Summary: Indoor Routing of Robots & Metaheuristics

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Broad Classification - Routing and task planning

- **Vehicle Routing Problem (VRP):** A combinatorial optimization and integer programming problem seeking to service a number of customers with a fleet of vehicles, while optimizing an objective subject to certain constraints

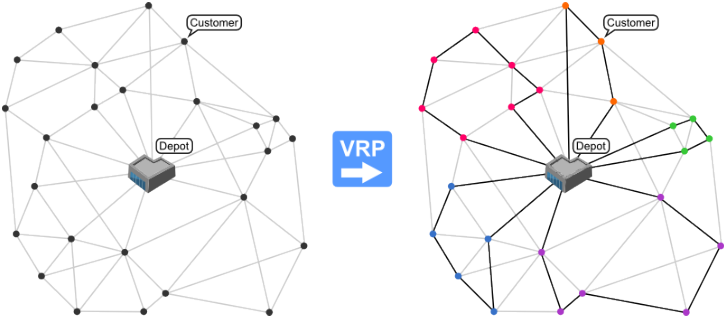
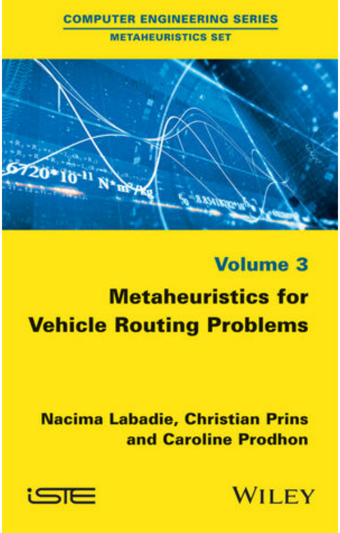
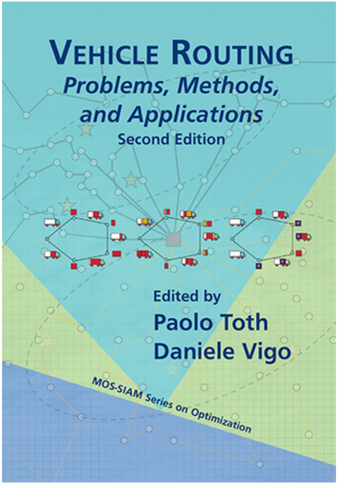


Figure: Networking and Emerging Optimization, University of Malaga

Insightful Reference Materials





Vehicle Routing Problem (VRP)

- **Variants:**
  - Capacitated VRP (CVRP) ✓
  - Periodic VRP (PVRP) ✓
  - Stochastic VRP (SVRP) ✓
  - VRP with Time Windows (VRPTW) ✓
  - VRP with Pick-Up and Delivery (VRPPD)
  - Hybrid combinations of the above

[1] Vehicle Routing: Problems, Methods, and Applications: Toth & Vigo, 2014

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- **Problem Objective(s)[1]:**

  Minimize **(i)** overall distance covered (ii) number of vehicles, (iii) waiting time, or maximize (iv) profit (v) customer satisfaction

  - Single Objective ✓
  - Hierarchical Objectives
  - Multi-criteria

[1] Vehicle Routing: Problems, Methods, and Applications: Toth & Vigo, 2014

Background

- **Choice of Constraints:**
  - Number of Depots ✓
  - Demand vs Capacity of goods ✓
  - Time Window and Scheduling ✓
  - Locations known (offline) vs Dynamic/Stochastic (online) ✓
  - Unpaired (either pickup or delivery) vs Paired (both, simultaneously)
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- **Solution Methods:**
  - Heuristics ✓
  - Metaheuristics ✓
    - Local search methods. Ex: Tabu, Greedy, Variable neighborhood search, Iterated local search, SA, Large neighborhood search
    - Population-based heuristics. Ex: ACO, MA, PSO, **GA**, Scatter search
  - Hybrid Heuristics

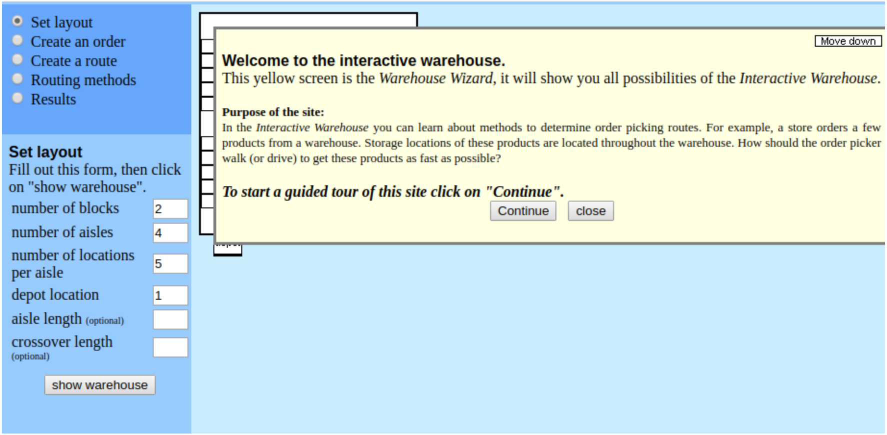


Figure: Interactive Warehouse by Roodbergen. This can be used as a heuristic comparison tool for simple setups of variants like CVRP

1. CVRP: Prior Simulations

- **Metaheuristic: Genetic Algorithm (MATLAB and Python)**
  - Setting - Offline, *Centralized*
  - Objective - Minimize total distance traversed by all vehicles
  - Model - 20*20 area, delivery nodes chosen at random
  - Assumptions - (i) Each vehicle has a capacity of 30 items (ii) Delivery demands may/may not vary with nodes
  - Inputs - Number of nodes, Number of vehicles, Min-max demand
  - Outputs - (i) Route taken, i.e. nodes covered by each vehicle (ii) Value of objective at each iteration (iii) Runtime
- **Algorithm-specific Parameters:**
  - $\mathbb{P}(\text{crossover}) = 0.7$
  - $\mathbb{P}(\text{mutation}) = 0.5$
  - $\mathbb{P}(\text{nearest neighbor}) = 0.5$
  - Generations = 500 or 1000 (decides runtime)

Result: Objective Value

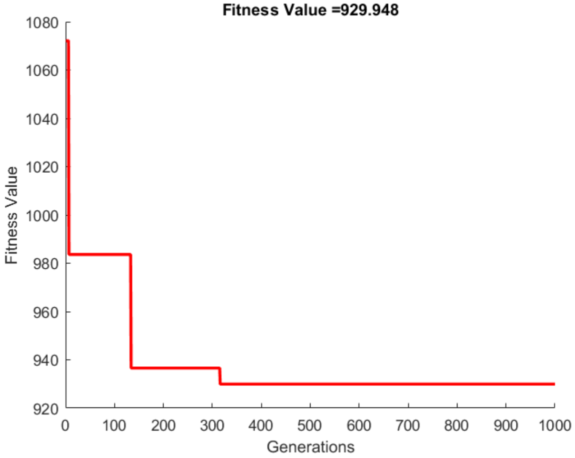


Figure: The 'fitness function' is the problem objective. In this case, it is the total distance traversed by all vehicles

Result: Graphical Representation

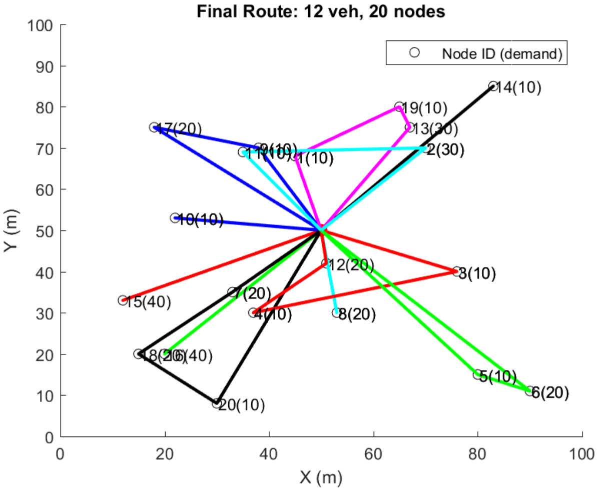


Figure: Vehicles (colored) either pick, or deliver goods from the nodes (circled)

Generic notation for Vehicle Routing Problems

P ... set of backhauls or pickup nodes
D ... set of linehauls or delivery nodes
n ... number of pickup nodes, indexed $i = 1, ..., n$
$\tilde{n}$ ... number of delivery nodes, in case of paired pickups and deliveries $n = \tilde{n}$, indexed $i = n + 1, ..., n + \tilde{n}$
q_i ... load at vertex i; pickup nodes are associated with a positive value, delivery nodes with a negative value
e_i ... earliest time to begin service at vertex i
l_i ... latest time to begin service at vertex i
d_i ... service duration at vertex i
L_i... maximum ride time of user i $(i = 1, ..., n)$
c_{ij}^k... cost to traverse arc or edge (i, j) with vehicle k
t_{ij}... travel time from vertex i to vertex j
K ... set of vehicles
m ... number of vehicles, indexed $k = 1, ..., m$
$\bar{Q}^k$... capacity of vehicle k
T^k... maximum route duration of vehicle / route k

$$x_{ij}^k = \begin{cases} 1, & \text{if arc } (i,j) \text{ is traversed by vehicle } k \\ 0, & \text{else} \end{cases}$$

Q_i^k... load of vehicle k when arriving at vertex i
B_i^k... beginning of service at vertex i

2. VRPTW: Problem Formulation

$$\min \sum_{k \in K} \sum_{i \in V} \sum_{j \in V} c_{ij} x_{ij}^k$$

subject to:

$$\sum_{k \in K} \sum_{j \in V} x_{ij}^k = 1 \qquad \forall i \in V \setminus \{0, n + \tilde{n} + 1\}$$

$$\sum_{j \in V} x_{0j}^k = 1 \qquad \forall k \in K$$

$$\sum_{i \in V} x_{i,n+\tilde{n}+1}^k = 1 \qquad \forall k \in K$$

$$\sum_{i \in V} x_{ij}^k - \sum_{i \in V} x_{ji}^k = 0 \qquad \forall j \in V \setminus \{0, n + \tilde{n} + 1\}, k \in K$$

$$x_{ij}^k (B_i^k + d_i + t_{ij}) \leq B_j^k \qquad \forall i \in V, j \in V, k \in K$$

$$Q_j^k \geq (Q_i^k + q_i) x_{ij}^k \qquad \forall i \in V, j \in V, k \in K$$

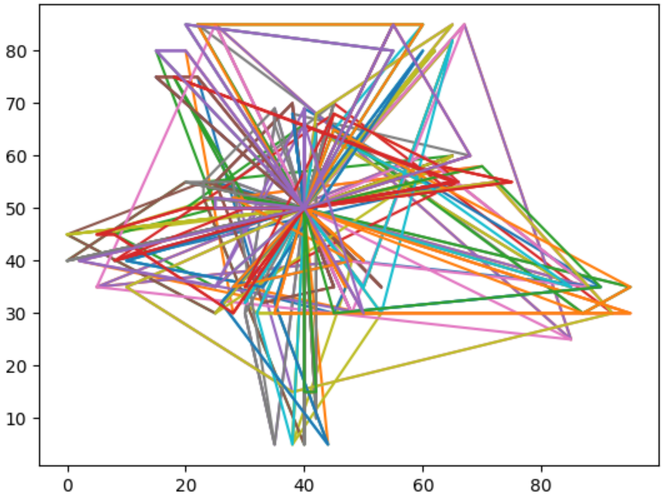
$$\max\{0, q_i\} \leq Q_i^k \leq \min\{\bar{Q}^k, \bar{Q}^k + q_i\} \qquad \forall i \in V, k \in K$$

$$x_{ij}^k \in \{0, 1\} \qquad \forall i \in V, j \in V, k \in K$$

$$\sum_{j \in V} x_{ij}^k - \sum_{j \in V} x_{n+i,j}^k = 0 \qquad \forall i \in P, k \in K$$

$$B_i^k \leq B_{i+n}^k \qquad \forall i \in P, k \in K.$$

Illustration: A large-scale VRPTW simulation



3. Periodic VRP

PVRP - CVRP is generalized by extending the planning period to M days. Each customer must be visited k times, where $1 \leq k \leq M$

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- In the first level, the objective is to generate a group of feasible alternatives for each customer (Example below)
- In the second level, select one of the alternatives for each customer, so that the daily constraints are satisfied (i.e. we must select the customers to be visited in each day)
- In the third level, we solve the CVRP for each day. In the example below, $M = 3$.

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CUSTOMER	DIARY DEMAND	N VISITS	N COMBINATIONS	POSSIBLE COMBINATIONS
1	30	1	3	1,2,4
2	20	2	3	3,5,6
3	20	2	3	3,5,6
4	30	2	3	1,2,4
5	10	3	1	7

4. Stochastic VRP

SVRP - VRPs where one or several components of the problem are random

- As some data are random, it is no longer possible to require that all constraints be satisfied for all realizations of the random variables.
- A first solution is determined before knowing the realizations of the random variables. In a second stage, a recourse or corrective action can be taken when the values of the random variables are known.

5. VRPPD: Work in Progress

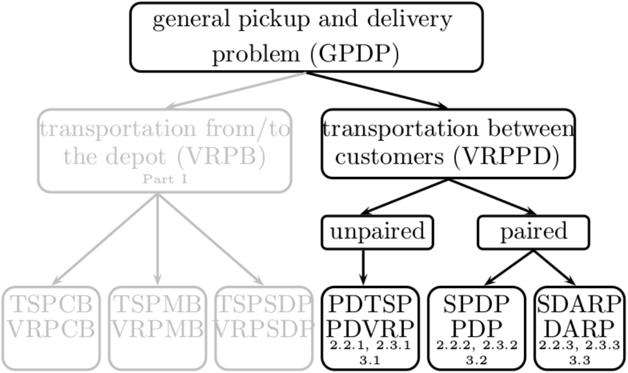

Figure: Classification of VRPPD[2]

[2] A survey on pickup and delivery models Part II: Transportation between pickup and delivery locations, Paragh et al., 2006

Final Objective

- **What would NOKIA like to see/use it for:**
  - Facility management - Office pickup and delivery of items by Sodexo. No fixed geometry, hence can look at *online, decentralized* **SVRPPDTW** approaches
  - Logistics transportation - Warehouse setup with some local cloud computing power. Fixed, aisle-like known paths, hence can look at *offline, centralized*, **PVRPPD(TW)** scheme

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- **What more can we bring to the table:**
  - Compare varying degree of vehicular decision making power (centralized vs decentralized) for the problems
  - Employ **online learning** for existing metaheuristic techniques, i.e. based on timely feedback, employ a reward-based scheme and incentivize the decisions taken.
  - For a given objective, how will a proposed learning scheme perform against expert/popular metaheuristic algorithms?

So far: An update

- **Solving through Metaheuristics:** (Constraints - Variant - Status)
  - 3/4 - VRPPD - Working on code
  - 5/6 - VRPPDTW - Hybrid
  - 6/7 - SVRPPDTW/PVRPPDTW - Hybrid
  - 9/10 - SVRPPDTW/PVRPPDTW for a *'Grid-with-isles'* setting

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- **Interesting industry resources:**
  - Market Vendors for VRP - here
  - Global Optimization Softwares that are publicly available - here (might be helpful for online setting)

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- **Some more helpful online tools:**
  - Gurobi - an MIP solver for Python
  - DEAP - A Metaheuristic solver for Python
  - GEATbx - A Metaheuristic solver for MATLAB

Concluding remarks

- **Explored methods:**
  - Internet Software Tools - VRP solvers and Commercial Software
  - Programming platforms - MATLAB, Python
  - Internet Resources - GITHUB, VRP Literature

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- **Future Work:**
  - Use hybrid heuristics to solve the mixed-IPPs (atleast a relaxed version) of VRP flavors that we have narrowed down on
  - Compare the results with current literature, or with Interactive tools
  - Understand and simulate the online and decentralized setting

Timeline

- **Dec** - Possible problem statements (Task planning, Path planning)
- **Jan** - An insight into the Vehicle Routing Problem and variants
- **Feb** - Survey of available Metaheuristics
- **Mar** - Solving the simplest two-constraint variant (CVRP)
- **Apr** - Python implementation of CVRP
- **May** - VRPTW
- **July** - PVRP and SVRP

Thank You