



## An interactive optimization system for the location of supplementary recycling depots

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### ABSTRACT

In order to increase participation in residential recycling, convenient access to recycling depots is essential. Currently, most vendors have established various take-back systems in local retail shops. The integration of the recycling depots established by local authorities with these private facilities can significantly improve access for residents. As a response to this need, an integrated system capable of providing optimization analysis and geographical information system functions has been designed to assist local authorities in identifying the regions where supplementary recycling depots need to be located to improve access to. A customized program which allows online optimization analysis has been developed and embedded in an integrated system. Through a user-friendly interface, users can interactively locate the supplementary depots within the desired regions. The interactive process improves the flexibility of the integrated system and avoids the shortcomings of impractical locations for recycling depots. A case study of battery recycling in central Taiwan is presented to demonstrate the effectiveness of the integrated system. By using the proposed integrated system to analyze the existing conditions, the locations of supplementary points to improve access to the existing regional recycling collection points can be determined. In short, the proposed methodology provides local authorities with an uncomplicated and streamlined system with which to determine the number and locations of supplementary recycling points.

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### 1. Introduction

The treatment of municipal solid waste (MSW) is one of the primary tasks for environmental authorities. Traditional treatments of MSW using landfilling and incineration have become more difficult and expensive due to land scarcity and environmental concerns. Thus, the recycling of resources has become important as either an alternative or addition to traditional MSW treatments. Researchers (McDonald and Ball, 1998; Tilman and Sandhu, 1998) have identified that the success of MSW recycling is decisively dependent upon the active participation of residents, which in turn is critically influenced by the proximity of drop-off depots. González-Torres and Adenso-Díaz (2005) also maintain that the distance between the drop-off depot and the residence affects participation and frequency in the recycling process: a shorter distance will significantly improve the level of participation and also increase the quantity of material recovered.

The problems associated with drop-off depots have been studied by researchers in the field of MSW management, such as Chang and Wei (2000), Kao and Lin (2002), and Gautam and Kumar (2005). Typically, these models simulate the collection services provided by local authorities. A primary factor analyzed in these models is spatial proximity, represented in this case by walking distance for residents. Other factors including cost and vehicle capacities are accounted for in finding the optimal plan for collection systems or/and recycling depot locations. In essence, these methods are designed to make the modeling objective more attractive by sorting out the best from the available sites. However, three obstacles may discourage local authorities from utilizing these models. First, the identification of possible choices is usually required for these models, which is a demanding step in itself, especially if the planning area is vast. Second, finding the personnel with expertise and experience in optimization techniques who can manipulate these models is also impracticable for local authorities. Finally, due to the variance in the status of merchandise stipulated vendors, these take-back points may change frequently. As a result, a re-evaluation of the supplementary drop-off depot plans is required but may be impeded because of the amount of time usually needed to resolve these models.

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The work involved in evaluating possible locations can be reduced by starting with the existing take-back points provided by the private sector, as only the regions with poor access to recycling facilities need to be analyzed. In Taiwan, because of the trend of Extended Producer Responsibility in waste management and the regulatory requirements, vendors of the products with stipulated recyclables assume the responsibility for the provision of drop-off containers or depots for recycling goods after use. These recyclables have either or both of the following properties: they are arbitrarily discarded (e.g. beverage bottles) and contain hazardous materials (e.g. batteries and fluorescent lights). These private containers are widespread and effective in the collection of the designated recyclable material and in providing closer proximity to the recycling depots in most regions. In other words, the local authorities only need to install supplementary recycling facilities in less serviced or less accessible regions. In previous work (Lin and Chen, 2009), an optimization model aiming to resolve these issues has been developed.

In order to address the obstacle posed by local authority personnel who lack the ability to implement optimization models, an integrated system consisting of a user-friendly interface and flexible functions has been developed. In addition, a tool capable of presenting and analyzing spatial information is essential to identify regions with poor access to recycling facilities. Geographical information systems (GISs), featuring flexibility, speed, accuracy and clarity, are widely utilized in studies with geo-referred objects. Chang et al. (1997) has asserted that GIS are flexible in scenario analysis and applications. Clarke and Maantay (2006) has also applied GIS to analyze many recycling indicators in New York City and adjoining regions, and he has concluded that GIS are versatile in the presentation of geo-referred index values presentation. Utilizing GIS, factors that influence recycling efforts can be analyzed clearly and presented intuitively. Other experiences using GIS in MSW management include landfill siting (Kao et al., 1996; Lin and Kao, 2005), collection routing (Shih and Lin, 1999; Sahoo et al., 2005), and the location of recycling depots (Kao and Lin, 2002; Chang et al., 2005). In addition to the GIS functions, an information system should also provide an approach to assessing different alternatives for efficient and realistic applications. For example, Chang et al. (2008) has provided a successful experience in the evaluation of landfill sites. GIS has also been used to screen potential landfill sites and they, in turn, have utilized the analytic hierarchy process to rank potential sites. Vaillancourt and Waaub (2002) have utilized GIS and multi-criteria analysis to evaluate waste facilities. They asserted that if spatial analysis functions and assessment tools can be combined or at least work more closely together, their system will be more effective in dealing with problems on a global scale.

While the application of optimization models are commonly used to solve MSW management problems (e.g. Koa and Chang, 2008; He et al., 2008; Chaerul et al., 2008), it is rare for them to be embedded as the resolving tool in MSW information management systems. The reason for this, as mentioned in previous sections, is the fact that the processing time for optimization modeling is often prohibitively long and this impedes its application in reality. An enumeration technique developed in previous work (Lin and Chen, 2008) has been proven to be effective in significantly reducing the solution time and thus has been embedded in the proposed integrated system. The procedure involved in the implementation of the integrated system is described in later sections.

## 2. Methodology

Fig. 1 presents the flowchart used in the determination of the locations of supplementary recycling points using the integrated

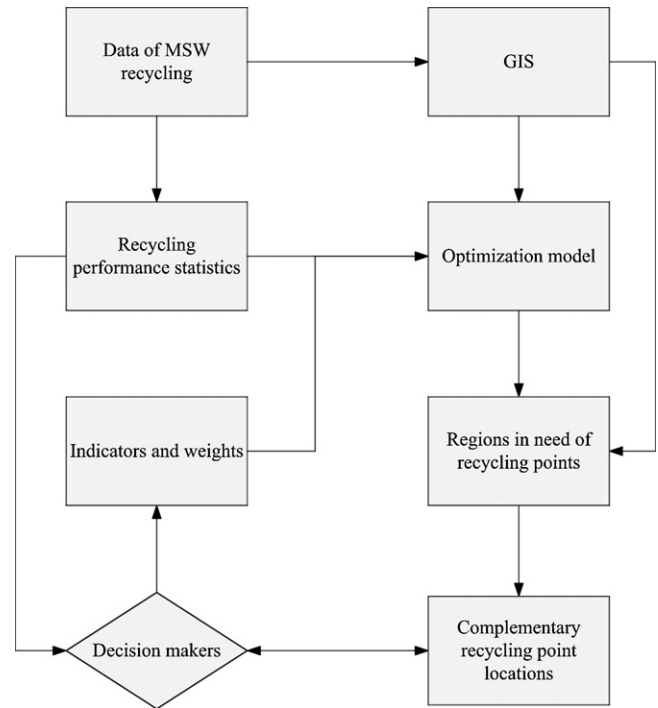


Fig. 1. Flowchart of the integrated system.

system. In the procedure, MSW recycling data are first collected, which can then be utilized for producing GIS map-layers or for developing statistic functions of recycling performances. With the assistance of these statistics, decision makers can evaluate if supplementary recycling points are necessary for a specific district or for a specific recyclable material. Once the scenario is determined, the decision makers can define the indicators/weights and then apply the optimization model to locate the regions in which a pressing need for supplementary recycling points exists. Decision makers can then determine the locations of the recycling points within the region via an interactive GIS interface. A report recording the locations of the recycling points can be generated after the decision makers have determined all of the recycling points. A detailed description of each step is described in later sections.

### 2.1. MSW recycling data

The MSW recycling data required for the integrated system include the quantity of each recyclable material collected, the locations and acceptable materials for the private vendor recycling points, and the population distribution of the focus area. These data can then be either transferred into GIS map-layers for presentation or linked to the database functions for the generation of recycling performance statistics.

### 2.2. GIS functions

The GIS functions of the integrated system provide intuitive and clear presentations. Information concerning a recycling point can be sought using a web-based graphic interface. In addition to the map-layers generated by the MSW recycling data, the background GIS map-layers, such as streets and landmarks, are also included in the integrated system to assist users to realize the surrounding environment of the locations concerned. Fig. 2 illustrates the GIS interface of the integrated system with recycling points represented by different symbols depending on the stipulated category to which they belong. The user can move the mouse cursor to a recy-

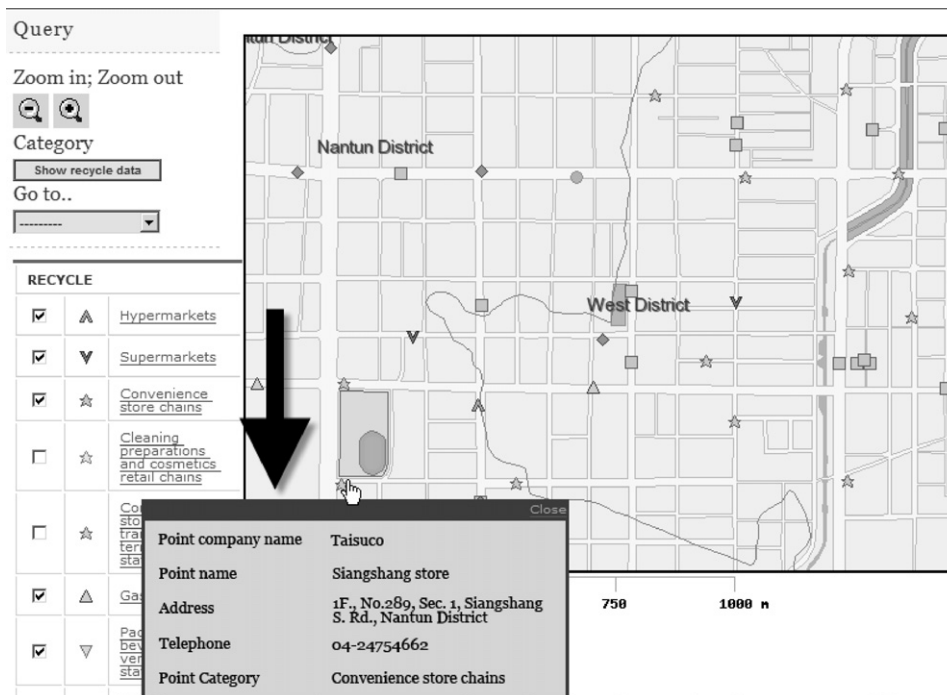


Fig. 2. Query interface of recycling points of the integrated system.

clicking point mark in order for an associated table, which includes detailed information concerning the recycling point, as indicated by the black arrow in Fig. 2.

### 2.3. Recycling performance statistics

With the statistical charts of MSW recycling data, users can have a clear picture of recycling status for an administrative district or of a specific recyclable material. In addition to creating routine reports for official records, three statistical graphs are also made available: trends, districts and category analyses. The trend analysis utilizes the periodical data and linear regression to provide a regression line which represents the recycling amount during a time period in the area of interest. The district analysis provides a bar chart illustrating the recycled quantities for different administrative districts. The category analysis provides pie charts representing the contribution ratio of the recycling efforts of each political district. Fig. 3(a)–(c) illustrates the trend analysis, districts analysis and category analysis, respectively. Customized charts can be made by setting up three options including time periods, recyclable material types and administrative districts to assist decision makers in the identification of recyclable materials or administrative districts requiring additional attention.

### 2.4. Indicators and weights

Indicators and weights reflect the preferences for the application of the optimization model to identify the regions in need of supplementary recycling points. Once the decision makers determine to add supplementary recycling points for a specific material/district, different strategies may be employed to install the recycling facilities. In a previous study, Lin and Chen (2008) used three indicators to analyze the various demands of local authorities. To simplify the illustration of the integrated system, only the population loading ( $PL$ ) indicator is implemented in this work, which is defined as the total number of recycling points over the total population in the analyzed region. A low  $PL$  value indicates that residents in this region share few recycling facilities, pointing toward

insufficient recycling storage that may discourage residential participation. Customized indicators and weights can also be defined via the interface of the integrated system, should these be desired.

### 2.5. Optimization model

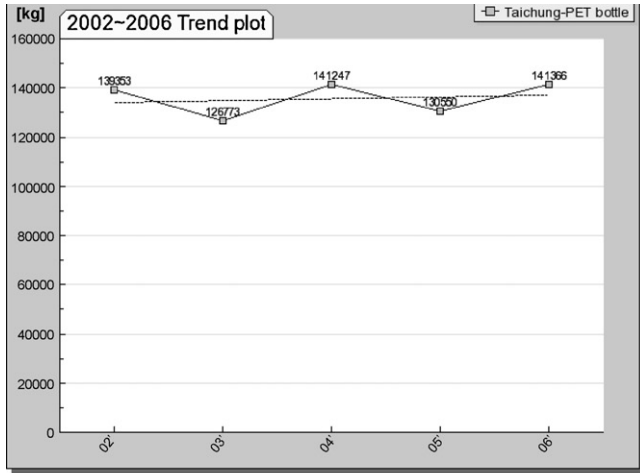
The optimization model is a mixed integer programming (MIP) model, which was originally designated for landfill siting (Lin and Kao, 2005) and has been improved to find regions in need of recycling facilities (Lin and Chen, 2008). The objective function of the improved model is to find the region with the minimal value of  $PL$  indicator. To mitigate the computational efforts required for solving a MIP model and to embed the improved optimization model in the integrated system, the improved model has been coded by C++ (Bell Labs, 1979) in an enumeration manner and a friendly interface to implement the parameters of the improved model is also developed in this study, which not only improve the time burden to solve the improved model but also avoid the shortcoming that users have to be expertized in mathematical programming to implement the model.

### 2.6. Regions in need of recycling points

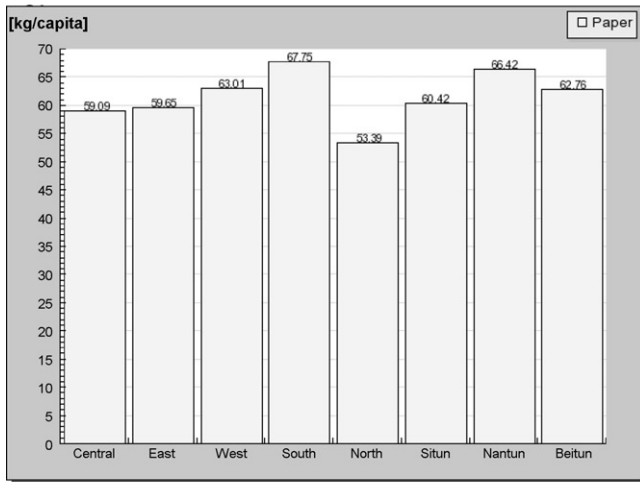
The priority list of the regions needing recycling points can be generated after applying the optimization model and this determines the order of the installation of supplementary recycling points. That is to say, the first region on the list has the minimum number of recycling points per capita among all the possible regions. To avoid the integrated system assigning supplementary recycling points to regions with very few people, a parameter setting identifying the minimum population of a region is also provided. After the application of the optimization model, resolved regions have to pass through this population check prior to being recorded on the priority list. In addition, the number of regions on the list should be defined by the user; its default value in the integrated system is equal to the number of allowable supplementary recycling points (ASRPs), as described in the next section.

2.7. Locations of supplementary recycling points

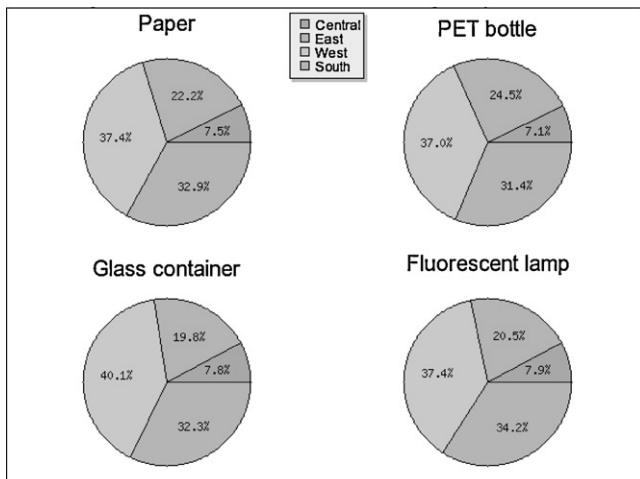
To assign the supplementary recycling points, the user has first to define the number of ASRP, which may depend on budget,



(a) Trend analysis :PET bottle recycled in Taichung



(b) District analysis :quantities of paper recycled among different districts of Taichung City



(c) Category analysis: ratios of four recyclable material among four different districts.

Fig. 3. Illustrations of statistic functions of the integrated system. (a) Trend analysis: PET bottle recycled in Taichung City; (b) district analysis: quantities of paper recycled among different districts of Taichung City; (c) category analysis: ratios of four recyclable material among four different districts.

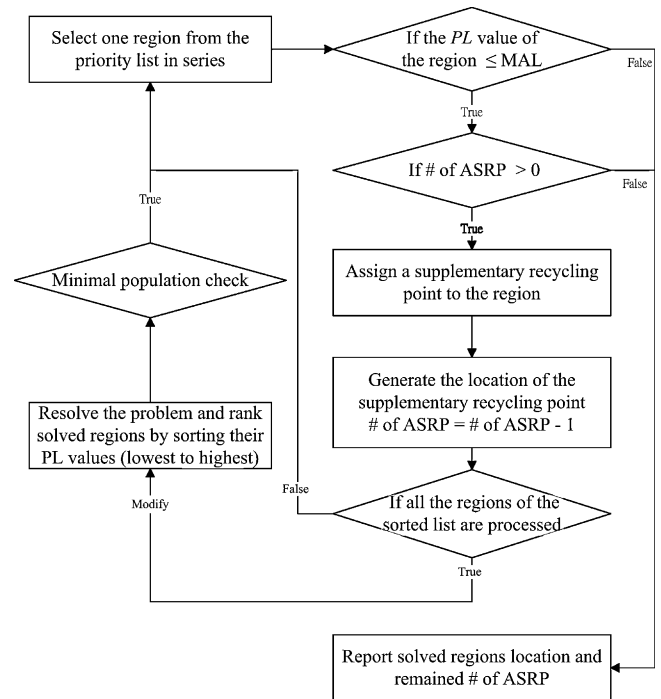


Fig. 4. Steps in the assignment of supplementary recycling collection points.

recycling containers in stock or the number of regions requiring recycling points. In addition, to ensure cost-effectiveness, a parameter called “minimal acceptable level” (MAL), essentially the minimal acceptable *PL* value of a region, is also provided. Only regions with lower *PL* values than the MAL are considered in need of supplementary recycling points. If the *PL* values of all regions are higher than the MAL, the integrated system will stop assigning the supplementary recycling points and report the remaining number of ASRP to the user. The default value of the MAL is the average value of *PL* in the entire study area.

Fig. 4 presents the steps in the integrated system used to determine the locations of supplementary recycling points. A region in the priority list will be selected in series each time. If a region’s *PL* value is less than the MAL and the number of the ASRP is still positive, a supplementary recycling point will be allocated to the region and the number of ASRP will be reduced by one. In general, this procedure will not be terminated until each region in the priority list is checked. However, if the number of ASRP is less than the number of regions in the priority list, some regions with higher *PL* values will not gain any supplementary recycling points. On the contrary, if the number of ASRP is more than the number of regions on the priority list and if the MAL is greater than all *PL* values of those regions on the priority list, each region on the list will be assigned a supplementary recycling point. The integrated system will resolve the modified problem after supplementary recycling points are added in order to find other regions requiring supplementary recycling points.

Essentially, the integrated system will automatically allocate a supplementary recycling point in the center of a region. The decision makers can manually change the location of the supplementary recycling point in the region. To realize the improvement generated by supplementary recycling points, an improvement indicator is defined as the difference between the original and the subsequent minimal recycling points per capita of a region. After all the locations of supplementary recycling points have been confirmed by the user, the integrated system will evaluate the value of the improvement indicator. Finally, a report containing supplementary recycling points will be generated with the location of

each new recycling point and the expected improvement after the installation of the new supplementary recycling points.

### 3. Case study

In order to demonstrate the applicability of the integrated system, a case study is presented: Taichung City, the third largest metropolis in Taiwan with an area of approximately 163 square kilometers and a population of more than one million inhabitants. In 2003, the total amount of recyclable materials collected was around 88,000 tonnes, about 33% of the total MSW (EPARC, 2006) from Taichung City. There were 1573 private recycling points in Taichung City collecting different recyclable materials. The procedure to illustrate the integrated system can be divided into five steps. First, the recyclable materials and the districts which require more recycling points are specified. Second, the parameters for the application of the integrated system have to be determined. Third, these selected districts are analyzed to find regions in pressing need of recycling points. Thereafter, the locations of recycling points in these regions are provided and verified by the user. The final step is to repeat the third and fourth steps if needed. For illustration, the recycling collection points for battery are analyzed. The steps in applying the integrated system to the recycling collection points of batteries are discussed as follows.

#### 3.1. Step 1: finding the district requiring extra recycling points

The total amount of batteries sold in Taiwan in 2005 was about 9946 tonnes while the recycled amount was 2177 tonnes in the same year, that is, 21.89% of the total sold (Chen et al., 2008). Estimating the amount of batteries consumed in Taichung City based on population ratio, the batteries consumed in Taichung City would be 452.7 tonnes, while the recycled amount was about 198 tonnes (EPARC, 2006). These waste batteries, including dry-cell batteries, cordless phone batteries, camcorder batteries and button batteries, usually contain high concentrations of heavy metals which are hazardous to public health and the environment. To improve the collection ratio of batteries in Taichung City, the statistical charts for different districts are examined via

the integrated system. Fig. 5 presents the battery recycling collection point information of different districts in Taichung City, including the total number of recycling collection points, populations and average recycling points per thousand capita in each district. It shows that Beitun and North Districts have the lowest recycling collection points per capita. Beitun and North Districts have an area of approximately 70 square kilometers and a population of about 350,000 inhabitants. The average recycling points for batteries in these two districts are 0.77 and 0.92 per thousand capita, respectively, significantly less than 1.31 of the average value of all of Taichung City. Therefore, Beitun and North Districts have been selected for further analysis. Fig. 6 illustrates the population distributions and the recycling points of these districts. The darker grids represent denser populated area (Fig. 6(a)) and the recycling collection points are indicated by dots (Fig. 7(b)).

#### 3.2. Step 2: defining the parameters of the integrated system

To apply the optimization model and the embedded program to find the regions in need of recycling points, several parameters have to be determined in advance, as illustrated in Fig. 7. A cell in the map-layer is defined by 50 m × 50 m. Therefore, the minimal area of a region is defined by 122,500 square meters (49 cells). The width/length ratio to ensure the compactness of a region is defined by 0.7. With this setting, the length of a short side of a solved region is never less than 70% of the length of its long side. The number of ASRP and the number of solved regions per run are defined by 260 and 20, respectively. The minimal population of a region to install a supplementary recycling point is 1000. The MAL of PL is defined by 0.002, indicating that one recycling point is shared by 500 persons.

#### 3.3. Step 3: applying the optimization model to resolve regions

After the application of the optimization model, the integrated system lists twenty regions which are in need of recycling points. These regions are then assigned a supplementary recycling point, as described in the next step. Fig. 8 presents the regions which are addressed by the model after the first run. All of the regions

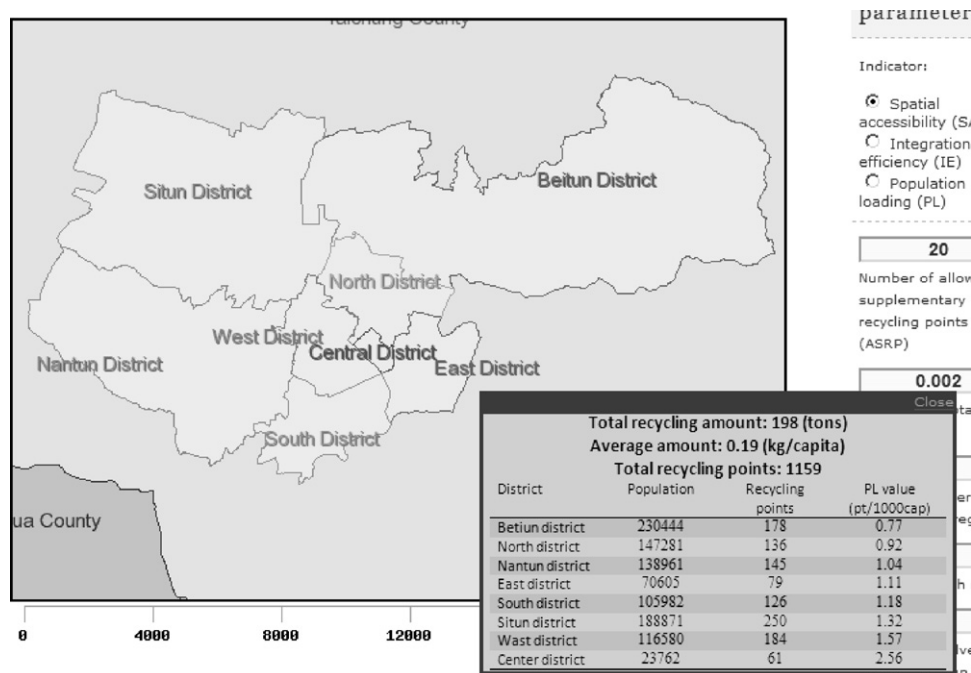


Fig. 5. Information on battery recycling collection points by districts in Taichung City.

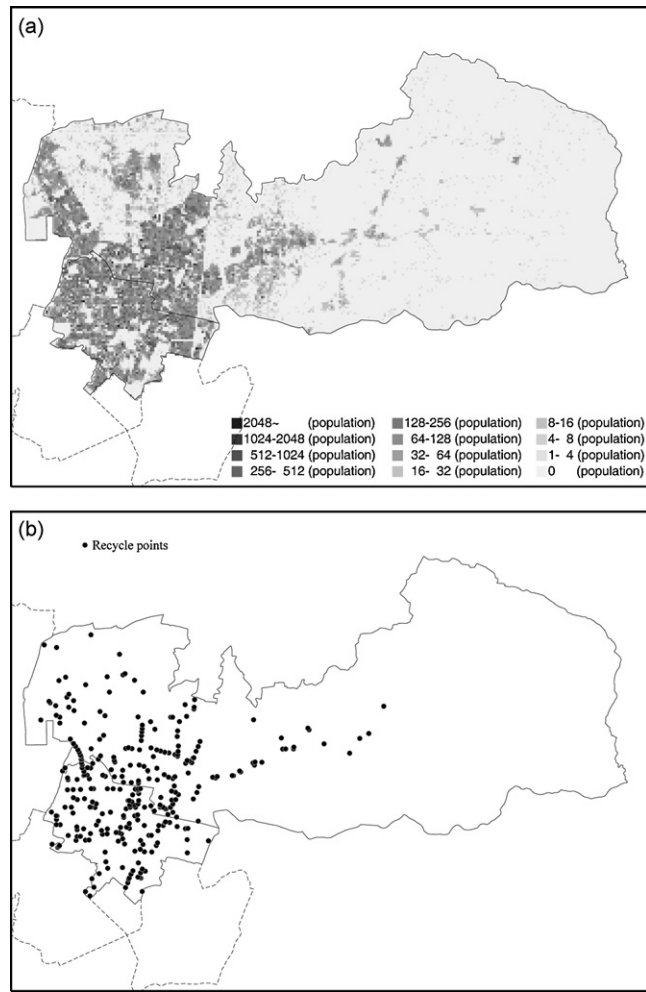


Fig. 6. (a) Population distributions of Beitun and North Districts. (b) Recycling collection points of Beitun and North Districts.

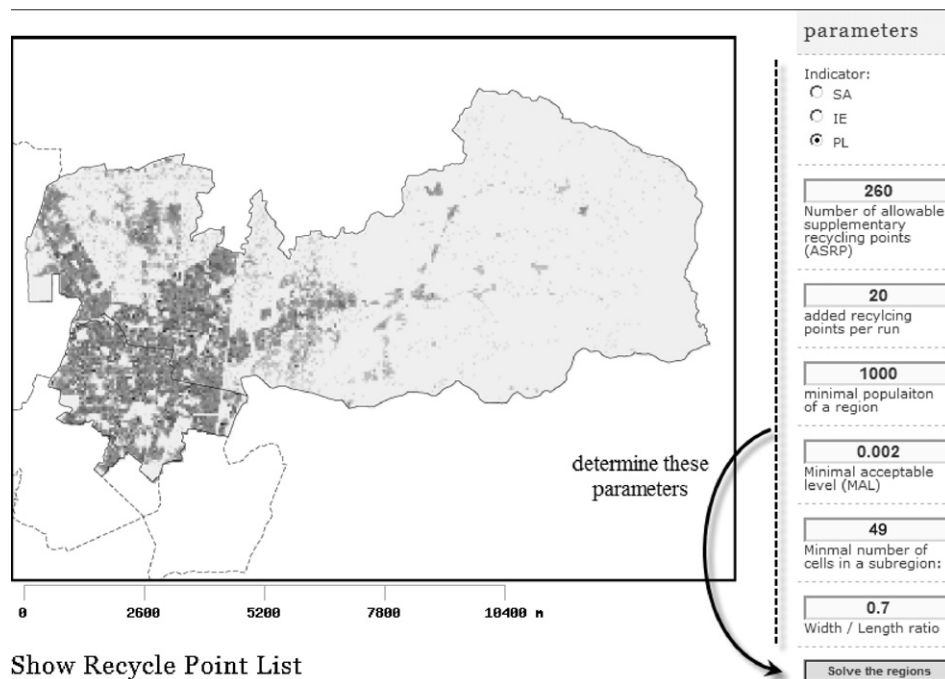


Fig. 7. Parameters setting for the integrated system.

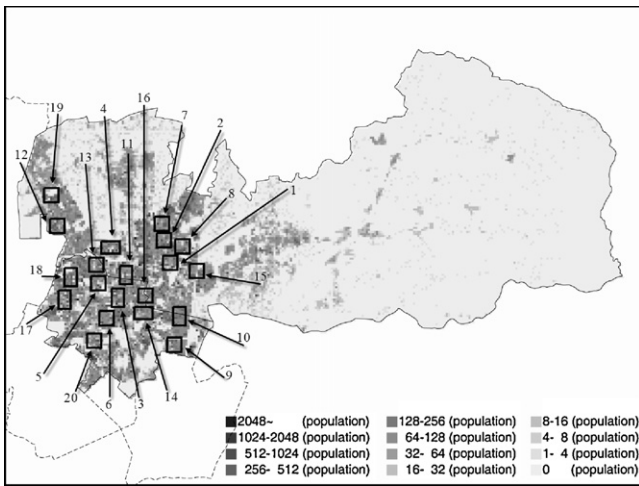


Fig. 8. Solved regions identified after utilizing the integrated system.

are in the left area where most residents dwell. Therefore, it is recommended that the supplementary points be installed in these regions.

3.4. Step 4: determining the locations of the recycling points

After the regions are addressed in the former step, the supplementary recycling points are then assigned to these regions. Fig. 9 illustrates the procedure used to add new recycling points. The location of the supplementary recycling point by default is in the center of the region, marked as a star, while other existing recycling points are represented by unfilled circles. The user can click the “modify the point” button to alter the default location of a supplementary recycling point inside a region, if so desired. Thereafter, the integrated system evaluates the minimal PL value among all the regions in the Beitun and North Districts after adding supplementary recycling points.

3.5. Step 5: repeating Steps 3 and 4 until the procedure is terminated

Steps 3 and 4 are repeated until the procedure is terminated. The conditions for the termination of the analysis include: the ASRP is spent out or all the regional PL values are better than the MAL, as

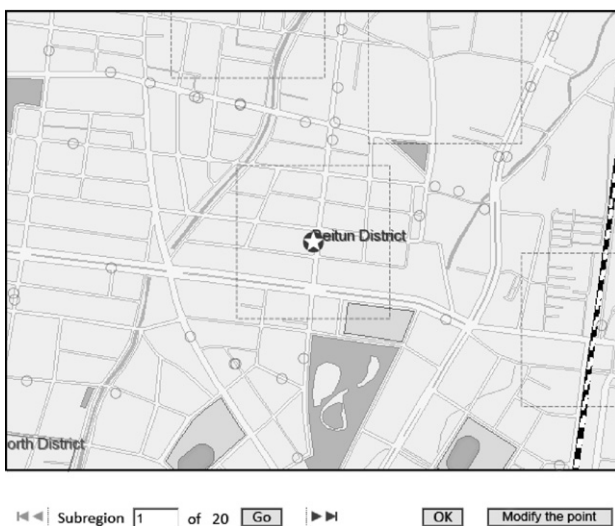


Fig. 9. Interface to modify supplementary recycling point inside a solved region.

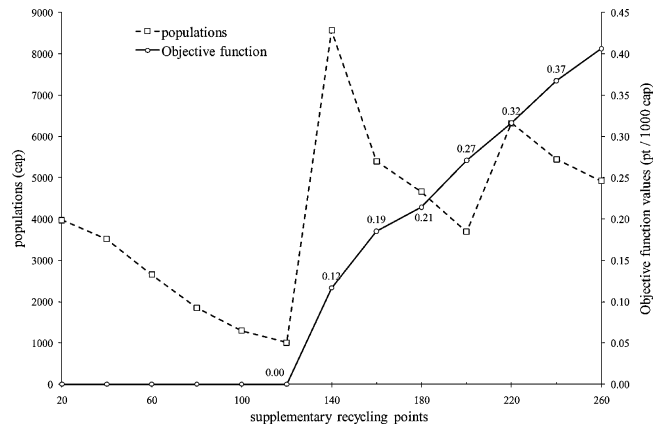


Fig. 10. Results of each model analysis run.

presented in Fig. 4. In the case of Taichung City, there is a total 13 runs of model analysis, and the procedure is not terminated until the ASRP is fully assigned.

4. Results and discussions

The objective of the integrated system is to assist the user in the installation of supplementary recycling depots. After finding the regions, the suggested recycling point locations are also identified. The modified locations of the new recycling points can be taken into consideration along with former recycling points in subsequent optimization analyses in order to find regions in most need of recycling points. This interactive process should continue to improve the accessibility for residents in the study area. Since the objective function value of the optimization model is the minimum PL value of any region in the study area, the objective function value will gradually improve. In another words, the amount of recycling points per thousand capita (PL value) of a region increases during the analysis process. Fig. 10 presents the results of each run, including population sizes and the PL values of the existing regions in most need of recycling points, which supports the demonstration aforementioned. Obviously, the PL values are fixed at zero until the seventh run (140 pts). The populations of these regions range from 6677 to 1002, and represent a monotonic decrease trend. In this stage, the objective function values (the minimum PL value of any region) were null, which indicates that no recycling point existed in these regions. The integrated system assigned a higher priority to regions with greater populations. After the seventh run, the objective function values improved after the assignment of the number of supplementary recycling points proportionally and finally achieved 0.367 points per thousand capita with 260 supplementary recycling points attained. By contrast, the population of the regions in this stage varied, unlike the trend of the former 140 points. In this stage (after 140 pts), the objective function values gradually improve and finally achieve a value of 0.367 points per thousand capita. The result also reveals that the recycling collection points in Beitun and the Northern Districts are very insufficient. In order to avoid the situation in which a region with more than 1000 persons does not have a recycling collection point, 140 supplementary recycling collection points need to be installed. While further improvement of the PL values may depend on the budgets or other concerns of local authorities, the results establish a clear relationship between the number of ASRP and improved PL values.

5. Conclusions

This work presents an innovative optimization model and system designed to assist local authority seeking to install supple-

mentary recycling points while taking into consideration of private take-back collection points. The optimization model was developed in order to identify regions requiring additional recycling collection points. For local authority responsible for allocating supplementary recycling facilities, the integrated system offers a level of flexibility which is superior to most typical methods of identifying exact locations. Everyday contingencies, the unwillingness of landowners and the unsuitability for facility installation can adversely affect the viability of selecting ideal locations. The user-friendly GIS interface and embedded rapid response programs for the proposed optimization model can be operated effortlessly without requiring expertise and experience of optimization techniques; this encourages local authorities to employ the system and, thus, to improve the practical use of the optimization model. Several parameters concerning installation strategies for different supplementary recycling collection points are also provided, which can satisfy a wide range of user demands. Due to the swift response time of the embedded program, local authorities can utilize the integrated system to modify the supplementary recycling points plan periodically in order to accommodate variations in demand over time.

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