SOLIDARITY BEHAVIOR FOR OPTIMIZING THE WASTE SELECTIVE COLLECTION

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1. INTRODUCTION (i)

Municipal Solid Waste (MSW) is the waste generated in households, commercial establishments, institutions, and businesses.

MSW includes food scraps, cans and bottles, used paper and other items.

1. INTRODUCTION (ii)

Other garbage such as residues of industrial processes, agricultural wastes, mining waste, and sewage sludge are not included in the terminology MSW.

1. INTRODUCTION (iii)

Phases of MSW management are:
- Waste generation
- Storage
- Collection
- Transportation
- Processing
- Recycling
- Disposal in a suitable landfill.

- Typically, collection costs consume the bulk of the MSW management budget.

1. INTRODUCTION (iv)

When trying to design an integrated management system, waste storage collection and transportation problems are the most difficult to solved.

- Waste generation
- **Storage**
- **Collection**
- **Transportation**
- Processing
- Recycling
- Disposal in a suitable landfill.

Eiselt and Marianov (2015) provide a survey based on 64 articles, classified according to the country, the technique, the criteria, the objectives and the type or installation to be located. All cases include real applications.

1. INTRODUCTION (v)

The MW collection is intrinsically connected to a Vehicle Routing (VR) model in order to optimize different criteria, such as the total distance traveled by vehicles, the emission of environmental pollutants and the investment costs.

1. INTRODUCTION (vi)

In real scenarios, the waste collection system is distributed in a set of urban areas. Each zone has a starting point and an ending point associated with all internal routes. Both nodes are used to determine the vehicle routes from their depots to the assigned landfill, where the waste has been previously collected in the containers visited.

1. INTRODUCTION (vii)

The problem of managing selective collection by means of waste containers, located inside a historic centre, can be performed in three sequential phases:

1. Locating the minimum number of containers at points along the streets.
2. Determining the minimum fleet size required to perform all collecting services
3. Allocating collection routes to vehicles so that the total number of kilometres travelled by the trucks was comparable.

Obviously, the result of the first phase (location of the containers) highly influences the scenario where determining the decision to be taken for the subsequent phases (routes of collection vehicles and programming of services).

CONTRIBUTIONS

- The main **contribution of this work** focuses on this first phase: the location of collection facilities (waste containers), where

1. the distances between facility and customer must be considered when the concept of optimality is modeled,
2. additionally, other features such as
    - 2.1 the size of container groups,
    - 2.2 its capabilities according to the nearest population
    - 2.3 and the cost of installing those containers at specific sites along the streets

must be taken into account.

- An **optimization model** is formulated to locate waste containers.

- Subsequently, its corresponding **solution algorithm** is developed.
- A **computational experience** is implemented, based on an application to a real case.

- Finally, **conclusions** are summarized

2. OPTIMIZATION MODEL (i)

We assume a connected graph *G= (V, A)*, composed of a node set *V* (portals) and an arc set *A* (directed edges representing street sections), so that the existence of a shortest path in terms of distance (or travel time) between each pair of points of *V* is guaranteed inside G.

Let us suppose that set *V* is composed of

- Type *I* nodes where urban waste is generated and
- Type *J* nodes where it is possible to locate the containers to place them.

Type I nodes:
located at the entrance gate of a building

Type J nodes:
Located at feasible sites along the street network

2. OPTIMIZATION MODEL (ii)

The following notation is used in our waste containers formulation:

I: set of demand nodes ($i \in I$).
There is a population p_i associated to each demand point $i \in I$.

J: set of possible location nodes to locate waste containers ($j \in J$).
There is an upper bound (cap_j, $j \in J$) in terms of capacity associated to each candidate point $j \in J$.

K: set of main types of solid waste generated in the urban area (for instance, cardboard, plastic, organic waste, etc.) ($k \in K$).

2. OPTIMIZATION MODEL (iii)

Additionally, we assume a compensation cost $\beta_j^k > 0$, that the municipal cleaning company would be willing to pay to inhabitants nearby node *j*, if the waste container is located in the proximity of node *j*.

If node *j* were located in the public domain far from any building, the compensation cost could be considered 0; on the other hand, if the location of the container in the proximity of a house were technically unfeasible, this cost could be associated to an infinite value.

Type I node that a compensation is required

2. OPTIMIZATION MODEL (iv)

Parameters:

- Each node *i* has a known weight w_i^k (which can be identified with the amount of waste in kg or dm^3 generated at node *i* of modality *k*; i.e., organic material, glass, packaging or paper units).

- The shortest distances between nodes of set *V*, along network *G*, have previously been determined and recorded in the matrix $D = (d_{ij}), d_{ij} \geq 0$.

- Inhabitants associated to node *i* would experience a displacement cost (discomfort) C_{ij}^k when having to take their type *k* waste to the container located at point *j*.

- This discomfort implicitly requires a restriction on travel distances. In practice, this restriction is modelled by the assignation of a feasible coverage radius from point *i*. A point *i* can be considered covered by another point *j* if the distance between them does not exceed a radius of displacement R^k.

2. OPTIMIZATION MODEL (v)

Let us assume that **each customer is willing to take out their garbage to another unfilled container *j* that is not excessively distant**.

This <u>solidary behavior</u> of the clients (associated to a gradual increasing of C_{ij}^{k}) would allow an efficient deployment of the containers in the area under analysis, reducing their total number and grouping them in the points of lowest cost.

2. OPTIMIZATION MODEL (vi)

Let $q_{ij}^{k} \in \{0,1\}$ be a binary expression that takes value 1 if the demand point *i* can be covered by site *j,* by means of a container of modality *k.*

Note that $q_{ij}^{k} = 1$ implies that $d_{ij} \leq R^{k}$, and value 0, otherwise.
Additionally, let $N_{j} > 0$ be an integer parameter that indicates the maximum number of containers that could be installed at location *j*.
We assume that all containers are provided with the same capacity *Q*.

Grouped containers

2. OPTIMIZATION MODEL (vii)

Moreover, the following variables are required in the model:

Variables.

y_j^k Binary variable that takes value 1, if container location *j* is activated to collect type *k* garbage, and value 0, otherwise.

n_j^k Number of type *k* containers to be installed at location *j*.

x_{ij}^k Percentage of type *k* garbage that the client corresponding to node *i* will deliver at location *j*.

Objective and constraints.

$$z_1 \equiv \text{Min} \sum_{j \in J} \sum_{k \in K} \beta_j^k n_j^k$$

Minimizes the cost of containers that should be installed

Subject to:

$$\sum_{j \in J} q_{ij}^k y_j^k \geq 1, \qquad i \in I, \quad k \in K$$

All demand is covered by the set of locations to be determined

$$\sum_{j \in J} q_{ij}^k x_{ij}^k = 1, \qquad i \in I, \quad k \in K$$

The sum of coverage percentages for every demand point must be equal to 1

$$x_{ij}^k \leq y_j^k, \qquad i \in I, \quad j \in J, \quad k \in K$$

If a location is activated, then at least one container must be installed at it

$$y_j^k \leq n_j^k, \qquad j \in J, \quad k \in K$$

If a location is not activated, then no demand point can be covered by it

$$\sum_{i \in I} w_i^k x_{ij}^k \leq Q \cdot n_j^k \qquad j \in J, \quad k \in K$$

Demand satisfied by location *j* cannot exceed its capacity

$$\sum_{k \in K} n_j^k \leq N_j \qquad j \in J$$

Upper bound on the number of containers that can be located at each site *j*

$$y_j^k \in \{0,1\}, \quad n_j^k \in Z^+, \quad x_{ij}^k \geq 0.$$

2. OPTIMIZATION MODEL (ix)

<u>New objective function</u>: to minimize travel cost for users combined with minimizing cost invested in the deployment of waste containers:

$$z_2 \equiv \mathrm{Min} \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} C_{ij}^{k} \, y_j^{k} + \sum_{j \in J} \sum_{k \in K} \beta_j^{k} \, n_j^{k}$$

Both models are of combinatorial nature and can be considered as instances of a Partial Set Covering problem.

The partial set covering model is NP-hard since it is a generalization of the traditional location Set Covering problem, which is NP-hard.

This fact justifies the use of algorithms that provide a good heuristic solution.

3. SOLUTION ALGORITHM (i)

Tests carried out on randomly generated data have shown that a simple heuristic of Overflowing Deviated to Immediate Neighbourhood (ODIN) yields the best results, if the inter-location spacing between adjacent containers is not excessively large.

Taking these precedents into account, we propose the heuristic ODIN for solving our optimization model in order to determine the most effective deployment of waste containers along the street network.

Heuristic ODIN

1. Sort the points that generate urban waste according to their production, from highest to lowest levels and **re-label** them.

3. SOLUTION ALGORITHM (ii)

Heuristic ODIN (cont.)

2. While there exists a generator point *i* whose collection requirement exceed the established upper limit N_i ; i.e., $\sum_{k \in K} n_i^k \geq N_i$ **do**

2.1 Identify the set of nodes *Prox(i; k)* whose distances to node *i* are less than R^k (excluding node *i*)

2.2 Sort the nodes $j \in Prox(i;k)$ from the lowest to the highest levels according to ascending values of β_j^k

2.3 For each $j \in Prox(i;k)$ **do**

2.3.1 While $(\sum_{k \in K} n_i^k) - N_i > 0$ and $N_j - (\sum_{k \in K} n_j^k) > 0$

do Decrease units from n_i^k and Increase them in n_j^k

3. If all the generating points satisfy condition $\sum_{k \in K} n_i^k \leq N_i$

then a solution to the problem has been obtained.
Otherwise, a modification of parameters R^k or *N* is required.

4. End.

4. COMPUTATIONAL EXPERIENCE (i)

Our model has been tested on a graph representing a part of the street system in the Historic Centre of Seville.
The streets of this sector of Seville are predominantly narrow and one-way. The most common type of dwellings is the single-family house or the multi-family building with a shared courtyard. In both housing models, there is hardly any space available for the establishment of selective garbage containers in the interior.

Narrow streets in the Centre of Seville

Shared courtyard in the Centre of Seville

4. COMPUTATIONAL EXPERIENCE (ii)

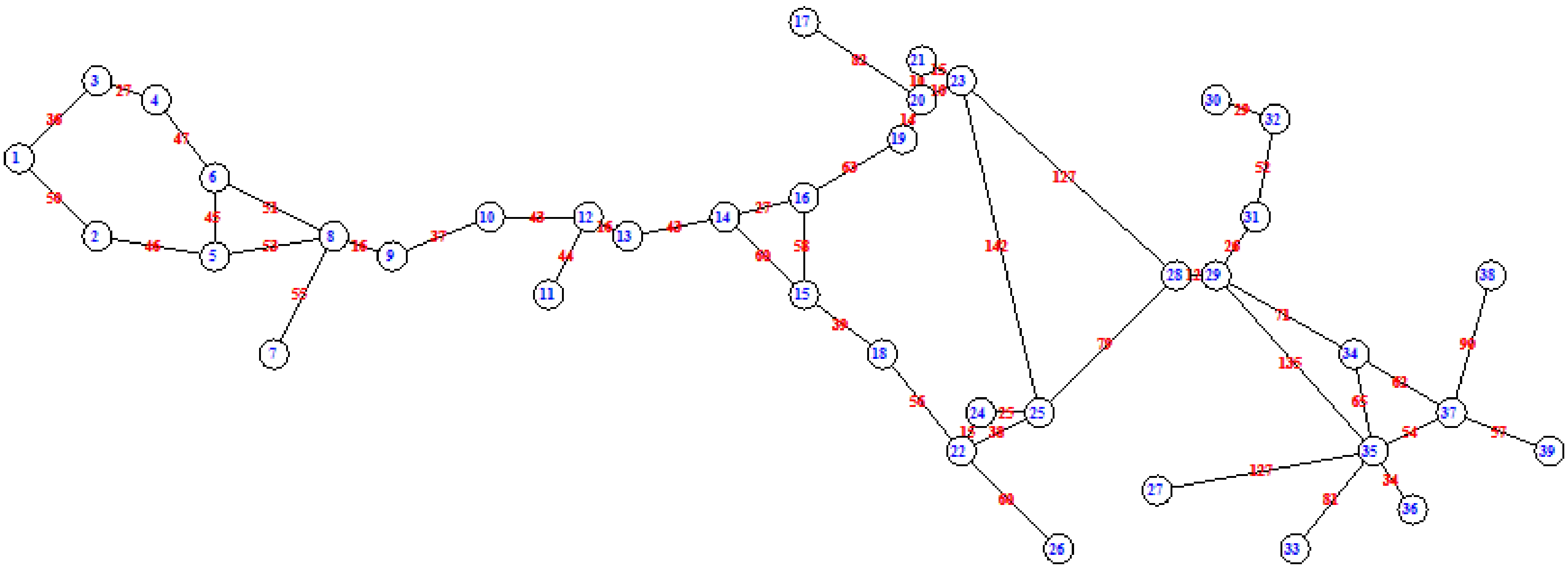
This unavailability of physical space for locating fixed containers forces to a widespread use of a small container (with a maximum capacity for 4 bags of garbage), mobile and polyvalent, which daily serves the community of neighbours.

Mobile waste selective containers

Mobile waste nonselective containers

4. COMPUTATIONAL EXPERIENCE (iii)

Our scenario is a network composed of 39 nodes (sites identified as elements of node set *I*). Location of nodes along the street network and the values of internode distances are illustrated in the Figure.



4. COMPUTATIONAL EXPERIENCE (iv)

The daily amount of produced waste at each node is random within the interval [400 kg, 16000 kg].

By considering homogeneous containers of capacity 500 kg, it is possible to initially assign to each residential place a container cluster (located at this same site) whose amount varies between 1 and 32.

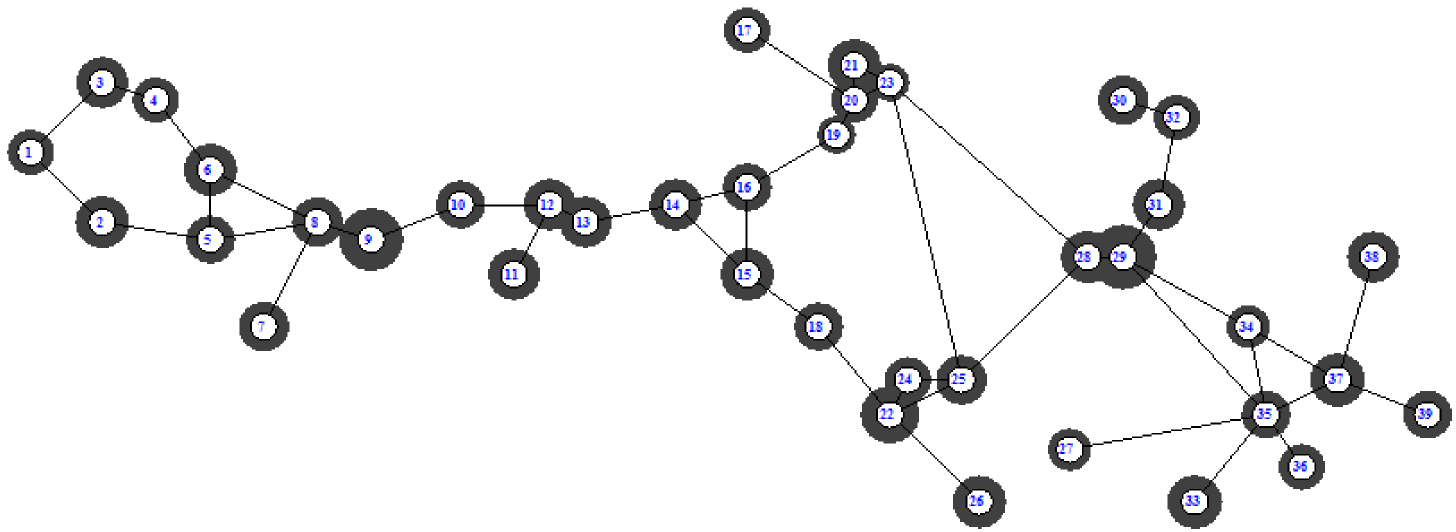
In order to provide the experiment a connection with a real context, a limitation on the number of containers that share the same geographical location has been set to 10.

Monthly cost in euros incurred when locating a container at this specific site *j* has been considered as random within interval [0, 10].

4. COMPUTATIONAL EXPERIENCE (v)

FIRST SCENARIO: Different types of garbage have not been distinguished.

Without solidarity behaviour, container clusters which are needed to guarantee the collection of all urban waste are represented in the Figure by circles whose areas are proportional to the corresponding cluster size.

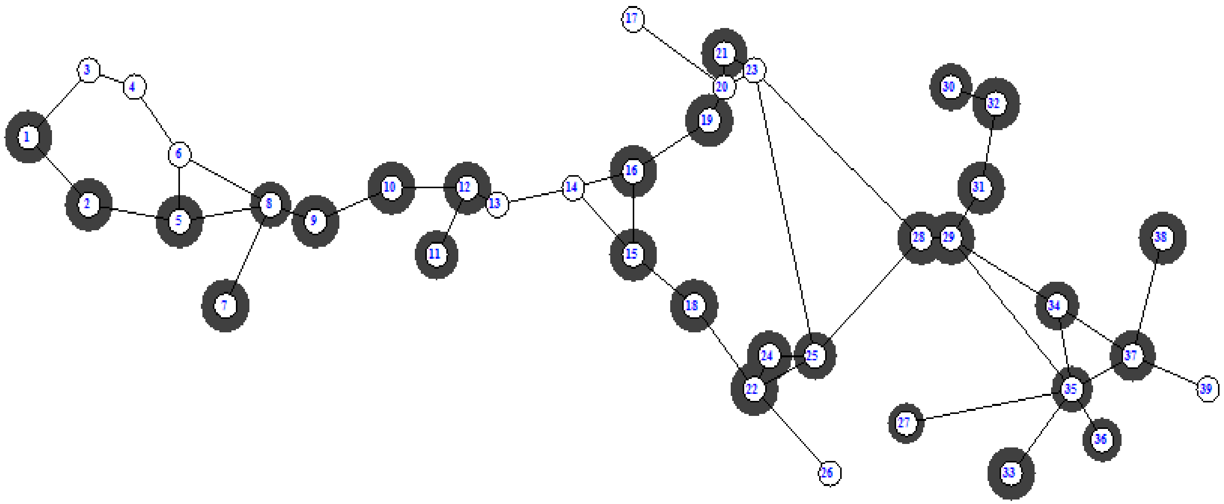


If **no optimization procedure** was applied, the **238** containers needed to collect all the global garbage produced would imply a cost of **1091 euros per month**.

4. COMPUTATIONAL EXPERIENCE (vi)

FIRST SCENARIO: Different types of garbage have not been distinguished.

With solidarity behaviour (not necessarily using to the closest container), a more efficient distribution of the containers can be obtained by means of the optimization model.



A smaller number of clusters: **29,** instead of 39.
The compensation cost of the maintenance of the 238 containers on the street, is reduced by 14.48 percent. The monthly cost associated to the solution shown in the Figure is now **933** euros (instead of 1091) .

4. COMPUTATIONAL EXPERIENCE (vii)

SECOND SCENARIO: Three different types of garbage have been distinguished.

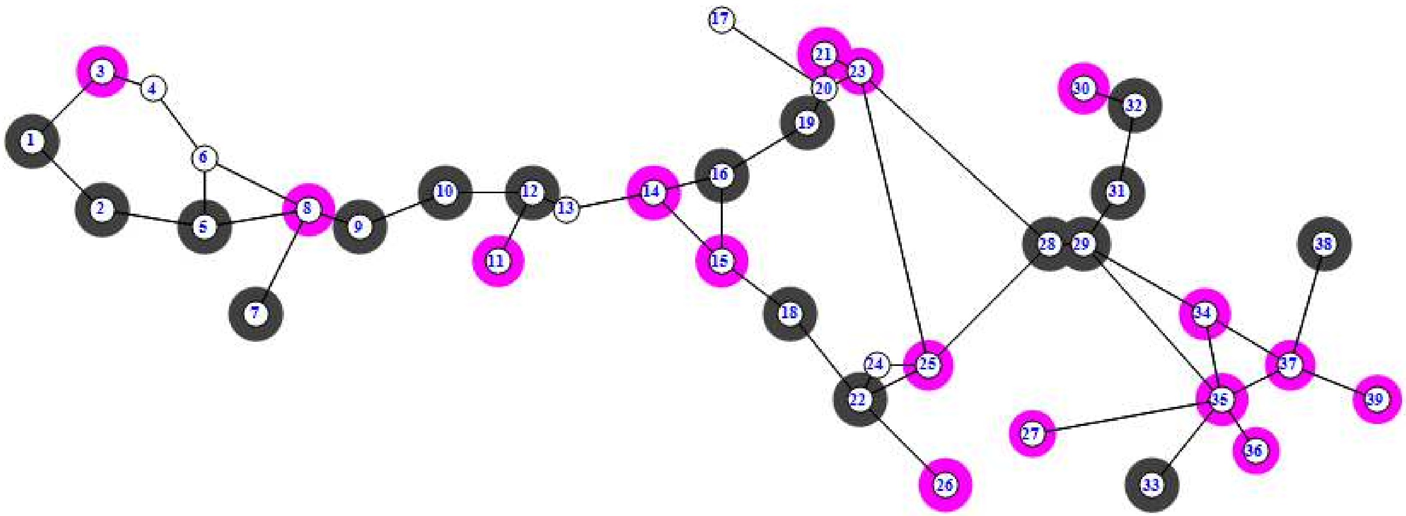
The requirement to separately dump the waste yields an increment in the number of containers needed to carry out the whole collection of waste.

Now, 280 containers (versus 238 in scenario 1) grouped in 39 clusters are required.

A new application of the ODIN heuristic, maintaining the parameter values established for the parameters R^k and N_j, provides redistribution of container clusters in 33 places, instead of the previous 39 sites.

4. COMPUTATIONAL EXPERIENCE (viii)

If we compare the solution obtained in scenario 2 with the proposal for scenario 1, we can observe that 17 nodes (marked with the magenta colour) have had to change their allocation of containers due to the increment caused by the selective collection of solid waste.



6. CONCLUSIONS

A methodology for the deployment of containers for selective collection of urban solid waste has been proposed in this work.

The mathematical optimization model formulated for this purpose has been identified as a version of the Partial Set Covering problem, whose computational complexity motivates the use of heuristics to face large real-life scenarios.

Following that recommendation, a greedy algorithm of Overflowing Deviated to the Immediate Neighbourhood has been developed to solve the proposed mathematical programming model.

To illustrate the performance of the developed methodology, a computational experience has been carried out on an urban system composed of 39 nodes inspired in a zone belonging to the area of Seville (Spain).

Two different scenarios are considered, by assuming selective collection or not. The analysis of results obtained in both scenarios shows that the developed methodology meets the objective of efficiently designing a deployment of containers, in special when customers have a solidarity behaviour.

Thanks for your attention!