A strategic approach for the optimal location of recycling bins in the city of Boudjlida in Algeria

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Abstract— **To increase the recycling rate of municipal waste, a dedicated infrastructure should exist, together with sorting facilities which should be set up. This is not the case in the emerging countries in Africa which are late in managing in an efficient manner their environmental problems. This article aims at designing a network for facilitating the collection of municipal waste. More precisely, mixed integer linear programming models are proposed in order to locate recycling bins in the city of Boudjlida in Tlemcen in Western Algeria. An allocation-location approach is used for the proper covering of residential zones while ensuring that the inhabitants agree on a common maximum distance to reach the bins. The size of the bins is optimised for each type of specific waste. Last, the real final location of the bins is calculated using a geographic information system GIS and the multi criteria decision making method PROMETHEE allowing the respect of the environmental and social criteria imposed by the city life.**

Keywords— Management of municipal waste; Location problems; Multi-criteria decision making; Promethee Method

I. INTRODUCTION

These last decades have witnessed a growing interest for waste management and more specifically municipal waste. Waste sorting constitutes an important step in the proper organization of waste management. It allows saving the natural resources preserved by the creation of a circular economy. Indeed, indirectly, it is possible to create from recycled waste, other sources for energy saving. However, to ensure the application of this step, one should ensure first that all the stakeholders involved in the sorting process are committed, raising awareness to the general public while respecting the legal framework.

Before the implementation of an efficient management of the recovery flows, the choice of the location of the recovery facilities is complicated and depends on criteria which ensure the balance between the economic and the environmental dimension of a sustainable and productive value chain [1]. Such facilities enable managing specific types of waste such as agricultural ones [2], or the ones from hospitals [3] thus limiting the number of waste incineration plants [4] and the landfill sites [5]. Most studies in the literature are aimed at the location of this type of facilities for the elimination of waste. They are based on multicriteria decision aiding approaches [6]. Other studies also use geographic information sysems GIS. The multicriteria assessment methods [7] such as the weighted linear combination one are particularly preferred for this type of application [8].

However, beforehand, a few studies are devoted to the design of a collection network of urban municipal waste with a sorting logic and a covering of the residences in their neighborhood. To this aim and in order to set up in an efficient manner a sustainable recovery chain [9], the sizes of the bins have to be designed depending on each different type of waste and the bins should be sufficiently close to the inhabitants. This means that one should limit the number of bins while ensuring that they are close enough to the population.

This article is structured in the following manner. In the following section, the real case problem studied is explained. It is based on real geographic data and the real data on the quantities of waste which are produced in a city in Algeria. Section III is dedicated to the technical description of the method used in this study. More precisely, the global view on the locations is obtained by applying and solving three mixed integer linear programming models which are described. Then the multicriteria decision aiding algorithm (of MCDM type) which helps adjusting the position of the collection points will be detailed. Discussions on the obtained results with regards different configurations will be presented and analysed in section IV. Last, this article will end with a proposition of perspectives for future research works.

II. PROBLEM DESCRIPTION

The aim of this study is to set up collection points in optimized locations for the strategic design of a sorting recovery network in a urban zone. To address this issue very influent on the environment and to foster a circular economy, this study aims at organising and planning a network of recycling bins in the urban area of Boudjlida in the wilaya of Tlemcen in Algeria. Boudjlida is a new city with 26000 inhabitants who are spread over a surface of 120 hectares and living in 5200 residences. This study is one of the firsts in Algeria where real studies on urban logistics are rare and works on waste management logistics and their treatment are lacking.

We got closer to the municipal authorities in charge of the waste management in the town of Tlemcen, which allowed us collecting the following information.

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- Each individual throws around 0.45 kg of waste per day. Thus, in average, a family composed of 5 people, produces around 2.25 kg of waste per day.
- There are two types of bins. One of 240 liters and another with a volume of 630 liters costing respectively 4000 and 6400 DA (Algerian dinars).

Moreover, as each building contains 10 apartments and each apartment contains in average 5 people, the mean quantity of waste produced each day by each building is as follows:

TABLE I. MEAN QUANTITY OF WASTE PRODUCED IN BOUDJLIDA

Quantity of waste produced per type, per building and per day in kg					
Plastic	***Glas***	***Organic waste***	***Cardboard***	***Metal***	***Other types***
5,42	6,41	14,3	12,33	1,97	8,88

In addition to that, as organic waste is biodegradable and is rapidly harmful to public health, this study is limited to the research for the best layout possible for the location of bins containing this organic waste. For the other types of waste, the location of their dedicated bins will be directly associated with the sites reserved for the organic waste. Then, a network for the waste collection and sorting will be more visible and apparent to the citizens. The remaining step will be to calculate the size of the bins required for each type of waste which will be allocated to each chosen collection point.

To this aim, we have used a modelling approach of allocation-location type [10], while seeking to maximise the closeness between the citizens and the point where they throw their household waste. In this way, this allowed in a first stage to design a strategic network for setting up the bins in a global manner. Then some adjustments of positions have been achieved using the Promethee method widely used for the classification of existing alternatives with regards to the criteria of visibility of the bins, the possibility for the garbage truck to park and the possibility of extending the collection site. This approach of refining the set of collection points for the layout of the sorting network is achieved through the relocation of certain sites chosen in their neighborhood while respecting the criteria imposed and used in the Promethee method.

III. MATHEMATICAL FORMULATION OF THE PROBLEM AND SOLUTION APPROACH

The studied problem consists in finding a maximal covering of the residential buildings in a urban area. The aim is to optimise the number of collection points dedicated to the setting up of a sorting network for the waste while allowing for a sufficient and acceptable closeness for the citizens living in that zone. Therefore, two procedures are used. The first is a search for the sites to locate by modeling the problem as a maximal covering one with a minimisation of the distances between the inhabitants and their new collection point for the waste. Then the second procedure consists in the adjustment of these first locations obtained with the maximum covering method, by using the multicriteria decision aiding technique PROMETHEE II which allows for the classification of the candidate points the most adapted in the neighborhood of these first points. Thus, the most suitable point is the one with the highest classification rank with regard to the visibility criterion, the possibility of parking, the possibility of extension and the distance between the bins and the residential buildings.

A. Covering approach

To reduce the search space of the candidate sites, a meshing with squares with A meters side, is proposed such that each meshing point is a collection point candidate for throwing waste. In a second step of the study, the positions retained will be adjusted if their selection is suitable. The Fig. 1 represents the configuration of the network of the candidate sites obtained with the help of a geographical information system QGIS. The meshing consists in squares with 50m long sides. Then the choice of the locations has to be taken among 256 candidate points.

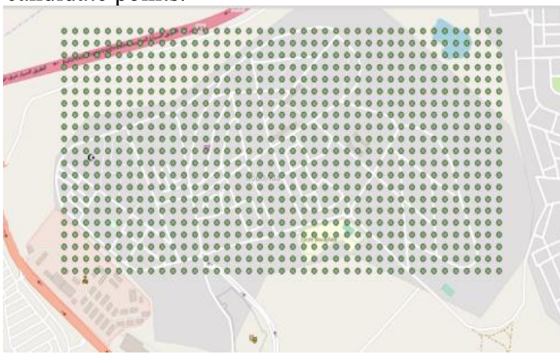

Fig. 1: Meshing with squares, A= 50m long on each side, with N= 620 candidate points in the Boudjlida area using QGIS

The green points of the meshing represent the bins candidates denoted by the index $i \in I=1,\ldots.N$.

Fig. 2.: Location of the 498 residential buildings obtained with QGIS

The buildings in Fig. 2 in purple represent the residential zones to cover denoted by the index $j \in J=1,\ldots M$.

Three covering models are proposed. The first formulation is based on a mixed integer linear programming method MILP [11]. The objective is the minimization of the investment costs [12] with the most suitable covering closeness. The second formulation is also based on the MILP [13] but also with considering a scenario analysis in accordance with the varying types of bins existing on the marketplace. In the last model, we consider the possibility to use different variants of bins in a same configuration. One should note that in the models II and III, the variants in the capacity of the bins are studied for the biodegradable waste to avoid any overflowing before the daily arrival of the garbage trucks.

The indices, variables and parameters of the optimization models are the following:

a) Indexes

i : index for the bins, $i \in I$.
j : index for the buildings, $j \in J$.
I= {1…620}.
J= {1…498}.

b) Parameters

x_i, y_i : geometrical coordinates for the bin i.
x_j, y_j : geometrical coordinates of the building j.
$d_{i,j}$: euclidian distance between the bin i and the building j.

c) Decision variables

P_i is equal to 1, if a bin is located at site i, 0 otherwise.
A_{ij} equals 1, if the bin i is allocated to the building j and 0 otherwise.

1) Model I

The objective is to ensure an optimised covering, while ensuring that any citizen should walk a maximum distance D_{max} acceptable to throw the daily waste.

$$Min \sum_{i=1}^{N} P_i$$

Such that

$$d_{ij} * A_{i;j} \leq P_i * D_{max} \qquad \forall\, i \in I, \forall\, j \in J \quad (1)$$

$$A_{ij} \leq P_i \qquad \forall\, i \in I, \forall\, j \in J \quad (2)$$

$$\sum_{i=1}^{n} A_{ij} = 1 \qquad \forall\, j \in J \quad (3)$$

$$A_{ij} \in \{0,1\}. \qquad \forall\, i \in I, \forall\, j \in J \quad (4)$$

$$P_i \in \{0,1\}. \qquad \forall\, i \in I \quad (5)$$

The constraints (1) impose to respect a maximal distance D_{max} between a bin i and the building j assigned to it [14]. The series of constraints (2) define the allocation of the buildings j to the sites for the sorting located in i.
The constraints (3) impose that each building j is assigned to one and only one site i for the sorting bins [15]. Last, the constraints (4) and (5) are linked to the binary nature of the decision variables [16].

2) Model II

In addition to the previous model, we add

a) Parameters

$cost_i$: cost of a bin located in i.
q_j: quantity of organic waste produced by each building j each day.
Q_i: Capacity of the bin located in i.

b) Decision variables

$Taux_i$: filling rate of the bin i dedicated to the organic biodegradable waste.
The aim is to minimise the investment costs linked with the purchase of the bins.

$$Min \sum_{i=1}^{n} P_i * cost_i$$

Under the following constraints, in addition to the former constraints numbered from (1) to (5) :

$$\sum_{j=1}^{n} q_j * A_{ij} \leq P_i * Q_i \qquad \forall\, i \in I \quad (6)$$

$$Taux_i = \sum_{j=1}^{n} q_j * A_{i,j} / Q_i \qquad \forall\, i \in I \quad (7)$$

The series of inequalities (6) impose that the quantity of organic waste does not exceed the capacity of the bin located in *i*.
The series of equalities (7) allows calculating the filling rate *of* the bin located in *i*.

3) Model III

In this model, we add the possibility to have different types of bins for the sites chosen in a same network.

a) Index

k : index of the type of bin, $k \in K$

b) Parameters

$cout_k$: cost of a bin of type k.

V_k : capacity of a bin of type k.

c) Decision variables

x_{ik} is equal to 1, if the bin of type k is assigned to the site i and 0 otherwise.

The objective is to minimise the investment costs for the purchasing of the bins allocated to the different sites.

$$\text{Min} \sum_{i=1}^{n} \sum_{k=1}^{n} x_{i,k} * cout_k$$

Under the following constraints:

$$d_{ij} * A_{i;j} \leq P_i * D_{max} \qquad \forall\, i \in I, \forall\, j \in J \quad (1)$$

$$A_{ij} \leq P_i \qquad \forall\, i \in I, \forall\, j \in J \quad (2)$$

$$\sum_{i=1}^{n} A_{ij} = 1 \qquad \forall\, j \in J \quad (3)$$

$$A_{ij} \in \{0,1\} \qquad \forall\, i \in I, \forall\, j \in J \quad (4)$$

$$P_i \in \{0,1\} \qquad \forall\, i \in I \quad (5)$$

$$\sum_{k=1}^{n} x_{ik} = P_i \qquad \forall i \in I \quad (8)$$

$$\sum_{j=1}^{n} q_j * A_{ij} <= \sum_{j=1}^{n} x_{ik} * V_k \qquad \forall i \in I \quad (9)$$

$$Taux_i = \sum_{j=1}^{n} q_j * A_{ij} \Big/ (1 - P_i) + \left(\sum_{k=1}^{n} V_k * x_{ik}\right) \qquad \forall i \in I \quad (10)$$

$$x_{ik} \in \{0,1\}. \qquad \forall i \in I, \forall\, k \in K \quad (11)$$

The series of constraints (8) stipulates that only one type of bin k can be assigned to the site located in *i.* Constraints (9) ensure that the bin of type k located at site i should contain the total volume of organic biodegradable waste of the building j assigned to the site i. The series of constraints (10) allows calculating the filling rate of each bin located in *i*. The last series of constraints (11) reflects the binary nature of the decision variable x_{ik}.

B. Promethee method

The main principle of the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) is based on a comparison of pairs of alternatives among all the recognised criteria [17]. The alternatives are assessed based on different criteria, which have to be maximised or minimised. The implementation of PROMETHEE II requires the consideration of two types of additional information:

- The calculation of the weights: This step is mandatory in most of the multicriteria mathods. This means that the decision maker is able to assign weights to the criteria at least when they are not numerous. In this work, four criteria are considered.
- The preference function: For each criterion, the preference function translates the difference between the evaluations obtained with two alternatives. In any case, this function is meaningful for the decision maker.

The PROMETHEE II procedure starts with a pair-wise comparison of alternatives to check whether an upgraded order exists or not. Then a preference function is applied on each criterion. Then the index of global preference is calculated. The next step calcuates the negative or positive ranking for each alternative and the partial ranking.

The application of the method ends with the calculation of the net preference flow for each alternative and the complete ranking.

This is the method which will be applied in the following with four different criteria for the final location of the sorting bins. For each candidate bin defined by the optimisation models, there will be three alternatives for the real location. These three options will be assessed and ranked in order to chose the best one.

IV. NUMERICAL RESULTS AND DISCUSSION

To design the network of sorting and recycling bins, a first sensitivity analysis is achieved depending on several scenarios.

A. Resuls of the covering problems

For all the scenarios, the meshing chosen for representing the candidate sites for the bins and for the residential buildings is the one shown in Fig. 1. with 50 meters side squares. The parameters fixing the maximum distance between the inhabitants and the bins have been fixed following the results of a survey achieved with some of the residents of the city. It reflects the age of these people and sometimes their unability to walk long distances. The results of each scenario are presented as follows.

1) Application of models I and II

In the three first scenarios, the maximum distance D_{max} is equal to 80 meters.

In the first scenario, it is the first optimisation model which is implemented in the LINGO solver. The execution of this scenario corresponds to 308760 constraints and a computation time inferior to one minute for finding the optimal solution. The location of 39 collection sites is illustrated in Fig. 3. where the locations for the bins are colored in red.

Fig. 3.: Location of the bins in the first scenario

In scenario 2, it is the optimisation model II which is implemented in LINGO for the setting of bins with a capacity of 240 L strictly dedicated to the organic biodegradable waste. The optimisation computation involves the respect of 308760 constraints and leads to the same number of bins localised. These 39 bins are represented in green in Fig. 4. Their filling rate $Taux_i$ are equal to 50% for four bins, 58 % for three bins and for the remaining bins, the filling rate is superior to 70 %, regarding to the 14,3kg which are produced daily per building.

Fig. 4.: Location of the bins found in scenario 2

Scenario 3 is the same as the preceding scenario excepted that the volume of the bin is now equal to 630 litres. The results are slightly different because some of the 39 bins are located exatly at the same place and the filling rates vary: 33 bins are filled at less than 50% of their volume and six bins are filled at between 51% and 66% of their capacity.

In scenario 4, the maximum distance D_{max} is equal to 120 meters. The maximum capacity of the bins allocated to the organic waste is 240L. The application of model II with these new data leads to the assignment and the location of 30 bins with a filling rate equal to 99 % on the whole set of points represented in the figure.

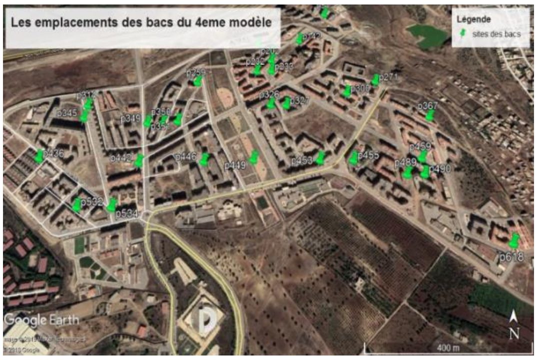

Fig. 5.: Location given by QGIS for 30 zones for the 240L containers

In the case of scenario 5, the maximum distance D_{max} is equal to 120 meters while the bins dedicated to the organic waste can contain 630L. The application of model II results in the location of 21 bins which do not reach their maximum filling rate for the majority of them.

Fig. 6: Location of the 630L containers (21 units)

2) *Application of model III*

In the two last covering scenarios it is the third model which is implemented in the LINGO solver.

Scenario 6 corresponds to a maximum distance D_{max} equal to 80 meters and the possibility to choose between containers of 240 L or 630 L. The execution of the optimisation program defined by model III gives 39 locations for bins of 240L, exactly as the results of scenario 2.

In scenario 7, the maximum distance D_{max} is equal to 120 meters and bins of 240 L or 630 L can be chosen. The application of model III gives an assignment of 21 bins with similar locations as the configuration of scenario 5, see Fig. 6. However, this time, the bins have different sizes. It is thus possible to save money because the bins of lower size are cheaper.

After analysing the results obtained with the seven scenarios, one can deduce that the configuration obtained with scenario 4 is the most valuable because a few bins of 240L are required and their filling rate is balanced. These results are then modified, using the Promethee method.

B. *Results of the Promethee method*

This step of the work consists in adjusting the location of the sorting bins localised in scenario 4. The PROMETHEE method has been applied using four criteria. The weight have been fixed in collaboration with the responsible of the municipality of Boudjlida, in accordance with the confort of the citizens :

- The visibility criterion is the one that imposes that the bin is sufficiently visible to the citizen and the lorry driver. It is the most important criteria with a weight w_1 equal to 0,3. As it is not quantitative, the values of X_{i1} are incremented from 1 to 5.
- The parking criterion has also a weight equal to 0,3 and the evaluation of X_{i2} varies from 1 to 5.
- The criterion which translates the distance between the bin and the nearest building is expressed in meters and a maximal distance is sought with a weight of 0.25.
- The last criterion is the possibility to extend the site which is for the moment less relevant, thus with a weight of 0.15. This criterion measures the surface available for a possible extension in the candidate depot zone.

After the application of the six steps of the PROMETHEE method, the positions of the bins have been moved to less than 10 m as shown by Fig. 7. This real new locations are given by the Google Earth software and show bins which respect the visibility criteria, the available parking space for the garbage truck, the possibility for the extension of the site, and the esthetic aspect of the view, which is facilitated by keeping the bins away from the residential buildings.

Fig. 7: New locations for the 30 bins calculated with the Promethee method

Moreover, to avoid an overflow of waste the days when there are more consumptions and then more organic waste produced, some of the bins with a volume of 240L are replaced by other ones of 630L. Indeed, each bin has been chosen in order to cover around 17 buildings. However, as the filling rate is high, the dimensions of some bins should be adjusted to better contain certain types of waste and avoid the overfilling. As the daily production of plastic waste per building is superior to 85kg, and its volumetric mass density is high, the dimension of the bins will be changed from 240L to 630L. Moreover, for the cardboard which represents 204 kg produced per day but a high volume when unfolded, the containers which will be chosen for the waste will have a volume of 630L.

V. Conclusion

In this study, an analysis of the design of a network of bins dedicated to the collection of waste sorted by type is presented. To obtain the optimal design, several mathematical models have been proposed for covering the different residential buildings while ensuring a maximal distance agreed by the inhabitants. These models are mixed integer linear programs. Then, in order to reduce the research space for this covering approach, a geographic information system or GIS was used to obtain a meshing of the zones considered. In this way, the map of the city of Boudjlida in Tlemcen in Algeria was used in this study together with the data of the production of waste of different types. The results obtained are promising and can help decision makers setting other waste collection networks in other zones. The forthcoming perspectives are to find a way to encourage the citizens to participate actively in the setting up of such a recycling network. Other studies on the anthropologic, social and legal fields are necessary. Last, it would be wise to integrate this configuration in a network of intelligent collection which would improve the system with a deeper data analysis.

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