Regional optimization model for locating supplemental recycling depots

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Abstract

Currently in Taiwan, various vendors/businesses which sell products belonging to six classes of recyclables are stipulated to provide recycling containers at local retail shops. The integration of these private sector facilities with the recycling depots established by local authorities has the potential to significantly improve residential access. An optimization model is accordingly developed in this work to assist local authorities with the identification of regions requiring additional recycling depots for better access and integration with private facilities. Spatial accessibility, population loading and integration efficiency indicators are applied to evaluate whether or not a region is in need of new depots. The developed program uses a novel algorithm to obtain the optimal solution by a complete enumeration of all cells making up the study area. A case study in central Taiwan is presented to demonstrate the use of the proposed model and the three indicators. The case study identifies regions without recycling points, prioritizes them based on population density, and also considers the option of establishing recycling centers able to collect multiple classes of recycling materials. The model is able to generate information suitable for the consideration of decision-makers charged with prioritizing the installation of new recycling facilities.

Keywords: material recovery and recycling, optimization, integer programming, geographical information system, municipal solid waste management
1. Introduction

Researchers (McDonald and Ball., 1998; Tilman and Sandhu, 1998) have acknowledged that the success of MSW recycling schemes is highly dependent upon the active participation of residents, which in itself is critically influenced by the proximity of drop-off depots. Speirs and Tucker (2001) have analyzed the behavior of recycling participants and concluded that only 22% take extra trips to the drop-off depots, and that more than 50% of the participants’ recycling efforts are primarily inspired by the convenience of drop-off depots. González-Torre and Adenso-Díaz (2005) also maintains that the distance between a drop-off depot and a residence has an impact on the frequency of recycling: a shorter distance between the two significantly improves the participation in MSW recycling and increases the quantity of materials recovered.

Due to the recent trend towards extended producer responsibility in waste management, along with increased regulatory requirements in Taiwan, vendors of products with stipulated recyclable materials assume responsibility for the provision of drop-off containers/depots essential for the recycling of goods after their useful life. These recyclables have either or both of the following properties: they are arbitrarily discarded (e.g. beverage bottles) and contains hazardous material (e.g. batteries and fluorescent lights). Table 1 displays eight recycling materials and six types of businesses required to provide drop-off containers for them. For readability, some types of businesses/categories of recycling materials have been modified from the original regulation. Although the private containers are wide-spread and have proven effective collecting the designated recyclables, they are not uniformly installed. In order to achieve higher recycling rates, local governments are interested in providing additional recycling depots in regions with poor access to recycling facilities.

The problems associated with drop-off depots have been studied by researchers in the MSW
management field. For example, Chang and Wei (2000) applied a non-linear integer programming model aided by a genetic algorithm to simultaneously determine depot locations and collection routing. Their goal was to minimize both the walking distance required by residents, and the costs of collection routes. Kao and Lin (2002) compared three models in siting waste/recyclable material pickup points. They concluded that the shortest service level model that minimized the walking distance required by residents significantly improved access to collection points. Gautam and Kumar (2005) utilized a maximal-coverage model incorporating a Geographical Information System (GIS) to generate the locations of MSW recycling stations. All of the models in these studies simulated the pickup and collection services provided by local authorities. A primary factor analyzed in these models was the spatial proximity, which was represented by the distance a resident had to walk to a collection point. Other factors, which included collection costs and service vehicle capacities, were accounted for when determining the optimal recycling system. The application of these models requires a priori, a list of plausible candidate locations requiring a large amount of investigations and planning, which increases sharply with the size of the area under study. The work involved in screening candidate locations can be mitigated by identifying existing recycling locations provided by the private sector, as only regions with poor access to recycling facilities need to be analyzed. This paper develops a methodology for identifying regions most in need of recycling facilities, instead of looking for the optimal combinations of locations.

The use of GISs enables a clear and progressive analysis of the factors with bearing on participation in recycling scheme. Studies that have heretofore incorporated GIS in MSW management make reference to landfill siting (e.g. Kao et al. 1996; Lin and Kao, 2005; Chang et al. 2008), collection routing (Ghose et al. 2006; Karadimas et al. 2007; de Oliveira Simonetto and Borenstein. 2007), and recycling depots (Caterina et al. 1998; Clarke and Maantay, 2006). In these studies, raster GISs were popularly applied to the study area, which was divided into a number of equally-sized cells. Most of these studies include mathematical models with very similar structures
that have constraints of decision variables across all cells that are able to be exploited to ease their solution. Unfortunately, the amount of time required to yield a solution through these models is often prohibitively long, thereby impeding application in some real-life scenarios. With a view to addressing these concerns, this paper proposes a methodology incorporating a customized computer program aimed at the facilitation of data compilation and to reduction of the problem-solving time associated with the modeling of MSW recycling depots.

2. Methodology

The analytical steps associated with the methodology are: (1) collating MSW data for GIS application and calculation, (2) defining recycling performance indicators, (3) implementing the proposed model to locate the recycling facilities, and (4) evaluating the optimal solution for the study area. A detailed explanation of each step follows.

2.1. Collation of MSW recycling data

Population statistics were utilized to estimate the quantities of potential recyclable material generated, which in turn were compared with the statistics of actual collected recyclables to determine any potential for increased recycling participation. Relevant data considered included the population density and quantities of recyclable material collected in each administrative tract. In addition, data for the location and allowable recycling materials of private recycling facilities were also collected. In this study, these relevant data were acquired from local authority.

These data were then transformed into raster GIS map-layers for use in the ensuing analysis. A cell is a geo-referred object which represents a small square area in reality, and is the elementary unit of a raster GIS map-layer (cf. Figure 1). To locate areas needing additional recycling facilities, “regions” are defined as random rectangular zones of similar size, containing groups of adjacent
cells. The size of a region, which represents the service area of a recycling depot, is specified by the decision-makers. A region is a subset of the entire study area, which also means that multiple regions can be found in a study area.

2.2. Indicators of recycling facilities

A number of researchers (e.g., Smoyer-Tomic et al., 2004; Talen and Anselin, 1998) have examined a multitude of indicators for the assessment of accessibility of facilities to the public. The proposed model outlined in this paper adopts three indicators: Spatial Accessibility ($SA$), Population Loading ($PL$) and Integration Efficiency ($IE$). $SA$ is defined as the ratio of cells with at least one recycling point, over the total number of cells in the region. $PL$ is used to evaluate the capacity of recycling facilities in a region. It is defined as the total number of recycling points, divided by the total population in the region being analyzed. $IE$ is given by equation (1):

$$IE = \sum_{k=1}^{K} \left( \frac{SA_k}{SA_k^{max}} \right)$$

Herein $k$ represents the $k_{th}$ recycling material in the study area; $K$ is the total number of categories of recyclable materials; $SA_k$ is the $SA$ indicator value of $k_{th}$ recyclable material in the region; and $SA_k^{max}$ represents the maximum $SA$ indicator value of the $k_{th}$ recyclable material among all regions in the study area.

The detailed description of these indicators can be found in Appendix 1.

2.3. The proposed model

The proposed model is built upon a previous model (Lin and Kao, 2005), a detailed description of which is given in Appendix 1. The goal of the proposed model is to find a region larger than a specified size ($A_{size}$), which has the fewest total accessible cells inside. In addition to using the accessibility analysis ($SA$) to locate the regions, two other indicators, $PL$ and $IE$, can also be used
2.4. The customized program for the proposed model

The proposed model uses integer programming, which can consume a large amount of time computation time for the solution of even modestly-sized problems. To enable solution time savings, a customized program written in C++ has been provided to solve the model by enumeration. The algorithm followed by the customized program is described as follows.

Two cells are selected during each iteration. The first cell is utilized as the upper-left corner of a region, and is selected one by one in sequence from all cells of the study area. The second cell marks the lower-right corner of a region, which is selected only from the cells whose row and column indices \((i,j)\) are greater than those of first cell. The area of the region is then calculated from the position of the two cells, and if the value is larger than the specified area constraint \((A_{size})\) the program then computes an objective value for this region and compares it with the minimum value previously recorded. If the new value is smaller than the existing record, the record will be replaced by the new value. For a study area with \(T\) cells, the number of computational iterations is \(C_2^T\), which is significantly less than \(2^T\), the maximum number of iterations required by typical branch and bound methods. Figure 2 presents the solution time of test cases with problem size varying from 10 to 10,000 cells, employing both the customized program and an optimization software package CPLEX (ILOG, 1997). The customized program presented with our model requires less computation time than the CPLEX package in all these test cases considered. As the number of cells increases, the difference in solution time between the two solving methods becomes increasingly larger. These experiments on test cases strongly support that the customized program is superior in computation time, especially when applied to large-scale problems.
3. Case Study

In order to demonstrate the applicability of the proposed model and associated customized program, a case study is presented. Taichung City is the third largest metropolis in Taiwan. It has an area of approximately 163 square kilometers, and it has a population of more than one million inhabitants. In 2003, the total recyclable material collected was around 88,000 tons, which was about 33% of the total MSW (Environmental Protection Agency, Republic of China, 2004) by the city. There were 1,573 private recycling points accepting a total of eight different recyclable materials in Taichung City. The three indicators used in the model to evaluate the recycling access and are discussed below.

3.1. Scenario A: SA indicator analysis of glass recycling points in the downtown area of Taichung City

The downtown area of the city includes three districts: North District, East District and Center District. The area is in the heart of Taichung City and has approximately 260,000 residents annually generating 76,000 tons of MSW. The ratio of recycled material collected to total MSW generated in this area is 27%, which is less than 33%, the average of Taichung City. The recycling points for glass containers, categorized as A3 in Table 1, are assessed in this scenario. There are 239 recycling points accepting A3 category materials in the downtown area. To analyze the proximity of these recycling facilities to residents, the SA indicator was applied. A cell in a GIS map-layer for the scenario was defined as a square of 50x50 m² and there were 14,352 cells of this size in the downtown area. The cells containing recycling points are classified as ‘accessible’. The acceptable walking distance for a recycling participant was set at 350 meters, which was roughly estimated as the length covered by a person walking slowly along a street for five minutes. Other
values of distance could be selected if desired. A ‘region’ was therefore defined as an area of 0.12 km² (\( A_{size} \)), the square of the acceptable walking distance, and the length or width of a region is confined to less than twice of the acceptable walking distance, 700 meters. These measurement criteria ensure that new recycling points, as well as existing ones, will be accessible to residents living within the region. Figure 3 presents the distribution of these points and the result of SA analysis for this scenario. Existing recycling points in the Center District, which are marked by solid circles, are located slightly denser than the other two districts. After application of the model of the downtown area, 35 regions without access to recycling depots were identified and are marked by dashed-line rectangles in the figure. They were therefore highlighted as requiring new A3 recycling facilities. If the budget for MSW management allows, the local authority can set up recycling facilities for A3 category within all of these regions, which would result in a significant improvement in access for local residents in these regions. However, one problem with this approach is that SA analysis provides no information about the priority for setting up new recycling facilities in these regions. An alternative that addresses this is to apply the \( PL \) indicator, as described in Scenario B.

3.2. Scenario B: \( PL \) indicator analysis of glass recycling points in the downtown area of Taichung City

If two regions both lack suitable access to recycling collection points, the region containing more residents should be given a higher priority when determining the location of new recycling facilities. The indicator, \( PL \), is able to reflect this priority. To illustrate the difference between \( SA \) and \( PL \), the A3 category recycling points of the downtown area were reevaluated using the proposed model incorporating the \( PL \) indicator. Figure 4 presents the distribution of population and recycling points in the downtown area after applying the proposed model with the \( PL \) indicator.
Each color in the figure represents a different cell population density, and existing recycling points are marked by a solid circle. In addition to this, the regions identified as requiring new recycling points are marked by rectangles with dashed lines and a priority number. A lower priority number (lower $PL$ indicator value) signals a more urgent need for new recycling points. In case where the same $PL$ value occurs in different regions, the priority numbers of these regions are then assigned by ranking the population densities only; that is, a lower priority number is assigned to a more populated region. In this scenario, as shown in Figure 4, there are ten regions without access to A3 category recycling points and consequently, the $PL$ values of these regions are null (given that the priority numbers are assigned in accordance with the region’s population density). Table 2 lists the properties of the ten regions, including priority number, population, area and population density.

Comparing the results of the two scenarios, most of the selected regions in Scenario B are subsets of the results found in Scenario A. However, consideration of the $PL$ indicator value will be potentially helpful to local authorities when making more cost effective and flexible decisions. This is particularly useful if the budget for locating new recycling points is limited, as the proposed model with $PL$ indicator will generate a priority list for implementation.

3.3. Scenario C: IE indicator analysis of Taichung City

In addition to the 1,573 recycling points that cover a range of different recyclable materials, nine recycling centers that accept the entire range of stipulated recyclable materials operate in Taichung City. A recycling center can differ from a recycling point insofar as it may be operated by private firms or charities, and is therefore more likely to accept all categories of recyclables and sell them onto the material-recovery companies before its storage space is exhausted. To help analyze preferred locations for these full-range recycling centers, the proposed model with the $IE$ was applied. In general, it is considered that recycling participants who send material to the
full-range recycling centers are more strongly motivated, either as a result of money or good intent, than those attending smaller recycling points. They usually accumulate materials for recycling, up until a certain manageable amount, and then transport them to a recycling center. The acceptable traveling distance is defined as 2,500 meters in this scenario; a vehicle traveling at a speed of 30 km/h would take five minutes to travel this distance. The corresponding region size ($A_{size}$) value is defined as 6.25 km$^2$, or 2,500 cells in total. In addition, the length or width of a region is confined to less than twice of the acceptable traveling distance. Figure 5 presents the entire area of Taichung City, which comprises 120,744 cells in total. The location of both recycling points and full-range recycling centers are marked by dots and boxes, respectively. Existing recycling centers are located in the north and southwest areas of Taichung City. Figure 5 also presents the results of modeling with the $IE$ indicator. Ten regions requiring additional recycling center access, with priority numbers, are marked by dashed rectangles. The priority numbers of these regions are based on their $IE$ indicator values, with the number “1” representing the highest priority level. For an evaluation of the cost effectiveness of a location for a new recycling center, an alternative ranking method can be achieved by dividing the $IE$ indicator values by the population density of the regions accordingly. Table 3 presents the priority number, population, area, and the alternative priority ranking method of $IE$ values for each region. The regions identified as first and second priority levels were the same using both ranking approaches. This would seem to indicate that new recycling centers in these two regions should be given precedence over all other regions. However, the priority numbers of the other regions are slightly different after the two approaches are applied because the $IE$ indicator priority emphasizes the access ratio of a region without considering population factors, whereas the alternative priority ranking method does. In order to obtain the best coverage of recycling depots for the maximization of public benefits, the $IE$ indicator priority approach is suggested. The use of additional priority ranking approach will be more cost effective if the budget for recycling centers is limited.
4. Conclusions

This paper develops a methodology for identifying regions most in need of recycling facilities, as opposed to concentrating on any optimal combination of locations. One inherent advantage lies with the flexibility that is conducive to the expeditious computational evaluation of competing design solutions. The proposed model and program proposed aims to find regions requiring new recycling facilities complementary to existing recycling points. For a local authority responsible for the provision and management of recycling facilities, the major attraction is the superior flexibility apparent when identifying for the recycling points. In this sense, the model is a dynamic management tool able to productively engage with the everyday contingencies that might have otherwise negatively impacted on the selection of ideal sites. These include the cooperation of landowners and land-use restrictions. Once suitable regions for evaluation have been identified, locations of complementary recycling points within these regions can be determined by the experience of local authorities easily.

Acknowledgement

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Appendix 1 Indicators and the proposed model

Indicators:
*Spatial accessibility (SA):* The spatial accessibility of a region is defined as the ratio of accessible cells over the total number of cells in the region. An accessible cell has at least one recycling point located within it. For a specific region and a specific category of recyclable material, the total number of cells is known, and thus the lower the SA value, the greater the inconvenience experienced by residents in this region when accessing recycling points.

*Population loading (PL):* This indicator is used to evaluate the capacity of recycling facilities within a region. It is defined as the total number of recycling points divided by the total population of the analyzed region. A low PL indicator value indicates that residents in this region have limited access to recycling facilities, pointing towards insufficient recycling capacity that may discourage residential participation in recycling schemes.

*Integration efficiency (IE):* Since recycling points provided by the private sector only accept a limited range of stipulated recycling materials, SA indicator values for different categories of recyclable materials may vary significantly among regions. To determine if a region requires a new recycling center that accepts the entire range of recyclable material categories, the IE indicator is defined. The indicator is made up of a combination of SA values of all recyclable materials collected within the region. Equation 1 clarifies the definition of the IE indicator. Firstly, the maximum SA indicator value of each recyclable material is obtained by analyzing all regions in the study area. The normalized SA indicator value of a region is then calculated by dividing the original SA indicator value by the maximum value. The IE indicator value of a region is finally represented by the sum of the normalized SA values of all applicable recyclable materials. A low IE indicator value implies a need for establishing a new recycling center in the region.

\[
IE = \sum_{k=1}^{K} \left( \frac{SA_k}{SA_k^{max}} \right)
\]  

Herein \( k \) represents the \( k_{th} \) recycling material in the study area; \( K \) is the total number of categories of recyclable materials; \( SA_k \) is the SA indicator value of \( k_{th} \) recyclable material in the region; and \( SA_k^{max} \) represents the maximum SA indicator value of the \( k_{th} \) recyclable material among all
regions in the study area.

The proposed model:

Objective function

\[
\text{Min} \sum_{i=0}^{M} \sum_{j=0}^{N} SS_{i,j} \cdot (u_{i,j} - v_{i,j})
\]  

(3)

Subject to:

\[
\sum_{j=0}^{N} u_{i,j} \leq 1 \quad \forall i \in \{0, ..., M\}
\]  

(4)

\[
\sum_{i=0}^{M} u_{i,j} \leq 1 \quad \forall j \in \{0, ..., N\}
\]  

(5)

\[
\sum_{i=0}^{M} \sum_{j=0}^{N} u_{i,j} = 2
\]  

(6)

\[
\sum_{i=0}^{M} \sum_{j=0}^{N} v_{i,j} = 2
\]  

(7)

\[
\sum_{j=0}^{N} (u_{i,j} - v_{i,j}) = 0 \quad \forall i \in \{0, ..., M\}
\]  

(8)

\[
\sum_{i=0}^{M} (u_{i,j} - v_{i,j}) = 0 \quad \forall j \in \{0, ..., N\}
\]  

(9)

\[
u_{i,j} + v_{i,j} \leq 1 \quad \forall i, j
\]  

(10)

\[
\sum_{i=0}^{M} \sum_{j=0}^{N} [AS_{i,j} \cdot (u_{i,j} - v_{i,j})] \geq A\text{size}
\]  

(11)

\[
u_{i,j} \in [0,1] \text{ integer variable.}
\]  

(12)

In this model, \(i\) and \(j\) are the coordinate indices of a land cell; with \(i\) in column and \(j\) in row. \(M\) and \(N\) are the numbers of column and row cells of the study area, respectively. \(SS_{i,j}\) is the total number of the recycling accessible cells, as defined in \(SA\), indexed from \(1\) to \(i\) for the column index and \(1\) to \(j\) for the row index. For convenience in calculation, one column (with \(i=0\)) and one row
(with \( j=0 \)) of pseudo cells, in which no drop-off centers/containers exist, are added. Figure A illustrates how the \( SS_{i,j} \) value map-layer is generated from a \( SA \) 0/1 map-layer. The \( SS_{i,j} \) value is calculated by summing up all values in cells in the 0/1 map-layer whose indices \((i,j)\) are less than or equal to the index of the cell in the \( SS_{i,j} \) map-layer. Variables \( u_{i,j} \) and \( v_{i,j} \) are used to determine whether grid \((i,j)\) is the corner grid of a region or not; \( u_{i,j} \) is equal to 1 if cell \((i,j)\) is at the upper-left or lower-right corner and \( v_{i,j} \) is equal to 1 for cell \((i,j)\) located at the upper-right or lower-left. \( Asize \) is the lower bound of the size (in number of cells) of a region; \( AS_{i,j} \) is the size of the region of cells indexed from \( 1 \) to \( i \) for the column index and \( 1 \) to \( j \) for the row index with pseudo cells excluded. Therefore, the value of \( AS_{i,j} \) is equal to the product of \( i \) and \( j \), the width multiplied by height.

Equation (2) is the objective function, which is used to find the region with the minimal value of \( SA \) or other indicators. Equations (3) and (4) ensure that, at most, one cell per column or row can be the corner of the region, and Equation (5) and (6) ensure only two such corners which are marked by \( u_{i,j} = 1 \) or by \( v_{i,j} = 1 \), respectively. Equations (7) and (8) ensure that either no corner or pairs of corners (actually, only one pair can be present) can exist in any column or row. Equation (9) ensures that at most a cell can be only one of the four corners in total. Equation (10) defines the lower bound (in number of cells) of the size of a desired region. This constraint guarantees that the model marks the upper-left or lower-right corners of the rectangle with \( u_{i,j} = 1 \), and the upper-right and lower-left ones with \( v_{i,j} = 1 \), to ensure a positive value for the size of a region. Figure B(a) presents the rectangular region, in which the \( u_{i,j} \) values of cell A and cell D, and \( v_{i,j} \) values of cell B and cell C, are equal to one. Note that only the lower-right corner (D) is located exactly inside the region, whereas the other three corners are not. Figure B(b) explains geometrically how the algorithm employed by the model calculates the area (or attribute values) of a region, where \( \text{sum}_A \) represents the sum of the attribute values of corner A and similarly for the other three corners, \( \text{sum}_B, \text{sum}_C \) and \( \text{sum}_D \). For the sample region, the attribute value is equal to \( \text{sum}_A \) plus \( \text{sum}_D \) then minus \( \text{sum}_B \) and \( \text{sum}_C \).
The objective function, Equation (2), is for the SA indicator evaluation. For the PL indicator, the objective function becomes

$$Min \sum_{i=0}^{M} \sum_{j=0}^{N} [PS_{i,j} \cdot (u_{i,j} - v_{i,j})/(PN_{i,j} \cdot (u_{i,j} - v_{i,j})]$$ (13)

$PS_{i,j}$ is the total number of the drop-off centers/containers of cells indexed from 1 to $i$ for the column index and 1 to $j$ for the row index. $PN_{i,j}$ is the total populations of cells indexed from 1 to $i$ for the column index and 1 to $j$ for the row index. With this objective function, the model will find the region in which drop-off centers/containers may be undersupplied.

For the IE indicator, the objective function becomes

$$Min \sum_{i=0}^{M} \sum_{j=0}^{N} SS_{i,j,k} (u_{i,j} - v_{i,j})/ SR_k^{max}$$ (14)

Parameter $k$ is the number of categories of recyclable materials in the study area. $SS_{i,j,k}$ is the total number of accessible cells of the $k_{th}$ material in cells indexed from 1 to $i$ for the column index and 1 to $j$ for the row index. $SR_k^{max}$ is the maximal value of $SS_{i,j,k}$ among all regions.
References


### Tables

**Table 1 Recycling materials and stipulated business**

<table>
<thead>
<tr>
<th></th>
<th>A1/A2/A3</th>
<th>B1</th>
<th>C1</th>
<th>D1</th>
<th>E1</th>
<th>F1</th>
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</thead>
<tbody>
<tr>
<td>Hypermarkets / supermarkets</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Convenience stores / cosmetics retailers</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Gas stations</td>
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<td></td>
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<tr>
<td>Photographic and mobile communication device retailers</td>
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<tr>
<td>Fast food restaurants</td>
<td></td>
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<tr>
<td>Fluorescent lamp stores</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>X</td>
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</table>

(A1) Metal containers: waste iron containers, aluminum containers, other metal containers.
(A2) Plastics containers: PET bottles, PE bottles, PVC bottles, PP bottles, PS bottles, other plastic bottles.
(A3) Glass: glass containers, beer bottles, cosmetics containers.
(B1) Paper containers: paper cartons, paper containers, waste paper, cardboard,
(C1) Battery: waste dry batteries, cordless phone batteries, camcorder batteries, button batteries.
(D1) Disposable tableware: waste paper tableware, plastic tableware, styrofoam tableware.
(E1) Automobile accessories: waste lubricating oil containers, tires, sealed rechargeable batteries.
(F1) Fluorescent lamps
Table 2 The results of Scenario B after applying the $PL$ indicator

<table>
<thead>
<tr>
<th>Priority</th>
<th>Population</th>
<th>Region area (# of cells)</th>
<th>Population density (people per cell)</th>
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<tbody>
<tr>
<td>1</td>
<td>6755</td>
<td>49</td>
<td>137.86</td>
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<td>6354</td>
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Table 3 The results of Scenario C after applying the $IE$ indicator

<table>
<thead>
<tr>
<th>Priority by $IE$</th>
<th>$IE$ value</th>
<th>Population</th>
<th>Region area (# of cells)</th>
<th>Population density (people per cell)</th>
<th>$IE$/ Population density</th>
<th>Priority by $IE$/ population density</th>
</tr>
</thead>
<tbody>
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Caption

Tables caption

Table 1. Recycling materials and stipulated business.
Table 2 The results of Scenario B after applying the PL indicator
Table 3 The results of Scenario C after applying the IE indicator

Figures caption

Figure 1. The relationship between cells, regions, and the study area.
Figure 2. Time taken by different analytical tools to solve test cases.
Figure 3. Model results of SA analysis of Scenario A.
Figure 4. Model results of PL analysis of Scenario B.
Figure 5. Model results of IE analysis of Scenario C.

Figures in appendix

Figure A. Transformation of SA 0/1 map-layer to SSi,j value map-layer.
Figure B. The model algorithm for analyzing the attribute value sum of a region.