Two heuristic approaches for solving the Smart Waste Collection Routing Problem

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Outline

1. WSmartRoute Project
2. Problem definition
3. Case study
4. Optimization approach
5. Alternative solution approaches
6. Hybrid SA/LS metaheuristic
7. Hybrid SA/LS metaheuristic results
8. Shift duration and route balance
9. Shift duration and route balance – Hybrid SA/LS results
10. Solutions comparison
11. Conclusions

WSmartRoute Project

New paradigm: **smart waste management**

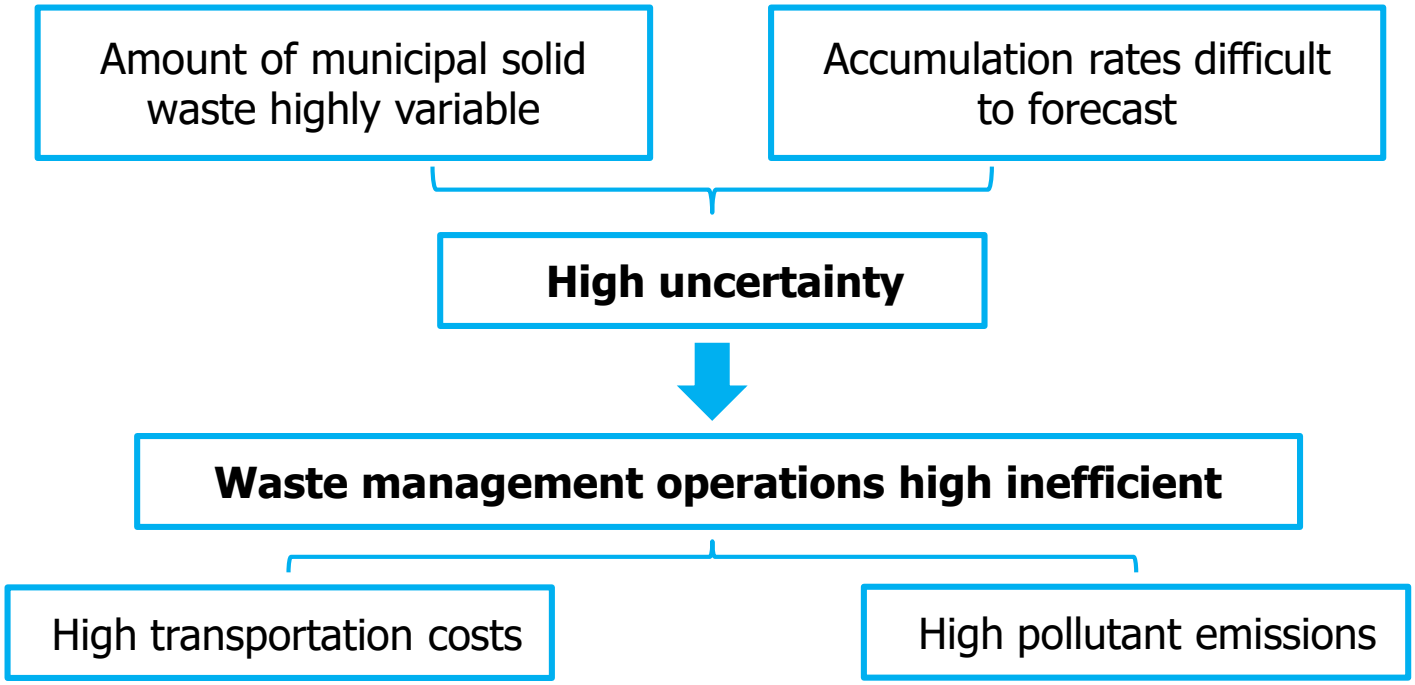
The tool to be developed integrates:

- 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%**

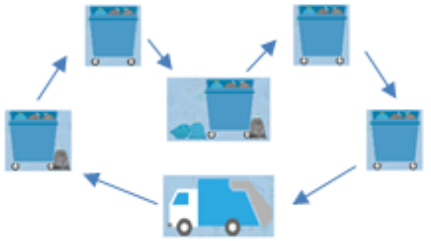
http://wsmartroute.tecnico.ulisboa.pt/

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).

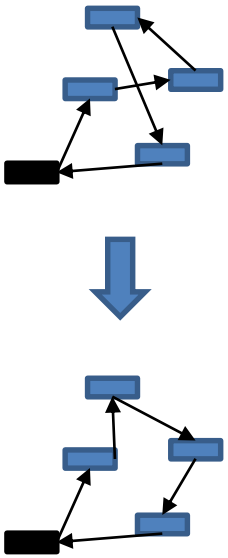
Alternative solution approaches

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

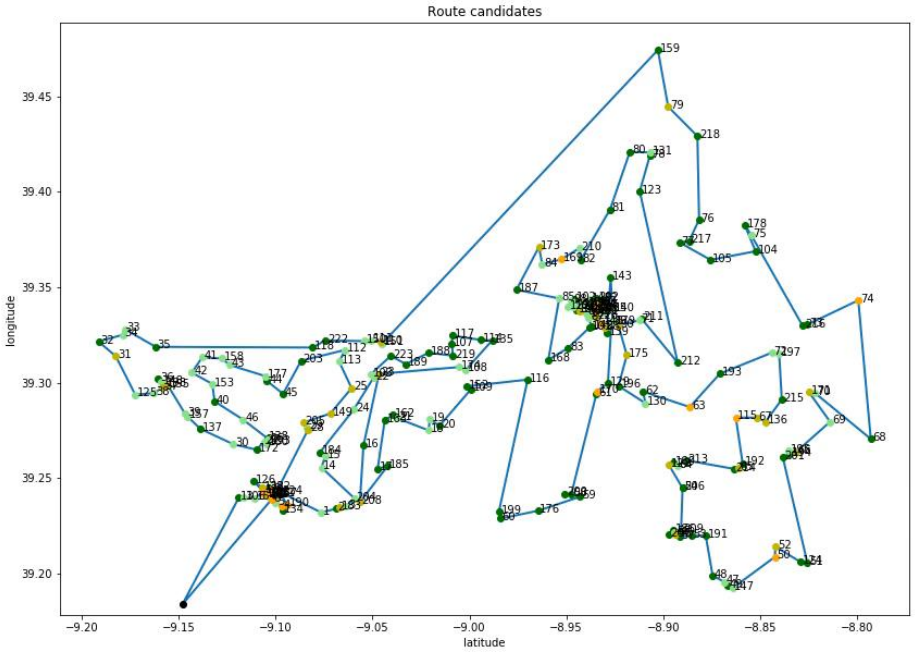
- Initial solution generation
  - Nearest neighbor
  - Random
- Uncross arcs
- Simulated Annealing
  - Move
  - Swap
  - Add
  - Remove
  - Rearrange
  - Random: all with the same probability
  - With different probabilities
- Uncross arcs
- Local search
  - Insert
  - Remove
- Uncross arcs



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

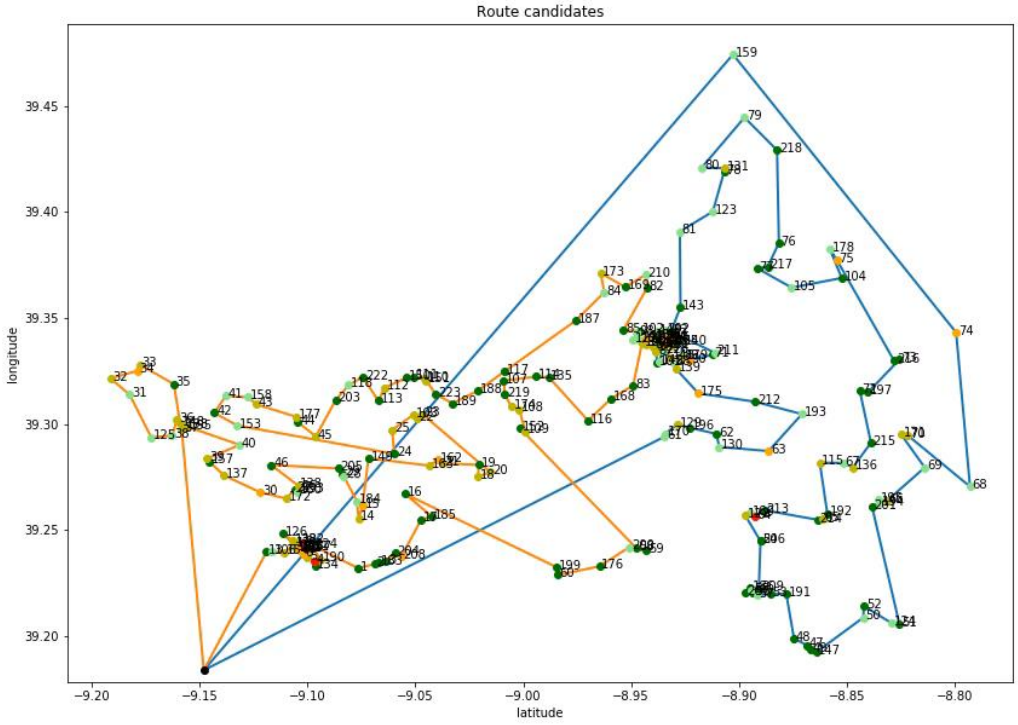
Additional constraints:

- 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.

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THANK YOU FOR YOUR ATTENTION

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