# Two heuristic approaches for solving the Smart Waste Collection Routing Problem

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# WSmartRoute Project


New paradigm: **smart waste management**

The tool to be developed integrates:

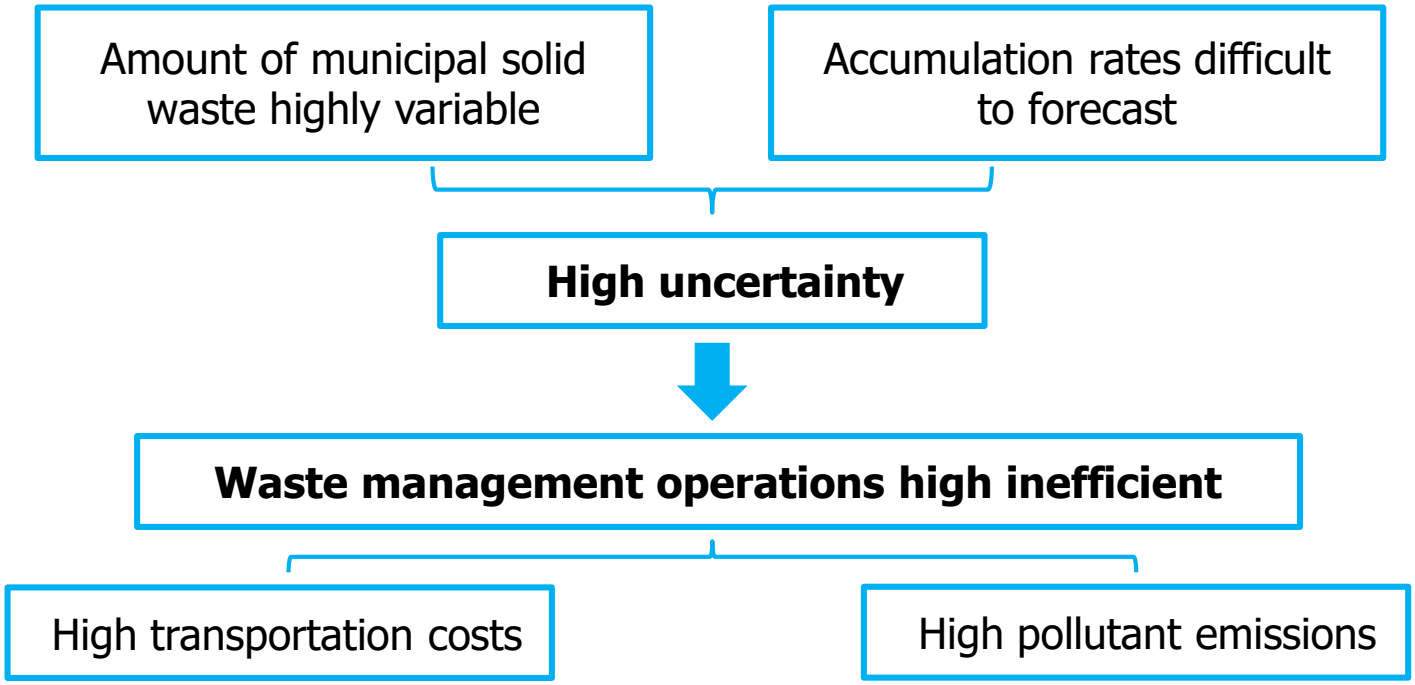
- Technology to obtain **real-time data** → **static to dynamic routes**
- **Management** concerns related to the routes

↓

Estimation of: a decrease of companies' operational costs of around **35%** and an increase of their kg/km ratio of **40%**

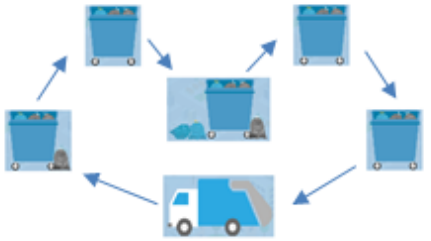
http://wsmartroute.tecnico.ulisboa.pt/

# Problem definition [1/3]



# Problem definition [2/3]

**"Blind collection"**: routes are **static** and vehicles visit partially full bins and empty bins.



**Smart Collection:** routes are **dynamically** defined to **maximize** operational **profit** and bins are visited taking into consideration fill levels transmitted by **volumetric sensors placed inside the bins** and accumulation rates (historical data).


**PROFIT** = revenues (recyclable waste collected) – collection transportation costs

# Problem definition [3/3]

**Decisions:**

- In which days should route(s) be performed?
- Which waste bins should be visited?
- Which is the optimal visiting sequence for each vehicle in each day that route(s) need to be performed?

**Objectives:**

- **Maximization of the profit: revenues obtained through recyclable waste collected – collection transportation costs**

**Constraints:**

- Vehicles capacity
- Bins' capacity

# Case study [1/2]

Case-study from a Portuguese company responsible for the recyclable waste (glass, paper/cardboard and plastic/metal) collection at 14 municipalities in Portugal.

Paper/cardboard: 26 different static routes performed periodically.

**Period:** 3rd January 2013 to 2nd February 2013 (30 days)

**Routes:** route 6 – 68 bins – collected 2 times in the period, route 11 - 74 bins - collected 3 times in the period and route 13 – 84 bins – collected 5 times in the period (total of 226 bins)

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# Case study [2/2]

| Date | 10/01 | 10/01 |
|---|---|---|
| Route | Route 6 | Route 13 |
| KPI | Day 8 | Day 8 |
| Profit (€) | -73.2 | 112.1 |
| Weight (kg) | 1420.4 | 2564.1 |
| Distance (km) | 208.2 | 131.5 |
| Attended bins | 68 | 84 |
| Empty visited bins | 26 | 7 |
| Ratio (kg/km) | 6.8 | 19.5 |
| Vehicles used | 1 | 1 |
| Vehicles usage rate (%) | 35.5 | 64.1 |

| KPI | Total | Average |
|---|---|---|
| Profit (€) | 636.3 | 63.6 |
| Weight (kg) | 22154.3 | 2215.4 |
| Distance (km) | 1468.4 | 146.8 |
| Attended bins | 778 | 78 |
| Empty visited bins | 81 | 8 |
| Ratio (kg/km) | 15.1 | 15.1 |
| Vehicles used | 10 | 1 |
| Vehicles usage rate (%) | - | 55.4 |

673 min 630min

66% of the collected waste bins had a fill-level equal or lower than 50%

# Optimization approach [1/2]

- **Heuristic** to decide in which days route(s) should be performed: if any bin is expected to overflow at a given day, route(s) should be performed on that day.

- **VRP with Profit (VRPP) mathematical model**: solved, in the morning, after receiving sensors' information on the bins' fill-level, when there is at least one waste bin expected to overflow.

# Optimization approach [2/2]

| KPI | Day 1 | Day 6 | Day 13 | Day 20 | Day 25 | Day 30 | Total | Average |
|---|---|---|---|---|---|---|---|---|
| Profit (€) | 253.1 | 186.9 | 224.4 | 223.9 | 147.9 | 106.7 | 1142.8 | 190.5 |
| Weight (kg) | 3999.6 | 3990.5 | 3953.6 | 3998.6 | 3781.5 | 2865.3 | 22589.2 | 3764.9 |
| Distance (km) | 126.8 | 192.2 | 151.2 | 155.9 | 211.3 | 165.5 | 1002.8 | 167.1 |
| Attended bins | 98 | 118 | 121 | 119 | 136 | 97 | 689 | 115 |
| \|L\| | 226 | 226 | 226 | 226 | 226 | 226 | 1356 | 226 |
| Ratio (kg/km) | 31.5 | 20.8 | 26.2 | 25.6 | 17.9 | 17.3 | 22.5 | 22.5 |
| Gap (%) | 2.8 | 7.3 | 6.3 | 9.4 | 13.4 | 10.6 | - | - |
| Computational time (s) | 16201.2 | 16203.7 | 16200.4 | 16201.1 | 16204.4 | 16203.2 | 97213.9 | 16202.3 |
| Vehicles used | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 1 |
| Vehicle Usage Rate (%) | 99.99% | 99.76% | 98.84% | 99.97% | 94.54% | 71.63% | - | 94.12% |
| | 693 min | 898 min | 847 min | 844 min | 1018 min | 750 min | | |

> 8h (480mins)

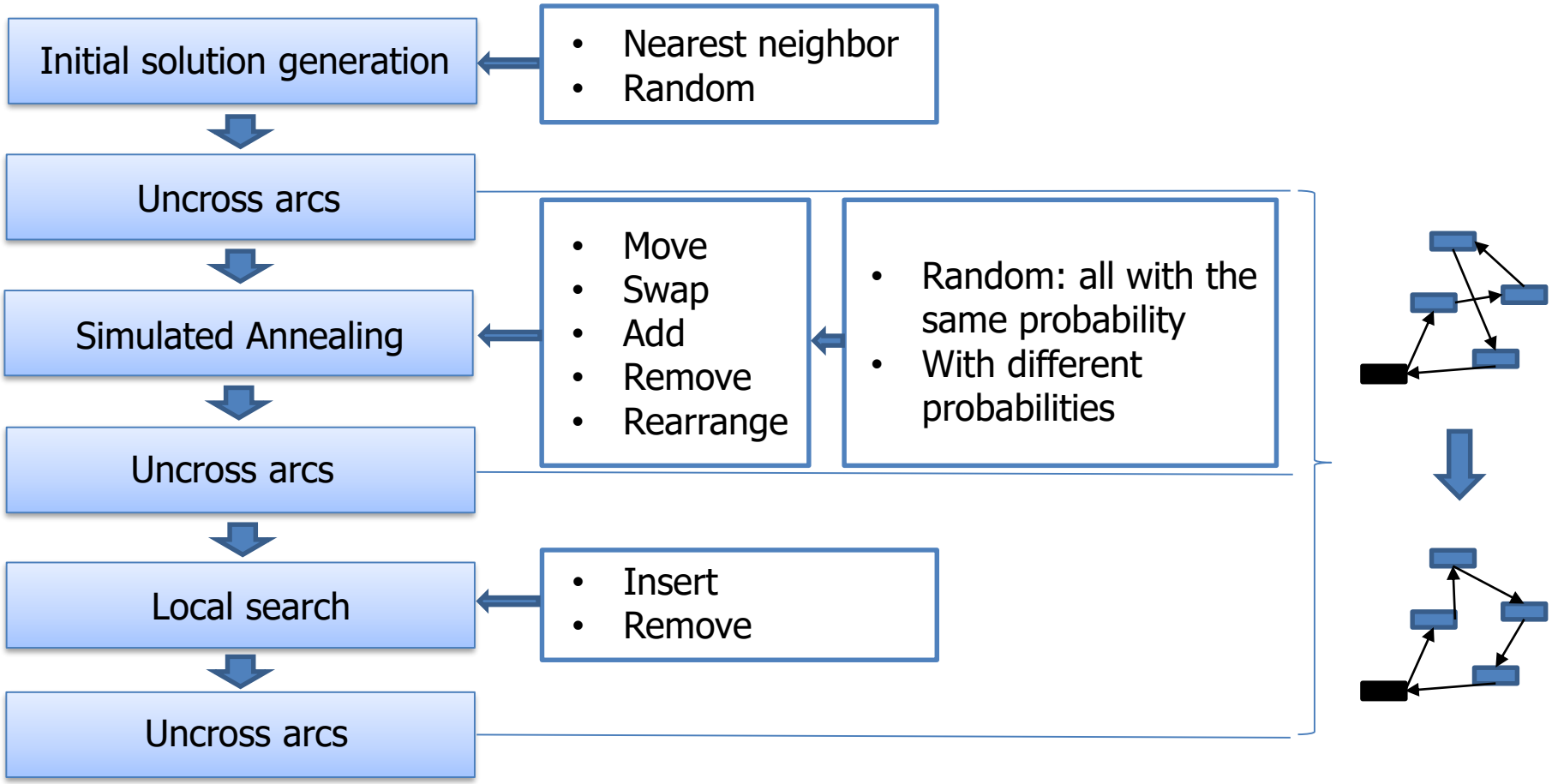
Low computational performance and low solution quality (significant gaps).

# Alternative solution approaches

Two **heuristic approaches** to better solve the SWCRP, improving the solution performance of the VRPP model.

- Optimization-based heuristic
- **Hybrid simulated-annealing/local-search metaheuristic**

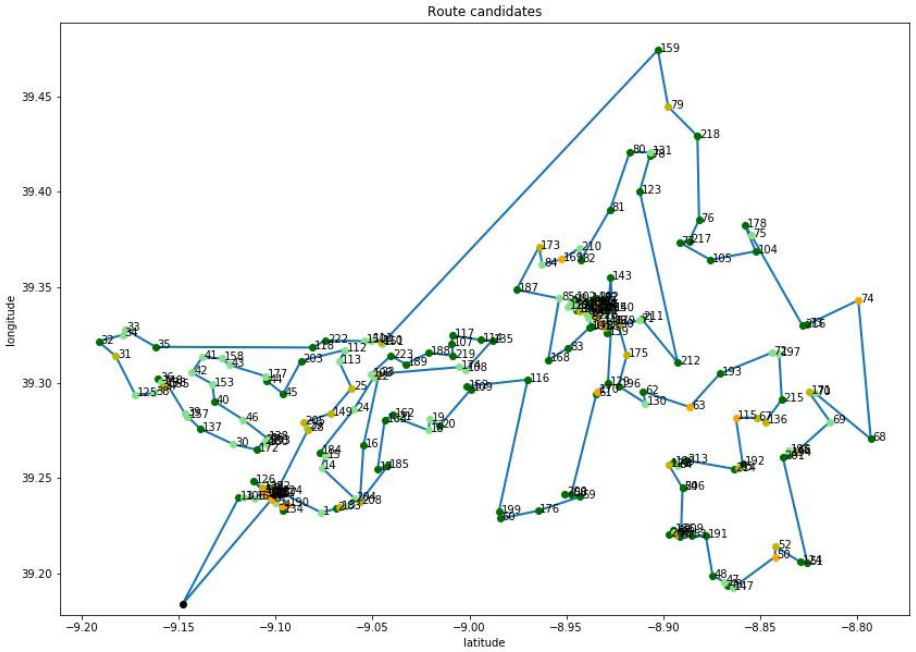
# Hybrid SA/LS metaheuristic



# Hybrid SA/LS metaheuristic results [1/2]

| KPI | Day 1 | Day 7 | Day 13 | Day 19 | Day 26 | Total | Average (/route) |
|---|---|---|---|---|---|---|---|
| **Profit (€)** | 242.36 | 134.35 | 185.94 | 157.83 | 213.66 | 934.14 | 155.69 |
| **Weight (kg)** | 5193.14 | 2974.61 | 2817.26 | 3427.66 | 3997.03 | 18409.70 | 3068.28 |
| **Distance (km)** | 250.79 | 148.14 | 193.93 | 167.70 | 166.03 | 926.59 | 154.43 |
| **Attended bins** | 144 | 92 | 129 | 120 | 115 | 600 | 100 |
| **Bins considered** | 226 | 226 | 226 | 226 | 226 | 1130 | 188.33 |
| **Ratio (kg/km)** | 20.71 | 20.08 | 14.53 | 20.45 | 24.07 | 16.66 | 16.66 |
| **Routes time (min)** | 445+656 | 687 | 945 | 858 | 831 | 4422 | 737 |
| **Computational time (s)** | 2130 | 1725 | 2081 | 2058 | 1998 | 9990 | 1665 |
| **Vehicles used** | 2 | 1 | 1 | 1 | 1 | 6 | 1 |
| **Vehicle usage rate (%)** | 64.91 | 74.37 | 70.43 | 85.62 | 99.93 | - | 65.88 |

# Hybrid SA/LS metaheuristic results [2/2]



# Shift duration and route balance

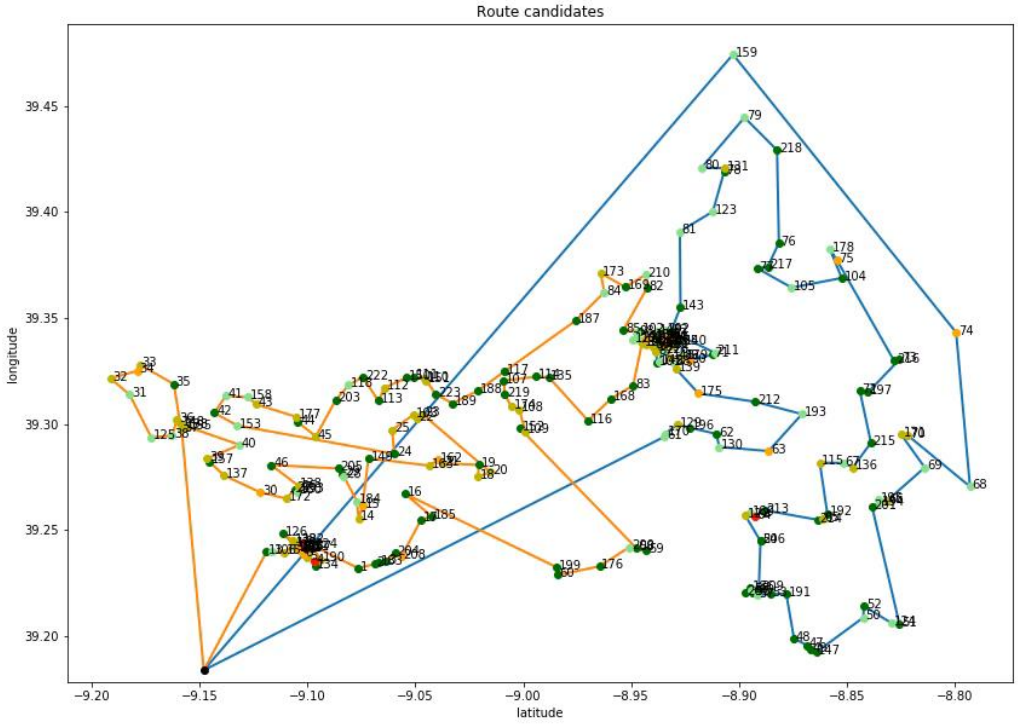
**Additional constraints:**

- Shift duration: 8h shifts
- Route balance: routes performed on the same day should be similar in terms of duration

# Shift duration and route balance results – Hybrid SA/LS results [1/2]

| KPI | Day 1 | Day 7 | Day 13 | Day 19 | Day 26 | Total | Average (/route) |
|---|---|---|---|---|---|---|---|
| **Profit (€)** | 202.74 | 98.69 | 153.21 | 91.82 | 174.91 | 721.37 | 80.15 |
| **Weight (kg)** | 4687.94 | 2515.65 | 4175.55 | 3633.57 | 3865.35 | 18878.06 | 2097.56 |
| **Distance (km)** | 242.41 | 140.20 | 243.27 | 253.16 | 192.85 | 1071.89 | 119.10 |
| **Attended bins** | 113 | 54 | 118 | 116 | 105 | 506 | 56 |
| **Bins considered** | 226 | 226 | 226 | 226 | 226 | 1130 | 226 |
| **Ratio (kg/km)** | 19.34 | 17.94 | 17.16 | 14.35 | 20.05 | 9.87 | 9.87 |
| **Routes time (min)** | 466+466 | 484 | 480+479 | 481+484 | 407+405 | 4152 | 461 |
| **Computational time (s)** | 2164 | 1366 | 1898 | 1845 | 1525 | 8798 | 977.56 |
| **Vehicles used** | 2 | 1 | 2 | 2 | 2 | 9 | 1 |
| **Vehicle usage rate (%)** | 58.60 | 62.89 | 52.19 | 45.42 | 48.32 | - | 29.71 |

# Shift duration and route balance results – Hybrid SA/LS results [2/2]



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# Solutions comparison

| Solution | Current | | Optimization | | Hybrid SA/LS | | Hybrid SA/LS + shift duration + route balance | |
|---|---|---|---|---|---|---|---|---|
| **KPI** | **Total** | **Average** | **Total** | **Average** | **Total** | **Average** | **Total** | **Average** |
| **Profit (€)** | 636.3 | 63.6 | 1142.8 | 190.5 | 934.14 | 155.69 | 721.4 | 80.2 |
| **Weight (kg)** | 22154.3 | 2215.4 | 22589.2 | 3764.9 | 18409.0 | aprox. 18.3% lower | | 097.6 |
| **Distance (km)** | 1468.4 | 146.8 | 1002.8 | 167.1 | 926.59 | 154.43 | 1071.9 | 119.1 |
| **Attended bins** | 778 | 78 | 689 | 115 | 600 | 100 | 506 | 56 |
| **Bins considered** | 2260 | 226 | 1356 | 226 | 1130 | 188.33 | 1130 | 226 |
| **Ratio (kg/km)** | 15.1 | 15.1 | 22.5 | 22.5 | 16.66 | 16.66 | 9.9 | 9.9 |
| **Routes time (min)** | 6239 | 624 | 5050 | 842 | 4422 | aprox. 10 times lower | | 61 |
| **Computational time (s)** | - | - | 97213.9 | 16202.3 | 9990 | 1665 | 8798 | 977.6 |
| **Vehicles used** | 10 | 1 | 6 | 1 | 6 | 1 | 9 | 1 |
| **Vehicle usage rate (%)** | - | 55.4 | - | 94.1 | - | 65.88 | - | 29.7 |

# Conclusions

- Both optimization and hybrid SA/LS approaches are more efficient when defining more profitable routing plans than what happens in the current situation.
- The hybrid SA/LS metaheuristic is much faster than the optimization approach. However, the profit is a little lower when SA/LS metaheuristic is utilized.
- When shift duration and route balance constraints are introduced, the SA/LS metaheuristic proved to be efficient in dealing with these additional constraints.
- After introducing these constraints, the solution is still more profitable than the current situation performed by the company.

# THANK YOU FOR YOUR ATTENTION

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