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Integration of spatial and descriptive information to solve the urban waste accumulation problem: a pilot study

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Abstract

The paper reports about a pilot study that gives a numerical solution to the *solid waste accumulation problem* (SWAP). The purpose is to show both a simple and effective way to implement the theory using the technology of the Spatial DataBase Management Systems (SDBMSs), and the versatility of the proposed solution from the point of view of those responsible for the MSW management who, in fact, are offered a dual-mode display of the results: one tabular (typical of relational databases) and the other based on geographical maps, the latter particularly useful to highlight the spatial component of the data of the SWAP.

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Keywords: *solid waste; garbage accumulation point; garbage bin; spatial database; User Defined Functions*

1. Introduction

The present paper complements (Di Felice, 2013), where the reader may learn about the reference scenario, the motivations behind our research, the definition of the SWAP, and two algorithms (called *LocatingOfGAPs* and *SizingOfGAPs*) that solve it. Those stuff are not repeated here because we are short with space. For the purposes of the present paper it is sufficient to say that the two algorithms achieve, in sequence, an appropriate localization, over a given urban area, of the garbage accumulation points (GAPs) as well as a correct estimation of the number of garbage bins (GBs) composing each GAP. The method integrates tightly *spatial* information (i.e., the public

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roads and the homes located in the territory) with *descriptive* information (i.e., the number of people living inside dwellings, the daily production of solid waste (SW) for each dwelling, …).

This paper reports about a pilot study applied to Cansatessa, a political district of the town of L'Aquila (Italy). The outcome of the study has been recently formally submitted to the local authority in charge of the management of the municipal SW. The remainder of the paper is structured as follows. Sec. 2 touches on a way to implement the two algorithms in terms of open source software. Sec. 3 is about the municipal SW accumulation system of L'Aquila, while Sec. 4 describes the study area and the input dataset. Sec. 5 presents and discusses the results. Sec. 6 ends the paper.

2. Implementation

The implementation of the algorithms *LocatingOfGAPs* and *SizingOfGAPs* was achieved in two steps. The first step was about the design of a Spatial DataBase (SDB) and its subsequent implementation in PostgreSQL/PostGIS, followed by loading in it the spatial and descriptive data necessary to solve the WAP. Then (step 2), we coded the two algorithms in the language PL/pgSQL (http://www.postgresql.org/docs/9.1/static/plpgsql.html) as User Defined Functions (UDFs).

The SDB is composed of the following five tables (the underlining identifies the primary keys):

```
road      (id, name, the_geom)
house     (id, road_id, GAP_id, num, density, the_geom, the_geom_c, the_geom_h)
GAP       (id, the_geom, road_id, glass, plastic, paper, organic, unsorted)
GB        (id, type, capacity, collection)
GAP_GB    (GAP_id, GB_id)
```

among which there exist the following foreign key constraints:

house(road_id)	references **road(id)**
house(GAP_id)	references **GAP(id)**
GAP(road_id)	references **road(id)**
GAP_GB(GAP_id)	references **GAP(id)**
GAP_GB(GB_id)	references **GB(id)**.

road, **house**, **GAP** and **GB** store, in sequence, the elements in the sets $\mathfrak{R}$, $\mathfrak{H}$, $\mathfrak{GAP}$, and $\mathfrak{GB}$ (see Di Felice, 2013).

The implementation of *LocatingOfGAPs* required 227 lines of code, while the implementation of *SizingOfGAPs* required 105 lines of code. The coding of the two UDFs has been facilitated by the use of the following PostGIS functions: **ST_Area()**, **ST_Centroid()**, **ST_Distance()**, **ST_Intersection()**, **ST_Intersects()**, **ST_Length()**, **ST_Line_Interpolate_Point()**, **ST_LineMerge()**, **ST_Line_Locate_Point()**, **ST_Line_Substring()**, **AddGeometryColumn()**.

The computation of the set H* (Line 14 of the algorithm *LocatingOfGAPs*) with regard to a given GAP, let say *gap*, requires the visit of *all* the routes that lead to dwellings not far away from *gap* more that *distance* moving along the public roads. This action was carried out by visiting in depth the graph having as arcs the roads in $\mathfrak{R}$ and as nodes the crossings between the roads, the houses in $\mathfrak{H}$ and the GAPs in $\mathfrak{GAP}$.

The software architecture of our implementation offers two major benefits: first of all, it relies on the DBMS technology which allows to take advantage of the expressiveness of the SQL language for querying the SDB (expressiveness that can be further improved by invoking either some of the implemented UDFs or the built-in functions); second, it makes exclusive use of open source software, choice in a sense mandatory for the municipal administrations chronically short of cash flow.

3. The municipal solid waste accumulation system of L'Aquila

L'Aquila municipality (the capital of the Abruzzo region, Italy) is responsible for the management of the SW life cycle. At the present days, household SW is accumulated using two complementary methods. From many years, the municipality has spread on the major crossroads of the town large-sized GBs. Daily, households leave their SW in these public containers, while cyclically (Tab.1) municipality-owned machines take away the SW from the containers. A more recent method consists in providing families with smaller GBs and the municipal workers collect the household SW door-to-door. In L'Aquila, but the same happens in many Italian regions, the first method covers the largest waste disposal production (83.57% - OBRA, 2011).

Fig.1 shows the five categories of large-sized GBs adopted in L'Aquila, while their capacity is given in Tab.1.

Fig. 1. The categories of large-sized GBs used in L'Aquila. From left to right they store: organic waste (i.e., biodegradable waste coming from the scraps of the kitchen), plastic, paper/cardboard, glass, and unsorted waste.

Table 1. The capacity of the different types of GBs adopted in L'Aquila and the periodicity of collection by means of municipal garbage trucks.

Types of household SW	Frequency of collection	Capacity of the GBs (m^3)
Organic	Each 3 days	2.4
Plastic	Each 3 days	2.4
Paper/cardboard	Each 5 days	3.3
Glass	Each 7 days	1.8
Unsorted	Daily	2.4

4. Study area and the input dataset

4.1. The Cansatessa district

As study area, about 7 mq, we refer to the political district of Cansatessa, part of the town of L'Aquila. In the district reside 1464 inhabitants, distributed in 226 separate buildings, while 17 are the public roads.

Tab. 2 summarizes the current situation in the district of Cansatessa in terms of GAPs and number of GBs.

Table 2. GAPs and GBs in Cansatessa

Total number of GAPs	Total number of GBs about					Total number of GBs
	Glass	Paper	Plastic	Organic	Unsorted	
6	4	4	4	8	10	30

4.2. The datasets

The datasets are composed of spatial and descriptive data.

Spatial data

The spatial data, concerning public roads and houses of Cansatessa, were extracted (in the ESRI shape format) from the Regional Numerical Map at the 1-5000 scale provided by the Abruzzo Region (http://www.regione.abruzzo.it/xcartografia/). These spatial data are sufficient to feed the algorithm *LocatingOfGAPs*.

Descriptive data

The situation is much more complex with regard to the descriptive data necessary to feed the algorithm *SizingOfGAPs*. The data we are talking about concern the number of people living inside dwellings and their per capita daily production of SW of the different typologies. Have reliable data at this level of detail is not trivial because, as stated in recent field studies (e.g., Lebersorger & Beigl, 2011), these values are dependent on many variables, including the time of year, the weather, the household income, the size of their homes, the type of heating system of the apartments, etc.

The over time volatility of data is another critical issue against the acquisition of reliable data to feed the algorithm *SizingOfGAPs*. In fact, what we are witnessing is that, partly because of legislative pressures that exist in all European countries, the quotas of separate collection of MSW increase from year to year. By contrast, the data available date back to several years ago. For example, the latest study within the Abruzzo region (i.e., OBRA, 2011) reports data of 2009.

Last practical difficulty, but certainly not least, comes from the fact that there is no unique transformation ratio between the weight of SW (expressed in kg) and their volume, while it is precisely of this data that we need to solve the WAP properly, given that the capacity of the GBs is expressed in m^3. Nor are there any studies on the subject (as far as we know) from which to draw. The relevance of this issue has been stressed recently by Bhada-Hoornweg & Tata (2012), where we read: “Although waste composition is usually provided by weight, waste volumes tend to be more important, especially with regard to accumulation”.

All the above mentioned issues have a direct impact on the outcome of the sizing of the number of GBs per each GAP. That is, it is correct, as well as a duty, be clear about the fact that the goodness of the estimates provided by the method proposed in (Di Felice, 2013) depends directly and largely on the accuracy of its input data. In the present pilot study, given the impossibility of making use of updated data on a local basis, we adopted "synthetic" data (Tab. 3). The 2-nd column sets the number of residents served by a specific GB before it becomes full at 85%, according to the weekly periodicity of collection of the SW by the municipal workers. So, for instance, from Tab. 3 we learn that one GB of type Glass can serve at most 120 people within seven days.

Table 3. The descriptive data used to run the algorithm *SizingOfGAPs*.

Category of household SW	Number of residents served by one GB
Organic	80
Plastic	130
Paper/cardboard	100
Glass	120
Unsorted	210

The number of people living inside dwellings was acquired through a door-to-door survey. Evidently this approach is viable only when the study area is small, as in our case, differently the data have to be acquired asking the local institutions.

5. The results

Tab. 4 collects the results of a campaign of experiments carried out by varying the value of the *distance* parameter that sets the constraint about the GAP-house maximum distance. The values used were: 50, 100, 150, 200, 250, 300, 500 (meters). The findings in Parrot et al. (2009) advise against going further. The seven experiments were performed by visiting the roads in ℛ (i.e., the tuples of table `road`) in decreasing value of length, in this way it happens that a large number of GAPs are positioned on the longest roads that, likely, are also those that offer the best road conditions, aspect, the latter, important for the operations of waste collection by the municipal trucks.

Table 4. The results of the campaign of experiments.

Distance (m)	GAPs	Organic	Plastic	Paper	Glass	Unsorted	Total	GBs/GAPs	GAP average area (m^2)
50	43	51	43	43	43	43	223	6	9
100	28	37	29	28	28	29	151	6	9
150	22	36	24	23	23	24	130	6	9
200	15	34	21	17	18	21	111	8	12
250	12	32	21	15	16	20	104	9	13.5
300	8	29	16	13	13	16	87	11	16.5
500	6	28	15	11	13	15	82	14	21

Column 9 shows that the average number of GBs per GAP increases, actually as it was expected, as the number of GAPs does. We go from 6 GBs (*distance* = 50m) to 14 (*distance* = 500m). The data in the column "Total" shows, however, that the total number of GBs decreases as the number of GAPs does. This finding, only apparently surprising, is easily interpretable remembering that every GAP in its minimum configuration consists of 5 GBs, one for each category of SW. Since *distance* = 50m gives rise to 43 GAPs, it follows that the minimum number of GBs is equal to 215 (very close to the value 223); while *distance* = 500m gives rise to 6 GAPs, which corresponds to a minimum number of 30 GBs (significantly below 82). Column 10 shows the average value of the area on the ground occupied by a GAP, assuming that the area occupied by a single GB is equal to $1.5m^2$ (value consistent with the size of GBs available from the net. An example: http://www.greco-ecology.it/).

Fig. 2 shows the GAPs position for *distance* = 250m and *distance* = 300m.

The current situation in Cansatessa (Tab. 2) is comparable with the outcome produced by the value *distance* = 500m (Tab. 4) with regard to the total number of GAPs, but it is definitely insufficient in the total number of GBs (30 vs. 82).

6. Conclusions

Tab. 4, along with maps that can be obtained by querying the SDB, constitutes the numeric basis from which those responsible for the management of the MSW have a concrete help to set in the "real world" a satisfactory trade-off between the GAP-house distance and the number/sizing of the GAPs.

The study confirmed what was in a sense obvious to expect, namely that as the distance increases the number of GAPs decreases that, however, are composed of a growing number of GBs. Having few areas of accumulation definitely accelerates the waste collection by the municipal workers, while on the citizens' side this may cause the drawbacks mentioned below. First of all, such a solution forces many residents to use the car to go to throw the SW into the GBs, which may not be necessary if the GAP is closer (e.g., within 100m). It is also plausible to foresee that such a solution may impact on the aesthetics of the area, on the smells, as well as on the commercial value of the surrounding dwellings. Another aspect not to be underestimated is the fact that it may not be trivial to find, within modern urban areas, sites adequate to accommodate large GAPs.

In closing it is worthwhile to repeat that the estimate of the number of GBs within each GAP is directly related to the availability of certain data about the number of people living inside dwellings and the daily production of waste for each dwelling. It serves, also, to know what is the conversion factor of the weight of the SW (expressed in kg) in space (m^3), because this latter value has to be correlated with the capacity of the bins (expressed in m^3). Obviously, the responsibility to get hold of this input data burden on the society, either private or public, responsible of the management of the SW.

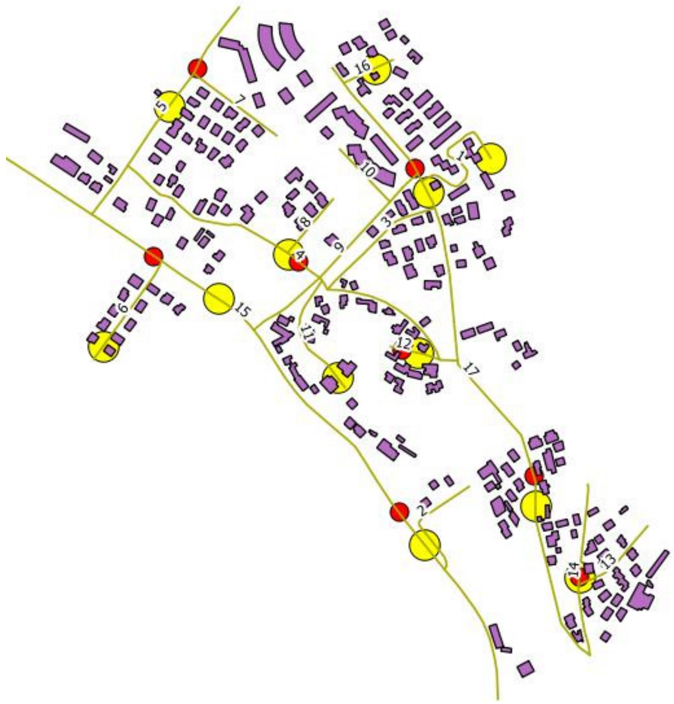

Fig. 2. The (12) yellow and (8) red circles denote, respectively, the GAPs for *distance* = 250m and *distance* = 300m. The numbers identify the roads. Display produced by QGIS.

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