LocalSolver

Solving the Capacitated Arc Routing Problem with LocalSolver in an industrial context

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www.localsolver.com

LocalSolver

Optimization & Decision-Making Tool

- A generic, powerful solver
- 200 customers, 10,000 users, 25 countries
- Linear, non-linear and collection modeling
- Exact and heuristic techniques
- Quality solutions in seconds

Business problem

Public Asset Maintenance

Business problem : public asset maintenance

- Client's Goal: Efficient public asset maintenance.
    - Traverse entire road network within a specified area.
    - Service each road segment once.
- Constraints & Objectives:
    - Minimize total travel time and operational costs.
    - Navigate through various factors:
        - Traffic direction.
        - Speed limits.
- Desired Outcome:
    - Optimized route selection.
    - Boosted productivity and reduced overheads.

Arc routing: the underpinning concept

- Defining Arc Routing:
  - Routes are designed on arcs (or edges) rather than vertices (or nodes).
  - Ideal for problems where service is needed on roads/lanes, not at specific points.
- Ubiquity in the Industry:
  - Chinese Postman Problem (Classic example).
  - Other applications include snow removal, street cleaning, and mail delivery.
- Why It Matters:
  - CARP (Capacitated Arc Routing Problem) is NP-hard.
  - Solutions are computationally intensive and time-consuming.
  - The state-of-the-art usually involves heuristics like tabu search.
- Our Challenge:
  - Mapping the business problem to CARP.
  - Seeking optimal routes that fulfill constraints and minimize costs.

Our approach

Problem resolution

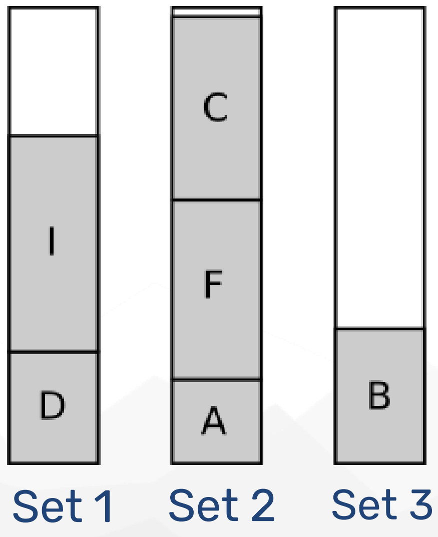
LocalSolver set modelling

Set

```
x <- set(n);
```

x : subset of {0, 1, …, n-1}

- unicity
- Variable size

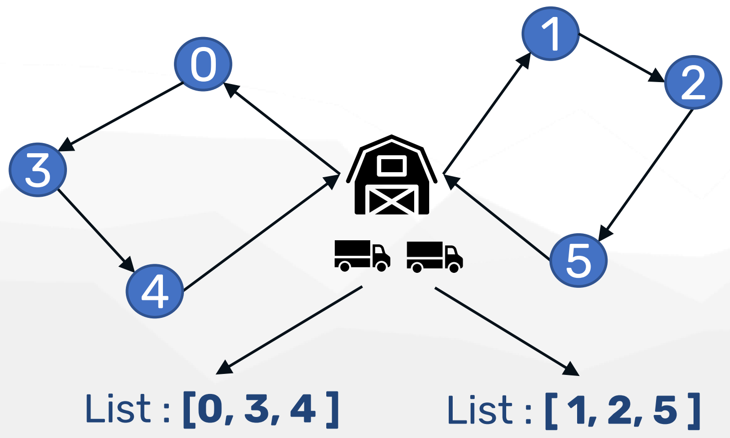


List

```
y <- list(n);
```

y : permutation of a subset of {0, 1, …, n-1}

- unicity
- Variable size
- **order**



LocalSolver set modelling: TSP example

```
function model() {
    // A list variable
    cities <- list(nbCities);

    // All cities must be visited
    constraint count(cities) == nbCities;

    // Minimize the total distance
    obj <- sum(1..nbCities-1, i =>
                distance[cities[i-1]][cities[i]])
              + distance[cities[nbCities-1]][cities[0]];

    minimize obj;
}
```

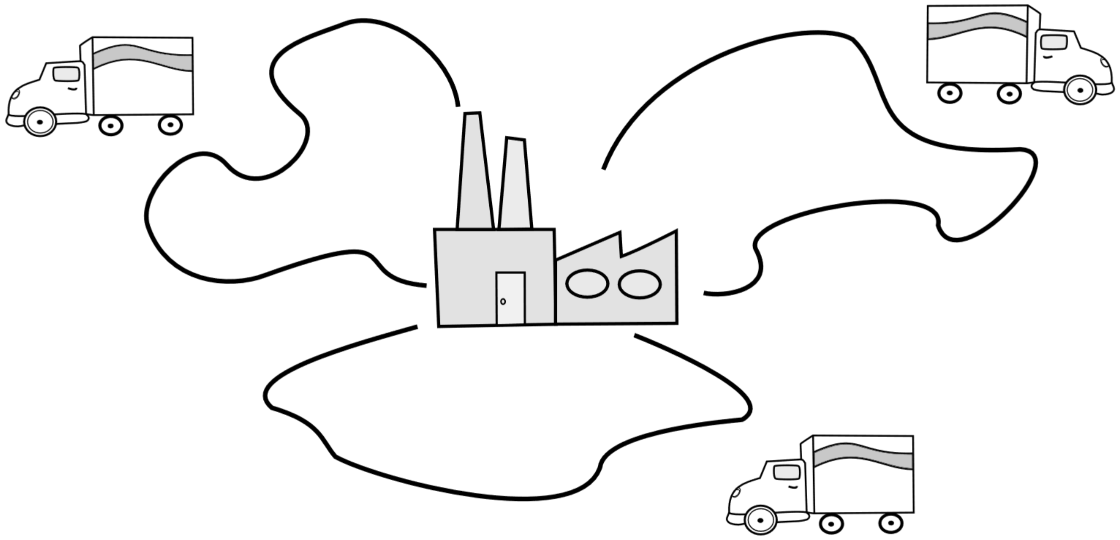
```
PS C:\localsolver_11_0\examples\tsp> localsolver .\tsp.lsp inFileName=
LocalSolver 11.0.20220214-Win64. All rights reserved.
Load .\tsp.lsp...
Run input...
Run model...
Run param...
Run solver...

Model:  expressions = 495, decisions = 1, constraints = 1, objectives
Param:  time limit = 60 sec, no iteration limit

[objective direction ]:     minimize

[  0 sec,       0 itr]: No feasible solution found (infeas = 2)
[  1 sec,   40639 itr]:         3036
[  2 sec,  105606 itr]:         2835
[  3 sec,  161355 itr]:         2787
[  4 sec,  223548 itr]:         2751
[  5 sec,  223548 itr]:         2751
[  6 sec,  342635 itr]:         2725
[  7 sec,  342635 itr]:         2725
[  7 sec,  404510 itr]:         2720
[ optimality gap     ]:           0%

404510 iterations performed in 7 seconds

Optimal solution:
  obj    =         2720
  gap    =           0%
  bounds =         2720
```

$$\sum_{i=1}^{n-1} distance[C_{i-1}][C_i]$$

LocalSolver set modelling: VRP example

Multiple trucks available:

```
tours[k] <- list(nbClients);
constraint partition(tours);
```



Capacity constraint for each tour k

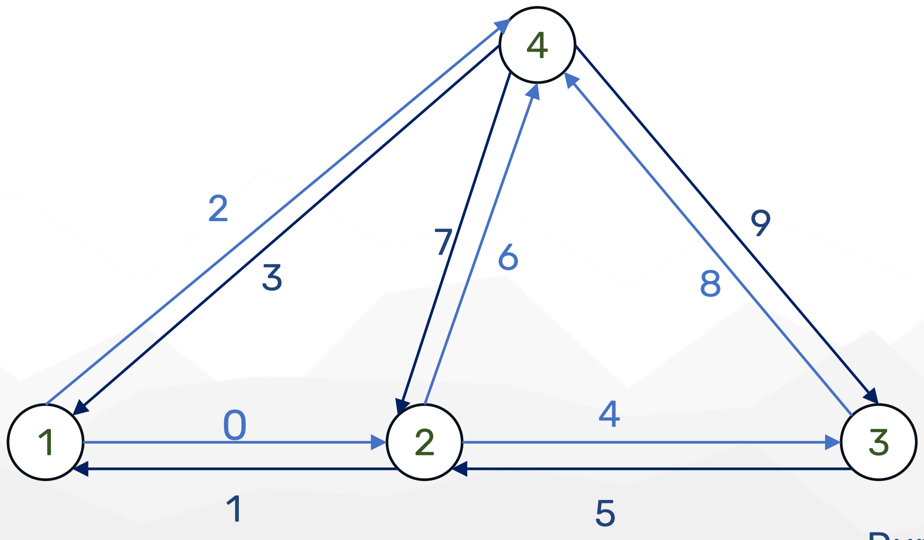
```
sum(tours[k], c => quantity[c]) <= capa;
```

$$\sum_{c \in tours[k]} quantity[c] \leq capa$$

Variadic number of elements in the sum

LocalSolver set modelling: CARP

- Duplicate edges of the graph and associate a unique number
  - Only one direction of the edge can be serviced
- List variable to model vehicles



edges = [(1, 2), (2, 1), (1, 4), (4, 1), (2, 3), (3, 2), (2, 4), (4, 2), (3, 4), (4, 3)]

edges = [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]

Duplicate values are **alternatives**

LSP model overview

```
// Sequence of edges visited and "serviced" by each truck
// A sequence can contain an edge in one direction or its reverse
edgesSequences[k in 0..nbTrucks-1] <- list(2 * nbRequiredEdges);

// An edge must be serviced by at most one truck
constraint disjoint(edgesSequences);

// An edge can be travelled in both directions, but its demand must be satisfied only once
for [i in 0..nbRequiredEdges-1] {
 constraint contains(edgesSequences, 2 * i) + contains(edgesSequences, 2 * i + 1) == 1;
}
```

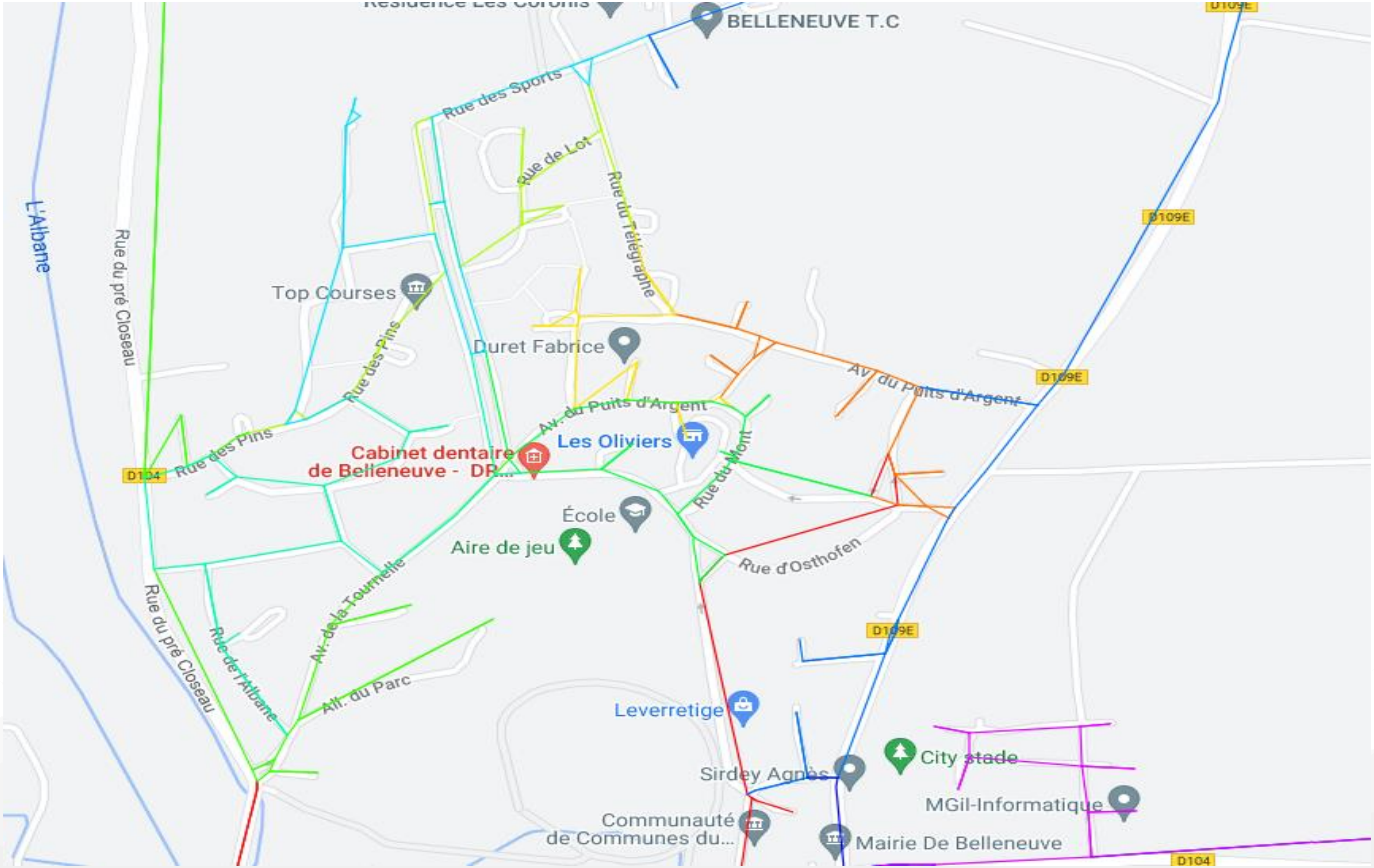
LSP model overview

```
for [k in 0..nbTrucks-1] {
    local sequence <- edgesSequences[k];
    local c <- count(sequence);

    // Quantity in each truck
    routeQuantity <- sum(0..c-1, i => requiredEdgesDemands[sequence[i]]);

    // Capacity constraint : a truck must not exceed its capacity
    constraint routeQuantity <= truckCapacity;

     // Distance travelled by each truck
    routeDistance[k] <- sum(1..c-1, i => requiredEdgesCosts[sequence[i]]
            + distanceBetweenEdges[sequence[i - 1]][sequence[i]])
            + (c > 0 ? requiredEdgesCosts[sequence[0]] + distanceFromDepot[sequence[0]]
            + distanceToDepot[sequence[c - 1]] : 0);
}
```

LSP model overview

```
// Total distance travelled
totalDistance <- sum[k in 0..nbTrucks-1](routeDistance[k]);

// Objective: minimize the distance travelled
minimize totalDistance;
```

Results obtained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Communauté
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Numeric results

- J. Brandão, et R. Eglese. A Deterministic Tabu Search Algorithm for the Capacitated Arc Routing Problem (CARP), Computers & Operations Research., 2008
- 34 instances of 3 categories
  - 98 edges
  - 190 edges
  - 375 edges

Results

Instance	Gap to BK in 60 sec	Gap to BK in 600 sec
98	**0.27%**	**-0.19%**
egl-e1-A	0.00%	0.00%
egl-e1-B	0.60%	0.00%
egl-e1-C	0.32%	0.00%
egl-e2-A	0.00%	0.00%
egl-e2-B	0.11%	-0.36%
egl-e2-C	0.55%	-0.71%
egl-e3-A	0.00%	0.00%
egl-e3-B	0.18%	-0.22%
egl-e3-C	-0.33%	-0.58%
egl-e4-A	0.05%	0.05%
egl-e4-B	0.81%	0.18%
egl-e4-C	0.93%	-0.65%

Results

Instance	Moyenne de Gap to BK en 60 sec	Moyenne de Gap to BK en 600 sec
98	**0.27%**	**-0.19%**
190	**1.25%**	**0.03%**
egl-s1-A	0.00%	0.00%
egl-s1-B	-0.73%	-0.73%
egl-s1-C	0.76%	0.00%
egl-s2-A	2.29%	0.07%
egl-s2-B	4.86%	2.85%
egl-s2-C	0.18%	-1.09%
egl-s3-A	0.83%	0.09%
egl-s3-B	-0.52%	-1.43%
egl-s3-C	1.76%	0.31%
egl-s4-A	1.01%	-0.44%
egl-s4-B	-0.33%	-0.93%
egl-s4-C	4.89%	1.68%

Results

Instance	Moyenne de Gap to BK en 60 sec	Moyenne de Gap to BK en 600 sec
98	**0.27%**	**-0.19%**
190	**1.25%**	**0.03%**
375	**0.32%**	**-0.45%**
egl-g1-A	-0.30%	-0.81%
egl-g1-B	1.84%	0.84%
egl-g1-C	-0.01%	-0.38%
egl-g1-D	0.94%	0.28%
egl-g1-E	2.33%	0.94%
egl-g2-A	0.54%	-0.54%
egl-g2-B	-0.46%	-1.01%
egl-g2-C	-2.32%	-2.63%
egl-g2-D	0.18%	-0.84%
egl-g2-E	0.50%	-0.34%

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