Computational intelligence for locating garbage accumulation points in urban scenarios

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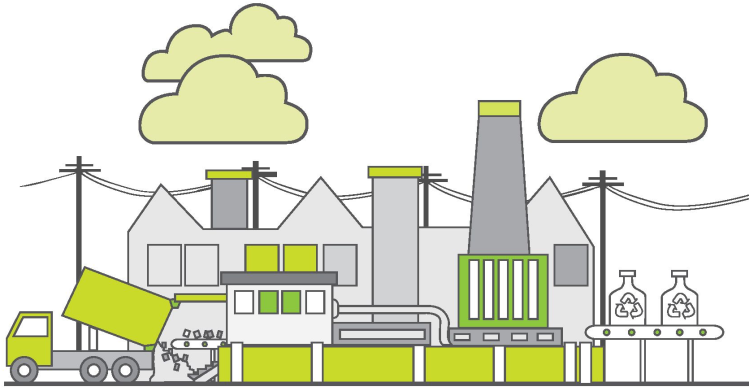
Introduction. Solid waste management

Solid waste management is an important issue in modern cities which requires efficient practices → *collecting*, *treating*, and *disposing* of solid material

It is one of the main challenges for local governments in order to mitigate ***environmental*** and ***social*** impacts, especially in highly populated cities



Introduction. Solid waste management

A specific problem related to solid waste management refers to **find a proper location for *garbage accumulation points* (*GAPs*)** where a set of waste bins are to be installed. A paltry spatial distribution of bins in the city **may negatively affect the inhabitants'** quality of life

- people must walk **long distances** for garbage disposal
- certain waste bins **fill quickly** while others remain empty
- an overmuch dense distribution also has a **negative impact on the budget**

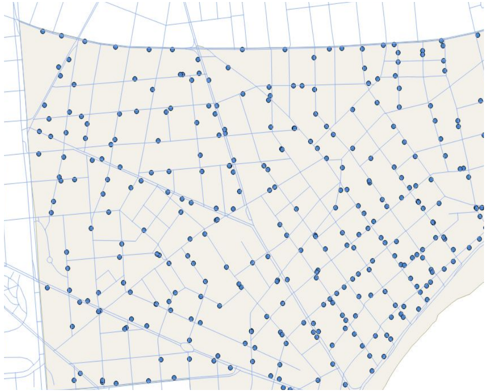
Introduction. GAP location problem

The GAP location problem aims to select the best locations of GAPs from a predefined set of potential places

determining the **number and type of waste bins** to be install in each chosen one

Three different objectives:

- **maximizing** the total **amount of waste** collected
- **minimizing** the installation **cost** of bins
- **minimizing** the average **distance**



Introduction. GAP location problem

Examples of different possible configurations (GAP size 3 m²)

 j_1

 j_2

Bin type	Price	Capacity	Space
j_1	200 €	1m³	1 m²
j_2	380 €	20m³	2 m²

Config. id	Bins distribution	Cost	Capacity
0	No bins	0	0
1		200 €	1m³
2		400 €	2m³
3		380 €	2m³
4		600 €	3m³
6		580 €	3m³

Problem formulation: Mixed Integer Programming model

Elements:

- Set $I = \{i_1, . . . , i_M\}$ of **potential GAPs** for bins, each one with available space S_i.
- Set $P = \{p_1, . . . , p_N\}$ of **generators** that produces b_p (tons) of waste. **Distance** from generator p to GAP i is $d_{p,i}$. The maximum distance between generator and GAP is D.
- Set $J = \{j_1, . . . , j_H\}$ of **bin types**, with **price** c_j , **capacity** C_j , and required **space** e_j. The maximum number of bins of type j available is MB_j .

Variables:

- $t_{j,i}$ is the number of bins of type j installed in GAP i.
- $x_{p,i}$ is 1 if generator p is assigned to GAP i and 0 otherwise
- $f_{p,i}$ is the fraction of the waste produced by generator p that is deposited in GAP i.

Problem formulation: Mixed Integer Programming model

$$\max \sum_{p \in P,\ i \in I} f_{p,i} \times b_p \qquad (1)$$

Total waste able to dispose

$$\min \sum_{p \in P,\ i \in I} \frac{d_{p,i} \times f_{p,i}}{|P|} \qquad (2)$$

Average distance between generators and GAPs

$$\min \sum_{j \in J,\ h \in H,\ i \in I} t_{j,h,i} \times c_j \qquad (3)$$

Total investment cost

subject to

$$\sum_{i \in I} (f_{p,i}) \leq 1 \qquad \forall\, p \in P$$

Sum of relative waste fractions

$$\sum_{j \in J,\ h \in H} (t_{j,i} e_j) \leq S_i \qquad \forall\, i \in I$$

Available space in a GAP

$$\sum_{p \in P} (b_p f_{p,i}) \leq \sum_{j \in J} (C_j t_{j,i}) \qquad \forall\, i \in I$$

Installed capacity in a GAP

$$\sum_{h \in H,\ i \in I} t_{j,h,i} \leq MB_j \qquad \forall\, j \in J$$

Total containers availability

GAP location problem solvers

This problem is a variation of the Facility Location Problem, an **NP-hard** problem

Heuristics and metaheuristics allow computing good configurations for waste bin locations in reduced execution times

- **PageRank** constructive heuristic
- Multi-objective Evolutionary Algorithm: **NSGA-II**

PageRank for the GAP location problem

PageRank has been applied to location problems defined over graphs in the field of smart cities, e.g., install infrastructure elements for handling vehicle traffic.

Information about generators and GAPs is modeled as a fully connected weighted graph *G=(V,E)* (*G* is the set of generators *P* and the set of edges *E*).

The PageRank value to sort the potential GAPs:

$$PR^W(v_i) = (1-d) + d \times \left(\sum_{v_j \in In(v_i)} w_{ij} \times \frac{PR^W(v_j)}{\sum\limits_{v_k \in Out(v_j)} w_{jk}} \right)$$

The weight of each edge:

$$w_{jk} = \frac{b_j + b_k}{d_{j,k}}$$

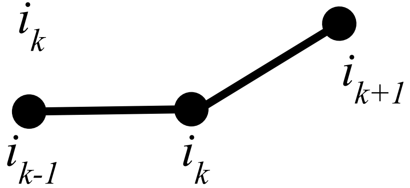
Three constructive heuristic according to which objective is prioritized:

- PageRank-Vol
- PageRank-Dist
- PageRank-Cost

PageRank for the GAP location problem

Example of PageRank application to construct GAP location problem solutions.

Selecting a given configuration to be placed in i_k



PageRank-Cost selects config. **0**

PageRank-Vol selects config. **1**

PageRank-Dist selects config. **3**

Config. for i_k	**Waste to dispose**	**Distance**	**Cost**
0	150	200	400
1	250	225	500
2	200	150	600
3	200	125	700

MOEA for the GAP location problem: NSGA-II

- **Solution encoding**: vector of integers; index represents each potential GAP and integer represents one of the *Z* possible configurations

an arrangement of of bins (which can include different types) that can been placed in a GAP.

- **Solution evaluation** according to **three objectives:** Pareto dominance rank and crowding distance values
    - **Maximization** of total **waste able to dispose**
    - **Minimization** of average **distance** between generators and GAPs
    - **Minimization** of total investment **cost**

MOEA for the GAP location problem: NSGA-II

- **Initialization:** Uniform random procedure that selects one of the Z possible configurations for each potential GAP
- **Selection:** Binary tournament. Criteria: dominance (and crowding distance as tiebreaker)
- **Recombination:** Two points crossover
- **Mutation:** Randomly modifying the configuration at the i-th component of the solution with probability *mut_prob*
- **Solution feasibility:** Guaranteed through a constructive heuristic

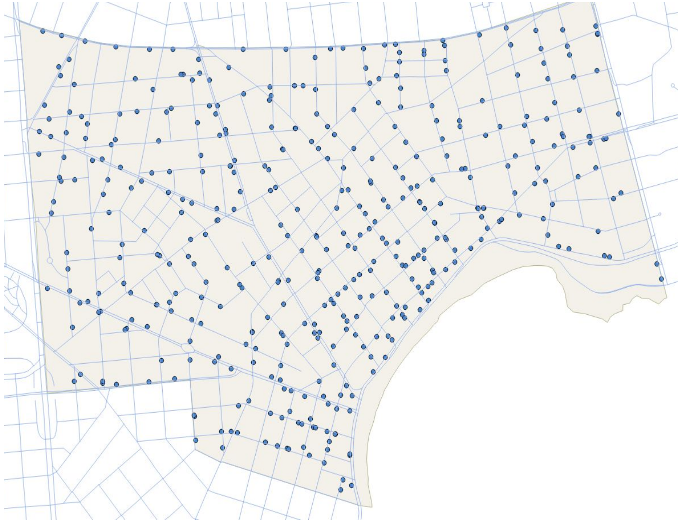
Experimental evaluation

Real problem instances from Montevideo, urban and suburban areas

- Trouville: **82** generators and potential GAPs
- Villa Española: **70** generators and potential GAPs

Normal, **low** and **high** demand scenario, data from Uruguayan authorities

Maximum distance generator-assigned GAP (D): **300m**, according to suggestions for accessibility to public services



Experimental evaluation

Real bins in Montevideo (3 types):

- Type 1: $1m^3/1m^2/1000$ MU
- Type 2: $2m^3/2m^2/2000$ MU
- Type 3: $3m^3/3m^2/3000$ MU

Available space for GAP: **5 m²**

12 GAP configurations

config. id	*number of bins* j_1	j_2	j_3	*required space* (m^2)	*installation cost (m.u.)*	*maximum capacity* (m^3)
0	0	0	0	0	0	0
1	1	0	0	1	1000	1
2	2	0	0	2	2000	2
3	3	0	0	3	3000	3
4	4	0	0	4	4000	4
5	5	0	0	5	5000	5
6	1	1	0	3	3000	3
7	1	2	0	5	5000	5
8	1	0	1	4	4000	4
9	0	1	0	2	2000	2
10	0	1	1	5	5000	5
11	0	0	1	3	3000	3

We executed **30 independent runs** of the MOEA and one run of each PageRank based algorithm

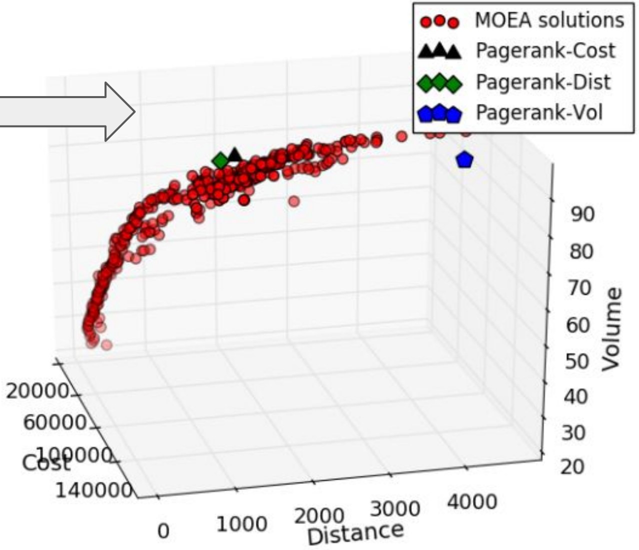
Experimental evaluation. Optimization performance

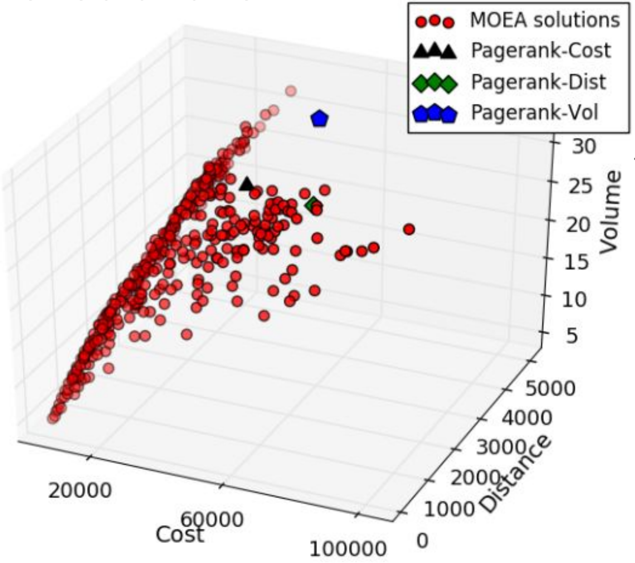
MOEA is able to accurately sample the **set of trade-off solutions** for the problem instances studied

Pagerank-Dist and **Pagerank-Cost** computed accurate solutions

PageRank-Vol computed significantly worst solutions

Trouville





Villa Española

Experimental evaluation. Optimization performance

The proposed **MOEA computes accurate** solutions for all problem instances

Results show that **Trouville scenarios are more difficult** to solve than the Villa Española scenarios

they involve a ***larger number of generators*** *and potential locations for GAPs*

scenario	*waste generation*	*minimum*	*median*	*maximum*
Trouville	low demand	0.848981	0.915520	0.959794
	normal demand	0.835673	0.918477	0.971029
	high demand	0.856235	0.924728	0.973995
Villa Española	low demand	0.917414	0.938922	0.960938
	normal demand	0.911611	0.943481	0.969071
	high demand	0.875456	0.941840	0.965635

Experimental evaluation. Comparative analysis

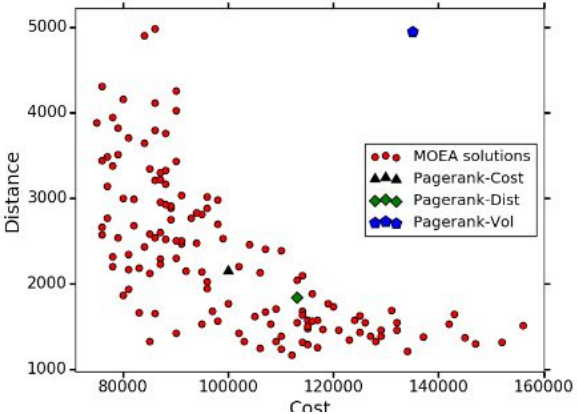
Improvements of the MOEA results over the PageRank heuristics

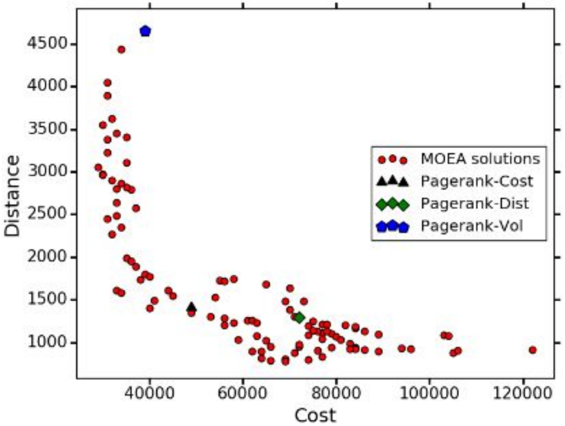
The reported values accounts for the **average** and **best improvements** in each one of the three problem objectives (distance, cost, and volume) over each Pagerank solution → **up to 10% difference on the volume** of the collected waste

The analysis is focused on the **benefits for both citizens** (i.e., QoS, given by the average **distance** they must walk to dispose the waste) and the **city administration** (evaluating the **cost** of implementing a certain GAP planning).

Experimental evaluation. Comparative analysis

scenario	*waste generation*	*baseline*	*average improvement* distance	cost	volume	*best improvement* distance	cost
Trouville	low demand	PageRank-Cost	6.0%	8.0%	8.7%	15.6%	13.6%
		PageRank-Dist	9.9%	7.3%	8.9%	33.5%	14.1%
		PageRank-Vol	44.0%	17.7%	5.1%	79.5%	37.2%
	normal demand	PageRank-Cost	16.8%	9.4%	6.7%	38.0%	20.0%
		PageRank-Dist	18.0%	9.9%	6.6%	36.5%	26.6%
		PageRank-Vol	44.8%	23.8%	4.7%	76.3%	44.4%
	high demand	PageRank-Cost	18.1%	10.4%	8.5%	33.3%	20.2%
		PageRank-Dist	14.8%	10.5%	8.4%	22.1%	21.0%
		PageRank-Vol	47.5%	18.9%	4.0%	80.7%	35.5%
Villa Española	low demand	PageRank-Cost	9.3%	0.0%	9.1%	9.3%	0.0%
		PageRank-Dist	16.8%	12.1%	4.4%	36.6%	37.1%
		PageRank-Vol	23.7%	14.0%	3.8%	59.1%	33.3%
	normal demand	PageRank-Cost	2.3%	9.2%	7.1%	4.07%	18.37%
		Pagerank-Dist	19.8%	10.8%	6.0%	40.0%	22.2%
		PageRank-Vol	31.8%	13.0%	4.8%	66.0%	25.6%
	high demand	PageRank-Cost	10.0%	7.4%	6.2%	11.7%	7.4%
		PageRank-Dist	16.8%	12.4%	5.6%	31.7%	25.3%
		PageRank-Vol	36.3%	19.8%	5.1%	69.7%	37.0%





Experimental evaluation. Validation

Comparison with **current GAP locations in Montevideo** (as of February, 2018)

Distance:

- **Trouville**: From 150.81–199.75m to 28.75–23.84m (**average reduction of 84%**)
- **Villa Española**: from 167–188m to 21–26m (**average reduction of 86%**)

		Trouville			*Villa Española*		
		low demand	normal demand	high demand	low demand	normal demand	high demand
MOEA	*distance*	84.6%	84.2%	84.2%	86.0%	86.3%	87.2%
	cost	31.4%	23.6%	10.7%	2.3%	-4.4%	4.1%
	volume	4.5%	4.0%	3.3%	4.1%	3.3%	4.8%
PageRank-Cost	*distance*	84.8%	85.4%	87.6%	89.5%	90.1%	90.7%
	cost	38.2%	23.7%	13.0%	24.1%	15.5%	6.9%
	volume	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%
PageRank-Dist	*distance*	88.6%	87.5%	89.4%	90.3%	90.9%	92.2%
	cost	24.4%	13.7%	9.2%	-20.7%	-24.1%	-29.3%
	volume	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Main conclusions and future work

An optimization model to a tricky problem that is important for local authorities nowadays is proposed

Three PageRank heuristic and a MOEA are developed for solving the problem

Experimental evaluation over real-world cases of the city of Montevideo, considering different waste generation rates. MOEA clearly outperformed the PageRank heuristics and the current strategy of the authorities

Main lines for future work: extend experimental evaluation on other real scenarios and include to the model uncertainty in the waste generation rate to enhance the robustness of the solution

Thank you!

Comments?