A Hybrid Clustering algorithm for solving the Vehicle Routing Problem in Waste Management

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Outline

- Problem description
- Solving the VRP
    - Construction
    - Clustering VRP
    - Local search
    - Meta-heuristics
- Work plan
- Challenges

Waste management

Waste management plan involves a lot of steps:

- Waste generation
- Waste collection
- Waste processing
- Waste treatment
- Waste disposal
- Recycling

Waste collection

- Is one of the major steps in waste management plan
- Must be done in many different steps:
  - selection of a proper container storage
  - collection vehicles (optimal capacity, fuel consumption)
  - proper crew (organization, operation mechanism)
  - routing and collection
  - segregation of different types (plastic, paper, glass, etc.)
  - optimal location of disposal sites
- Frequency of collection must be determined
- Collection routing

Collection routing

Proper planning of collection routing need for

- decreasing overall cost of labor
- conserving energy by minimizing vehicle fuel consumption

Construct of each route based on:

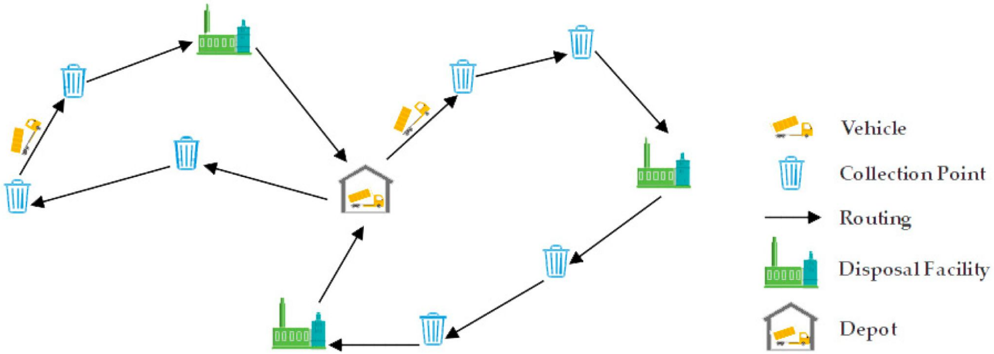
- the amount of collected waste per stop
- capacity of vehicle
- distance between stops
- loading time

Collection routing

Collection routing is the subclass or version of the Vehicle Routing Problem

A simplified route map always should illustrate:

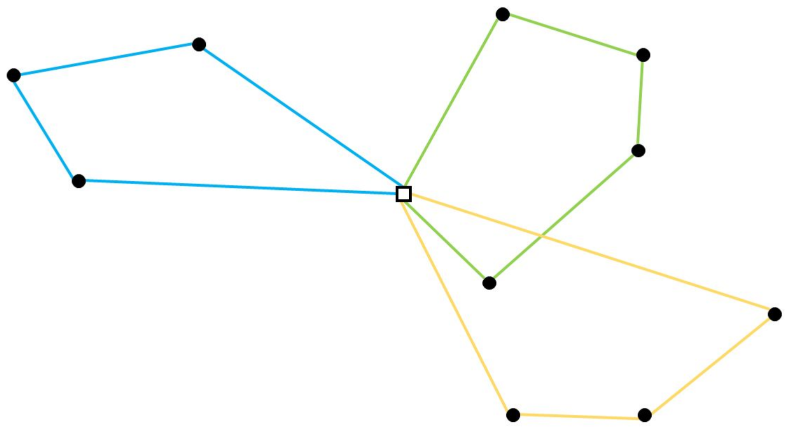
- collection points
- depot (one or many)
- location of disposal sites
- Vehicles usually represented as a routes



*The last point of waste generation should be located near one of the disposal sites

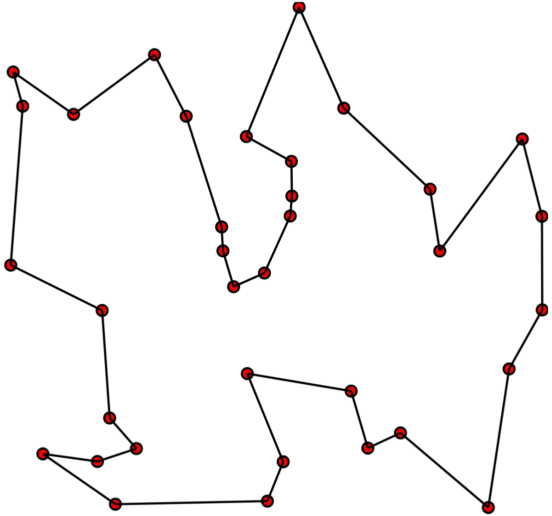
Vehicle Routing Problem

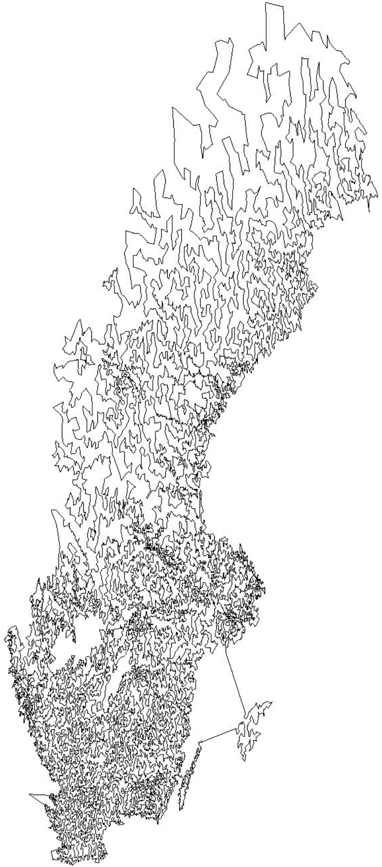
- Giving a set of customers and a fleet of vehicles to make deliveries, find a set of routes that services all customers at minimum cost.
- VRP is NP-hard problem



Traveling Salesman Problem

- Find the tour of minimum cost that visits all cities





Vehicle Routing Problem

For each customer we know:

- Quantity required
- The cost to travel to every other customer

For the vehicle fleet we know:

- The number of vehicles
- The capacity of each vehicle

We must determine which customer each vehicle serves, and in what order, to minimize cost

Vehicle Routing Problem

In academic studies, usually a combination:

- minimize the number of routes
- minimize total distance or total time

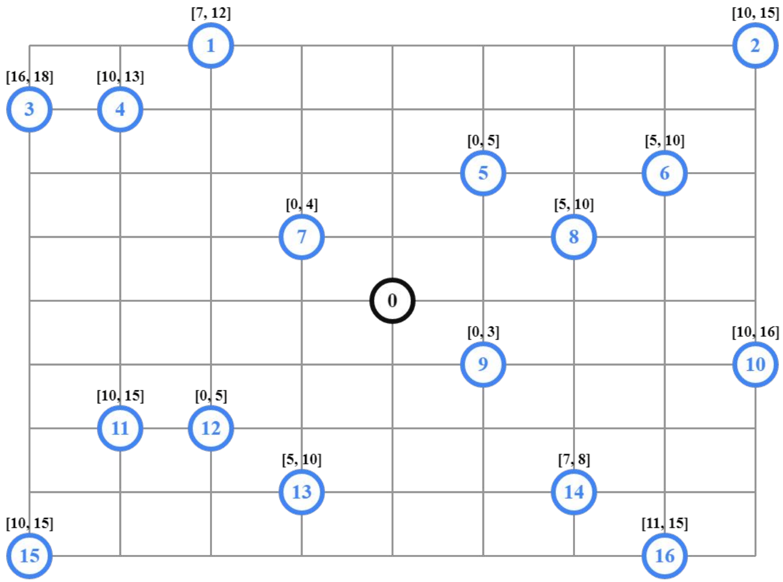
In real world:

- it is a combination of time and distance
- must include vehicle- and staff-dependent cost
- number of vehicles is fixed
- can have soft and hard constraints

Time window constraints

- A window, during which service can start
- E.g. only accept collection between 09:00 and 11:00
- Penalties for soft time windows

- Additional input data required
  - duration of each customer visit
  - time between each pair of customers
- Makes the route harder to visualise



VRP in the real world problems

Vehicle Routing Problem with the real world constraints:

- Multiple Time Windows
- Multiple commodities (or types of waste)
- Multiple depots
- Heterogeneous vehicles
- Compatibility constraints
  - E.g. hazardous waste can’t be transferred on standard collection trucks

Solution Methods

Exact:

- Integer programming
- Constraint programming

Heuristic:

- Construct
  - Insertion algorithm
  - Clustering algorithm
- Improve
  - Local search
  - Meta-heuristic

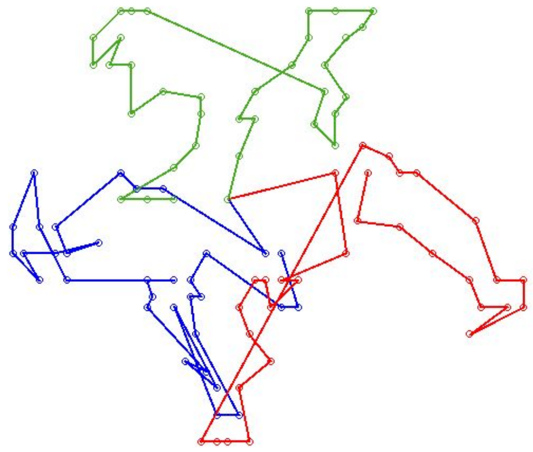
Construction Heuristic

Construction by insertion

- Start with an empty solution
- Add one element to the solution at a time
  - Choose which customer to insert
  - Choose where to insert it

E.g. (Greedy)

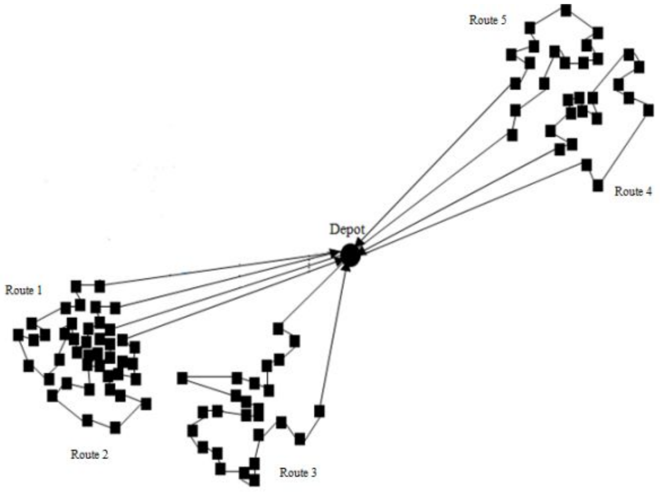
- Choose the customer that increases the cost by the least
- Insert it in the position that increases the cost by the least



Construction Heuristic

Capacitated K-means Clustering

- K is the number of vehicles
- Centroid-based clustering
- Finding the k cluster centers and assign the objects to their nearest cluster center
- Gets the minimum squared distance
- Each customer is assigned to exactly one cluster



Capacitated K-mean Clustering

The steps in k-means for VRP:

1. Choose the number of clusters, k.
2. Randomly generate centroids of clusters,
3. Assign each point to the nearest centroid (Euclidean distance).
4. Recompute the new cluster centroids.
5. Repeat steps 3 and 4 until convergence criterion is met.

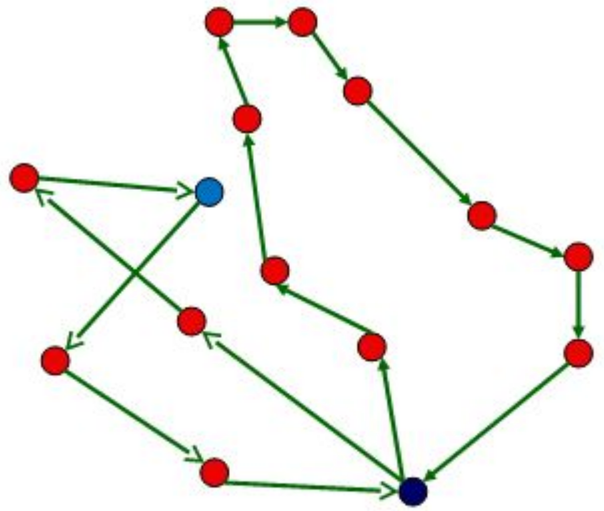
Routing in each cluster with a simple greedy algorithm:

- First customer should be closest to the depot, the second - closest to the first one, etc
- Send the truck to the disposal site once it's "full"
- Resume trip with the closest unvisited site
- Last visited customer should be the closest to the near disposal site

Improvement Methods

Local search

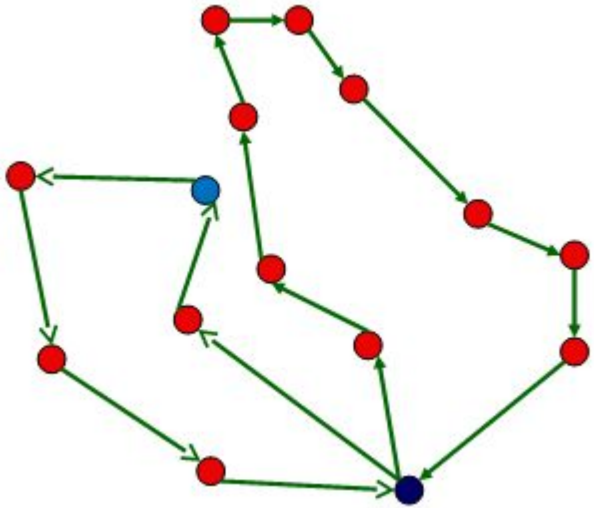
- Often defined using an “operator”
  - e.g. 1-move



Improvement Methods

Local search

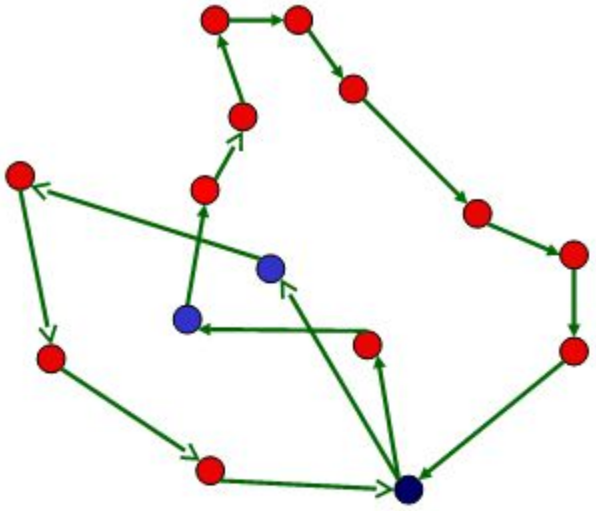
- Often defined using an “operator”
  - e.g. 1-move
- Solutions that can be reached using the operator termed the neighbourhood
- Local search explores the neighbourhood of current solutions



Local Search

Other neighbourhood for VRP:

- Swap 1-1



Local Search

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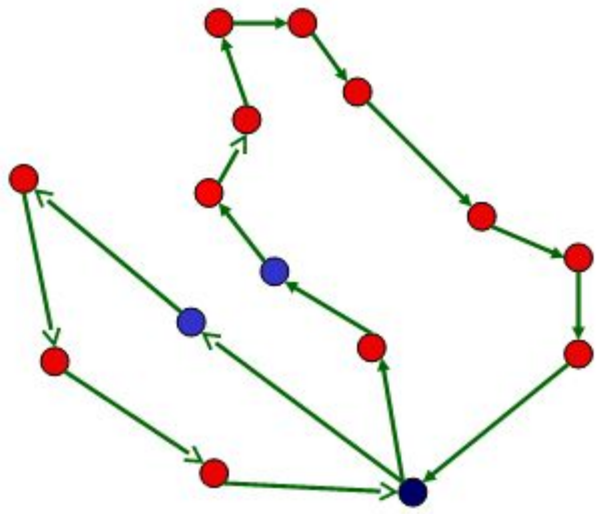
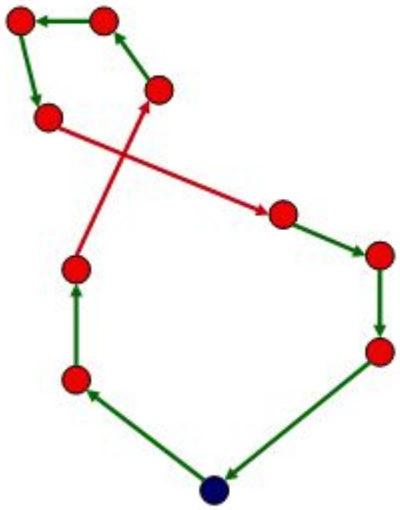


Improvement Methods

2-opt (3-opt, 4-opt...)

- Remove two arcs
- Replace with two others



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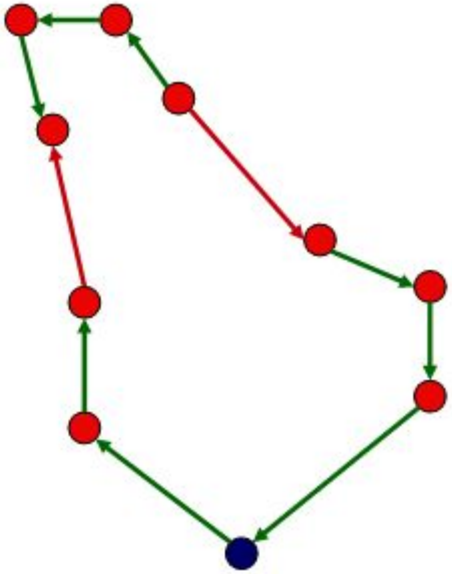

Improvement Methods

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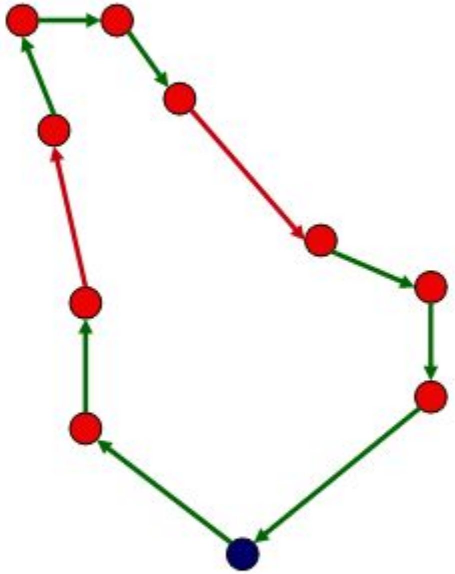


Improvement Methods

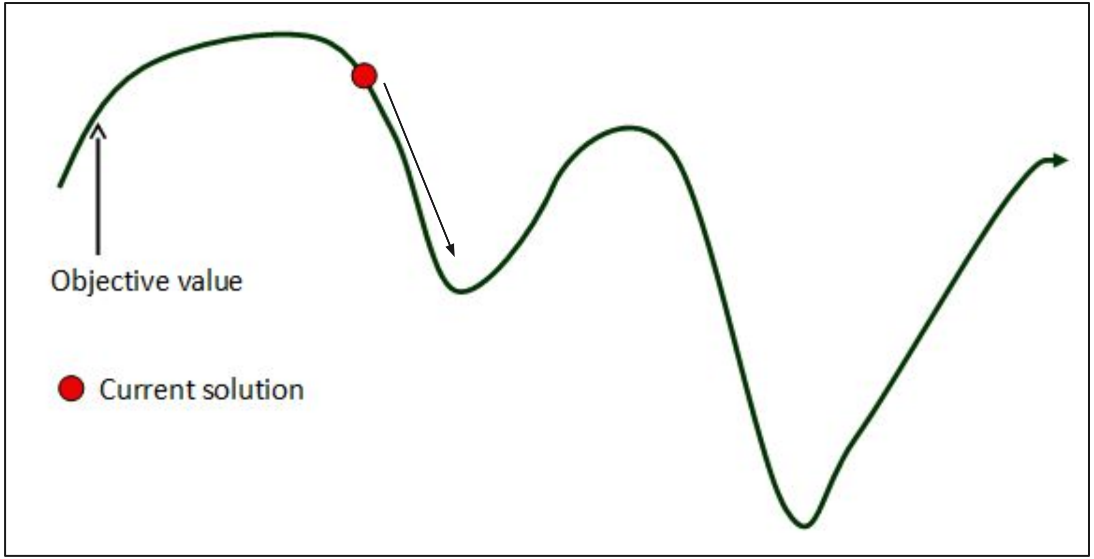
Or-opt

- Consider chains of length k (with value 1...n/2)
- Remove the chain from its current position
- Consider placing in each other possible position
  - in forward orientation
  - and reverse orientation
- Very effective

Tail exchange

- Swap final portion of routes

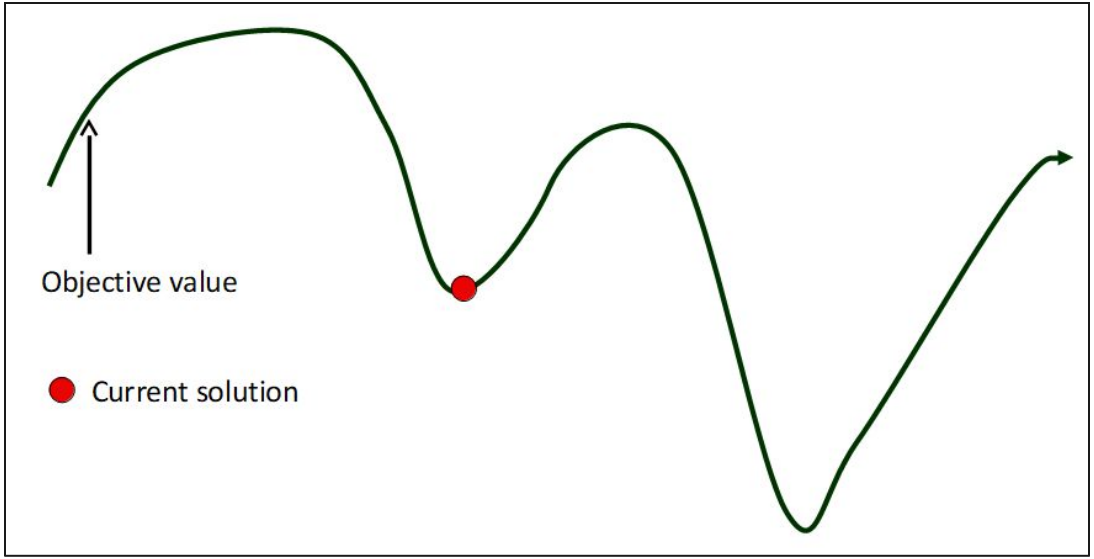
Local Search



- Local search is always trying to find neighboring solution that have a better objective value

Local Search

Local minima:



- Local search is always trying to find neighboring solution that have a better objective value
- In some cases we can't reach global minima
- Metaheuristics for escaping the local minima

Variable Neighbourhood Search

- Consider multiple neighbourhoods
    - 1-move (move 1 visit to another position)
    - 1-1 swap (swap visits in 2 routes)
    - 2-2 swap (swap 2 visits between 2 routes)
    - 2-opt
    - Or-opt size 2 (move chain of length 2 anywhere)
    - Or-opt size 3 (chain length 3)
    - Tail exchange (swap final portion of routes)
    - 3-opt
- Explore one neighbourhood completely
- If no improvement found, advance to next neighbourhood
- When an improvement is found, return to level 1

Other Metaheuristics

Escaping local minima with other meta-heuristics:

- Large Neighborhood Search
- Tabu Search
- Simulated Annealing
- Genetic Algorithm
- Ant Colony

And many more

Work plan

- Literature review
- Defining a problem and solution methods
- Implementing the clustering algorithm
    - Java

- Implementing the improvement algorithm with Local Search
- Testing

Future challenges

- Time windows
- Types of waste
- Road traffic

References

- Kim, B.-I., Kim, S., & Sahoo, S. (2006). Waste collection vehicle routing problem with time windows. Computers & Operations Research, 33(12), 3624–3642. doi:10.1016/j.cor.2005.02.045
- Improved K-Means Algorithm for Capacitated Clustering Problem (S. Geetha, P. Vanathi)
- Solving the Heterogeneous Capacitated Vehicle Routing Problem using K-Means Clustering and Valid Inequalities (Noha Mostafa, Amr Eltawil)
- Das, S., & Bhattacharyya, B. K. (2015). Optimization of municipal solid waste collection and transportation routes. Waste Management, 43, 9–18. doi:10.1016/j.wasman.2015.06.033
- Bodin, L., Mingozzi, A., Baldacci, R., & Ball, M. (2000). The Rollon–Rolloff Vehicle Routing Problem. Transportation Science, 34(3), 271–288. doi:10.1287/trsc.34.3.271.12301

Thank you!

Any questions?