Introduction to web services

Optimization, statistics, graphical interfaces and web services for urban vehicle routing problems

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in collaboration with P. Bomel, M. Soto, M. Chassaing, I. Crépeau, F. Lucas. . .

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Outline

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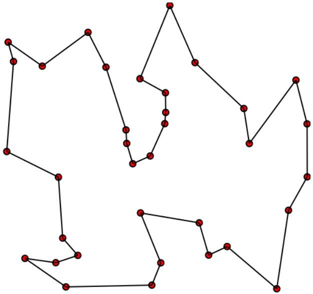
The travelling salesman problem

Definition

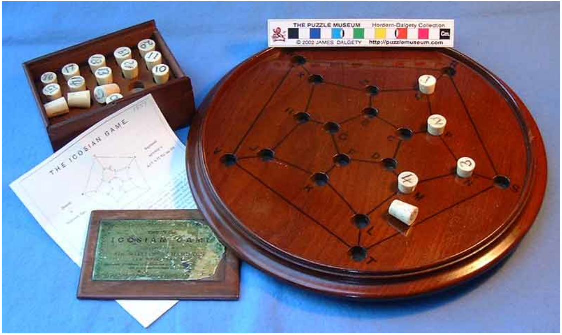
The travelling salesman problem (TSP) asks the following question: "Given a list of cities and the distances between each pair of cities, what is the shortest possible route that visits each city exactly once and returns to the origin city?"
Graph theory: shortest Hamiltonian circuit

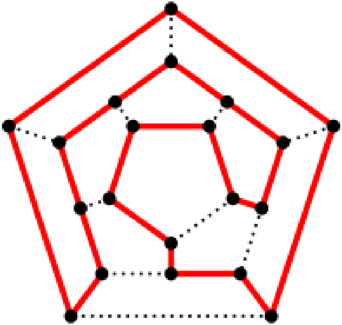


Remember that TSP is $\mathcal{NP}$-hard!!!

History

1857 Sir W.R. Hamilton and T. Penyngton Kirkman played the Icosian Game [20 nodes]

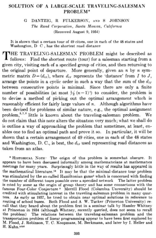




History (cont'd)

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]


SOLUTION OF A LARGE-SCALE TRAVELING-SALESMAN PROBLEM*

G DANTZIG, R FULKERSON, AND S JOHNSON

The Rand Corporation, Santa Monica, California

(Received August 9, 1954)

It is shown that a certain tour of 49 cities, one in each of the 48 states and Washington, D C, has the shortest road distance

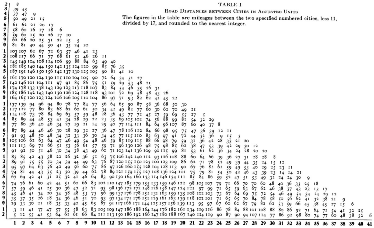
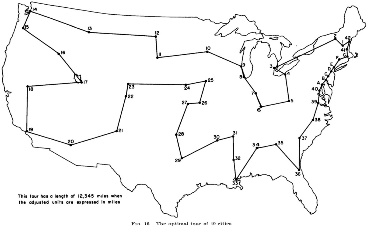


TABLE I

ROAD DISTANCES BETWEEN CITIES IN ADJUSTED UNITS

The figures in the table are mileages between the two specified numbered cities, less 11, divided by 17, and rounded to the nearest integer.



History (cont'd)

1962 Proctor and Gamble contest ($10,000 prize) won by G. Thompson [33 cities]

History (cont'd)

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

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]

History (cont'd)

1998 Applegate, Bixby, Chvátal, and Cook found the optimal tour of cities in the USA with populations greater than 500 [13,509 cities]

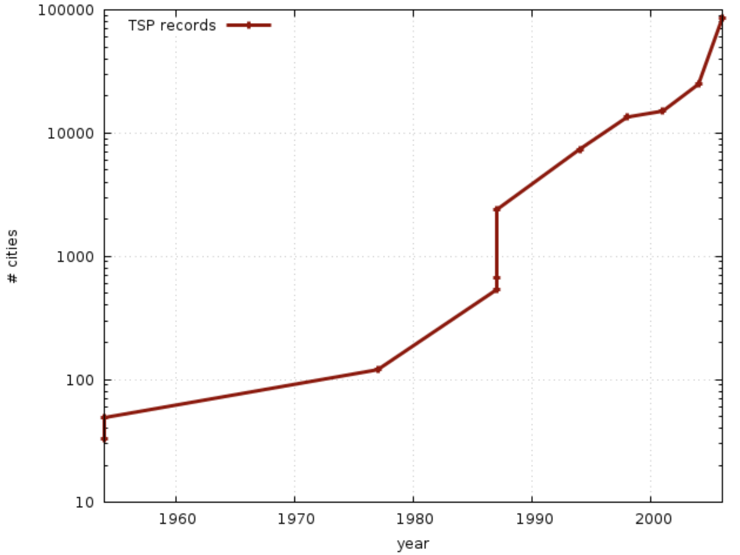
2001 Applegate, Bixby, Chvátal, and Cook found the optimal tour of 15,112 cities in Germany

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



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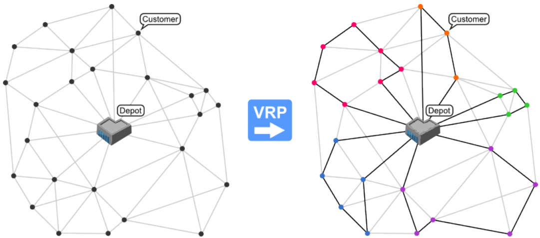
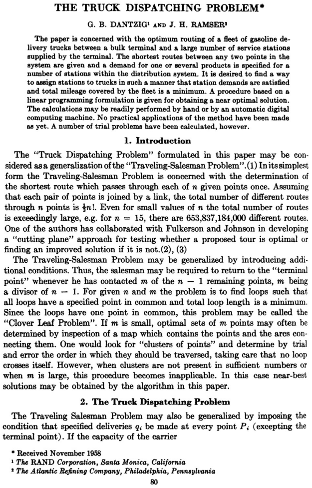
The vehicle routing problem

Definition of VRP

Vehicle routing problem (VRP): "What is the optimal set of routes for a fleet of vehicles to traverse in order to deliver to a given set of customers?"
[Dantzig & Ramser 1959]





THE TRUCK DISPATCHING PROBLEM*

G. B. DANTZIG[1] AND J. H. RAMSER[2]

The paper is concerned with the optimum routing of a fleet of gasoline delivery trucks between a bulk terminal and a large number of service stations supplied by the terminal. The shortest routes between any two points in the system are given and a demand for one or several products is specified for a number of stations within the distribution system. It is desired to find a way to assign stations to trucks in such a manner that station demands are satisfied and total mileage covered by the fleet is a minimum. A procedure based on a linear programming formulation is given for obtaining a near optimal solution. The calculations may be readily performed by hand or by an automatic digital computing machine. No practical applications of the method have been made as yet. A number of trial problems have been calculated, however.

1. Introduction

The "Truck Dispatching Problem" formulated in this paper may be considered as a generalization of the "Traveling-Salesman Problem".(1) In its simplest form the Traveling-Salesman Problem is concerned with the determination of the shortest route which passes through each of n given points once. Assuming that each pair of points is joined by a link, the total number of different routes through n points is $\frac{1}{2}n!$. Even for small values of n the total number of routes is exceedingly large, e.g. for $n = 15$, there are 653,837,184,000 different routes. One of the authors has collaborated with Fulkerson and Johnson in developing a "cutting plane" approach for testing whether a proposed tour is optimal or finding an improved solution if it is not.(2), (3)

The Traveling-Salesman Problem may be generalized by introducing additional conditions. Thus, the salesman may be required to return to the "terminal point" whenever he has contacted m of the $n - 1$ remaining points, m being a divisor of $n - 1$. For given n and m the problem is to find loops such that all loops have a specified point in common and total loop length is a minimum. Since the loops have one point in common, this problem may be called the "Clover Leaf Problem". If m is small, optimal sets of m points may often be determined by inspection of a map which contains the points and the arcs connecting them. One would look for "clusters of points" and determine by trial and error the order in which they should be traversed, taking care that no loop crosses itself. However, when clusters are not present in sufficient numbers or when m is large, this procedure becomes inapplicable. In this case near-best solutions may be obtained by the algorithm in this paper.

2. The Truck Dispatching Problem

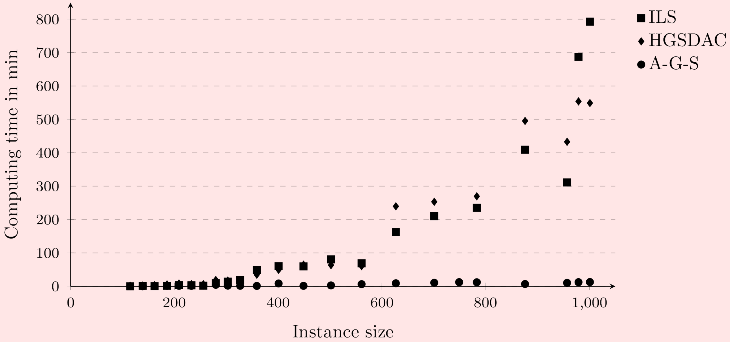
The Traveling Salesman Problem may also be generalized by imposing the condition that specified deliveries q_i be made at every point P_i (excepting the terminal point). If the capacity of the carrier

* Received November 1958
[1] *The* RAND *Corporation, Santa Monica, California*
[2] *The Atlantic Refining Company, Philadelphia, Pennsylvania*

80

Today's records

Efficiently Solving Very Large Scale Routing Problems



Today's records

Efficiently Solving Very Large Scale Routing Problems

Instance	D	L	CW			A-G-S (short)			A-G-S (long)		
			Value	Gap	T	Value	Gap	T	Value	Gap	T
L1 (3,000)	C	14.8	200,971	2.94	0.1	195,504	1.36	3.0	195,239	0.00	15.0
L2 (4,000)	E	85.1	125,613	9.39	0.1	117,839	2.62	4.0	114,833	0.00	20.0
A1 (6,000)	C	17.5	498,422	3.06	0.1	484,647	0.22	6.0	483,606	0.00	30.0
A2 (7,000)	E	58.3	322,902	7.85	0.1	304,419	1.68	7.0	299,398	0.00	35.0
G1 (10,000)	C	20.6	490,783	3.0	0.1	478,174	0.35	10.0	476,489	0.00	50.0
G2 (11,000)	E	100	287,371	7.25	0.1	271,350	1.27	11.0	267,935	0.00	55.0
B1 (15,000)	C	29.3	532,558	4.0	0.1	516,042	0.77	15.0	512,089	0.00	75.0
B2 (16,000)	E	87.9	386,048	7.01	0.1	367,561	1.89	16.0	360,760	0.00	80.0
F1 (20,000)	C	29.2	7,525,575	2.78	0.1	7,352,810	0.42	20.0	7,321,847	0.00	100.0
F2 (30,000)	E	117.2	4,805,608	6.16	0.1	4,618,954	2.04	30.0	4,526,789	0.00	150.0
Average				5.34	0.1		1.14	12.2		0.00	61.0

Contents

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

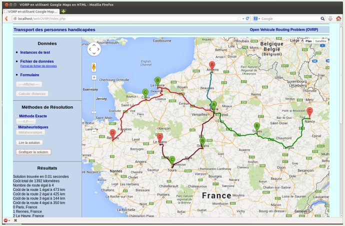
Objective

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 & S = 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

Contents

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

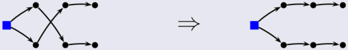
List of neighborhoods (cont'd)

Inter route moves

Relocate (feasible)

Path-Exchange – Cross/ICross Exchange (feasible)

2-Opt* (feasible)

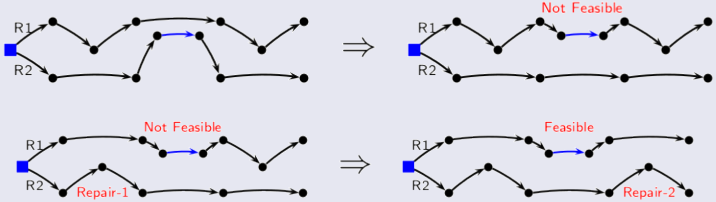


List of neighborhoods (cont'd)

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: $s^\star \leftarrow s$
Init: $k \leftarrow 1$
while *stopping conditions not satisfied* **do**
    $s \leftarrow \text{TabuSearch}(\mathcal{N}_{inter}(s))$; Update $s^\star$
    $s \leftarrow \text{TabuSearch}(\mathcal{N}_{intra}(s))$; Update $s^\star$
    $s \leftarrow \text{TabuSearch}(\mathcal{N}_k(s)))$; Update $s^\star$
    if $k = 3$ **then** $k \leftarrow 1$
    else $k \leftarrow k + 1$
    Update stopping condition parameters
end

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And now, what about the real problem?

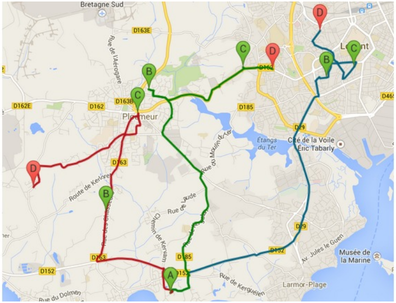
Kerpape is not really taking care of transportation

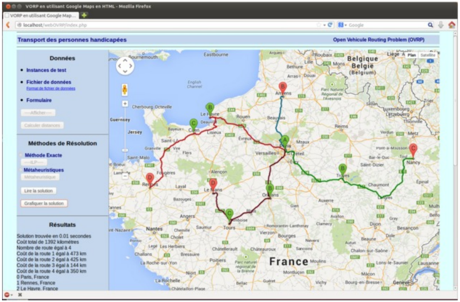
- taxis are in charge of patients
- minivans from Kerpape can be used
- → combination of open and close tours
- → distance objective is replaced by a cost objective

All transportation costs are at the expense of social security!

Any return for us?

Yes!!!, it was our first experience with graphical interfaces. . .





And with this, we are ready to sell our work to industry.

And how do the MNS-TS behave today?

An enormous effort has been made to update the MNS-TS code (many thanks to Flavien!)

Performance on the largest CVRP instances

Instances	Init. sol.		Final sol.		AGS
L1 (3000)	1.98%	0.9m	1.50%	3.2m	15m
L2 (4000)	5.17%	1.7m	4.84%	2.5m	20m
A1 (6000)	1.86%	4.1m	1.49%	12m	30m
A2 (7000)	4.19%	5.1m	3.70%	10m	35m
G1 (10000)	1.59%	12m	1.35%	33m	50m
G2 (11000)	3.62%	13m	3.32%	19m	55m
B1 (15000)	2.17%	25m	1.89%	70m	75m

Conclusion: our MNS-TS is safe enough to be used for other VRP variants

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Ideas where the stochastic part may come from?

Before stochastic parameters, reality is already more complicated
$\rightarrow$ 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

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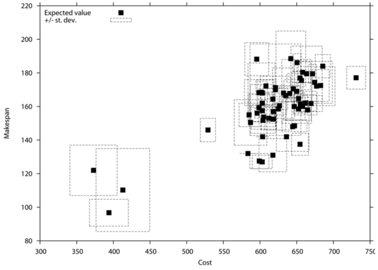
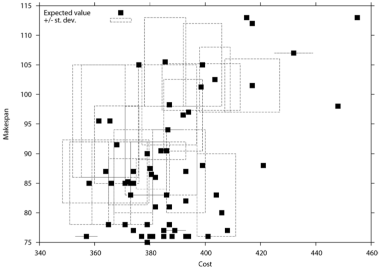
Multiobjective Stochastic CARP = Waste collection

MOSCARP

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 (NSGA-II + LS)



Initial population



After 100 iterations

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Example of RETRITEX

A specific encounter $\rightarrow$ 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 a very interesting problem

- 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

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Dynamic Stochastic Periodic VRP with Intermediate Facilities (+ capacity)

The RETRITEX company example

Problem description

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

Dynamic Stochastic Periodic VRP with Intermediate Facilities (+ capacity)

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

RETRITEX stock at the depot

RETRITEX final products

Lessons learnt from RETRITEX

Project stopped because lack of fundings ☹

But we are now convinced that we need

- a good algorithm basis .... ✓
- a nice interface .... ✗
- real distances calcultation .... ✗
- real maps (google-like) .... ✗
- clickable, zoomable, with visible routes .... ✗

Contents

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Mobility in evolution

Car and truck mobility more and more restricted

- CRIT'Air tags in France
- Restricted zones in city centre
- Tolls for city centre access
- Pedestrian zones (shared with vehicles)
- Electric vehicles (even microvans)
- Increasing cost for parking

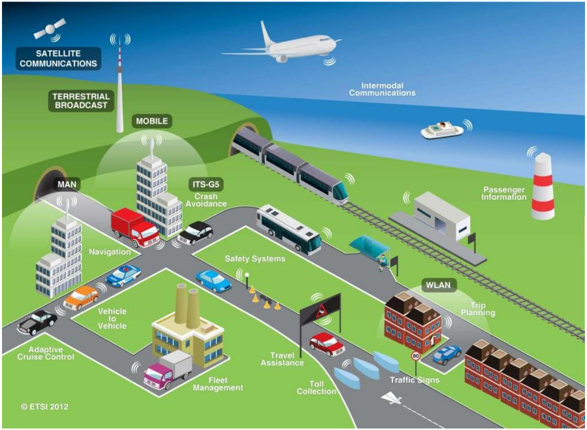
Mobility in evolution

Car and truck mobility more and more restricted

- CRIT'Air tags in France
- Restricted zones in city centre
- Tolls for city centre access
- Pedestrian zones (shared with vehicles)
- Electric vehicles (even microvans)
- Increasing cost for parking

→ How could we still reach the city centres for logistic?

Connected mobility



Contents

Goals

Global objectives

- Improve the urban transportation problems
- Being able to answer tomorrow's challenges
- Use massive open data available
- Combine OR and Machine Learning

Our variant of the CVRP

Objective: minimize the global cost of the routes

Several types of vehicles

- Different speeds
- Different capacities
- Restricted access zones

Prediction from real data

Collect data

Predict travel times

1. Spatio-temporal clustering
   - Laharott et al. 2015
   - Lopez et al. 2017
2. Machine Learning
   - Zhong et al. 2017
   - Elfar et al. 2018

→ **Random Forests**

→ `v-traffic.com`

React depending on traffic congestion

- Collect data in real time
- Compare with prediction
  - Detect increasing traffic in used roads
  - Detect decreasing traffic on not-used roads
- Adapt dynamically the routes
  - Quick modification (short repair)
  - Neighborhood search (long repair)
- Store the experience as new data to be exploited later
- ...

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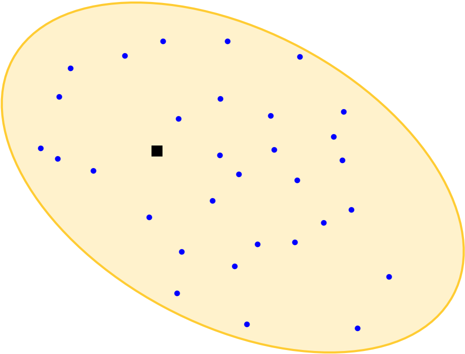
Example

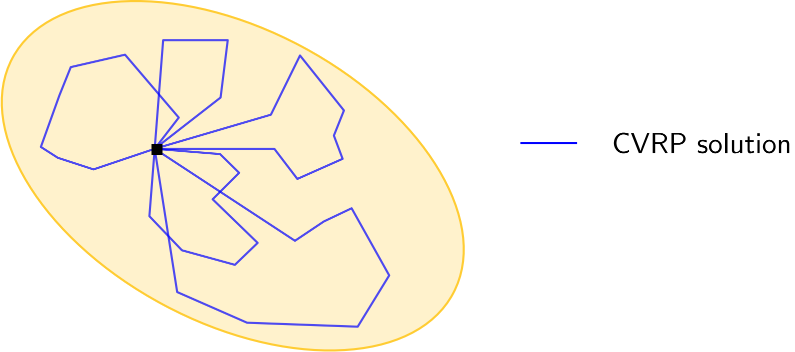


1 Depot

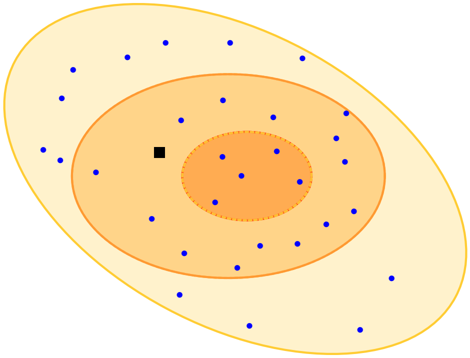
5 Vehicles

8 Customers max / vehicle

Example



Example

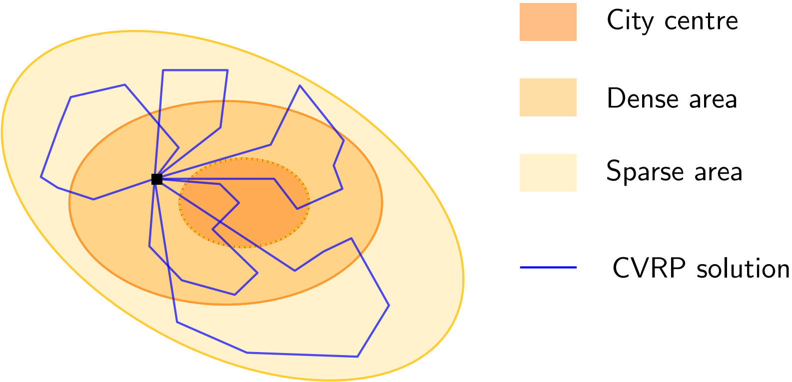


City centre

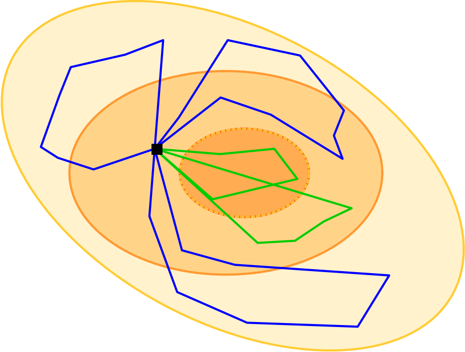
Dense area

Sparse area

Example



Example



City centre

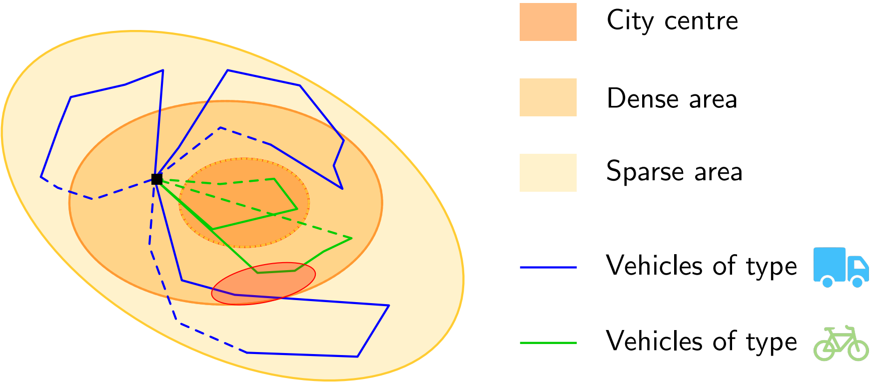
Dense area

Sparse area

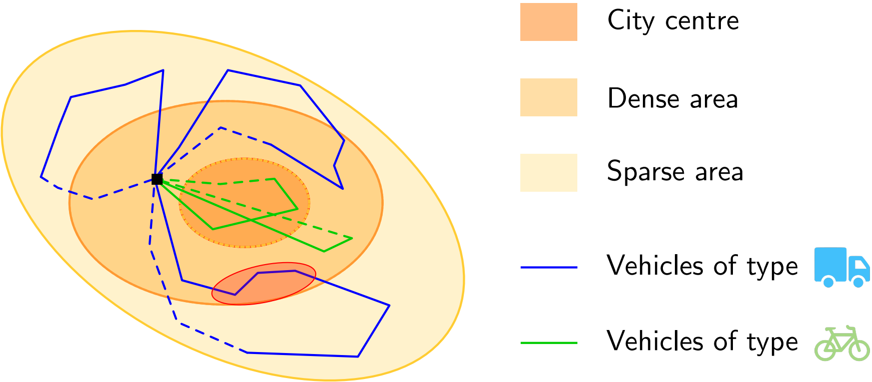
Vehicles of type (truck)

Vehicles of type (bicycle)

Example


City centre
Dense area
Sparse area
Vehicles of type
Vehicles of type

Example


City centre
Dense area
Sparse area
Vehicles of type
Vehicles of type

Prediction from previous results

Combine machine learning and OR

- Learn
  - Instance generation
  - Resolution
  - Learning
- Create an initial solution
- Solve
- React & adapt

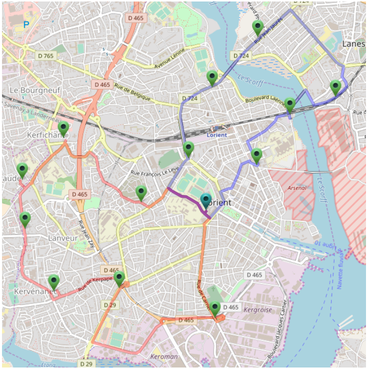
A new way of research

Many open questions

- How making the resolution really dynamic?
- Real data exploitation
- Which performance level?
  - Size of the instances
  - Running time
  - Reaction time (in case of event)

Operational aims

- Several types of vehicles
- Industrial expectation for performances
- Real data
- Restricted areas
- Dynamic resolution
- Simlulation platform
- Need for efficient interface



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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. . .

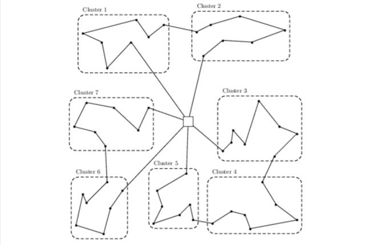
In the past years, several projects were addressed:

- 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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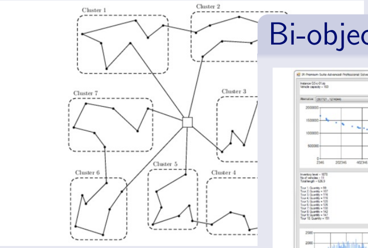
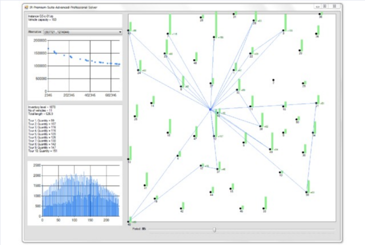
Clustered CVRP



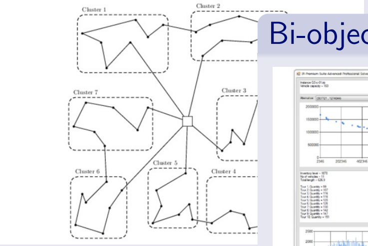
Bi-objective IRP



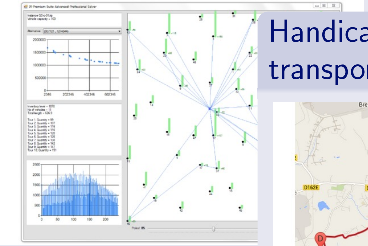
Interfaces

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

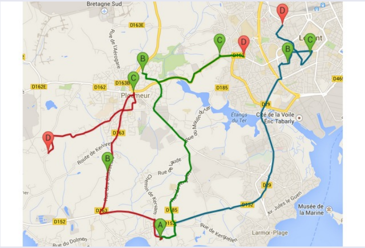
Clustered CVRP



Bi-objective IRP



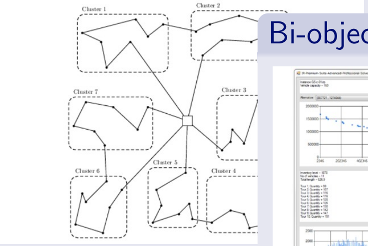
Handicapped people transportation



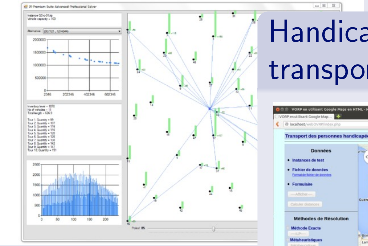
Interfaces

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

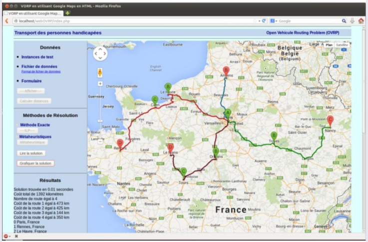
Clustered CVRP



Bi-objective IRP



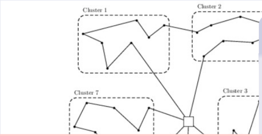
Handicapped people transportation



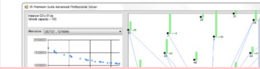
Interfaces

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

Clustered CVRP



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

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Demo

Let's cross our fingers...

`http://labsticc.univ-ubs.fr/WS4RP/V2/`

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Enjoy the lab sessions with captain Pierre Bomel ;-)

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