TÉCNICO LISBOA

Searching for a solution method for the Smart Waste Collection Routing Problem

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WSMARTROUTE

WSmartRoute Project

Aims to explore a new paradigm that relies on smart waste collection, where real-time data plays a central role in changing the way operations are managed today, moving from static to dynamic routes.

The tool to be developed will integrate technology with management concerns contributing to improve the companies' operations decision-making process.

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

Agenda

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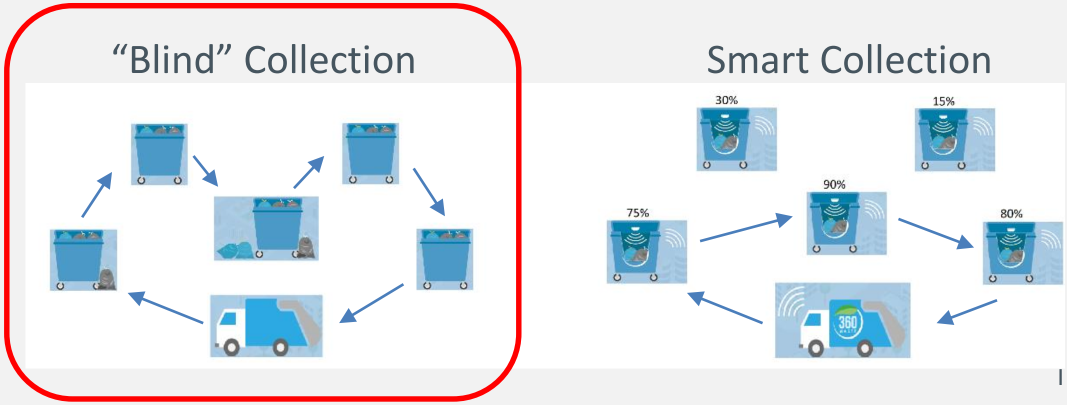
Introduction

Amount of municipal solid waste is highly variable, and its accumulation is difficult to forecast[1]: high uncertainty regarding bins' fill-levels.

As a result, Waste collection operations are particularly inefficient, characterized by high transportation costs and high pollutant emissions.

"Blind collection": static routes that visit all bins (some almost empty).



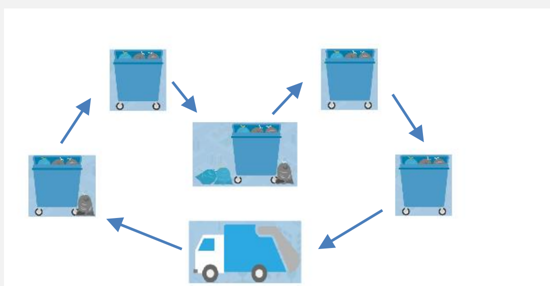
[1](Nuortio *et al.*, 2006)

Introduction

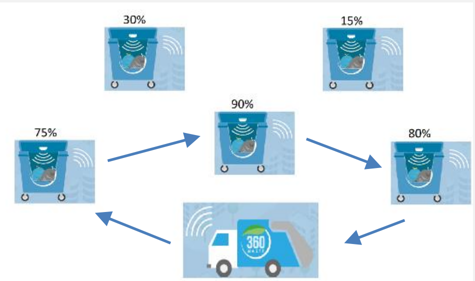
Smart Collection: requires the reduction of bins' fill-levels uncertainty through the installation of sensors and increase of collection operations' efficiency.

How?

"Blind" Collection



Smart Collection



The Smart Waste Collection Routing Problem

Use of real-time information on the bins' fill-level (transmitted by volumetric sensors placed inside the bins) to define dynamic collection routes that maximize daily operational profit[2];

Max PROFIT = revenues obtained from the recyclable waste collected - transportation costs of collecting that waste

Maximize waste collected while minimizing distance travelled

[2](Ramos *et al.*, 2018)

The Smart Waste Collection Routing Problem

Use of real-time information on the bins' fill-level (transmitted by volumetric sensors placed inside the bins) to define smart collection routes that maximize operational profit[2];

Max PROFIT = revenues obtained from the recyclable waste collected - transportation costs of collecting that waste

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Decision: To select the waste bins to be visited (if any) and the optimal visiting sequence in each day t for each vehicle k, which will maximize the profit while satisfying the vehicles' fixed capacity and preventing bin overflows.

The Smart Waste Collection Routing Problem

Decision: To select the waste bins to be visited (if any) and the optimal visiting sequence in each day *t* for each vehicle *k*, which will maximize the profit while satisfying the vehicles' fixed capacity and the bins' capacity

Defines when (in which day) the model should be run to prevent bin overflows.

Solution Approach:

Heuristic + VRP with Profit (VRPP) model[2]:

Model is solved at day t, in the morning, after receiving sensors' information on the bins' fill-level, when at least *H* waste bins are expected to overflow (to comply with the defined service level).

[2](Ramos *et al.*, 2018)

The Smart Waste Collection Routing Problem

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Decision: To select the waste bins to be visited (if any) and the optimal visiting sequence in each day *t* for each vehicle *k*, which will maximize the profit while satisfying the vehicles' fixed capacity and the bins' capacity

Solution Approach:
Heuristic + VRP with Profit (VRPP) model[2]:

KPI	Day 1	Day 7	Day 12	Day 18	Day 24	Day 25	Day 30	Total	Average
Profit (€)	261.0	131.2	154.1	143.6	131.6	-59.9	111.3	872.9	124.7
Weight (kg)	5158.4	2644.0	4019.7	3625.6	2874.1	1310.6	2833.5	22465.8	3209.4
Distance (km)	229.0	120.0	227.8	200.9	141.5	184.4	157.9	1261.4	180.2
Attended bins	138	77	151	134	105	95	94	794	113
Ratio (kg/km)	22.5	22.0	17.6	18.1	20.3	7.1	17.9	17.8	17.8
Gap	**8.0%**	**11.0%**	**7.0%**	**15.3%**	**16.2%**	**58.6%**	**20.3%**	**-**	**-**
Comp. Time (s)	**14400**	**14400**	**14400**	**14400**	**14400**	**14400**	**14400**	**100800**	**14400**
Vehicles used	2	2	2	2	2	2	2	14	2

[2](Ramos *et al.*, 2018)

Problem: Low computational performance

Objectives

To propose an optimization-based heuristic approach to solve the SWCRP, improving the solution performance of the VRPP mathematical model.

Computational experiments are performed to support the proposed method.

But, in what does it consist?

Optimization-based Heuristic

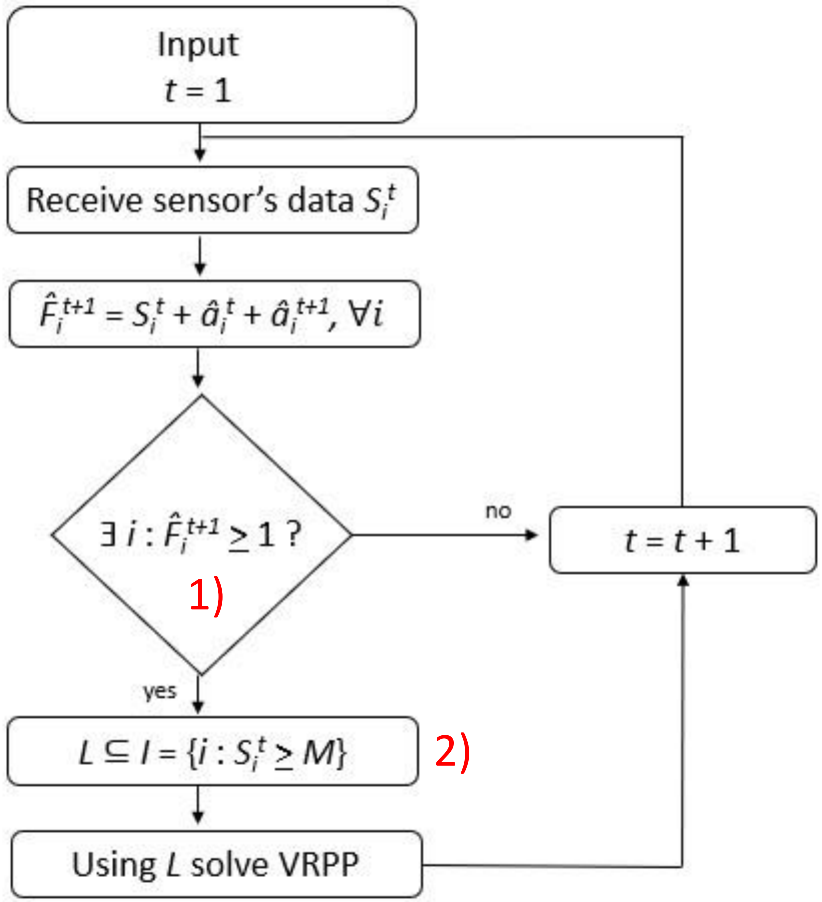
Optimization-based Heuristic

Decomposes the problem by reducing the set of waste bins to be inserted as input to the VRPP mathematical model

Cluster First - Route Second:

Selects a dynamic subset of waste bins to be considered, and then uses this dynamic set to feed the VRPP model that decides which waste bins are worth to be collected, considering their fill-levels and locations.

Optimization-based Heuristic



VRPP model is combined with two heuristics:

1) Waste bins are visited as late as possible

Heuristic procedure that defines when (in which day) the model should be run to maximize the profit within a time horizon;

2) Cluster First - Route Second

Heuristic rule that selects as a dynamic set of waste bins to be considered as an input for the VRPP model only those bins that have fill-levels higher than a defined threshold M. → Sensitive analysis

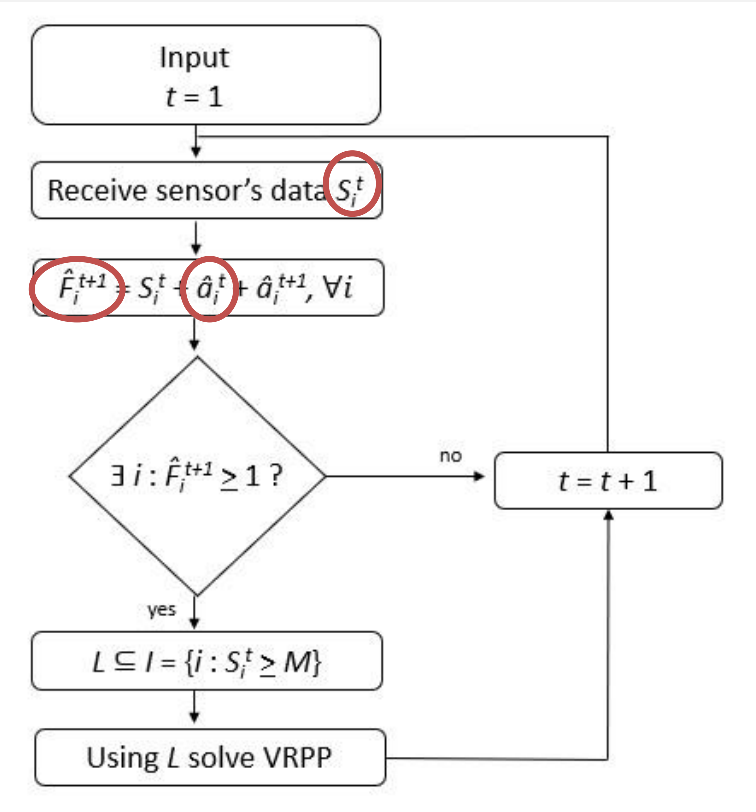
Optimization-based Heuristic

S_i^t: waste bins' fill-level → Sensors' information

$\hat{a}_i^t$: expected daily accumulation rate

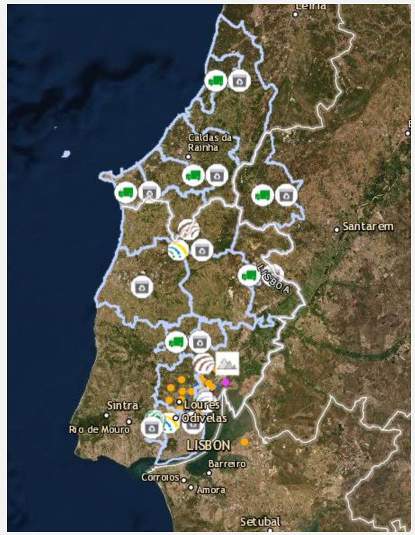
$\hat{F}_i^t$: estimate of the waste bins' fill-level at the end of day t

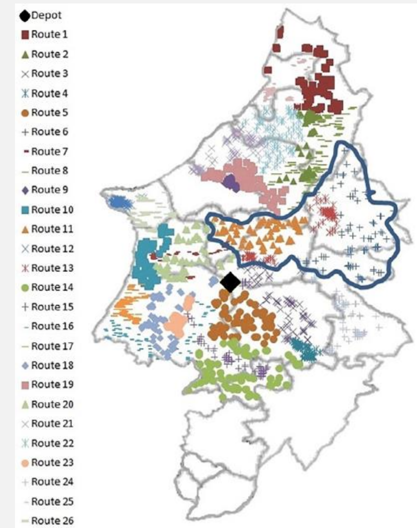
$\hat{F}_i^{t+1}$: estimate of the waste bins' fill-level at the end of day t+1



At day t, if there are waste bins about to overflow at t+1, then the waste bins for which the fill level S_{it} is higher than M are selected and, for those bins the model is solved and the routes are defined; if not, the next iteration is set to be carried out on the next day ($t = t$+1).

Results for real-case instance





Case-study from a portuguese company responsible for the recyclable waste collection at 14 municipalities in Portugal;

Recyclable materials: glass, paper/cardboard and plastic/metal;

Paper/cardboard: 26 different static routes performed periodically.

Routes number 6, 11 and 13
226 bins

3rd January - 2nd February
(T = 30 days)

Route 6 (68 bins): performed 2 times
Route 11 (74 bins): performed 3 times
Route 13 (84 bins): performed 5 times

Results for real-case instance

Case-study from a portuguese company responsible for the recyclable waste collection at 14 municipalities in Portugal;

Recyclable materials: glass, paper/cardboard and plastic/metal;

Paper/cardboard: 26 different static routes performed periodically.

Date	03/01	09/01	10/01	10/01	17/01	21/01	24/01	24/01	01/02	01/02		
Route	Route 13	Route 11	Route 6	Route 13	Route 13	Route 11	Route 6	Route 13	Route 11	Route 13		
KPI	Day 1	Day 7	Day 8	Day 8.	Day 15	Day 19	Day 22	Day 22.	Day 30	Day 30.	Total	Average
Profit (€)	117.5	94.0	-73.2	112.1	125.5	74.9	-77.1	81.7	73.5	107.6	636.3	63.6
Weight (kg)	2471.8	2342.7	1420.4	2564.1	2693.2	2250.5	1512.6	2195.1	2213.6	2490.3	22154.3	2215.4
Distance (km)	117.3	128.6	208.2	131.5	130.4	138.9	220.8	126.9	136.8	129.0	1468.4	146.8
Attended bins	84	74	68	84	84	74	68	84	74	84	778	78
Empty visited bins	6	17	26	7	7	2	1	7	2	6	81	8
Ratio (kg/km)	21.1	18.2	6.8	19.5	20.7	16.2	6.9	17.3	16.2	19.3	15.1	15.1
Vehicles used	1	1	1	1	1	1	1	1	1	1	10	1
Vehicles usage rate (%)	61.8	58.6	35.5	64.1	67.3	56.3	37.8	54.9	55.3	62.3	-	55.4

Results for real-case instance

Optimization-based heuristic

KPI	Day 1	Day 6	Day 13	Day 20	Day 25	Day 30	Total	Average
	M = 0%							
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%

KPI	Day 1	Day 6	Day 13	Day 19	Day 26	Day 29	Total	Average
	M = 10%							
Profit (€)	253.9	187.4	219.2	181.6	195.4	38.8	1076.3	179.4
Weight (kg)	3991.7	3968.0	3994.6	3994.6	3818.2	2490.9	22258.0	3709.7
Distance (km)	125.3	189.5	160.3	197.8	167.2	197.8	1037.9	173.0
Attended bins	88	112	119	140	111	113	683	114
|L|	124	121	154	165	158	131	853	142
Ratio (kg/km)	31.9	20.9	24.9	20.2	22.8	12.6	21.4	21.4
Gap (%)	0.0	2.6	5.8	7.8	5.9	27.9	-	-
Computational time (s)	3275.0	16205.3	16201.2	16203.1	16202.2	16202.6	84289.3	14048.2
Vehicles used	1	1	1	1	1	1	6	1
Vehicle usage rate (%)	99.79%	99.20%	99.86%	99.86%	95.46%	62.27%	-	92.74%

KPI	Day 1	Day 6	Day 13	Day 20	Day 25	Day 29	Total	Average
	M = 20%							
Profit (€)	253.9	166.1	193.8	220.6	137.8	80.3	1052.5	175.4
Weight (kg)	3991.7	3657.5	3616.4	3995.9	3409.1	2754.1	21424.8	3570.8
Distance (km)	125.3	181.3	149.7	159.0	186.0	181.2	982.5	163.8
Attended bins	82	90	114	104	110	100	600	100
|L|	114	98	137	132	135	114	730	122
Ratio (kg/km)	31.9	20.2	24.2	25.1	18.3	15.2	21.8	21.8
Gap (%)	0.0	3.6	4.8	4.6	5.4	13.3	-	-
Computational time (s)	883.7	16208.9	16204.7	16203.0	16202.9	16200.1	81903.3	13650.5
Vehicles used	1	1	1	1	1	1	6	1
Vehicle usage rate (%)	99.79%	91.44%	90.41%	99.90%	85.23%	68.85%	-	89.27%

KPI	Day 1	Day 7	Day 13	Day 19	Day 25	Day 29	Total	Average
	M = 30%							
Profit (€)	238.8	178.2	196.3	199.8	172.6	3.0	988.8	164.8
Weight (kg)	3976.8	3488.2	3421.9	3998.4	3512.2	1677.0	20074.5	3345.7
Distance (km)	139.0	153.1	128.8	180.0	161.0	156.2	918.0	153.0
Attended bins	75	70	82	95	87	43	452	75
|L|	96	78	96	129	98	53	550	92
Ratio (kg/km)	28.6	22.8	26.6	22.2	21.8	10.7	21.9	21.9
Gap (%)	0.0	5.5	0.0	4.2	0.0	75.0	-	-
Computational time (s)	6717.8	16210.0	1547.8	16203.9	1846.7	16200.0	58726.3	9787.7
Vehicles used	1	1	1	1	1	1	6	1
Vehicle usage rate (%)	99.42%	87.20%	85.55%	99.96%	87.80%	41.93%	-	83.64%

- M=0% presents both the highest profit and computational times.
- In general, as M increases, the amount of time to obtain an optimized solution decreases & the number of solutions with GAP 0% increases.

Results for real-case instance

Optimization-based heuristic

M = 0%								
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.[illegible]
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[illegible]
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%

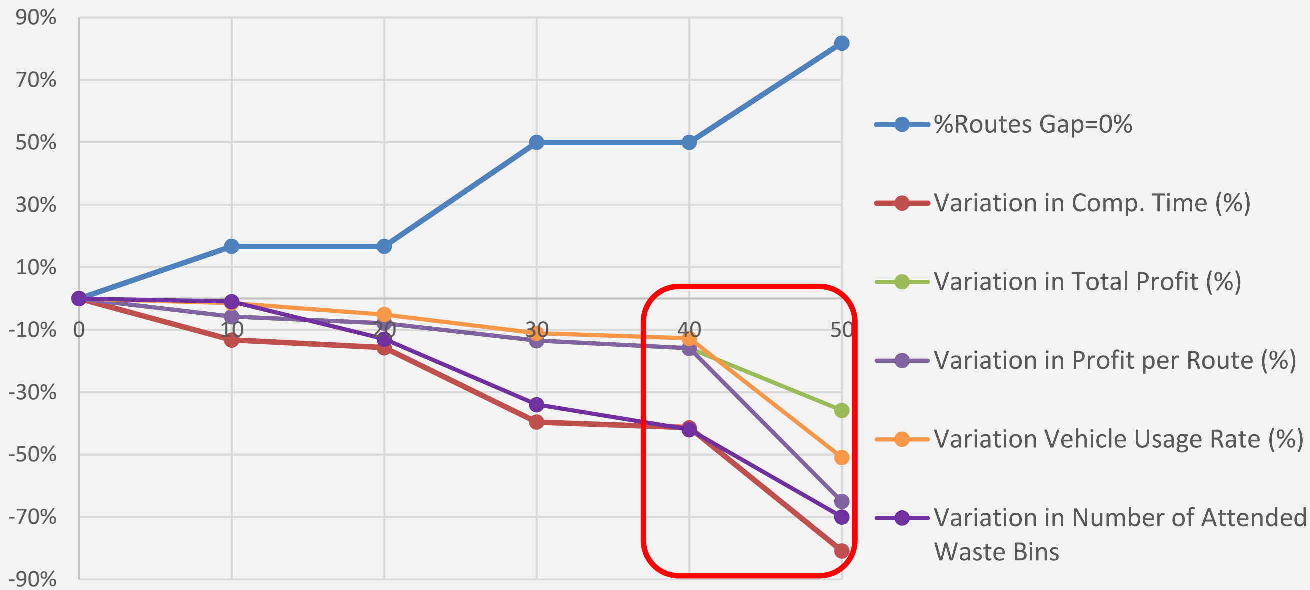
M = 40%								
KPI	Day 1	Day 7	Day 13	Day 19	Day 25	Day 29	Total	Average
Profit (€)	230.5	142.8	213.2	196.5	167.2	10.1	960.3	160.0
Weight (kg)	3858.9	3092.0	3534.0	3929.3	3315.9	1965.6	19695.7	3282.6
Distance (km)	136.1	150.9	122.5	176.7	147.7	176.6	910.5	151.7
Attended bins	71	62	70	83	69	45	400	67
|L|	88	56	77	89	83	49	442	74
Ratio (kg/km)	28.4	20.5	28.8	22.2	22.4	11.1	21.6	21.6
Gap (%)	0.0	6.4	0.0	2.1	1.4	0.0	-	-
Computational time (s)	4415.6	16213.2	3847.6	16212.2	16203.6	96.4	56988.6	9498.1
Vehicles used	1	1	1	1	1	1	6	1
Vehicle usage rate (%)	96.47%	77.30%	88.35%	98.23%	82.90%	49.14%	-	82.07%

M = 50%													
KPI	Day 1	Day 6	Day 8	Day 13	Day 15	Day 17	Day 19	Day 21	Day 22	Day 25	Day 30	Total	Average
Profit (€)	206.1	69.2	29.2	152.1	3.8	44.6	3.2	41.4	-48.5	34.9	197.0	732.9	66.6
Weight (kg)	3882.3	1398.6	1504.3	3065.0	520.3	1959.0	559.2	1537.4	689.8	1822.8	3383.4	20321.9	1847.4
Distance (km)	162.7	63.7	113.7	139.0	45.6	141.5	49.9	104.6	114.0	138.2	124.3	1197.1	108.8
Attended bins	68	24	29	55	10	38	32	10	14	36	60	376	34
|L|	72	34	38	61	25	43	22	41	17	44	70	467	42
Ratio (kg/km)	23.9	22.0	13.2	22.1	11.4	13.8	11.2	14.7	6.0	13.2	27.2	17.0	17.0
Gap (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	4.0	0.0	0.0
Computational time (s)	197.2	3.7	123.3	1275.6	3.5	28.8	0.7	45.3	2.3	16228.3	16200.0	34108.8	3100.8
Vehicles used	1	1	1	1	1	1	1	1	1	1	1	11	1
Vehicle usage rate (%)	97.06%	34.96%	37.61%	76.62%	13.01%	48.97%	13.98%	38.43%	17.24%	45.57%	84.58%	-	46.19%

- However, by increasing M, less bins are visited, reducing the total profit and the vehicles usage, in turn increasing the total number of routes.

Results for real-case instance

KPIs's Summary, as a variation reporting to the solution with M=0%

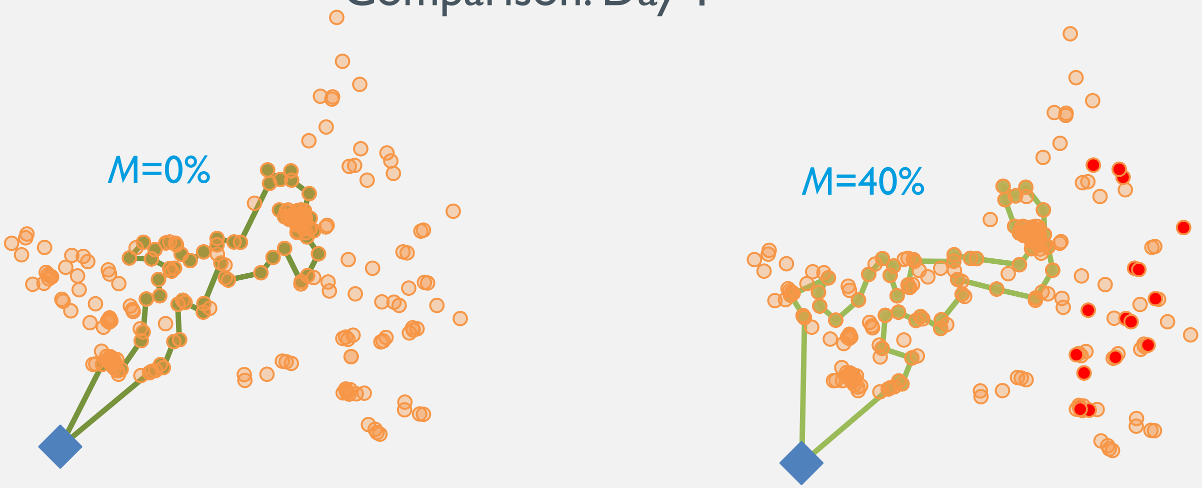


The **decrease in solution performance** from M=40% to M=50% in all indicators (except for GAP & Comp. time), is far greater than any of the previous increments of 10% in the value of M.

M=40% is the selected value for the parameter.

Results for real-case instance

Comparison: Day 1



KPI	M=0%	M=40%
Profit (€)	253.1	230.5 ↓
Weight (kg)	3 999.6	3 858.9 ↓
Distance (km)	126.8	136.1 ↑
Attended bins	98	71
|L|	226	88
Ratio (kg/km)	31.5	28.4
Gap (%)	2.8	0
Comp. time (s)	16 201.2	4 415.6
Vehicles used	1	1
Vehicles usage rate (%)	99.9	96.5

Results for real-case instance

In real-life settings, it would be preferable to design dynamic routes with current data, leading to the need of obtaining a solution quickly.

Results after 15 minutes run.

M (%)	Weight (Kg)	Distance (km)	GAP(%)	Profit (€)	
				CPU limit: 15 min	CPU limit: 4h
0	-	-	-	-	253 (GAP 2,8%)
10	3 992	125	1,64	254 ↑	254 (GAP 0%)
20	3 992	125	1,29	254 ↑	254 (GAP 0%)
30	3 977	139	2,00	239	239 (GAP 0%)
40	3 859	136	2,51	231	231 (GAP 0%)
50	3 882	163	0	206 ↓	206 (GAP 0%)

Best solution found

→ Better to use **smaller values of M**. However, there is the **danger of not obtaining any solution.**

→ Since the solutions for both M=10% and M=20% are the same, the selected **value of M should be 20%.**

Conclusions

To solve the SWCRP, a new solution approach was proposed: an optimization-based heuristic, dependent on the parameter M:

- The profit decreases as the value of M increases;
- The computational time required to obtain solutions decreases with the increase of M;
- The number of routes performed in the planning horizons is constant until M=40% but then, it seems to increases as M increases, which might imply additional operational costs.
- Not only the compromise between the value of M and the number of routes, but also the relatively grater decrease in the performance in KPIs for the solution of M=50% lead us to suggest that the best value for M is 40%.
- When CPU running time is small, the selected value for M should be 20%.

Future Work

- Improving the optimization-based heuristic to consider not only the fill-levels, but also the locations;
- Exploring the balance between routes, limiting shift time;
- Exploring Inventory Routing Problem models that allow a weekly profit maximization instead of daily.

THANK YOU FOR YOUR ATTENTION!

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

WSMARTROUTE

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