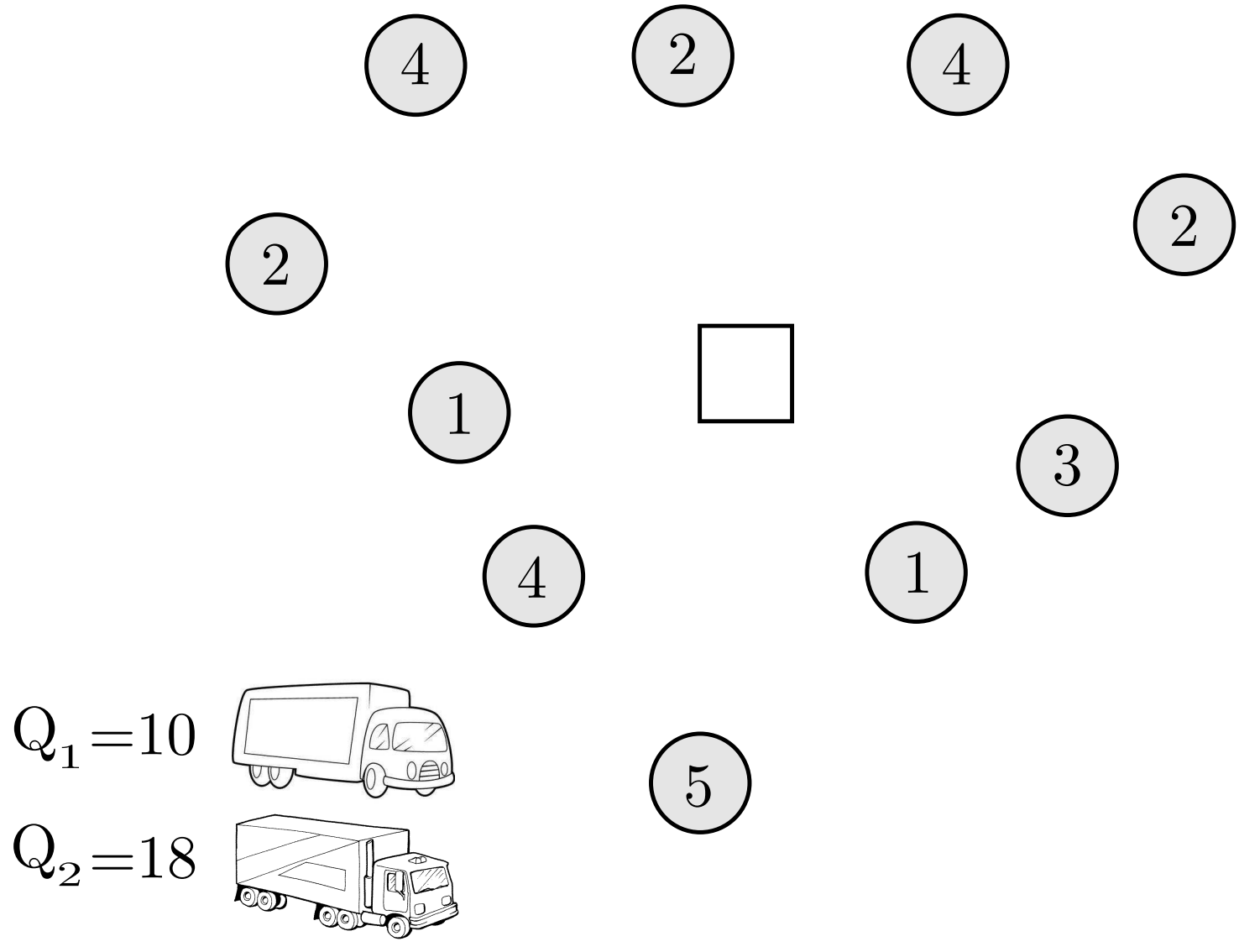
Instance : CVRP data + traveling times t_{ij} between points i and j, visiting time s_i and time windows $[a_i, b_i]$ at each customer.

Solution : K routes starting and ending at the depot, visiting all customers **within the time windows**, respecting the vehicle capacities and minimizing total cost.

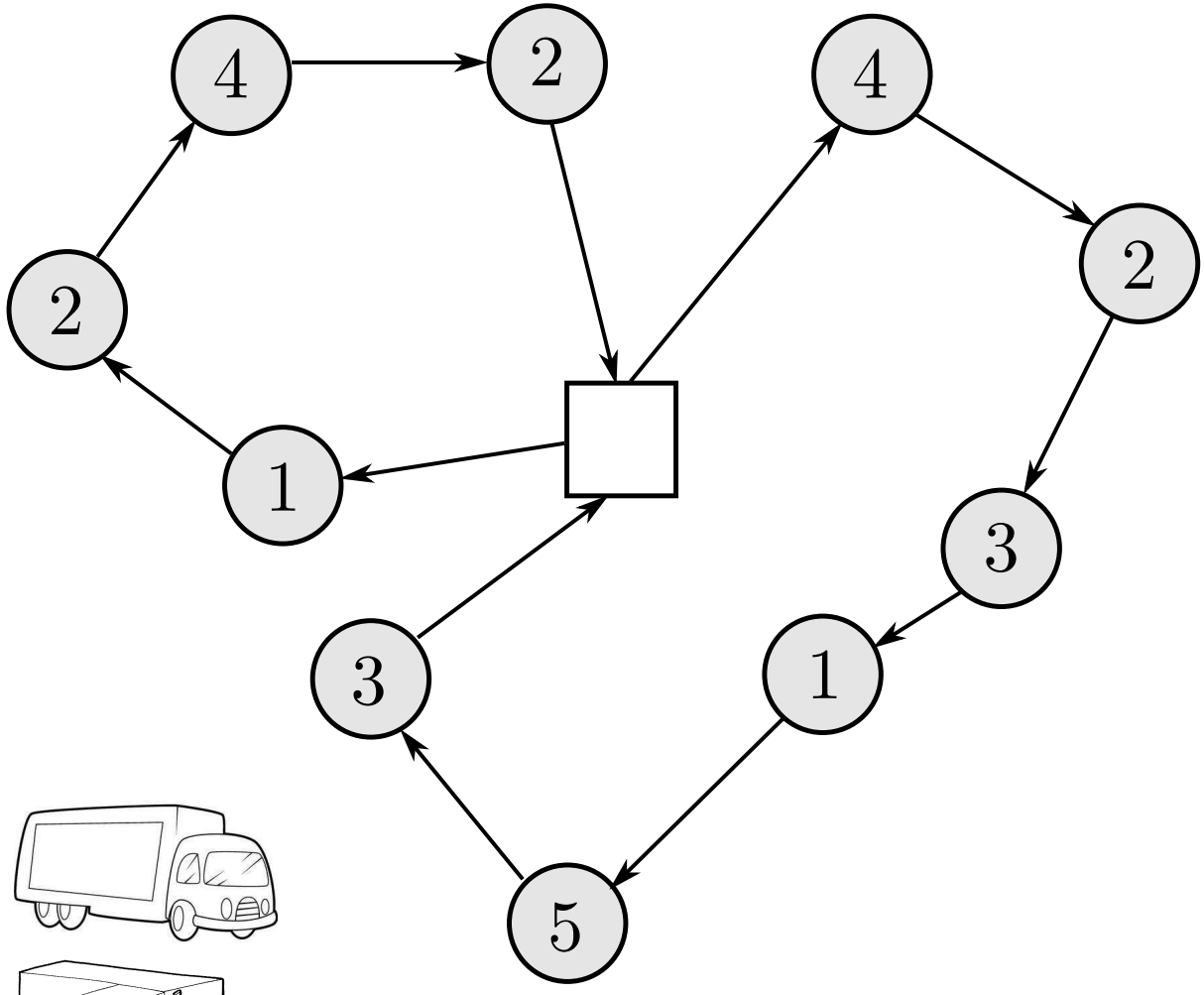
- Waiting in the middle of the route is usually allowed



Heterogeneous Fleet VRP (HFVRP)

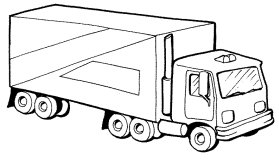


Heterogeneous Fleet VRP (HFVRP)



$Q_1 = 10$

$Q_2 = 18$

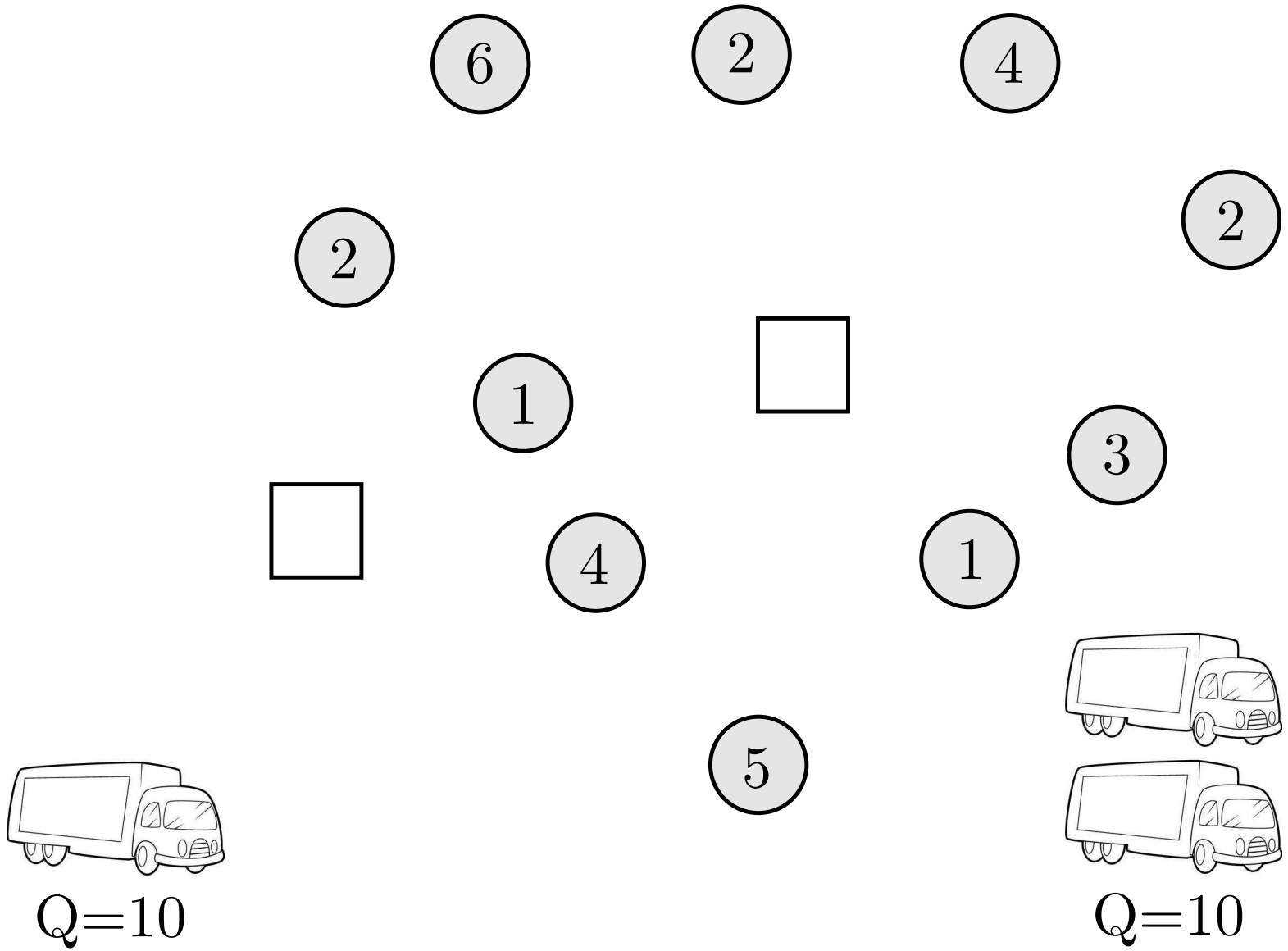


Heterogeneous Fleet VRP (HFVRP)

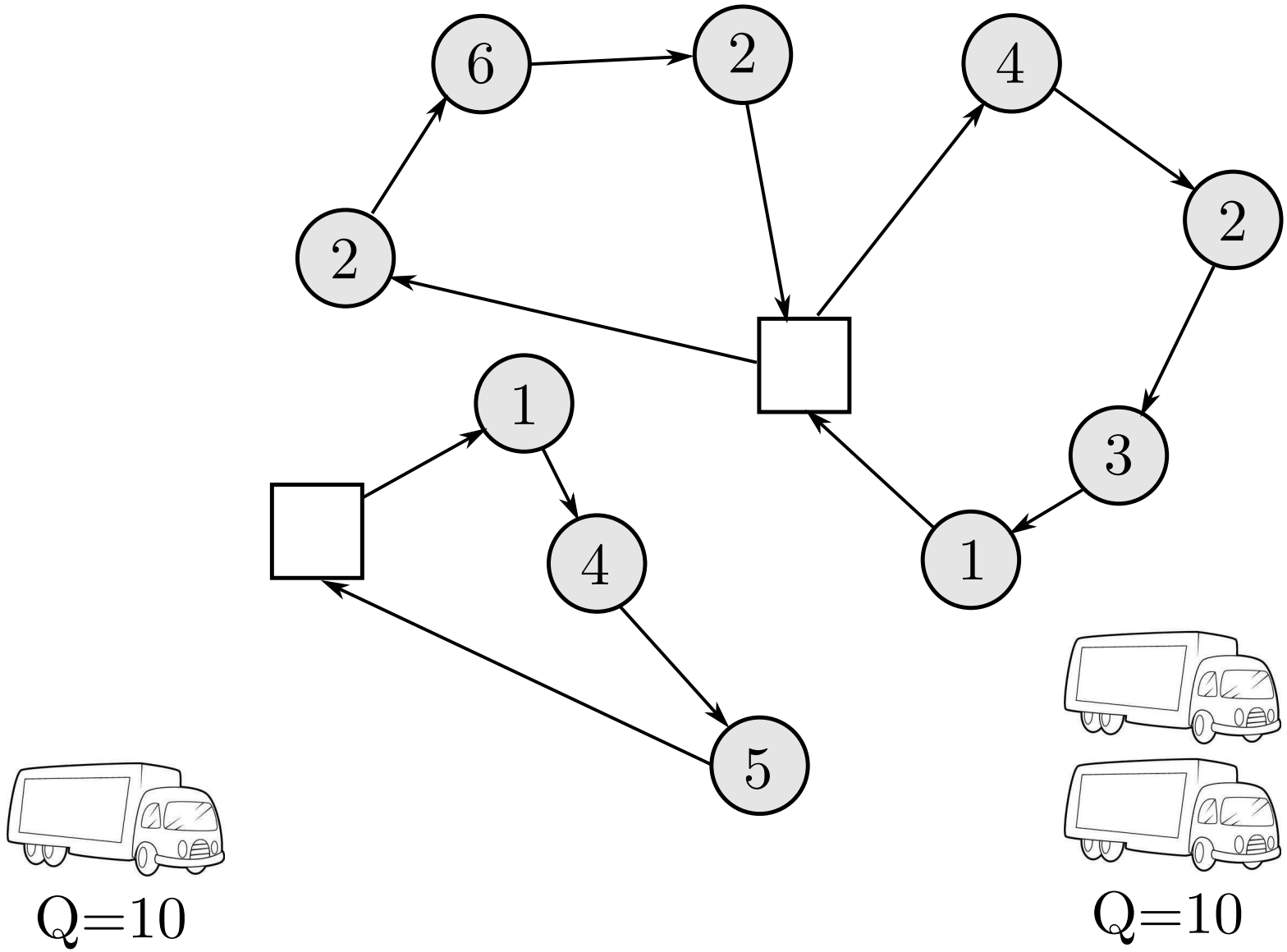
Very important in practice :

- It is established that heterogeneous fleets lead to significant economies in many real systems

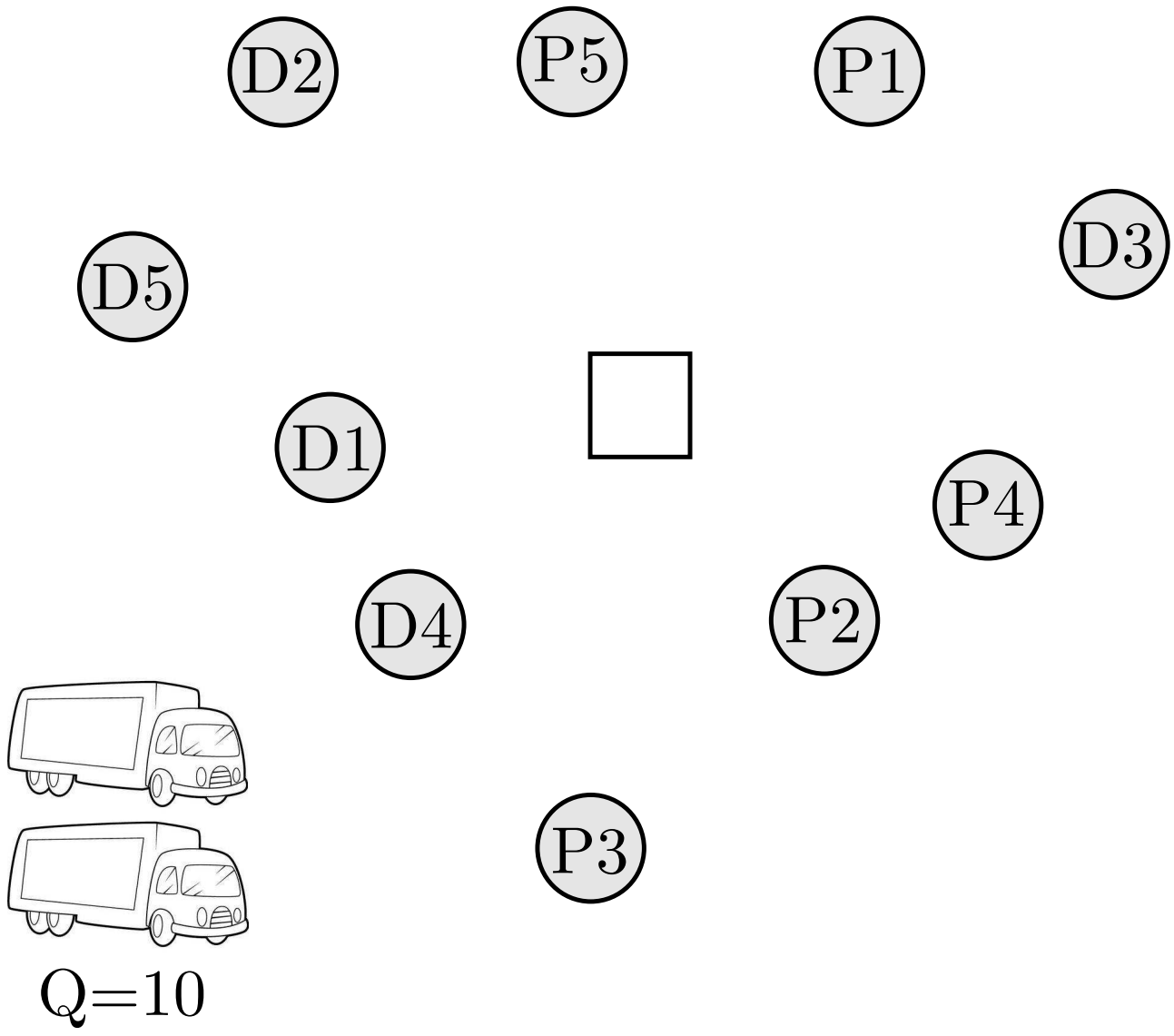
Multi-Depot VRP (MDVRP)



Multi-Depot VRP (MDVRP)



Pickup and Delivery VRP (PDVRP)



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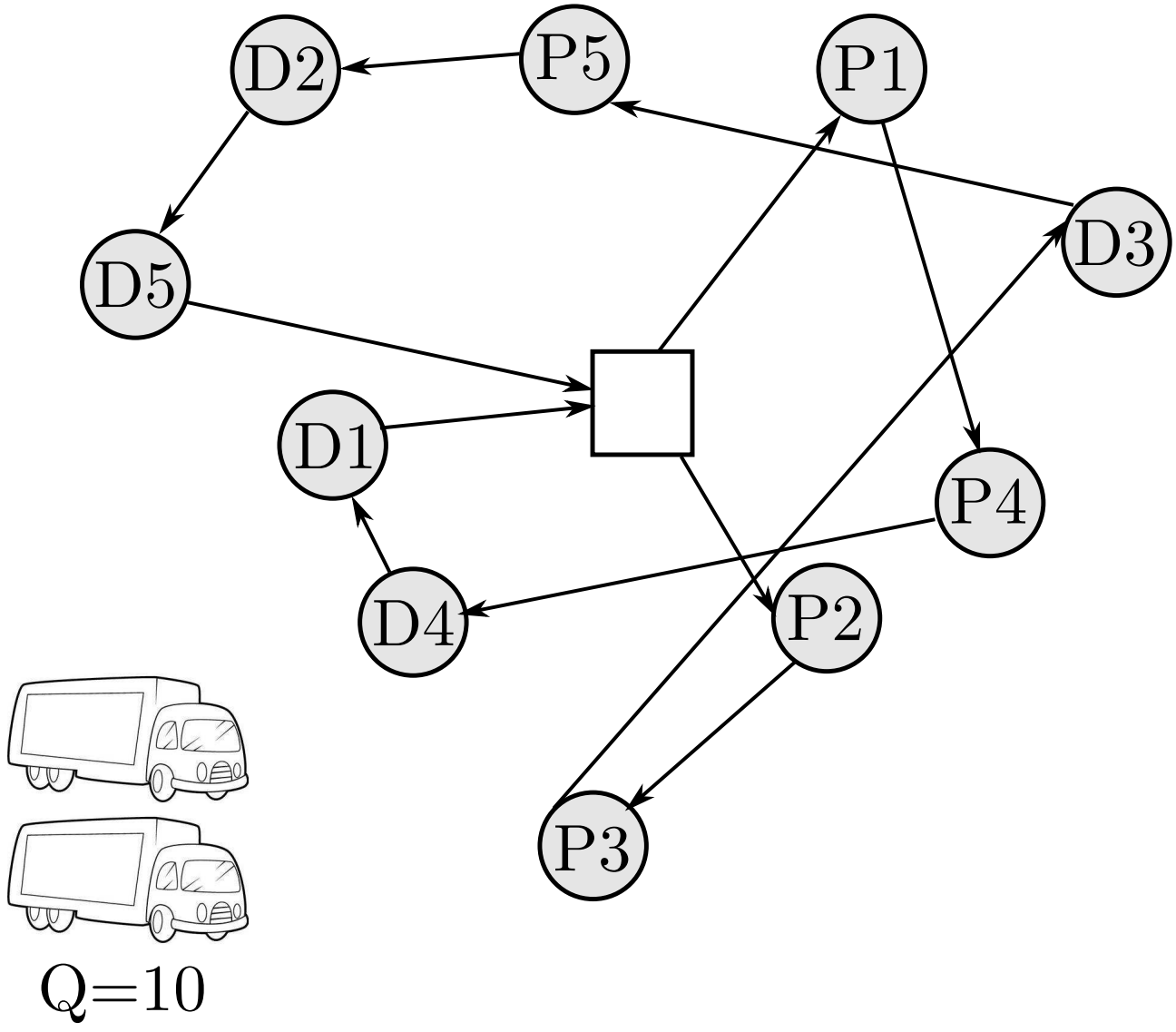

“Emerging” variants (I)

Routing of electrical vehicles :

- Limited autonomy. Recharge is only available at few points and is slow

Routing inside warehouses :

“Emerging” variants (II)

Dynamic Routing :

- Ongoing routes may be changed due to unexpected events (accidents, heavy traffic, new demands, ...)
- Only possible after GPS and mobile phone technology

Drone routing :

Contents

Exact approaches

Mixed Integer (Linear) Programming

- MIP solvers (bad performance for VRPs)
- Specialised Branch-and-Cut algorithms (mediocre performance and bad for rich VRPs)
- Column generation and Branch-Cut-and-Price (the best performance so far, can be used up to 100-150 points) — VRPSolver to be presented in the Integer Programming 3 course

Constraint Programming

- VRPs are similar to scheduling problems
- However, exact CP solvers have bad performance due to different objective functions and different instance structure

Heuristic approaches

Constraint Programming

- Can be good when combined with limited enumeration

Machine learning

- Bad performance when used alone (end-to-end approaches)
- Unknown whether can be successfully combined with limited enumeration (in the « Alpha-Zero style »)
- Has some potential for real-time and dynamic VRPs

« Classic » heuristics

- Combination of local search and diversification (f.e. genetic algorithm)
- The best approach for solving practical and large-scale problems
- Several heuristic solvers are available for rich VRPs

Contents

Open-source packages/solvers

- OR-Tools (C++, Java, Python) : local search and meta-heuristics on top of a CP solver
- Optaplanner (Java, Python via OptaPy) : a local search and meta-heuristic solver
- VROOM (C++) : a local search and meta-heuristic solver, a limited number of problems
- Jspirt (Java) : a meta-heuristic solver, a limited number of problems
- LKH-3 (C) : a heuristic solver, a finite list of problems
- VRPy (Python) : a column generation heuristic solver, a limited number of problems

Commercial packages/solvers

- LocalSolver (C++, Java, Python, own modeller) : local search, meta-heuristics and some lower bounding mechanisms
- NextMV (Go) : ALNS and decision diagrams
- ... many « route planners » with unclear solution methods

Contents

The work to do for your project

- You work in groups of 3-4 people
- You choose a paper (a list will be given)
- You read the paper (introduction, problem definition, experimental results)
- You find instances (or generate similar ones)
- You model the problem (or its simplification) both with OR-Tools AND LocalSolver
- You compare experimentally two models on the instances from the paper
- You produce a report (4-5 pages), where you indicate clearly how the work has been divided between the members of the group.
- You present your results on December 8 (20 minutes per group + questions)