ISSN 2616-5902 Vol. 3, Issue 7: 28-41, DOI: 10.25236/AJBM.2021.030706

Increasing waste recycling efficiency in Mega cities: A new recycling mode in Southeast China

Guangfu Liu, Zifan Chen*

School of Economics and Management, Tongji University, Shanghai, 200092, China
**Corresponding Author*

Abstract: *Efficient recycling of recyclable waste is regarded as a crucial countermeasure for mega cities facing current shortage of resources and achieving sustainable development. This research discussed existing government-dominating and enterprise-dominating recycling modes in Southeast China and proposed a modified mode with higher efficiency. In particular, this study integrated partitioned vehicle routing problem with time windows into recycling mode and thus realized cost savings and promoted scheme efficiency. Subsequently, cost-effective analysis and Rough set-based grey-TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) framework have been applied to evaluate the recycling modes. The results show that: (i) Applying partitioned vehicle routing problem with time windows, cost savings of modified mode can be realized during process of waste collection and transporting; (ii) Under case study conducted in Jiading District, Shanghai, modified mode achieves 57% cost savings compared with enterprise-dominating mode; (iii) Modified recycling mode incorporates participation of both government and enterprises, and therefore has been proved as a highly efficient mode according to adopted evaluation framework. These findings would provide vital insights for the design of recycling system in mega cities.*

Keywords: *Recycling modes, Recyclables, Vehicle routing problem, Recycling efficiency, Waste recycling*

1. Introduction

Accelerating waste generation driven by population and economic growth in accompany with resource depletion and environmental pollution has raised increasing concerns on waste management in China [1]. The statistical data shows that the domestic generation of municipal solid waste (MSW) in China has reached 203.6 million tons in 2016 [2] while the estimated amount can reach 480 million tons in 2030 [3]. This sharp increase in the volume of MSW has become problematic [4], and particularly, mega cities face the significant challenges regarding limited waste treatment capacity [5]. In China, there are three main treatment methods including landfills, incineration and compost, among which, landfills are the most prevalent [6]. According to Shanghai Statistical Yearbook, 9 million tons MSW was generated in 2017 which is expected to be kept growing during the next 30 years while there only existed 4 landfill sites with treatment capacity of 10350 tons per day [7]. Therefore, it is urgent to promote the recycling of recyclable wastes and upgrade MSW management strategies to optimized options such as Waste to Materials (WtM) and Waste to Energy (WtE), and thus increasing disposal efficiency and eliminating the negative environmental impacts [8]. In addition, The Chinese central government has announced that recycling of recyclable wastes should be one of the main approaches to sustainable development and circular economy [9].

Recyclable wastes (RW) are the important streams of MSW, which include waste plastic, waste glass, waste electrical and electronic equipment (WEEE) and so on, defining as the waste from the residential resources that can be recycled after appropriate processing [10]. Management on RW has become a hot spot in academia and reached significant achievements in developed countries [11]. For instance, Japan has implemented various regulations in the late 1990s and early 2000s, and formed the legal system to support waste recycling, which includes the “Electric and Household Appliances Recycling Law” [12]. Apart from regulations, policy tools have been introduced to the RW recycling system to promote efficiency. For instance, a diversity of Extended Producer Responsibility (EPR) programs have been introduced in the WEEE recycling schemes in Canada, of which, modifications are required to respond to various markets with different supply and demand functions [13-14]. Moreover, 28 countries within EU have developed recycling schemes for plastic related waste [15]. In contrast, in the early stage of RW management in China, waste disposal has been regarded as public affairs, and the Chinese government played complete role including investment, construction, operation and so on. However, resulted from the low efficient single-role management scheme, Chinese government has broken the threshold and allowed the enterprises to participate in RW management since the late 1980s.

With increasing awareness of sustainable development, RW management is more regulated in China and the government has advocated the principles of "reduce reuse and recycle" regarding waste management. In 2016, the Ministry of Commerce (MOC) of China has launched RW recycling programs in 26 pilot cities, most of which are located in the eastern and southeast China. At present, there exist various RW recycling modes, within which public and private stakeholders' rights and responsibilities are fully clarified and allocated. Xiao et al. presented the qualitative analysis on China's RW recycling scheme and concluded that ineffective government administration and immature markets are the problems of current recycling scheme [16]. Moreover, the data shows that RW recycling rate in mega city, Shanghai, only account for 18.8% [17]. On the other hand, some studies have focused on the RW with high residual value. For instance, Chen et al. conducted research on waste plastic and evaluated the economic benefits with application of advanced recycling technologies [11]. Liu et al. considered the policy implications when designing the WEEE recycling scheme [18]. Another academic focus falls on the existing of informal RW recycling systems [19-20][20].

Compared with existing literatures examining the RW recycling schemes in developed countries [21-22], limited studies have focused on the RW recycling schemes in China. Moreover, only few researches have analyzed the RW recycling schemes by not only considering single categories of RW. Therefore, in order to enrich the literature and promote the RW recycling rate in mega cities in China, this study aims to propose a more efficient RW recycling scheme based on the typical references driven from two pilot cities in southeast China. In addition, this study is highlighted by integrating waste collection and transportation problems into RW recycling scheme in order to realize the cost savings and promote scheme efficiency. Hence, this study not only makes significant contributions to RW recycling literature, but also provides vital reference for the design of RW recycling scheme in mega cities.

The rest of this study is organized as follows: The method of Vehicle Routing Problem (VRP) and the rationality and feasibility of applying VRP into RW recycling scheme design are discussed in Section 2. Section 3 analyzes two typical RW recycling schemes from pilot cities and presents the modelling of proposed RW recycling scheme. Section 4 provides the numerical studies and results. Finally, section 5 presents the discussion and conclusions.

2. Methods and Methodology

2.1 Methods

Vehicle Routing Problem (VRP) is first proposed by Dantzig and Ramser [23] and has been a research hotspot since 1950s [24]. Starting from the most basic VRP, which refers to travelling salesman problem (TSP) and describes the situation where one travelling salesman needs to visit a series of designated points before returning to its beginning point, there are no restrictions on the capacity of the goods he carries. Regarding capacity, this problem evolves into the Capacitated Vehicle Routing Problem (CVRP), where vehicles are set with capacity restriction, implying that the vehicles need to consider more constraints when choosing the route [25-26]. Subsequently, Solomon further introduced vehicle routing problem with time windows (VRPTW) by considering time limits on the VRP [27]. With the development of VRP variants, VRPTW has been applied in various subjects including waste management. For instance, Kim et al. extended Solomon's insertion algorithm and proposed a VRPTW algorithm for waste collection [28]. Kim et al. also argued that route compactness should be the crucial aspects when applying it in reality [28]. Hence, in this work, considering the practical applications and economic potential, we focused on the route compactness and route distance minimization in order to promote the efficiency of proposed RW recycling scheme.

In the actual vehicle routing problem, there exist various complex constraints and relatively large scale of problems. The existing literature have adopted miscellaneous intelligent algorithms including Tabu Search (TS), Simulated Armaeling (SA), Ant Colony Optimization (ACO), Genetic Algorithms (GA), Artificial Neural Network (ANN), and Particle Swarm Optimization (PSO) to solve the VRPTW [29-42]. Among the present metaheuristics, the GA is highlighted for solving combinatorial optimization problems by mimicking the natural biological evolution of species. Many scholars have applied GA to solve VRP variant and concluded GA to be an efficient and highly competitive approach [43-44]. Therefore, this work adopted GA as the solution algorithm.

2.2 Methodology

The economic efficiency of RW recycling mode is mainly realized through cost savings resulted from cooperative waste collection according to the work done by Liu et al. [45]. We would adopt theorems below into our process of solving the VRPTW, of which the rationality is explained as follows.

Theorem 1

In a rectangular area S, it is assumed that $n-1$ communities and 1 recovery branch are evenly and randomly distributed. The expected length of the minimum total distance traveled by all vehicles is $\alpha\sqrt{Sn}$, and α is constant.

Proof

Beardswood found that the shortest path of n points is uniformly distributed in a fixed rectangular region (area S); the shortest path length can be approximately expressed as $\alpha\sqrt{Sn}$, and α is constant [46]. Helsgaun found that the conclusion is completely valid in the traveling salesman problem; and the constant $\alpha \approx 0.7124$ [47]. Therefore, assuming that $n-1$ communities are evenly and randomly distributed in a rectangular area of S, the number of communities served by the No.i ($1 \leq i \leq v$) vehicle is $a_i n$, and the area of communities' coverage is $b_i S$. According to the conclusions above, the expected distance of the shortest driving path of V-vehicle can be presented through formula 1.

$$\begin{aligned} TL &= \sum_{i=1}^{v} \alpha\sqrt{a_i n b_i S} \\ &= \alpha\sqrt{nS}\sum_{i=1}^{v}\sqrt{a_i b_i} \end{aligned} \tag{1}$$

Therefore, Theorem 1 can be testified through proving $\sum_{i=1}^{v}\sqrt{a_i b_i} = 1$. Since assuming that communities are evenly and randomly distributed, then $a_i = b_i$ ($1 \leq i \leq v$). Moreover, in case of that V vehicles serve all communities, $\sum_{i=1}^{v} a_i = \sum_{i=1}^{v} b_i = 1$.formula 1 can be rewritten to formula 2.

$$\begin{aligned} TL &= \alpha\sqrt{nS}\sum_{i=1}^{v}\sqrt{a_i a_i} \\ &= \alpha\sqrt{nS}\sum_{i=1}^{v} a_i = \alpha\sqrt{nS} \end{aligned} \tag{2}$$

According to the proof above, Theorem 1 is valid. Based on Theorem 1, we could further prove that Theorem 2 is valid.

Theorem 2

Assuming that the communities and branches are evenly and randomly distributed in a rectangular area S, the area of branches is B ($\leq S$); and the transportation cost of vehicles is proportional to the distance of routes. Thus, the cost allocation problem of cooperative distribution of N ($N \geq 3$) branches is a convex game problem, which means assuming that any two branch-collaborations F and P, where$F \subseteq N$, $P \subseteq N$, are not empty, the inequality $C(F \cup P) \leq C(F) + C(P) - C(F \cap P)$ holds.

Proof

ISSN 2616-5902 Vol. 3, Issue 7: 28-41, DOI: 10.25236/AJBM.2021.030706

Case 1. When $F \cap P = \emptyset$, noting that the minimum cost of branch-collaboration F is $C(F)$, according to the minimal optimization problem, the merging of optimal solution of F and P is obviously also a feasible solution of $F \cup P$. Furthermore, it is clear that the optimal solution of $F \cup P$ cost ($C(F \cup P)$) must not be higher than any of its feasible solutions. In this case, $C(F \cup P) \leq C(F) + C(P) - C(F \cap P) = C(F) + C(P)$ is always valid.

Case 2. When $F \cap P \neq \emptyset$, assuming that the branch-collaboration F ={ $e, e+1, \ldots g$ }, P = { $f, f+1, \ldots, h$ }, and $1 \leq e \leq f \leq g \leq h \leq N$, n_e means the number of communities allocated to the e branch, then formula 3 to formula 6 holds based on Theorem 1.

$$C(F \cup P) = \alpha\sqrt{(n_e + n_{e+1} + \cdots + n_h)S} + \alpha\sqrt{(h-e+1)B} \tag{3}$$

$$C(F) = \alpha\sqrt{(n_e + n_{e+1} + \cdots + n_g)S} + \alpha\sqrt{(g-e+1)B} \tag{4}$$

$$C(P) = \alpha\sqrt{(n_f + n_{f+1} + \cdots + n_h)S} + \alpha\sqrt{(h-f+1)B} \tag{5}$$

$$C(F \cap P) = \alpha\sqrt{(n_f + n_{f+1} + \cdots + n_g)S} + \alpha\sqrt{(g-f+1)B} \tag{6}$$

For convenience of description, formula 3 to formula 6 are simplified by formula 7 to formula 9.

$$x_1 = \sqrt{n_e + n_{e+1} + \cdots + n_g}, \qquad x_2 = \sqrt{g-e+1} \tag{7}$$

$$y_1 = \sqrt{n_f + n_{f+1} + \cdots + n_h}, \qquad y_2 = \sqrt{h-f+1} \tag{8}$$

$$z_1 = \sqrt{n_f + n_{f+1} + \cdots + n_g}, \qquad z_2 = \sqrt{g-f+1} \tag{9}$$

In particular, for any n_e (≥ 1), it is obvious that $1 \leq z_1 \leq \min\{x_1, y_1\}$, $1 \leq z_2 \leq \min\{x_2, y_2\}$, and formula 10 holds.

$$C(F \cup P) = \alpha\sqrt{(x_1^2 + y_1^2 - z_1^2)S} + \alpha\sqrt{(x_2^2 + y_2^2 - z_2^2)B} \tag{10}$$

Theorem 2 is valid if formula 11 and the formula 12 are both valid.

$$\sqrt{x_1^2 + y_1^2 - z_1^2} \leq x_1 + y_1 - z_1 \tag{11}$$

$$\sqrt{x_2^2 + y_2^2 - z_2^2} \leq x_2 + y_2 - z_2 \tag{12}$$

Since x_1, y_1, z_1 and x_2, y_2 and z_2 are all greater than or equal to 1, formula 11 and the formula 12 are valid if formula 13 and the formula 14 are both valid.

$$x_1^2 + y_1^2 - z_1^2 \leq (x_1 + y_1 - z_1)^2 \tag{13}$$

$$x_2^2 + y_2^2 - z_2^2 \leq (x_2 + y_2 - z_2)^2 \tag{14}$$

ISSN 2616-5902 Vol. 3, Issue 7: 28-41, DOI: 10.25236/AJBM.2021.030706

The validity of formula 13 and formula 14 can be proved if formula 15 holds when $1 \leq z \leq \min\{x, y\}$.

$$f(z) = (x + y + z)^2 - (x^2 + y^2 + z^2) \geq 0 \tag{15}$$

Find the first derivative of $f(z)$.

$$f'(z) = 2z - (x + y) \tag{16}$$

Clearly, since $1 \leq z \leq \min\{x, y\}$, $f'(z) \leq 0$ holds. Moreover, when $z = \min\{x, y\}$, $f(z) = 0$, $f(z)$ reaches its minimum value. Therefore, $f(z) \geq 0$ is always valid as $1 \leq z \leq \min\{x, y\}$. Hence, Theorem 2 is valid.

The establishment of Theorem 2 shows that the cost of RW recycling by different branch-collaboration must be lower than that of self-governing. Regarding each branch-collaboration, vehicle collaboration will also effectively reduce the costs. Therefore, the rationality of applying partitioned VRPTW in the new recycling mode has been proved. Next, we would build up a specific model to better illustrate the cost savings of the RW collection through new approach.

3. Modelling

3.1 Mode Description

In this section, we would firstly explain the two existed recycling modes in which private enterprises and local government play the dominant roles respectively. The typical enterprise-dominating recycling mode conducted in Hangzhou is called HuGe (HG) recycling mode, while the current Shanghai (SH) recycling mode is dominated by Shanghai government. After conducting the comprehensive analysis including advantages and disadvantages on these two existing modes, we subsequently proposed a modified recycling mode named Shanghai-Adapted HuGe (SAH) recycling mode, where both government and private enterprises play the crucial roles.

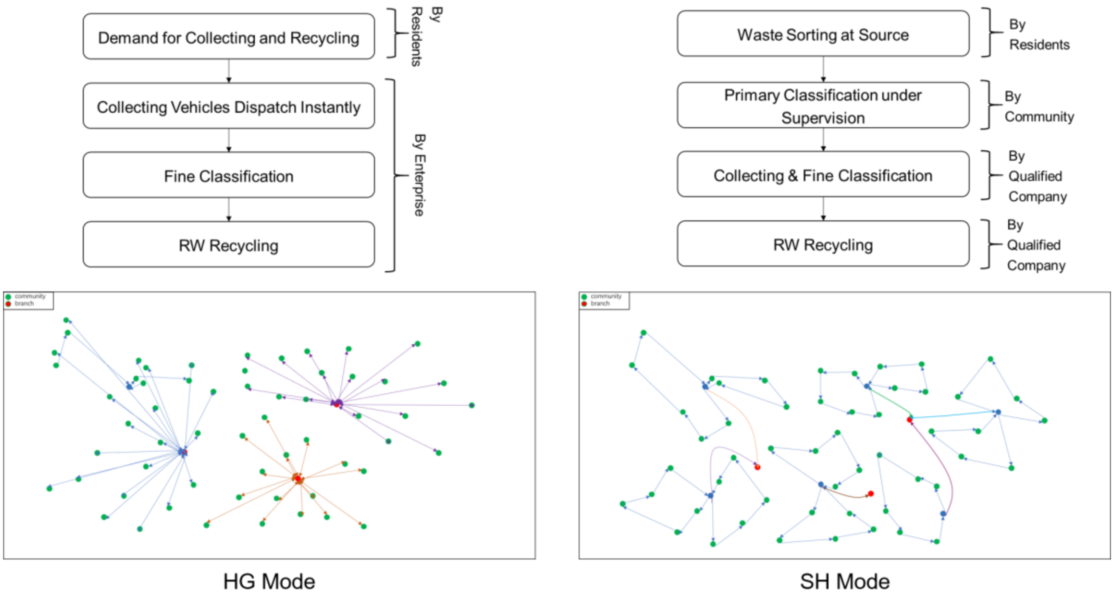

Figure 1 Presentation and Route Sequence of HG and SH Modes

The detailed process of HG and SH recycling modes are presented in Fig 1. Under HG recycling mode, households are responsible for the classification of RW such as glass, metal, plastics, waste paper and so on. Households need to notify HuGe-recycling Company for their collection requirements, after which, the enterprise would provide door-to-door service to collect RW. Subsequently, the collected RW are transported to the company for fine classification and resource utilization. In contrast, under SH recycling mode, households are responsible for waste source separation into four categories (recyclables, dry, wet, and hazardous waste) and dispose them under the supervision of community staff, while the qualified companies that signed contracts with government would collect and transport all waste including recyclables to the waste station for further classification. Finally, the classified recyclables are shipped to waste treatment plant for disposal. In order to visualize the waste collection under HG and SH mode, Fig 1 presents their route sequence where the red circles represent the branches and the green circles represent the communities.

Compared with SH mode, the superiority of HG mode mainly manifests in that the convergence of recyclables collection and recycling networks, improving the operational efficiency of the sorting, disposal and recycling. The superiority has been observed through significantly higher RW recycling rate in YuHang, Hangzhou. Hence, this convergence of networks can be regarded as the key to increase the effectiveness of RW recycling. On the other hand, HG also has drawbacks. The RW are directly collected from every single household, and thus, the nonstandard classification of RW can undermine the efficiency of recycling mode. Moreover, since the households claim the recycling requirements randomly, this can cause barriers to the optimization of vehicle route planning. However, SH mode, where communities are in charge of the primary classification and RW are collected intensively and regularly, tends to make up deficiencies of HG mode. Therefore, we would propose a modified recycling mode named SAH mode, which inherits advantages and overcomes the shortages of HG and SH modes.

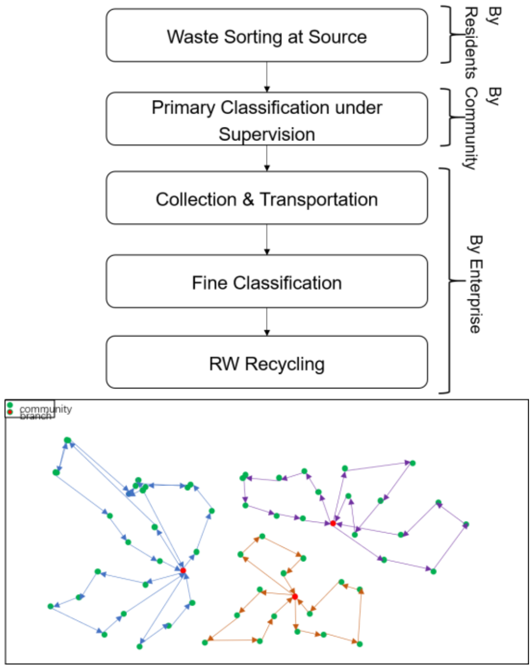

Figure 2 Shanghai-Adapted Huge Recycling Mode

The hybrid process of SAH mode is presented in Fig 2, where households classify the waste and dispose under the supervision of community staff. Subsequently, the private enterprise will collect the RW for further classification and recycling. In particular, Fig 2 indicates the route sequence under SAH mode by partitioned VRPTW. In order to achieve effective cost savings and promote sustainable development, the optimal approach of RW recycling, including the initial classification and delivery from community to utilization company, requests vehicles to work in collaboration.

3.2 Model Formulation

The mathematical model for SAH recycling mode would be constructed by following steps. Firstly, each community needs to be assigned to one and only one branch. K-Means clustering analysis would be used to reach the purpose. Secondly, for each branch and its assigned communities, in case of that the branch has a number of vehicles for recycling transportation, there also exists vehicle collaboration among them. Moreover, partitioned VRPTW is argued to be the proper approach considering the practical application and is capable of achieving the minimum cost of the recycling. The key programming process is displayed in flowchart showed in Fig 6.

ISSN 2616-5902 Vol. 3, Issue 7: 28-41, DOI: 10.25236/AJBM.2021.030706

The requirements of the vehicle dispatch problem in this paper are mainly embodied as follows:

1) Every vehicle has loaded capacity limitations.

2) Every community has a limited collection time, which refers to time window. Instead of collecting RW dispersedly, the concentrative collection is done in certain time period every day.

Considering the actual situation and the clarity of the model results, the following assumptions are made for the model:

1) There exists adequate transportation capacity.

2) Each community must be visited by one and only one vehicle.

3) Each vehicle can enter each community at most once.

4) Each vehicle starts and ends with the sole branch.

5) The number of vehicles used in the logistics scheme shall not exceed the number of vehicles owned by the branch.

6) The volume of RW at any community is less than the rated load of the vehicle.

7) During process, the total weight of RW of each vehicle must be less than the rated load of the vehicle.

8) The volume of RW, service time and time window of each community are known to us.

9) The starting time of vehicle from branch is five.

10) The linear distance between any community and branch is the distance in the model.

11) The factors of vehicle failure and road congestion in the process of recycling are eliminated.

Table 1 Variables

Variables	Interpretations
P	Set of communities
V_k	Set of vehicles of branch k
K	Set of branches
U	Set of communities and branches, subscript u, $U = P \cup K$
C	Transportation cost per unit distance of vehicle
d_{ij}	Euclidean distance from community i to community j, $i,j \in U$
w_i	Waste volume at community i, $i \in P$
Q	Rated load weight of every vehicle
t_i	The earliest service time set by community i, $i \in P$
e_i	The latest service time set by community i, $i \in P$
epu	Opportunity cost per unit time for a vehicle reaching communities earlier than time window
lpu	Penalty cost per unit time for a vehicle reaching communities later than time window
l_i	The time when the vehicle arrives at community i, $i \in P$
f_i	The time when the vehicle leaves at community i, $i \in P$
g_i	The serving time of the vehicle at community i, $i \in P$
m_{ij}	The duration time from community i to community j for a vehicle, $i,j \in U$
s	speed of the vehicle
x_{vij}	$x_{vij} = \begin{cases} 0, & \text{vehicle v misses between community i and j.} \\ 1, & \text{vehicle v passes between community i and j.} \end{cases} i,j \in U$
y_{vi}	$y_{vi} = \begin{cases} 0, & \text{vehicle v misses community i.} \\ 1, & \text{vehicle v passes community i .} \end{cases} i \in U\ ,\ v \in V_k$

In order to describe the model more clearly and accurately, we define the variables used in the model in Table 1. Subsequently, optimizing vehicle routing for each branch and assigned communities

ISSN 2616-5902 Vol. 3, Issue 7: 28-41, DOI: 10.25236/AJBM.2021.030706

has been conducted. In our model, recycling logistics cost mainly consists of transportation costs and penalty costs of vehicles. The transportation cost of a vehicle increases with its driving distance, which is proportional to the mileage of the vehicle. In the actual recycling logistics activities, communities will set a time window for the collection service of the branches due to various reasons. However, due to vehicle scheduling and other reasons, vehicles cannot completely guarantee arriving within the specified time window. Therefore, communities often restrict the soft time window for recycling companies. Soft time window limit allows vehicles to arrive outside the specified time window, but the branches will be punished. The penalty cost incurred by branches for violating the time stipulated by the communities should be taken into account when constructing VRPTW model. In detail, the penalty cost includes the opportunity penalty cost for both early and late arrival of vehicles at the community.

Based on the above assumptions, combining with the analysis of objective function and constraints, the following model can be established for each branch and its assigned communities. Furthermore, the interpretations of modelling equations are presented in Table 2.

$$\min \quad C\sum_{v\in V_k}\sum_{i,j\in U} x_{vij}\, d_{ij} + \sum_{v\in V_k}\sum_{i\in P}\left(epu * max(l_i - t_i, 0) + lpu * max(t_i - e_i, 0)\right), \forall k \in K \tag{17}$$

$$\sum_{v\in V_k}\sum_{i,j\in U} x_{vij} = \sum_{v\in V_k}\sum_{i,j\in U} x_{vji}, \forall k \in K \tag{18}$$

$$\sum_{v\in V_k} y_{vi} = 1, \forall k \in K, \forall i \in U \tag{19}$$

$$\sum_{i\in P} y_{vi}\, w_i \le Q, \forall v \in V_k \tag{20}$$

$$\sum_{v\in V_k}\sum_{i\in P} x_{vi} \le |V_k|, \forall k \in K \tag{21}$$

$$\sum_{i,j\in U} x_{vij} \le |P|, \forall v \in V_k \tag{22}$$

$$t_0 = 5 \tag{23}$$

$$m_{ij} = d_{ij}/speed, \forall i, j \in U \tag{24}$$

$$f_i = l_i + g_i, \forall i \in U \tag{25}$$

$$l_j = \sum_{i,j\in U} x_{vij}\left(f_i + m_{ij}\right), \forall v \in V_k \tag{26}$$

Table 2 Interpretations of equations

Equation	Interpretations
Formula 17	Objective function consists of transportation cost in the process of recycling and penalty cost incurred by the branch due to violating the time window.
Formula 18	Each vehicle starts and ends with the sole branch.
Formula 19	Each community must be served exactly once.
Formula 20	Total weight of recyclables collected from communities by each vehicle is less than the rated load of the vehicle.
Formula 21	Total number of vehicles in the recycling process is less than the total number of vehicles owned by the branch.
Formula 22	The number of communities per vehicle responsible for is less than or equal to the total number of communities.
Formula 23	The departure time of the vehicle from the branch is five.
Formula 24	The duration time from community i to j is equal to Euclidean distance between communities i and j divided by the driving speed of vehicle.
Formula 25	The time when the vehicle leaves the community i equals the sum of the time when the vehicle arrives at the community i and the service time at the community i.
Formula 26	The time vehicle arrive at community j equals to the time it takes to leave its previous community i plus the time it takes to travel from community i to j.

According to the characteristics of the model, natural number coding method is adopted, where chromosome length is $m+s+1$. In detail, 'm' refers to the number of communities allocated to this branch and 's' denotes the number of vehicles this branch owns. The code of the branch is 0 while code A, B, C,..., M represents the natural number assigned to each community. For instance, the branch has three vehicles to complete the recycling of eight communities. Assuming that one of the chromosomes is: 0-G-D-F-0-B-A-E-0-H-C-0, the route can be indicated as follows: the driving path of the first vehicle is 0-G-D-F-0, meaning that the vehicle starts from the branch and then returns to the branch through the communities G, D and F; the route of the second car is 0-B-A-E-0, meaning that the car starts from the branch and then returns to the branch through the communities B, A and E; the route of the third car is 0-H-C-0, meaning that the car starts from the branch and then returns to the branch through the community H and C. It is worth mentioning that the genetic algorithm deals with the population of solutions affected by reproductive processes. Bergeretal proposed a hybrid GA approach, in which a roulette wheel selection scheme was adopted to select the parents [48]. Mutations refer to the removal and reinsertion of a number of customers from the routes. The reinsertion consists of customer visiting under a variable ordering scheme through a branch and bound search process. This algorithm is argued to be the best solution for the problems with a definite number of vehicles. Therefore, we would propose the appropriate GA and apply the roulette method in selection of genetic algorithms. Regarding crossing, in order to maximize the continuation of paternal excellent path, the paternal passage A (selected randomly) of chromosome 1 was taken as a part of the offspring chromosome 1, and coding 0 should be added at the end of chromosome.

4. Results

4.1 Cost-effective analysis

Since the recycling rate of SH mode only reaches 18.8%, we would only apply cost-effective analysis between modes with relatively high recycling efficiencies, which are SAH mode and HG mode. Therefore, we conducted the numerical analysis in Jiading District, Shanghai. Data of 53 communities and 3 branches have been collected, including locations and everyday volume of RW. Furthermore, combined with practical basis, we assumed that:

1) Each branch owns three same vehicles.

2) The vehicle load is 3 tons.

3) The departure time of the vehicle from the branch is 5:00 AM.

4) Driving speed is constant at 40 km/h.

5) The driving cost of each vehicle is 10 yuan/km.

ISSN 2616-5902 Vol. 3, Issue 7: 28-41, DOI: 10.25236/AJBM.2021.030706

6) Penalty cost coefficient epu is 20 yuan/h and lpu is 30 yuan/h.

7) In this paper, Python 3.7.1 is used to compile the above genetic algorithm program to present the numerical analysis. The corresponding parameters are set as follows: population size is 100, maximum iteration number is 3000, crossover probability is 0.9, and mutation probability is 0.1. On the other hand, K-Means clustering analysis has been applied to allocate the communities to one and only one branch. In detail, there are 3 branches (b1, b2, b3), each of which includes a series of communities (presented in Figure 3).

8) The results of route optimization of RW recycling for each for each branch and assigned communities are presented in Figure 3. The results show that the transportation costs of each part are 154.3318 yuan, 195.7475 yuan, and 206.3639 yuan respectively, adding up to 556.4432 yuan total cost. However, the total transportation cost of HG mode is 1289.92 yuan. As a result, a significant reduction in the transportation cost can be obtained by SAH mode, which only accounts for around 43% of transportation cost under HG mode. Moreover, given the volume of RW, the compiling time is about 2 minutes for each branch in SAH mode. Hence, SAH mode tends to be feasible and proper approach in practical.

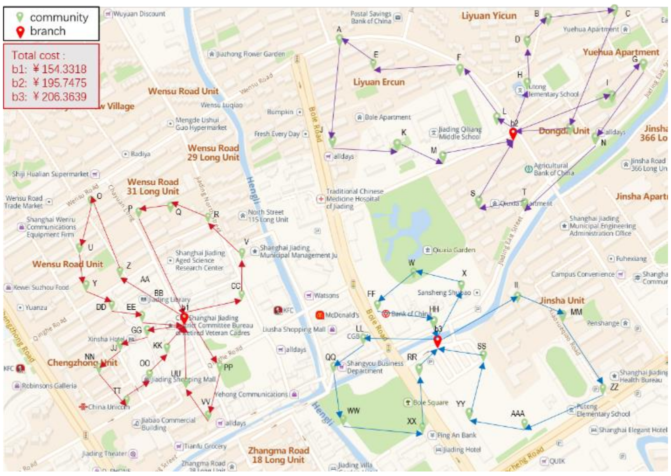

Figure 3 Route Consequence of SAH Mode

4.2 Multi-objective analysis

In order to further assess the SAH recycling mode with multi-objective approaches, we adopted Rough set-based grey-TOPSIS framework, which is firstly proposed by Li to evaluate third party reverse logistics [49]. This framework includes seven criteria, which is presented in Table 3 and is argued to be an effective and rational measurement system. Subsequently, we invited five professionals including professors and senior engineers to participate in the expert board and rate different modes by index. During the process of evaluating indicators, the synthesis of several experts' opinions should be more proper in achieving objectivity and risk control.

Table 3 Main Criteria for Evaluation

Main criteria	Explanation
Management (M)	Recycling and disposal efficiency and recovery rate.
Technology (T)	Technical personnel ratio, technology leadership and further researching and developing capability.
Information (I)	The level of information standardization, information processing, and information security.
Transportation (Tr)	Vehicle condition and time accuracy.
Coordination (C)	Response speed, cultural compatibility, network coverage, and communication skills.
Economy (E)	Cost and investment.
Society (S)	Environmental protection effect and market prestige.

In particular, M1 refers to HG mode; M2 refers to SH mode; and M3 refers to SAH mode. The grey decision matrix contained the score rated by experts is presented in the below. To discretized data of grey decision matrix, we adopted the principle: [0,0.5]→1, [0.5,0.8]→2, [0.8,1]→3. After eliminating the relatively insignificant index, we obtained the criteria that actually display discrimination {M, T, Tr, C, E, S}. Consequently, we could get the weight of each attributes. Finally, we could calculate the similarity of each mode to the ideal solution. All the evaluation results are presented in Table 4.

$$\begin{array}{c} \\ M_1 \\ M_2 \\ M_3 \end{array} \begin{array}{c} \begin{array}{ccccccc} M & T & I & Tr & C & E & S \end{array} \\ \left(\begin{array}{ccccccc} [0.3,0.5] & [0.5,0.6] & [0.5,0.6] & [0.6,0.8] & [0.3,0.5] & [0.3,0.5] & [0.3,0.5] \\ [0.6,0.8] & [0.8,1] & [0.5,0.6] & [0.3,0.5] & [0.8,1] & [0.5,0.6] & [0.8,1] \\ [0.6,0.8] & [0.8,1] & [0.5,0.6] & [0.8,1] & [0.6,0.8] & [0.8,1] & [0.8,1] \end{array}\right) \end{array}.$$

Table 4 Evaluation Results

Discretized Data of Index

	M	T	I	Tr	C	E	S
M_1	1	2	2	2	1	1	1
M_2	2	3	2	1	3	2	3
M_3	2	3	2	3	2	3	3

Weight of Attributes Reduced

Criteria	M	T	Tr	C	E	S
Weight	0.156	0.128	0.196	0.128	0.196	0.196

Similarity of Each Mode to Ideal Solution

Mode	M_1	M_2	M_3
Similarity	0.363	0.671	0.783

According to the value of the similarity of the evaluated mode, the overall ranking for the modes is in the order: $M_3 > M_2 > M_1$. Hence, M_3, which refers to SAH mode, should be the optimized solution considering the management, technology, transportation, coordination, economy and society.

5. Discussion and Conclusions

To establish an effective recycling mode that creates a low carbon economy and sustainable development can be regarded as the most vital and urgent strategy for mega cities. This paper proposed a new RW recycling mode with references to the existed modes in the southeast China. The modified SAH mode involves the participation of both local government and private enterprises, where effective classification is led by the communities and private enterprise is charge of collecting, refined classification and recycling RW. In particular, with reference to theorems in chapter 2 and VRPTW, the mathematical modelling has been introduced to verify the cost saving achieved by SAH mode. Together with the application of GA and K-Means cluster, the case study conducted in Jiading District, Shanghai, provides the numerical analysis to indicate the economic effective of SAH recycling mode.

In particular, SAH recycling mode involves the participation of private sector, contributing to the marketization and development of RW recycling industry. Regarding government-dominating recycling mode, they face the problem of lack of market competition since the local governments creates barriers to entry and are more willing to grant access certificate to the state-owned enterprises. However, SAH mode adopts market-oriented operation mechanism, where enterprises seek to reduce their processing cost and increase their market competition. For instance, enterprises can achieve the cost savings through introducing the partitioned VRPTW and optimizing the RW collection/transportation plan. The results from numerical study conducted in Jiading District, Shanghai have showed that SAH mode involves significantly lower transportation costs. Moreover, specialized enterprises can integrate the RW collection, transportation, classification, recycling and treatment, form the industrial chain, and thus optimize their profits and recycling efficiency.

On the other hand, SAH mode not only reduces the administrative and fiscal burden falling on local governments, but also retains the effective waste classification. Combined with the practical policies, SAH mode requires the households to perform source separation and dispose RW under supervision of local communities, which facilitates the centralized collection and transportation by enterprises. This can be verified through the numerical study in Jiading District, where SAH mode achieves 57% cost savings compared with HG mode. In addition, rough set-based grey-TOPSIS framework has also been applied to evaluate the recycling mode and the results show that SAH mode would be the optimal choice considering multi-objectives.

Overall, this study enriches the literature on RW recycling and contributes to integrating VRPTW into waste recycling scheme. The proposed SAH mode promotes the cooperation between the local governments and private enterprises to achieve the higher recycling efficiency, which provide a constructive reference for mega cities. Regarding future research, improvement can be made through adding weight to different route in VRPTW according to traffic condition, which may portrait the more realistic demand. In addition, other evolving methods could be introduced in programming to promote GA.

References

[1] Gu, C., Hu, L., Zhang, X., Wang, X., Guo, J(2011) Climate change and urbanization in the Yangtze River Delta. Habitat Int. 35 (4), 544–552. doi:10.1016/j.habitatint.2011.03.002

[2] NBS, National Bureau of Statistics (2017) China's Statistical Yearbook. China Statistics Press, Beijing, China (in Chinese).

[3] Yu, J., Sun, L., Wang, B., et al(2016) Study on the behavior of heavy metals during thermal treatment of municipal solid waste (MSW) components. Environ. Sci. Pollut. Res. 23, 253-265. doi: 10.1007/s11356-015-5644-7

[4] Hoornweg D, Bhada-Tata P(2012) What a Waste: A Global Review of Solid Waste Management 2012. Urban development series; knowledge papers no. 15. World Bank, Washington, DC. © World Bank.

[5] Zhang, D.Q., Tan, S.K., Gersberg, R.M.(2010) Municipal solid waste management in China: status, problems and challenges. J. Environ. Manage. 91 (8), 1623–1633. doi:10.1016/j.jenvman.2010.03.012

[6] Song J , Sun Y , Jin L(2017) PESTEL analysis of the development of the waste-to-energy incineration industry in China[J]. Renewable and Sustainable Energy Reviews, 80:276-289. doi:10.1016/j.rser.2017.05.066

[7] Shanghai statistics yearbook(2018) http://tjj.sh.gov.cn/tjnj/nj18.htm?d1=2018tjnj/C0618.htm

[8] Jens Van Engeland,Jeroen Beliën,Liesje De Boeck,Simon De Jaeger(2020) Literature review: Strategic network optimization models in waste reverse supply chains[J]. Omega, 91. doi:10.1016/j.omega.2018.12.001

[9] SCC, State Council of China(2013) Development Strategy of Circular Economy and Recent Action Plan. (in Chinese).

[10] MOC, NDRC, MPS, MOHURS, SAIC, MEP(2007). Measures for the Administration of Recyclable Resources Recycling. (in Chinese). Ministry of Commerce, National Development and Reform Commissions, Ministry of Public Security, Ministry of Housing and Urban-Rural Development, State Administration for Industry & Commerce, Ministry of Environmental Protection.

[11] Chen, X., Xi, F., Geng, Y., Fujita, T(2011). The potential environmental gains from recycling waste plastics: simulation of transferring recycling and recovery technologies to Shenyang, China. Waste Manage. 31 (1), 168–179. doi:10.1016/j.wasman.2010.08.010.

[12] Okuda, I., Thomson, V.E.(2007) Regionalization of municipal solid waste management in Japan: balancing the proximity principle with economic efficiency. Environmental Management 40, 12-19. doi:10.1007/s00267-006-0194-x

[13] Tasaki, T., Tojo, N., Lindhqvist, T.(2019) Differences in perception of extended producer responsibility and product stewardship among stakeholders: an international questionnaire survey and statistical analysis. J. Ind. Ecol. 23, 438-451. doi:10.1111/jiec.12815

[14] Stéphanie H. Leclerc, Madhav G. Badami(2020) Extended producer responsibility for E-waste management: Policy drivers and challenges[J]. Journal of Cleaner Production, 251. doi: 10.1016/j.jclepro.2019.119657

[15] European Commission(2014) New Proposals to Reduce Plastic Bag Use. https://ec.europa.eu/environment/efe/news/new-proposals-reduce-plastic-bag-use-2014-02-26_en

[16] Shijiang Xiao, Huijuan Dong, Yong Geng, Matthew Branderc(2018) An overview of China's recyclable waste recycling and recommendations for integrated solutions. Resources, Conservation and Recycling:112-120. doi: 10.1016/j.resconrec.2018.02.032

[17] Du H.Z(2019) Current Situation, Difficulties and Countermeasures of Domestic Waste Treatment in Shanghai[J].Scientific Development, (08):77-85.

[18] Guangfu Liu, Yi Xu, Tingting Tian, Tao Wang, Yang Liu(2020) The impacts of China's fund policy on waste electrical and electronic equipment utilization[J]. Journal of Cleaner Production, 251. doi: 10.1016/j.jclepro.2019.119582

[19] Fei, F., Qu, L., Wen, Z., Xue, Y., Zhang, H.(2016) How to integrate the informal recycling system into municipal solid waste management in developing countries: based on a China's case in Suzhou urban area. Resour. Conserv. Recycl. 110, 74–86. doi:10.1016/j.resconrec.2016.03.019

[20] Steuer, B., Ramusch, R., Part, F., Salhofer, S.(2017) Analysis of the value chain and network structure of informal waste recycling in Beijing China. Resour. Conserv. Recycl. 117, 137–150. doi: 10.1016/j.resconrec.2016.11.007

[21] Dong, S., Tong, K.W., Wu, Y.(2001) Municipal solid waste management in China: using commercial management to solve a growing problem. Util. Policy 10 (1), 7–11.doi:10.1016/S0957-1787(02)00011-5

[22] Wang, H., Nie, Y.(2001) Municipal solid waste characteristics and management in China. J. Air Waste Manage. Assoc. 51 (2), 250–263. doi:10.1080/10473289.2001.10464266

[23] Dantzig G B, Ramser J H(1959) The truck dispatching problem[J], Management science, 6(1):80-91.doi: 10.1287/mnsc.6.1.80

[24] Thibaut Vidal, Gilbert Laporte, Piotr Matl(2019) A concise guide to existing and emerging vehicle routing problem variants[J]. European Journal of Operational Research. doi: 10.1016/j.ejor.2019.10.010

[25] Toth, P., & Vigo, D(2001) The vehicle routing problem, monographs on discrete mathematics and applications. Philadelphia: SIAM.

[26] T.K. Ralphs, L. Kopman, W.R. Pulleyblank, L.E. Trotter(2003) On the capacitated vehicle routing problem, Mathematical Programming 94 2003:343-359. doi: 10.1007/s10107-002-0323-0

[27] M. Solomon (1987) Algorithms for the vehicle routing and scheduling problems with time window constraints, Operations Research (INFORMS) 35 (March-April (2)) 254-265. doi:10.1287/opre.35.2.254

[28] Kim B I , Kim S , Sahoo S(2006) Waste collection vehicle routing problem with time windows[J]. Computers and Operations Research, 33(12):3624-3642. doi:10.1016/j.cor.2005.02.045

[29] Glover F(1989), Tabu search-part I[J], ORSA Journal on computing, 1(3):1 90-206. doi:10.1007/0-387-33416-5_3

[30] Willard J A G(1989) Vehicle routing using r-optimal tabu search[J], Master's thesis, The Management School, Imperial College, London, 3(2):23-25.

[31] Kohl N, MaVen O B G(1997) An optimization algorithm for the vehicle routing problem with time windows based on lagrangian relaxation[J]. Operations Research, 45(3):395-406. doi:10.2307/172017

[32] Badeau P, Guertin F, Gendreau M, et a1(1997) A parallel tabu search heuristic for the vehicle routing problem with time windows[J], Transportation Research Part C: Emerging Technologies, 5(2) 109.122. doi:10.1016/S0968-090X(97)00005-3

[33] Holland J H(1975), Adaptation in natural and artificial systems: an introductory analysis with applications to biology, control, and artificial intelligence[M], U Michigan Press,1975:34-38. doi:10.2307/3036051

[34] Lawrence S, Mohammad A(1996) Parametric experimentation with a genetic algorithmic configuration for solving the vehicle routing problem[C], Proceedings Annual Meeting of the Decision Sciences Institute, Decis Sci hast, 1996:488-490.

[35] Potvin J Y DuM D, Robillard C(1996) A hybrid approach to vehicle routing using neural networks and genetic algofithins[J], Applied Intelligence, 6(3):241-252. doi:10.1007/bf00126629

[36] Thangiah S R (1995) An adaptive clustering method using a geometric shape for vehicle routing problems with time windows[C], Proceedings of the 6th International Conference on Genetic Algorithms. Morgan Kaufmann Publishers Inc. 1995:536.545.

[37] Blanton Jr J L, Wainwright R L(1993) Multiple vehicle routing with time and capacity constraints using genetic algorithms[C], Proceedings of the 5th International Conference on Genetic Algorithms Morgan Kaufraann Publishers Inc, l993:452-459.

[38] Cheng R, Gen M(1996) Fuzzy vehicle routing and scheduling problem using genetic algorithms[J], Genetic Algorithms and Soft Computing, 1996:683-709.

[39] Gen M, Cheng R(2000), Genetic algorithms and engineering optimization[M], John Wiley& Sons, 2000:47-52.

[40] Xueli Cui, Ma Liang, Bingquan Fan(2004) Ant searching algorithm for vehicle routing problem[J], Journal of Systems Engineering, 19(4):418-422. doi:10.2116/analsci.20.717

[41] Xiaoyan HUANG, Zhan WEN, Kechang FU(2009) Vehicle routing optimization based on improved PSO[J]. Natural Science Journal of Xiangtan University, 31(2):166-170.

[42] Sivanandam, S.N; Deepa, S.N(2007) Introduction to Genetic Algorithm, Springer, New York, USA.

[43] Berger J, Barkaoui M(2004) A parallel hybrid genetic algorithm for the vehicle routing problem with time windows[J]. Computers & Operations Research, 31(12):2037-2053. doi:10.1016/s0305-

0548(03)00163-1

[44] Arjun T Mulloorakam,Nidhish Mathew Nidhiry(2019) Combined Objective Optimization for Vehicle Routing Using Genetic Algorithm[J]. Materials Today: Proceedings, 11(Pt 3). doi:10.1016/j.matpr.2018.12.016

[45] Liu R , Jiang Z , Liu X , et al(2010) Task selection and routing problems in collaborative truckload transportation[J]. Transportation Research Part E: Logistics and Transportation Review, 46(6):0-1085. doi:10.1016/j.tre.2010.05.003

[46] Beardswood J, Hammersley J M (1959) The shortest path through many points[J], Proceedings of the Cambridge Philosophical Society, 55: 299 -327. doi:10.1017/S0305004100034095

[47] Helsgaun K(2000) An elective implementation of the Lin-Kernighan traveling salesman heuristic[J], European Journal of Operational Research, 126: 106 -130. doi: 10.1016/s0377-2217(99)00284-2

[48] J. Berger, M. Barkaoui, O. Braysy(2003) A route-directed hybrid genetic approach for the vehicle routing problem with time windows, Information Systems and Operational Research 41: 179-194. doi:10.1080/03155986.2003.11732675

[49] Xiaoli Li(2013) Research on the evaluation of the third party reverse logistics supplier based on the grey TOPSIS method of rough set [J]. Science and technology management research, 33,(14): 67-71.