A MODEL TO EVALUATE THE CONVENIENCE OF A TWO-SHIFT MSW CURBSIDE COLLECTION RECYCLING SCHEME

Hung-Yueh Lin,1,* Guan-Hwa Chen,2 and Jing-Kai Lin1

1Deptment of Environmental Engineering and Management
Chaoyang University of Technology
Taichung 413, Taiwan
2Institute of Environmental Engineering
National Chiao Tung University
Hsinchu 300, Taiwan

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ABSTRACT

Municipal solid waste (MSW) collection is one of the most important services provided by local authorities and one which accounts for more than half of their MSW management budget. Due to an increasing level of environmental awareness and the efforts of related authorities, the number of households willing to separate and recycle household wastes continues to increase significantly. In Taiwan, the quantity of recycled materials from curbside collections constitutes the great majority of total recycling efforts. In order to encourage residents to participate in a recycling program, a MSW collection plan needs to take into account the proximity of the collection site and the busy lifestyles of residents. A mixed integer program which evaluates both factors is developed in this study. The proximity is evaluated by the coverage radius of alternative accessible collection points, while a greater convenience in terms of time can be achieved by applying a two-shift collection plan to replace the typical single-shift one. A case study based on four minor scenarios is also performed by applying mixed integer programming and genetic algorithm tools to solve the developed model. The analytical results indicate that the total collection duration of a two-shift collection plan will gradually increase as the coverage radius decreases. In the case study presented, if the coverage radius is preset to 100 m, the total collection duration only increases by an average of 18% on the original collection duration. Furthermore, the residents are provided with greater flexibility and closer proximity of collection points.
INTRODUCTION

Economic growths together with technological advances have combined to stimulate public consumption, which has resulted in an increase in the quantity and complexity of municipal solid waste (MSW). Traditional treatments of MSW which involve landfill and incineration have become more difficult and expensive on account of land scarcity and environmental concerns. As a response, resource recycling is used as either an alternative or a replacement for traditional MSW treatments. In Taiwan, due to the efforts of environmental authorities over many years, the recycling ratio of MSW has been significantly improved. Hence, the average quantity of MSW per capita per day collected in Taiwan has been reduced from 1.135 kg in 1998 to 0.585 kg in 2006 [1].

The primary method of MSW collection in Taiwan is from residential curbsides, which is also the most popular way for residents to deliver recyclable MSW material. However, an essential part of this ‘curbside’ collection method in Taiwan requires residents to deposit the separated recyclable material, as well as the non-recyclable items, directly into the collection vehicle at a set day and time. The advantage of such a policy is that it avoids generating noxious accumulations of waste which would cause odors, attract flies and create unsightly environments. However, the single preset collection timetable may not be suitable to all the residents and this would require them to dispose of their garbage at more distant collection points at times more convenient to them. Such a scenario undermines the effectiveness of the program in that it may discourage resident participation in MSW recycling.

The best place to separate waste materials for recycling is at the source of generation [2]. The demonstrable superiority of this approach over mass recycling facilities is also true for the removal of household hazardous materials from MSW, such as mercury batteries and pesticides containers. Indeed, researchers [3-4] have acknowledged that the success of MSW recycling schemes is highly dependent upon the participation of residents, which in itself is critically influenced by the convenience of access to a recycling point. Speirs et al. [5] have analyzed the behavior of recycling participants and have concluded that their recycling efforts are primarily influenced by the proximity of drop-off depots.
Typically, the primary concern of MSW collection routing research is the collection cost, or other similar factors, such as the total travel time or distance of a proposed route. In addition to cost, other factors, such as the capacity required by the collection vehicle, are analyzed if relevant. These approaches are usually based on mixed integer programming (MIP) models, which are widely used to address waste collection problems, (e.g. [6-9]). In this study, such a model has been explored to evaluate the collection cost, collection duration and proximity of collection points.

In location selection models, distance also plays an important role. Toregas and ReVelle [10] have proposed a location set covering model where the distance factor is defined as a maximal coverage length. The model can be applied to determine the minimal number of emergency facilities, such as fire stations, by a given maximal coverage length. Church and ReVelle [11] followed the coverage concept and developed a maximum covering location model, which optimizes the maximal number of residents for a given number of facilities. For waste collection points, Kao and Lin [12] suggest using the walking distance for a resident instead of coverage length. They analyzed four different walking distances, from 50 to 100 meters, using their shortest service location model to determine how distance influences the number of collection points required. In this study, the collection points have already been determined by the local authorities. However, to evaluate the proximity of these points, a proximity indicator, coverage radius, is implemented in the developed model.

In waste collection models, the collection duration at each collection point is seldom evaluated except in time window problems [7, 9, 13]. For a time window problem, each collection point and customer is assigned with an acceptable period in which to be serviced. This condition usually occurs in collecting specific waste or products from private or public sectors, e.g. the collection of infectious waste from different hospitals [13]. When MSW collection is involved, it is not practical to apply time window constraints in a mathematical model. In addition to the impractical computational efforts required to solve even a small-scale problem, the preferred visiting time of a collection point may differ for the nearby residents. In reality, it is obvious that two major temporal preferences exist to collect MSW: day or night time. For residents working in the proximity of the collection point, collection during the day time (office hours) is preferred; for residents dwelling in the collection point nearby, they would expect to be backing home after work
and collecting at evening is preferred. Instead of considering the occasion to collect MSW at each collection point, a two-shift (day and night) collection plan is suggested as the time flexibility indicator in the proposed model.

Although mathematical programming models are an obvious option, the required time for an iteration solving process is impractical for a large-scale problem. Hereafter, heuristic skills, such as genetic algorithm (GA) [14], tabu search [15] and other network simplification skills are often applied in order to address the existing shortcomings [16-17]. Moreover, GA can perform a parallel search and avoid being trapped in a local optima [18], which is widely applied in vehicles routing problems [18-19] and with sound results [20]. In this study, GA is also applied to save the computational time for large-scale problems.

ACCESSIBLE ALTERNATIVE COLLECTION POINTS

As aforementioned, it is impractical to find a collection time which satisfies all residents near a collection point. Instead, the proposed two-shift collection routing plan is seen as a viable way to increase convenience for residents. However, if each collection point is served twice, a day and night shift, the waste collection plan will be infeasible due to increased collection costs. Therefore, accessible alternative collection points (AACP) are introduced in the developed model. Using the original collection point as the point of reference, all other collection points whose distances to it are less than a predetermined value, \( R \), are defined as AACP of the collection point. Figure 1 illustrates the relationship of AACP; collection points 3 and 4 are AACPs of collection point 1 in this example. The developed model is designated to find a two-shift routing plan in which each collection point or its AACPs will be visited in both shifts. In other words, residents can access the proximal collection point or its AACPs in their preferred shift due to increased access and convenience. In addition, the value of \( R \) plays the role of the proximity indicator. A small value for \( R \) indicates the collection point and its AACPs are closer, which implies the distances for nearby residents to access the AACPs are short, and vice versa.

MODEL DEVELOPMENT
The developed model is designed to find the optimal two-shift routing plan in which each collection point or its AACP is visited in both shifts. The equations are described as follows.

Objective:

\[
\text{Min} \quad \sum_{i=0}^{N-1} \sum_{j=1}^{N} \sum_{k=1}^{K} t_{i,j} x_{i,j,k} \quad (1)
\]

Subject to:

\[
\sum_{j=1}^{N-1} x_{0,j,k} = 1 \quad \forall k \quad (2)
\]

\[
\sum_{i=1}^{N} x_{i,N,k} = 1 \quad \forall k \quad (3)
\]

\[
\sum_{j=1}^{N} \sum_{k=1}^{K} x_{i,j,k} \geq 1 \quad \forall i \in \{1,\ldots, N-1\} \quad (4)
\]

\[
\sum_{j=1}^{N} x_{i,j,k} = \sum_{j=0}^{N-1} x_{j,i,k} \quad \forall i \in \{1,\ldots, N-1\}, \forall k \quad (5)
\]

\[
t_{i,k} + t_{i,j} - t_{j,k} \leq (1-x_{i,j,k})M \\
\forall i \in \{0,\ldots, N-1\}, \forall j \in \{1,\ldots, N\} i \neq j, \forall k \quad (6)
\]

\[
\sum_{r=1}^{N} \sum_{j \neq i} x_{r,j,k} \geq 1 \quad \forall i, \forall r \in i \cup R(i), \forall k \quad (7)
\]

\[
x_{i,j,k} \in \{0,1\} \quad (8)
\]

Where \(i, j\) and \(r\) represent the index of collection points; \(k\) represents the number of collection shifts. \(N\) and \(K\) indicate the total number of collection points and shifts, respectively. The starting point is denoted by 0 (starting) and \(N\) (terminal) simultaneously for model evaluation convenience. \(t_{i,j}\) represents the time required to travel and collect from collection point \(i\) to \(j\). \(x_{i,j,k}\) is a binary variable to represent the edge if visited. \(R(i)\) represents the AACPs of collection point \(i\). \(t_{p,i}\) represents the visiting time of collection point \(i\) at shift \(k\). \(M\) is an arbitrary large number for model analysis.

Equation (1) is the objective function, which is to find the collection plan with the minimal total collection duration. Equation (2) ensures that only one edge is visited from the starting point...
to any other point and Equation (3) ensures that only one edge is visited from any other point back
to the starting point. Equation (4) ensures that each collection point is visited during either a day
or night shift. Equation (5) is a mass balance equation to ensure that the times of visit and
departure are equal for each collection point in each shift. Equation (6) is the collection time
constraint of a collection point, which utilizes the trichotomy law to avoid sub-tour conditions of
collection plans. Detailed explanations about trichotomy and sub-tour conditions can be found in
related literature, such as [21]. Equation (7) ensures that for each collection point, its AACP's and
the point itself will be visited in each collection shift. Figure 2 presents the arcs connecting the
AACP's of collection point 1, where the arcs connecting collection point (No.1) or its AACP's
(No.3 and No.4) are marked by broken lines. Equation (7) ensures that at least one of these arcs
is passed in each shift. Equation (8) indicates the binary variables used in the model; if the edge \(ij\)
in \(k\) shift is passed through, the value of \(x_{ijk}\) will be equal to one, otherwise it will be nil.

**GENETIC ALGORITHMS**

In this paper, GA is applied to reduce the computational efforts involved in mathematical
models. Each chromosome represents a combination of variable values of the developed model.
As the genes are binary encoded and as each gene represents an edge if it is visited, generating an
impractical number of possible solutions, the permuted encoded genes where each one
represents the index of a node are adopted in this paper. With this encoding method, the solution is
obtained by decoding the values of any two sequential genes in a chromosome which represent
both nodes of the same visited arc. In addition, a fitness function is also introduced to prioritize the
reproduction of chromosomes after the mutation and crossover steps. The fitness function in this
study is as follows:

\[
F_w = \frac{\sum_{i=0}^{N-1} \sum_{k=1}^{K} [1 - \prod_{r \in \mathcal{R}(i)} \prod_{j=1}^{N} (1 - x_{r,j,k})]}{\sum_{i=0}^{N-1} \sum_{j=1}^{N} \sum_{k=1}^{K} I_{i,j,k} x_{i,j,k}}
\]  

(9)

Equation (9) presents how the fitness value of a chromosome, \(F_w\), is evaluated. A
chromosome with a higher value of fitness, i.e. a high value numerator and a low value dominator,
has greater probability of being reproduced. The numerator represents the total number of collection points or their AACPs which are visited in all shifts and the dominator represents the objective value of a chromosome.

**CASE STUDY**

In order to demonstrate the applicability of the proposed model, a case study in the East District of Hsinchu City, Taiwan is provided. Hsinchu City includes the East, North and Shansan Districts. It has an area of approximately 104 square kilometers, and it has a population of 390,000 inhabitants. The quantity of collected MSW and recycled materials from the local agency were 150,138 tons and 38,467 tons in 2005, respectively [1] Figure 3 illustrates the collection points/routes in the East District, which are denoted by different symbols. Four minor scenarios based on segments of two collection routes are developed. Collection points in scenario I and III are both generated from the same collection route, while the latter considers all collection points of the route and the former only includes collection points near street intersections, similar to the Scenario II and IV, which are generated from collection points of another route. The only reason to establish scenarios, including intersectional collection points, is to reduce computational time, since the calculation time for a solution increases exponentially as the number of collection points increases. Table 1 presents the total number of collection points in each scenario. To evaluate the influence of AACPs, three values of coverage radius ($R$), 50 m, 70 m and 100 m are implemented in each scenario. The model is resolved using both GA and optimization techniques: the mathematical programming solving tool applied in this study is CPLEX [22], while the GA solving tool is GAlib C++ library [23]. To increase the probability of identifying the optimum using a GA, ten runs are executed for each test of a scenario.

Table 2 presents the results for all the scenarios. The null value $R$ means that no AACP exists; that is, each collection point is visited in both day and night shifts, and the total collection duration is gained by doubling the real collection duration of the day shift. In addition to the total collection duration resolved by the MIP or GA, the total collection duration ratios which are calculated by dividing the total collection duration with the full two-shift collections ($R=0$) of the scenario are also provided for comparison. It is obvious that as the value of $R$ increases, the
collection duration decreases significantly. For instance, if $R$ increases to 100 m, the total collection durations are only about 56% ~65% of the total of the two-shift collections ($R=0$). In comparison to the original one-shift collection duration in the area studied, it increases an average of 18.5% but provides more opportunities for residents to dispose/deliver their wastes/recyclables to the collection vehicles. As a direct consequence of the reduction in collection points, the total collection duration of scenarios I and II is less than that of Scenarios III and IV, respectively. However, since only intersectional collection points are included, the AACPs of collection points in these scenarios are more difficult to find than other scenarios. The model requires the collection points to be visited in each collection shift in order to fulfill the AACPs constraint. Results in Table 2 also confirm the above; that is, the time ratios in Scenarios I and II are higher than those in III and IV. The time ratios decrease rapidly as the value of $R$ increase in scenarios III and IV; it also suggests that there is a sufficient number of AACPs in these scenarios providing more alternative routes than those of Scenario I and II. Figure 4 illustrates the resolved collection routes using the MIP of scenarios II and IV, where broken and unbroken lines represent the day and night shifts, respectively. Additionally, empty and full circles in the figure represent the intersectional collection points and other collection points along the streets.

Table 2 also presents the results of GA. Doubtless, the solutions resolved by a GA cannot be better than those attained by using a MIP because the latter is an optimization skill while the former is a heuristic method. However, the GA can solve the problem with less computational time than the MIP. Moreover, when large scale problems are involved, MIP models cannot be resolved in an acceptable period of time, while GA models can be applied to provide acceptable solutions within a shorter period.

**CONCLUSIONS**

The degree of convenience for residents to deliver recycled materials is one of key factors in increasing their level of participation in identifying and separating recycling materials from MSW. In Taiwan, the majority of recycled materials is collected as part of a MSW curbside collection program. Hence, the location of a collection point and the collection time are important factors which can affect the participation of residents in municipal recycling programs. In this paper, the
level of convenience for residents involved in recycling is analyzed taking into account two factors: occasion to collect and proximity of collection point. For practical concerns, in order to increase the convenience of collection time, a two-shift collection plan is recommended. Meanwhile, the proximity of a collection point is implemented by a coverage radius which determines the maximal walking distance of residents to access AACPs. The developed model has taken into account the two factors to assist local authorities to determine the two-shift MSW collection routes. The case study is also performed by applying MIP and GA tools to solve the developed model. The analytical results indicate that the total collection duration of a two-shift collection plan will gradually increase as the coverage radius decreases. In the case study, if the coverage radius is devised to 100 m, the total collection duration increases an average of 18.5% of the original collection duration. However, in this case, the residents are provided with more opportunities and closer proximity of collection points, while the increased collection duration usually deemed as an estimator of increased collection cost is tolerable. The developed model can accommodate the varying needs of local authorities in order to determine the most convenient coverage radius. In addition to the MIP tool, this study also utilizes GA skills to achieve the model. Although GA methodology can provide acceptable solutions for the developed model, its performance is inferior to that provided by MIP solution methodology. Finally, a heuristic methodology designed to address the deficiency is being explored currently and will be the focus of a future study.

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REFERENCE


6. Chang, N.B., H.Y. Lu and Y.L. Wei, GIS technology for vehicle routing and scheduling in


8. Sahoo, S., S. Kim, B.I. Kim, B. Kraas and A. Popov, Routing optimization for waste


12. Kao, J.J. and T.I. Lin, Shortest service location model for planning waste pickup locations. J.


14. Holland, J.H, Adaptation in natural and artificial system, The MIT Press, Ann Arbor. MI.,
(1975).


CAPTIONS

Table 1. Number of collection points in each scenario.

Table 2. Results in all scenarios after applying MIP and GA tools.

Figure 1. The alternative accessible collection points (AACPs).

Figure 2. The arcs connecting AACPs of collection point 1.

Figure 3. Collection points within the case study area.

Figure 4(a) The preferred collection route for MIP of Scenario II (R=100).

Figure 4(b) The preferred collection route for MIP of Scenario IV (R=100).
Table 1. Number of collection points in each scenario.

<table>
<thead>
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<th>Scenario</th>
<th>Number of collection points</th>
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<tr>
<td>I</td>
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<tr>
<td>II</td>
<td>30</td>
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<tr>
<td>III</td>
<td>40</td>
</tr>
<tr>
<td>IV</td>
<td>50</td>
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Table 2. Results in all scenarios after applying MIP and GA tools.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$R$ (M)</th>
<th>MIP (min)</th>
<th>MIP (%)</th>
<th>GA (min)</th>
<th>GA (%)</th>
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</thead>
<tbody>
<tr>
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<td>96.07</td>
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<td>50</td>
<td>77.15</td>
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<td>72%</td>
<td>77.15</td>
<td>83%</td>
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<tr>
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<td>70.55</td>
<td>56%</td>
<td>83.02</td>
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Figure 1. The alternative accessible collection points (AACPs).

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