

Optimization, statistics and graphical interfaces for urban vehicle routing problems

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November 30, 2017



Outline

- 1 The vehicle routing problem
- 2 Example with the transportation of Handicapped people
- 3 Interfaces
- 4 Stochastic variants of routing problems
- 5 Master program at UBS
- 6 Contact us

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 - VRP flavours
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The travelling salesman problem

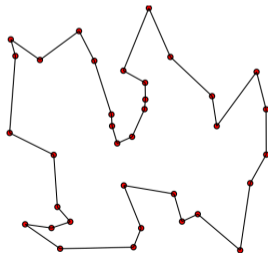
Definition

The travelling salesman problem (TSP) asks the following question: “Given a list of cities and the distances between each pair of cities, what is the shortest possible route that visits each city exactly once and returns to the origin city?” In graph theory, find a **shortest Hamiltonian circuit**

A not so simple example. . .

Remember that TSP is **\mathcal{NP} -hard**!!!

Now, let's play together!



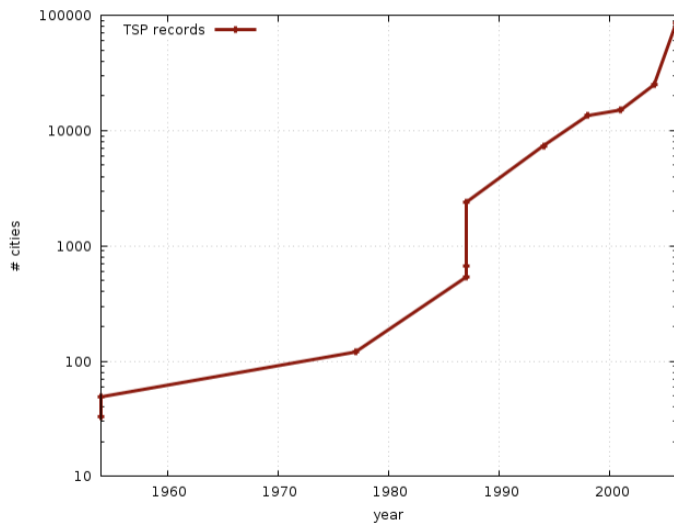
History

- 1800 Sir W.R. Hamilton and T. Penyngton Kirkman played the Icosian Game [20 nodes]
- 1920 K. Menger define the TSP as known today. H. Whitney and M. Flood promoted the problem (1930)
- 1954 G. Dantzig, R. Fulkerson, and S. Johnson published a description of a method for solving the TSP [49 cities]
- 1962 Proctor and Gamble contest (\$10,000 prize) won by G. Thompson [33 cities]
- 1977 M. Grötschel find an optimal tour on a west Germany map [120 cities]
- 1987 Padberg and Rinaldi found the optimal tour of AT&T switch locations in the USA [532 cities]
- 1987 Grötschel and Holland found the optimal tour of 666 interesting places in the world

History (cont'd)

- 1987 Padberg and Rinaldi (1987) found the optimal tour through a layout of obtained from Tektronics [2,392 points]
- 1994 Applegate, Bixby, Chvátal, and Cook found the optimal tour for a TSP that arose in a programmable logic array application at AT&T Bell Laboratories [7,397 points]
- 1998 Applegate, Bixby, Chvátal, and Cook found the optimal tour of cities in the USA with populations greater than 500 [13,509 cities]
- 2001 Applegate, Bixby, Chvátal, and Cook found the optimal tour of 15,112 cities in Germany
- 2004 Applegate, Bixby, Chvátal, Cook, and Helsgaun found the optimal tour of 24,978 cities in Sweden
- 2006 Applegate, Bixby, Chvátal, Cook, Espinoza, Goycoolea and Helsgaun found the optimal tour of a 85,900-city VLSI application
- 2013 Helsgaun found a solution to the giant 1,904,711-city world tour which has length at most 0.0474% greater than the optimal tour

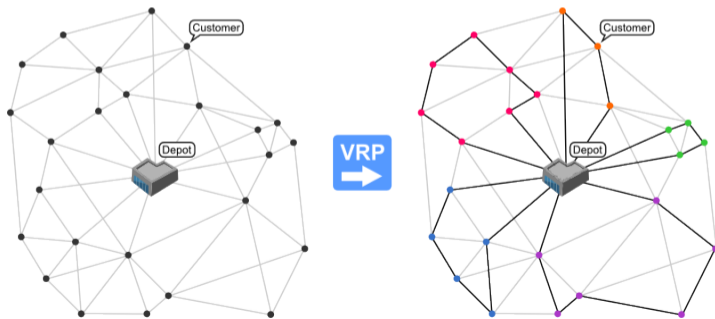
Evolution of records



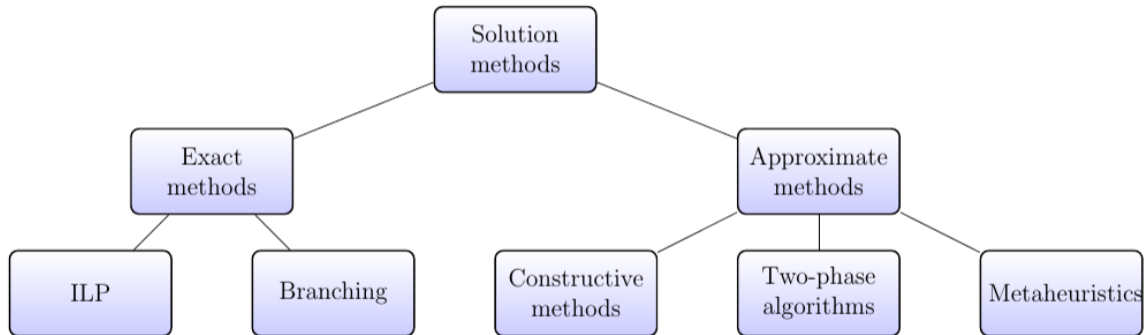
The vehicle routing problem

Definition

The vehicle routing problem (VRP) asks the following question: “What is the optimal set of routes for a fleet of vehicles to traverse in order to deliver to a given set of customers?” It’s generalization of the TSP



Solution methods



VRP flavours

Variants

There are so many variants that it is almost impossible to enumerate them

- Capacitated VRP (CVRP)
take into account the capacity of each vehicle
- Multi Depot VRP (MDVRP)
vehicles can start and end from different depots
- Periodic VRP (PVRP)
each customer should be visited k times over the period
- Split Delivery VRP (SDVRP)
each customer can be served by different vehicles
- VRP with Backhauls
after deliveries, the trucks will collect some goods to ship back to the depot

VRP flavours (cont'd)

- VRP with Pickup and Deliveries (PDVRP)
pickup and delivery requests: a pickup must appear before a delivery
- VRP with Satellite Facilities
replenishment of a truck can occur at a satellite facility
- Open VRP (OVRP)
vehicles do not return to the depot

VRP flavours (cont'd)

- VRP with Pickup and Deliveries (PDVRP)
pickup and delivery requests: a pickup must appear before a delivery
- VRP with Satellite Facilities
replenishment of a truck can occur at a satellite facility
- Open VRP (OVRP)
vehicles do not return to the depot

Time windows

The depot is open during a **time horizon**. Each customer can be served during its **time window** (sometimes multiple time windows). There is a **service time** for each customer

- VRPTW
- MDVRPTW
- PVRPTW
- SDVRPTW
- PDVRPTW
- ...

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A collaboration with KERPAPE



KERPAPE is a medical unit for reeducation of handicapped people in poly-traumatology



- full time patients
- patients on daily programs for several months

Transportation of handicapped persons

Medical units should organize daily the transportation of more than 75 patients:

- from home to medical center
- from medical center to home



Transportation of handicapped persons (cont'd)

- Human factor is very important
- Specialized service
- Individual needs
- Time and medical constraints



Cost of transportation

Cost is calculated from many factors

- transportation duration
- transportation distance
- number of vehicles used
- type of vehicles
- capacity of vehicles



- but most of the transportation is done by taxis. . .

Problem description

Objective

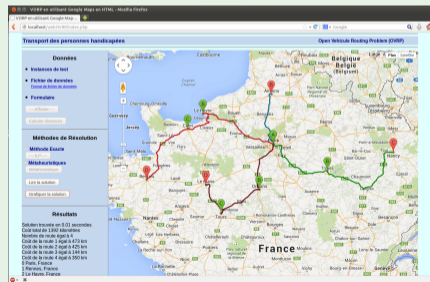
Design vehicle tours to ensure daily transportation of patients while minimizing the total transportation cost

Constraints

- vehicle capacity



Route structure



OVRP-1 & OVRP

Solution approaches

- ILP model (optimal \rightarrow 55 patients)
- ILS-TS with multiple neighborhoods

Competitive also on OVRP with Hybrid (1+1)-ES
from *Reinholz and Schneider (2013)*
and with the Tabu search heuristic (ABHC)
from *Derigs and Reuter (2009)*

110 instances from

`branchandcut.org` + Christophdes + Fisher & Jaikumar

- 104/110 best results
- D & R = 75/110, R & H = 20/110, CPU divided by 2
- Gap -0.01% from best and 0.10% from LB

Several care units

Kerpape is working with:

- the regional public hospital
- two private hospital units
- two radiography centers



Some of the patients have treatments in these units

- only in one unit
- in more than one unit
- in one of more unit and in Kerpape

Closest academic problem: Multi-depot OVRP

Metaheuristics: MNS-TS

Main characteristics:

- Use of several neighborhoods (intra/inter route)
- Combined in Ejection Chains
- Solutions improved by Tabu Search
- Neighborhoods used in token-ring
- balance diversification and intensification

Neighborhoods

- based on path moves
- may use infeasible path moves
- use intra and inter route exploration

Path and path moves

Path P_i^α

- sequence of consecutive customers in the same route
- P_i^α : starts at i in route r_i and visits α customers

Path move (P_i^α, j, ω)

- remove P_i^α from one route
 - reinsert it after customer j
 - same route or not
 - path can be reverted before insertion ($\omega \in \{1, 2\}$)
-
- Contribution to length can be computed easily
 - Infeasible route can be generated (capacity, length)

Ejection chains

EC from infeasible path moves

- EC are used as a repair operator
- path moves are searched (with minimal Δ^+ length)
- are added to the EC until a feasible solution is found
- cycle detection and avoidance mechanism is used

EC from feasible path moves

- search for several moves that remain feasible
- improve the total length of the routes

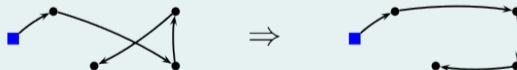
List of neighborhoods

Intra route moves

Relocate



2-Opt



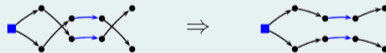
List of neighborhoods (cont'd)

Inter route moves

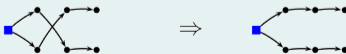
Relocate (feasible)



Path-Exchange – Cross/ICross Exchange (feasible)



2-Opt* (feasible)



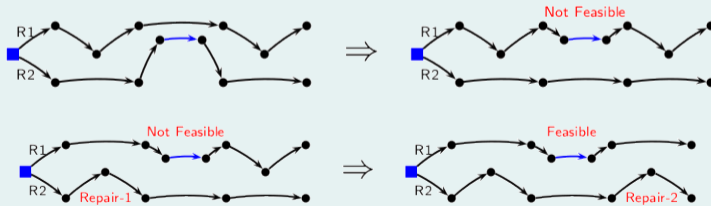
List of neighborhoods (cont'd)

Inter/Intra route moves

Split route (feasible)



Ejection chains (not feasible)



Elements of the MNS-TS

In the algorithm

- \mathcal{N}_{intra} : all intra route neighborhoods
- \mathcal{N}_{inter} : all inter route neighborhoods except EC from infeasible path moves

For the Tabu Search

- \mathcal{N}_1 : EC from infeasible path move with last customer
- \mathcal{N}_2 : EC from infeasible path move with length 2
- \mathcal{N}_3 : EC from infeasible path move with length 3
- Tabu status: list of visited customers

Initial solution: Best insertion heuristic based on path moves

Metaheuristic algorithm

Algorithm 1: MNS-TS

Compute initial solution s_0 (greedy insertion)

Improve: $s \leftarrow \text{TabuSearch}(\mathcal{N}_{intra}(s_0))$

Save best: $s^* \leftarrow s$

Init: $k \leftarrow 1$

while *stopping conditions not satisfied* **do**

$s \leftarrow \text{TabuSearch}(\mathcal{N}_{inter}(s));$ Update s^*

$s \leftarrow \text{TabuSearch}(\mathcal{N}_{intra}(s));$ Update s^*

$s \leftarrow \text{TabuSearch}(\mathcal{N}_k(s));$ Update s^*

if $k = 3$ **then** $k \leftarrow 1$

else $k \leftarrow k + 1$

 Update stopping condition parameters

end

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A complete restart. . .

Is a new project systematically a restart from scratch?

- Not for the ideas, but
- **Yes** for the interfaces. . .

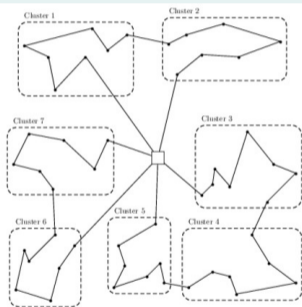
In the past years, several projects were addressed:

- School Bus Routing (Universiteit Antwerpen - BE)
- Inventory Routing (Helmut Schmidt Universität - DE)
- Robust VRP (Universiteit Antwerpen - BE)
- CARP (Université de Technologie de Troyes - FR)
- Bimodal urban transp. (Université de Valenciennes - FR)
- Clustered CVRP (Universidad de La Laguna - ES)

Interfaces

From the simplest to the more elaborate ones'...

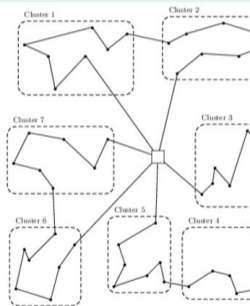
Clustered CVRP



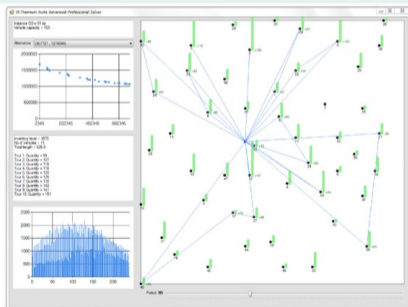
Interfaces

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Clustered CVRP



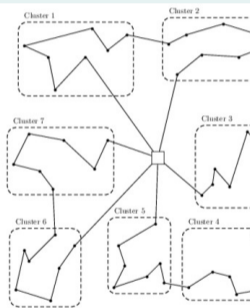
Bi-objective IRP



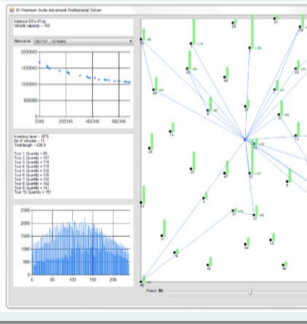
Interfaces

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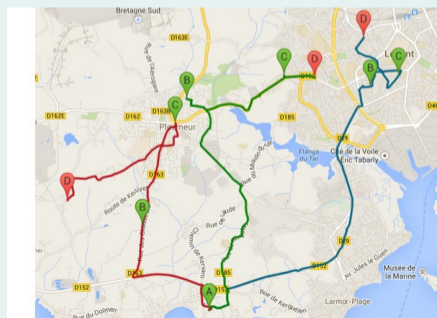
Clustered CVRP



Bi-objective IRP



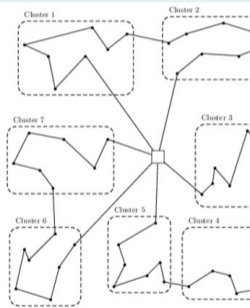
Handicapped people transportation



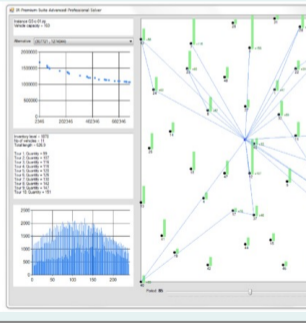
Interfaces

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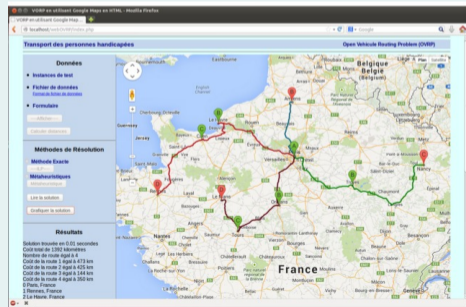
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Interfaces

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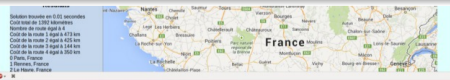
Bi-objective IRP



Handicapped people transportation

How can we capitalize on previous experiences?

- We should find a way to reuse our own work
- Concentrate on what we know (OR) and let the rest
- Disconnect the interface work from the algorithm's
- Ask help of the specialists of HMI



Demo

Let's cross our fingers. . .

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 - Stochastic parameters
 - Example of Retritex
 - An ongoing PhD program
 - The stochastic CARP
- 5 Master program at UBS

Ideas where the stochastic part may come from?

Before stochastic parameters, reality is already more complicated

→ Distance graph is **non-symmetric**

Stochastic parameters are everywhere

Ideas where the stochastic part may come from?

Before stochastic parameters, reality is already more complicated

→ Distance graph is **non-symmetric**

Stochastic parameters are everywhere

- Travel time (more realistic than travel distance)
- Customers may raise new orders
- Customers may cancel their orders
- Quantities to deliver/collect is not precisely known

Example of RETRITEX

A specific encounter → a general case

- general presentation at a round table
- contacted by RETRITEX a small “insertion” company



RETRITEX

- long term unemployed people
- favour manual labour
- is not a rich company

How can we collaborate?

- no data for routing
- no money for routing
- no competent people

What do they need?

One moto: **better nothing than paying**

- if they do not contribute, we cannot help them
- but the first step is often for free
- so, how do we proceed?

They have very interesting problems

- but classical algorithms do not apply
- **with real distances**
- have too many restrictions
- want reliable solutions
- need a user interface we cannot provide easily

Why don't they just buy a routing software?

- no money, no time, lack of competences

The RETRITEX company example

Problem description

- a small fleet of heterogeneous vehicles
- containers in Brittany to collect periodically
- no idea on the containers' filling
- two intermediate storage places
- minimum and maximum capacity at depot

Today they proceed as follows:

- seasonal planning (two sets of routes)
- no prediction of containers' filling
- follow the routes whatever happens
- estimate the annual cost by reading the odometers

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Should/Could we let them do that?

Heterogeneous fleet VRP

Flavien Lucas is starting a new PhD program

Urban VRP

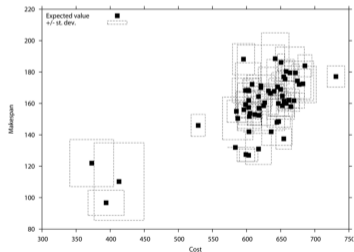
- Heterogeneous fleet
- Non-identical travel speed
- Restriction zones
- Stochastic travel time
- Pollution
- On-demand VRP
- Alternative vehicles
- Occasional drivers

Have a look to v-traffic.com

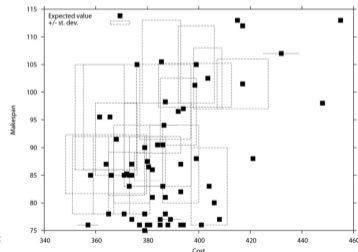
Multiobjective Stochastic CARP = Waste collection in cities

MOSCARP definition

In a network, visit a set of compulsory arcs with a fleet of capacitated vehicles, collect items along the arcs (stochastic quantities) and minimize the total travelled distance and maximum route duration



Initial population



After 100 iterations

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Master program at UBS

A simple link: www.master-im-ubs.fr

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