Hindawi
Mathematical Problems in Engineering
Volume 2023, Article ID 9761395, 1 page
https://doi.org/10.1155/2023/9761395

*Retraction*

# Retracted: An Empirical Study for Green Transportation Scheme of Municipal Solid Waste Based on Complex Data Model Analysis

**Mathematical Problems in Engineering**

Received 31 October 2023; Accepted 31 October 2023; Published 1 November 2023



This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

## References

[1] C. Xin, L. Wang, B. Liu, Y. Yuan, and S. Tsai, "An Empirical Study for Green Transportation Scheme of Municipal Solid Waste Based on Complex Data Model Analysis," *Mathematical Problems in Engineering*, vol. 2021, Article ID 6614312, 17 pages, 2021.

Hindawi
Mathematical Problems in Engineering
Volume 2021, Article ID 6614312, 17 pages
https://doi.org/10.1155/2021/6614312



*Research Article*

# An Empirical Study for Green Transportation Scheme of Municipal Solid Waste Based on Complex Data Model Analysis

**Chunlin Xin**,[1] **Lingjie Wang**,[1] **Bin Liu**,[1] **Yu-Hsi Yuan**,[2] **and Sang-Bing Tsai**[3]

[1]*School of Economics and Management, Beijing University of Chemical Technology, Beijing 100029, China*
[2]*Department of Labor & Human Resources, Chinese Culture University, Taipei 111, Taiwan*
[3]*Regional Green Economy Development Research Center, School of Business, WUYI University, Wuyishan 354300, China*

Correspondence should be addressed to Yu-Hsi Yuan; yuanyh@gm.ypu.edu.tw and Sang-Bing Tsai; sangbing@hotmail.com

Received 23 December 2020; Revised 22 February 2021; Accepted 18 March 2021; Published 8 April 2021

Academic Editor: Chenxi Huang



Solid waste management and air pollution are two pressing issues in the functioning of large cities. This paper studies the optimization problem of the green transportation route of municipal solid waste and establishes a mathematical planning model based on real-time traffic conditions of the city and consideration of a time window and multiple transfer stations with the goal of minimizing energy consumption. In the optimal green transportation process in this paper, comprehensive consideration of vehicle speed, vehicle load, road gradient, and driving distance in different road sections based on real-time traffic conditions is incorporated, which has a better fuel-saving potential than the shortest path. A green transportation program can alleviate the air pollution problem in big cities and promote energy conservation and emission reduction in solid waste transportation.

## 1. Introduction

With the development of the economy and the rise in the level of urbanization, the amount of municipal solid waste (MSW) is increasing day by day. We estimated that by 2030, the amount of MSW in China will reach 409 million tons, and the solid waste issue will be serious. The MSW treatment system includes collection, transportation, transfer, and final treatment. The cost of the transportation link accounts for 60%–80% of the total treatment cost [1]. Solid waste collection and transportation are limited by the load and capacity of vehicles, and these factors have a significant impact on the optimization of solid waste transportation routes. Since the turn of the century, energy and environmental issues have become hot topics globally. Carbon dioxide is one of the main sources of greenhouse gases, and the transportation industry, as the second most energy-intensive industry, accounts for 20% of the global emissions owing to its exhaust emissions [2]. Fuel consumption accounts for about 33% of the entire society's total consumption, which makes the implementation of green transportation an inevitable trend for energy conservation, emission reduction, and air protection [3]. Therefore, it is of significance to study the optimization problem of green transportation routes of domestic waste with capacity limitation to reduce the treatment cost.

*1.1. Capacitated Vehicle Routing Problem (CVRP).* The Vehicle Routing Problem (VRP) is a typical NP-hard problem. Based on different constraints, these problems can be divided into several categories, the most classic of which is the CVRP, also known as the classic VRP problem. CVRP refers to the capacitated vehicle routing problem, and it sets the capacitated constraint for the vehicle. Many scholars have conducted research on this and set relevant constraints and studied different types of CVRPs [4]. Aiming at the minimum driving distance of vehicles, Faiza [5] developed a decision support system with an integrated taboo search module to solve the CVRP problem and applied it to a food delivery company on Janduba Island in northwestern Tunisia. It was verified that the central processing unit running time of the decision support system was short. Hannan [6] proposed an improved particle swarm optimization algorithm based on the CVRP, which introduced a dataset with different threshold waste levels and scheduling concepts, and determined the best waste collection and route optimization solutions. Wang [7] studied the problem of vehicle routing with a capacity restriction. By establishing a mathematical model and using genetic algorithms (GAs) to plan the paths of logistics vehicles, the lowest logistics and transportation costs were obtained. Ali [8] proposed a new hybrid algorithm based on gravitational simulation local search and a GA to solve the CVRP problem with the goal of minimum travel distance. The experimental results showed that the algorithm is efficient and can obtain a better solution than many other alternatives.

*1.2. Green Transportation.* Green transportation refers to transportation characterized by saving energy and reducing exhaust emissions. It takes environmental factors into consideration. The green vehicle routing problem has been studied by a large number of scholars since 2006 [9]. Ghannadpour [10] set minimum energy consumption as one of the optimization objectives when optimizing the vehicle route, considered the distance and load factors, and solved optimal route planning by using a hybrid genetic algorithm. Demir [11] studied the double-objective pollution path problem aimed at minimizing fuel consumption and travel time, and proposed an adaptive large neighborhood search algorithm, combined with a speed optimization procedure, to solve the bi-objective Pollution-Routing Problem. Mohammad [12] introduced a green vehicle routing system, established a fuel consumption model, and achieved energy saving and emission reduction. Yoshi-nori [13] established a model with the objective function of minimizing energy consumption and carbon emissions and solved it using a multi-objective heuristic algorithm. Xiao [14] and other scholars proposed a model for calculating fuel consumption that posited a linear relationship between load and distance and fuel consumption. This model has been widely adopted.

There are few studies that consider energy consumption in the optimization of the transportation route of MSW. In studies, scholars have focused on different factors that affect fuel consumption. Some scholars hold that the emissions from solid waste collection vehicles are proportional only to the route distance, and therefore, a route optimization model aiming at the shortest distance is justified. However, the influence of other factors on fuel consumption is not considered [15]. Zsigraiova [16] pursued minimization of labor cost, fuel cost, and maintenance cost as the goal, and conducted sensitivity analysis with different loading weights in different roads as variables. It was demonstrated that the change of load has substantial influence on fuel consumption during transportation, but no specific path optimization was carried out. Tavares [17] set the objective as minimizing fuel consumption, considered the influence of road slope and vehicle load, and optimized the route by using geographic information system 3D route modeling. Compared with the shortest route, the proposed route reduced fuel consumption by 52%, but this study did not report a specific formula for calculating fuel consumption. In the following year, Tavares used the COPERT model to calculate fuel consumption and considered the relationship between speed, load, slope, and fuel consumption. However, the author used constant speed to calculate and did not consider that the speed is dynamically changing in different sections in reality.

In addition to this summary of the research on transportation of MSW from the two dimensions of route optimization and green transportation, a literature review is tabulated in Table 1.

We can note two shortcomings in the existing research on solid waste transportation:

(1) The solid waste transportation route problem is described as a simple vehicle route problem. After the vehicle leaves from a service point, it stops work only after completing one service. Without considering the fact that the vehicle may continue to work at the next collection point after emptying at the transfer station because it does not reach the maximum working time, the vehicle can cruise many times during service hours and working hours, thus improving the utilization rate of the vehicle and the collection and transportation efficiency of the whole solid waste collection and transportation system.

(2) The factors affecting fuel consumption can be divided into two categories: one is the factors unrelated to the vehicle path, such as vehicle model, engine displacement, and performance. The other is the factors closely related to vehicle routes, such as vehicle driving distances, road slopes, driving speeds, and different vehicle loads on different routes. In the green solid waste collection and transportation system, the parameters of the solid waste vehicle are fixed, mainly because the vehicle path factor in the transportation process has a major impact on the transportation cost. For the calculation of energy consumption, the distance is often taken as a single influencing factor without considering the joint influence of multiple factors such as distance, speed, load, and road slope. In route selection, the speed is often set to a fixed value, which ignores the reality that the vehicle is driving at a variable speed. The real-life transportation network is time-varying, change of speed is inevitable, and fuel consumption of vehicles is affected by changing speed.

Traffic big data have applications in solid waste collection and transportation. Urban traffic big data integrate and process road information, vehicle GPS information, and electronic map positioning and navigation data produce real-time traffic information with high accuracy and high coverage. For an urban domestic solid waste collection and transportation system, a MSW management information system can be used to obtain information such as road and real-time traffic conditions. A traffic big data processing platform can be designed to dispatch solid waste transport vehicles owned by sanitation companies, and the operators

Table 1: Comparison of the related literature.

| Subject | Cruise constraint | Influencing factors of oil consumption | | | |
|---|---|---|---|---|---|
| | | Distance | Load | Slope | Variable speed |
| Apaydin, Omer; Gonullu, M. Talha (2008) | | ✓ | | | |
| Li, Cheng ZhiZhang, Yan Liu, Zhi Hui Meng, Xian Yong, Du, Jing (2014) | | ✓ | | | |
| Zsigraiova, Zdena Semiao, Viriato Beijoco, Filipa (2013) | ✓ | ✓ | ✓ | | |
| Tavares, G. Zsigraiova, Z.Semiao, V. Carvalho, M. G. (2009) | | ✓ | ✓ | ✓ | |
| Jin Li, Danping Wang, Jianghua Zhang (2018) | | ✓ | ✓ | | ✓ |
| HE Dongdong, Li Yinzhen (2018) | | ✓ | ✓ | | |
| Analysis of a green transportation scheme of municipal solid waste based on traffic big data | ✓ | ✓ | ✓ | ✓ | ✓ |

of solid waste collection points can also query the vehicles through this platform to make preparations. Vehicles' feedback information such as road conditions and locations to the MSW management information system, and the data and information of all parties are collected by a data cloud platform through the MSW management information system and the traffic big data processing platform. The application of traffic big data in domestic solid waste collection and transportation is shown in Figure 1. In this paper, big data are used to obtain urban road congestion information, and according to this information, the influencing factor of vehicle running speed is described. Based on real-time road conditions of urban traffic and considering the influence of speed, load, distance, and road slope on fuel consumption, an optimization model for MSW green transportation routes with a time window and multiple transfer stations is established. The validity of the model is verified by CPLEX. As an example, the green transportation scheme of Xicheng District, Beijing, is obtained with a genetic algorithm. Finally, we compare the minimum fuel consumption target model (green transportation scheme) and the shortest distance target model (shortest path scheme). This study will help alleviate urban air pollution and promote energy conservation and emission reduction.

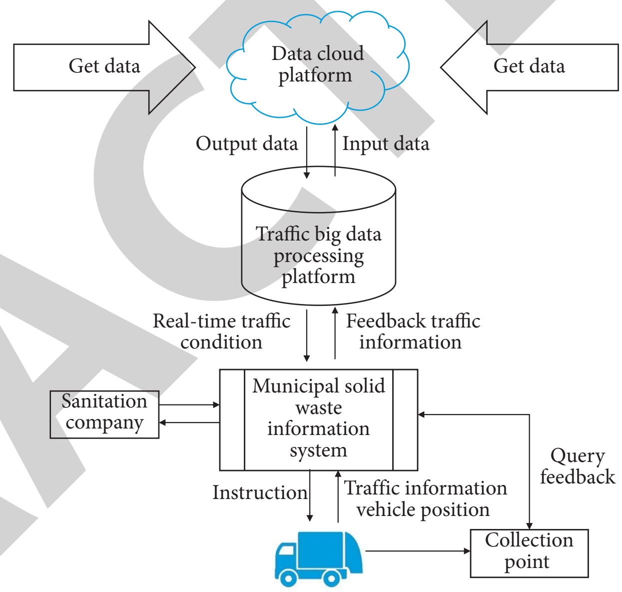


Figure 1: Application of traffic big data in the collection and transportation processes of MSW.

## 2. Establishment of the Model

*2.1. Problem Description.* In this paper, we set the aim as minimum fuel consumption. We incorporate the locations of existing solid waste points and big data information of real-time road conditions between points; consider the influence of speed, load, slope, distance, and other factors; and optimize the access sequence and route selection in the solid waste transportation process. We identify the route arrangement with the minimum fuel consumption and obtain the green transportation scheme. Our goal is to support the objectives of saving energy, reducing emissions, and protecting the environment. As shown in Figure 2, the problem is described as multiple homogeneous vehicles starting from the parking lot and collecting solid waste at unserved solid waste collection points in turns. When a vehicle is full and cannot continue to load solid waste, it is sent to the transfer station for emptying and unloading and then continues to collect after emptying until all solid waste collection points are served. After all solid waste is transported to the transfer station, all vehicles finally return to the garage. The process is shown in Figure 3. This paper defines "cruise" as the process from empty to empty, and the number of cruises of vehicles is the number of times the vehicles travel from the collection point to the transfer station.

In Figure 3, the transportation routes of two cars are shown to illustrate the transportation process of MSW. The green box on the left indicates the path of vehicle 1. Vehicle 1 starts from the depot to serve several solid waste collection points, enters the transfer station, empties, and then returns to the depot to finish the work. This constitutes only one cruise. The yellow box on the right represents the route of car 2 and two cruises. After vehicle 2 arrives at the first transfer station and empties, it completes the first cruise indicated by the orange arrow, but because it does not reach the maximum working time, it continues to work at the collection point. After serving another collection point, it empties at the transfer station, completes the second cruise indicated by the blue arrow, and returns to the depot to finish the work.

The main constraints of the model include time window constraints of each node, maximum vehicle capacity constraints, and vehicle route capacity constraints:

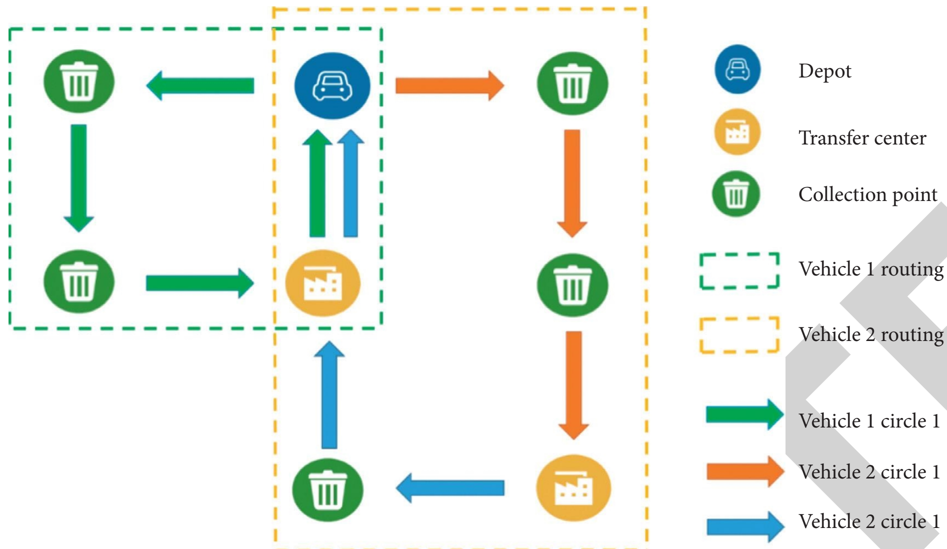


Figure 2: Optimization of MSW transportation routes based on real-time road conditions.

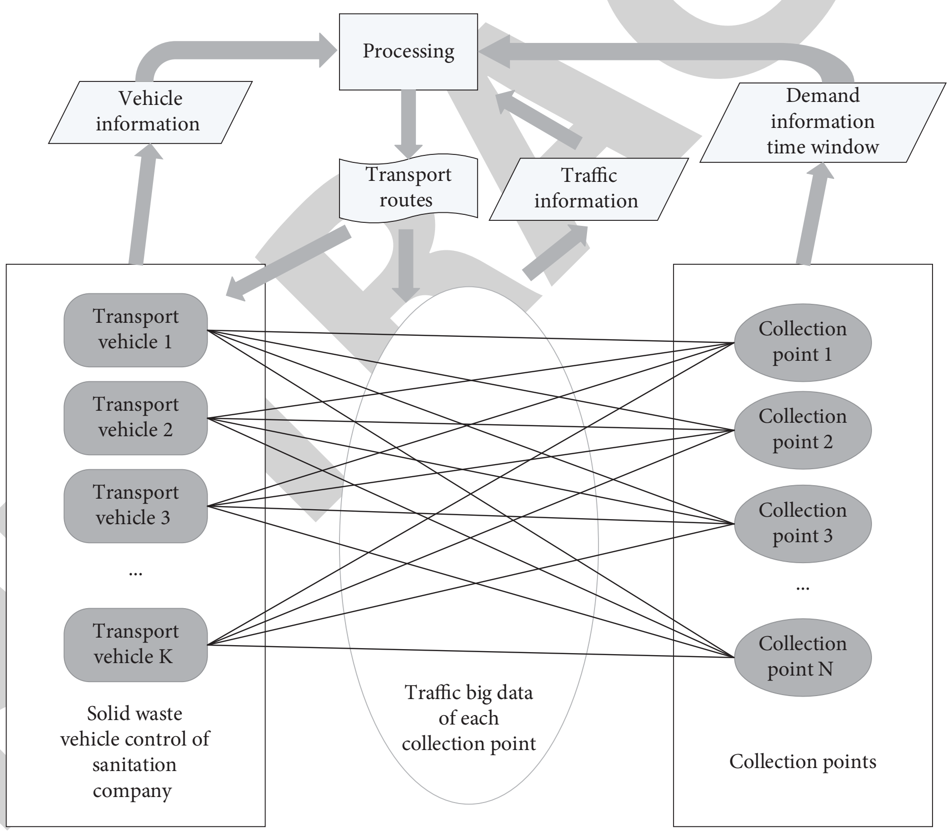


Figure 3: Flow chart of MSW transportation.

(1) Depot constraint: all homogeneous vehicles start from the depot and must return to the depot after service.

(2) Access uniqueness constraint: each solid waste collection point must be accessed only once.

(3) Vehicle maximum capacity constraint: the maximum load capacity of each vehicle is $Q$, and all vehicles are of the same type.

(4) Cruise constraint: a vehicle can go through many times from empty to empty in the longest working time. That is, a vehicle can continue to serve at the next collection point after being emptied at the transfer station.

(5) Constraint on the maximum working time of vehicles: the maximum working time of vehicles is seven hours per day, and vehicles can cruise during

working hours. That is, they can continue to collect after being fully loaded and emptied.

(6) Time window constraint: all collection points and transfer stations have time window constraints, and vehicles can only serve them within the specified time window.

*2.2. Symbols and Variables.* The optimization model of the solid waste green transportation path based on energy consumption can be expressed by a plane graph $G = (N, A)$, where the point set $N0 = \{0\}$ represents the parking lot, NC = $\{1, 2, \ldots, n\}$ is the collection point, and NS = $\{n+1, n+2, \ldots n+m\}$ is the transfer station. $N$ is the point set. A is the set of line segments between any two points. See Table 2 for specific parameters of the model.

*2.3. Calculation of Fuel Consumption.* Many scholars have studied the automobile energy consumption model. In this paper, the Comprehensive Fuel Consumption Model (CMCE) proposed by Demir [18] is used to calculate fuel consumption. Engine power demand is mainly obtained by engine traction power, and engine traction power (unit: kW) is expressed as follows:

$$P_{\text{tract}} = \frac{\left(Ma + Mg\ \sin\theta + 0.5C_d\rho Sv^2 + MgC_r cos\theta\right)v}{1000}. \tag{1}$$

Traction power is converted into engine power $P$ (kW); the calculation formula is as follows:

$$P = \frac{P_{\text{tract}}}{\eta_{tf}} + P_{\text{acc}}. \tag{2}$$

If the fuel consumption rate generated by the engine speed module is expressed by kfNVS, then the fuel consumption rate FR of the vehicle is

$$\text{FR} = \frac{\xi\left(k_f NV_s + P/\eta\right)}{\mu}. \tag{3}$$

TABLE 2: Model parameters.

| Symbol | Description |
|---|---|
| $[e_i, l_i]$ | The earliest and latest service start time of node $i$, $i \in N$ |
| $\omega_{ik}$ | Starting service time of vehicle $K$ at node $i$ |
| $s_i$ | Service hours at node $i$ |
| $T$ | The maximum working time of the vehicle |
| $M\infty$ | Infinite number |
| $d_{ij}$ | Distance between node $i$ and node $j$ |
| $v_{ij}$ | Travel speed of vehicle between nodes $i$ and $j$. |
| $qi$ | Solid waste quantity of collection node $i$ |
| $Q_{ik}$ | Accumulated load capacity of vehicle $k$ at node $i$ |
| $Q$ | Maximum load of vehicle |
| $K$ | Total number of vehicles |
| $x^c_{ijk}$ | Vehicle $k$ is 1 from $i$ to $j$ in the $c$ cruise, otherwise it is 0 |

In formula (1), the factors affecting fuel consumption can be divided into two categories: one is the factors unrelated to vehicle path, such as vehicle model, engine displacement, and performance. The other is the factors closely related to vehicle routes, such as different vehicle driving distances, different road slopes, different driving speeds, and different vehicle loads in different routes. According to the coordinates of each node, Baidu Map was used to collect data regarding the real shortest distance of each collection point. The real road conditions can be obtained free of charge through the free interface of real-time road conditions of urban roads provided by Baidu Map software. Thus, real-time speed information can be obtained. The road slope is determined according to the real terrain provided by Baidu map. The factor classification is shown in Table 3.

*2.4. Model*

*2.4.1. Objective Function.* The green transportation plan: minimize the total fuel consumption during solid waste transportation; and

$$\min \sum_{k=1}^{K} \sum_{(i,j)\in A} \sum_{c=1}^{C} \left( k_f NV_s \lambda \frac{d_{ij}}{v_{ij}} + W\gamma\lambda\alpha_{ij}d_{ij} + \gamma\lambda\alpha_{ij}Q_{ik}d_{ij} + \beta\gamma\lambda d_{ij}v_{ij}^2 \right) x^c_{ijk} . \tag{4}$$

The shortest route plan: minimize the travel distance during solid waste transportation:

$$\min \sum_{i=0}^{N+M} \sum_{j=0}^{K} \sum_{c=1}^{C} d_{ij}x^c_{ijk}. \tag{5}$$

*2.4.2. Flow Restrictions*

Each collection point can be served only once by a vehicle in a parade:

$$\sum_{i=0}^{N+M} \sum_{k=1}^{K} \sum_{c=1}^{C} x^c_{ijk} = 1, \quad \forall j \in \{1, 2, \ldots, N\},\ i \neq j. \tag{6}$$

Each vehicle can depart from the parking lot only once during the entire transportation process:

$$\sum_{j=1}^{N} \sum_{c=1}^{C} x^c_{0jk} = 1, \quad \forall k \in \{1, 2, \ldots, K\}. \tag{7}$$

Each vehicle will eventually return to the depot from the transfer station during the transportation process:

Table 3: Factors affecting vehicle fuel consumption.

| | |
|---|---|
| The first category: factors that have nothing to do with the path of the vehicle | |
| $g$—acceleration of gravity | $V_s$—engine capacity |
| Cd—coefficient of air resistance | $\xi$—mass ratio of fuel to air |
| Cr—rolling resistance coefficient | $\eta$—engine efficiency |
| $\rho$—air density | $\mu$—heat value of diesel |
| $\eta_{tf}$—vehicle transmission efficiency | $\Psi$—fuel conversion factor |
| $P_{\mathrm{acc}}$—other energy requirements of vehicles | $S$—windward area of vehicles |
| kf—engine friction factor | $W$—empty vehicle mass (kg) |
| $N$—engine speed | $Q$—maximum vehicle load (kg) |
| The second category: factors related to the vehicle path | |
| $Q_{ik}$—vehicle load (kg) | $di\ j$—vehicle driving distance (m) |
| $a_{ij}$—vehicle acceleration (m/square second) | $\theta_{ij}$—road angle |
| $vij$—vehicle speed (m/s) | M—total vehicle weight (kg) |

$$\sum_{i=N+1}^{N+M}\sum_{c=1}^{C} x_{i0k}^{c} = 1, \quad \forall k \in \{1,2,\ldots,K\}. \tag{8}$$

In a cruise, the vehicle leaves the transfer station at most once (0 or 1 times):

$$\sum_{i=N+1}^{N+M}\sum_{j=1}^{N} x_{ijk}^{c} \le 1, \quad \forall k \in \{1,2,\ldots,K\},\ c \in \{1,2,\ldots,C\}. \tag{9}$$

The vehicle arrives at a node and then leaves:

$$\sum_{i=1}^{N+M} x_{ijk}^{c} = \sum_{i=1}^{N+M} x_{jik}^{c}, \quad \forall j \in \{1,2,\ldots,N\}, \quad \forall k \in \{1,2,\ldots,K\},\ c \in \{1,2,\ldots,C\}. \tag{10}$$

*2.4.3. Capacity Constraints*

The cumulative load of each vehicle in a parade is less than the maximum load of the vehicle:

$$Q_{ik}^{c} \le Q, \quad i \in \{0,1,2,\ldots,N+M\}, \quad \forall k \in \{1,2,\ldots,K\},\ c \in \{1,2,\ldots,C\}. \tag{11}$$

The vehicle is empty after arriving at the transfer station and the vehicle load becomes 0:

$$Q_{jk}^{c} = 0, \quad j \in \{N+1,N+2,\ldots,N+M\}, \quad \forall k \in \{1,2,\ldots,K\},\ c \in \{1,2,\ldots,C\}. \tag{12}$$

The vehicle reaches the collection point $i$, and its load increases by $qi$ when it leaves. That is, the amount of solid waste at point $i$ is $qi$:

$$Q_{ik}^{c} + q_j - Q_{jk}^{c} \le \left(1 - x_{ijk}^{c}\right) M\infty, \quad \forall k \in \{1,2,\ldots,K\},\ c \in \{1,2,\ldots,C\}, \quad i \in \{0,1,2,\ldots,N+M\},\ j\{1,2,\ldots,N\}. \tag{13}$$

*2.4.4. Time Constraints*

The relationship between the arrival time, service time, and transportation time of each collection point ensures time continuity:

$$\omega_{ik}^{c} + s_i + \frac{d_{ij}}{v_{ij}} - \omega_{jk}^{c} \le \left(1 - x_{ijk}^{c}\right) M\infty, \quad \forall k \in \{1,2,\ldots,K\},\ c \in \{1,2,\ldots,C\}, \quad i \in \{0,1,2,\ldots,N\},\ j\{1,2,\ldots,N+M\}. \tag{14}$$

The number of vehicle cruises will increase every time a vehicle passes through the transfer station:

$$\omega_{ik}^{c} + s_i + \frac{d_{ij}}{v_{ij}} - \omega_{jk}^{c} \le \left(1 - x_{ijk}^{c+1}\right) M\infty, \quad \forall k \in \{1,2,\ldots,K\},\ c \in \{1,2,\ldots,C\}, \quad i \in \{N+1,N+2,\ldots,N+M\}, \quad j\{0,1,2,\ldots,N\}. \tag{15}$$

The clearing activities must be completed within the time allowed by the node (time window):

$$e_i \le \omega_{ik}^{c} \le l_i, \quad \forall i \in \{0,1,2,\ldots,N+M\}, \quad k \in \{1,2,\ldots,K\},\ c \in \{1,2,\ldots,C\}. \tag{16}$$

## 3. Algorithm Design

In this paper, we establish that the optimization model of MSW transportation based on energy consumption is an extension of the VRP problem with capacity constraints; so, it is also an NP-complete problem. Our paper uses a heuristic algorithm.

Genetic algorithm is a method to search for the better optimal solution by simulating the natural evolution process. It has strong robustness and global optimization ability, and it is suitable for solving complex multi-extreme optimization problems and combination problems [19]. Genetic Algorithm (GA) is designed and proposed according to the evolutionary laws of organisms in nature. It is a computational model that simulates the biological evolution process of natural selection and genetic mechanism of Darwin's biological evolution theory and is a method of searching for the optimal solution by simulating the natural evolution process. The algorithm transforms the problem-solving process into a process like the crossover and mutation of chromosomal genes in biological evolution by means of mathematics and computer simulation operations. When solving more complex combinatorial optimization problems, compared with some conventional optimization algorithms, better optimization results can usually be obtained faster [20].

*3.1. Coding Method.* We formulate relevant coding rules based on actual conditions and summarize the set of feasible routes for solid waste transportation. Each chromosome in this model represents a solid waste collection route plan describing the collection order of each collection point. If there are $n$ solid waste collection points, the code s can be set as an integer arrangement of length $n$.

*3.2. Fitness Function.* In the process of evolutionary search, the genetic algorithm only considers the fitness and searches according to the fitness value of the chromosomes in the population. This article sets the fitness function of chromosome as $F_i = (1/y_i + P_i)$, where $F_i$ is the fitness value of chromosome $i$, $y_i$ is the objective function of chromosome $i$, and $P_i$ is the penalty value of chromosome $i$.

*3.3. Selection.* After calculating the fitness value of each chromosome, the "roulette" method is used to select the best individual to directly enter the next generation, and the remaining individuals enter the crossover procedure based on the crossover probability. The basic idea is that the probability of an individual being selected is proportional to the value of its fitness function.

*3.4. Cross Operation.* The crossover operation performs the two-point crossover method. First, two chromosomes are randomly selected as the paternal parents. Second, two random natural numbers $r1$ and $r2$ are generated. Then, gene fragments between the two paternal chromosomes $r1$ and $r2$ are exchanged to obtain two offspring chromosomes.

*3.5. Mutation Operation.* For individuals who meet the mutation probability, a two-point reciprocal mutation method is used for mutation to increase the diversity of solutions. Two-point reciprocity first generates two random natural numbers $r1$ and $r2$ and then exchanges genes between $r1$ and $r2$.

## 4. Examples

*4.1. Model Verification.* CPLEX Studio can provide a method to quickly build efficient optimization models and to solve planning and scheduling problems from diverse perspectives. An example is given below and solved with CPLEX to verify the correctness of the model.

Suppose there are one parking lot, three solid waste collection points, and one transfer station in a solid waste collection and transportation network. The node number, solid waste volume (tons), and distance information (km) are shown in Table 4. The road gradient is set to 0, and the vehicle speed is set to 20 km/h. The transportation path obtained by CPLEX programming is shown in Table 5. Scenario 1 requires three vehicles to participate in transportation, and each vehicle only serves one node and ends the work owing to capacity constraints. In case 2, the number of cruises was increased, and the operation was completed with only two vehicles. Vehicle 1 went through two cruises. After the first cruise, it chose a closer collection point (3) for service. In Scenario 3, two vehicles are required to complete the service, but the route result and fuel consumption are different from Scenario 2 because of the different setting of the maximum load. According to formula (4), when the road gradient and vehicle speed are fixed, distance and load are the key factors affecting fuel consumption. Vehicle 1 should choose collection point 3 with a smaller gross tonnage-kilometer after serving collection point 1 rather than the nearest collection point 2 (1-3-4 ton-km 46, 1-2-4 ton-km 57). The calculation result is consistent with logical reasoning, and path 1-3-4 is a more fuel-efficient path than 1-2-4. From Scenario 1 to Scenario 3, the total transportation distance (km) decreased from 48 to 36, and the total fuel consumption (L) decreased from 9.6447 to 7.0525, indicating that the setting of the cruise link has a significant effect on the distance reduction and fuel consumption savings in the solid waste transportation process. This demonstrates that the model proposed in this article is valid and effective.

*4.2. Example Solution.* The Xicheng District of Beijing is located to the west of the central city of Beijing. It has a population of 1.259 million and a regional GDP of 327.035 billion yuan. There are 15 streets and 255 communities in the jurisdiction, with a total area of 50.70 square kilometers. Owing to its flat terrain of the North China Plain, the average slope is only 12–13 per ten thousandths (Figure 4).

In order to verify the effectiveness of the optimization model proposed in this paper, which takes the minimum fuel consumption as the goal and considers the influence of distance, load, slope, and speed on fuel consumption, this paper uses the solid waste compression truck collection points in the Xicheng District of Beijing to transport domestic waste. We take the transportation situation as an example to optimize the transportation route. The MSW collection and transportation system of Xicheng District includes one depot, 105 waste collection points, and one transfer station. The location of each collection point is shown in Google Earth (Figure 5).

Table 4: Example description.

| | Depot 0 | Collection node 1 | Collection node 2 | Collection node 3 | Transfer station 4 | Solid waste volume |
|---|---|---|---|---|---|---|
| Depot 0 | 0 | 5 | 5 | 6 | 7 | 0 |
| Collection node 1 | 5 | 0 | 5 | 6 | 7 | 5 |
| Collection node 2 | 5 | 5 | 0 | 2 | 4 | 3 |
| Collection node 3 | 6 | 6 | 2 | 0 | 2 | 3 |
| Transfer station 4 | 7 | 7 | 4 | 2 | 0 | 0 |

Table 5: CPLEX optimized transportation route.

| Situation | | Transportation route | Distance (km) | Sum (km) | Fuel consumption (L) | Sum (L) |
|---|---|---|---|---|---|---|
| Situation 1 | $Q=5,\ C=1$ | V1: 0-1-4-0;<br>V2: 0-2-4-0;<br>V3: 0-3-4-0. | 17;<br>16;<br>15. | 48 | 3.8394;<br>3.0183;<br>2.7870. | 9.6447 |
| Situation 2 | $Q=5,\ C=2$ | V1: 0-1-4-3-4-0;<br>V2: 0-2-4-0 | 23;<br>16. | 39 | 4.5410;<br>3.0183. | 7.5593 |
| Situation 3 | $Q=10,\ C=2$ | V1: 0-1-3-4-0;<br>V2: 0-2-4-0 | 20;<br>16. | 36 | 4.03423;<br>3.0183. | 7.0525 |

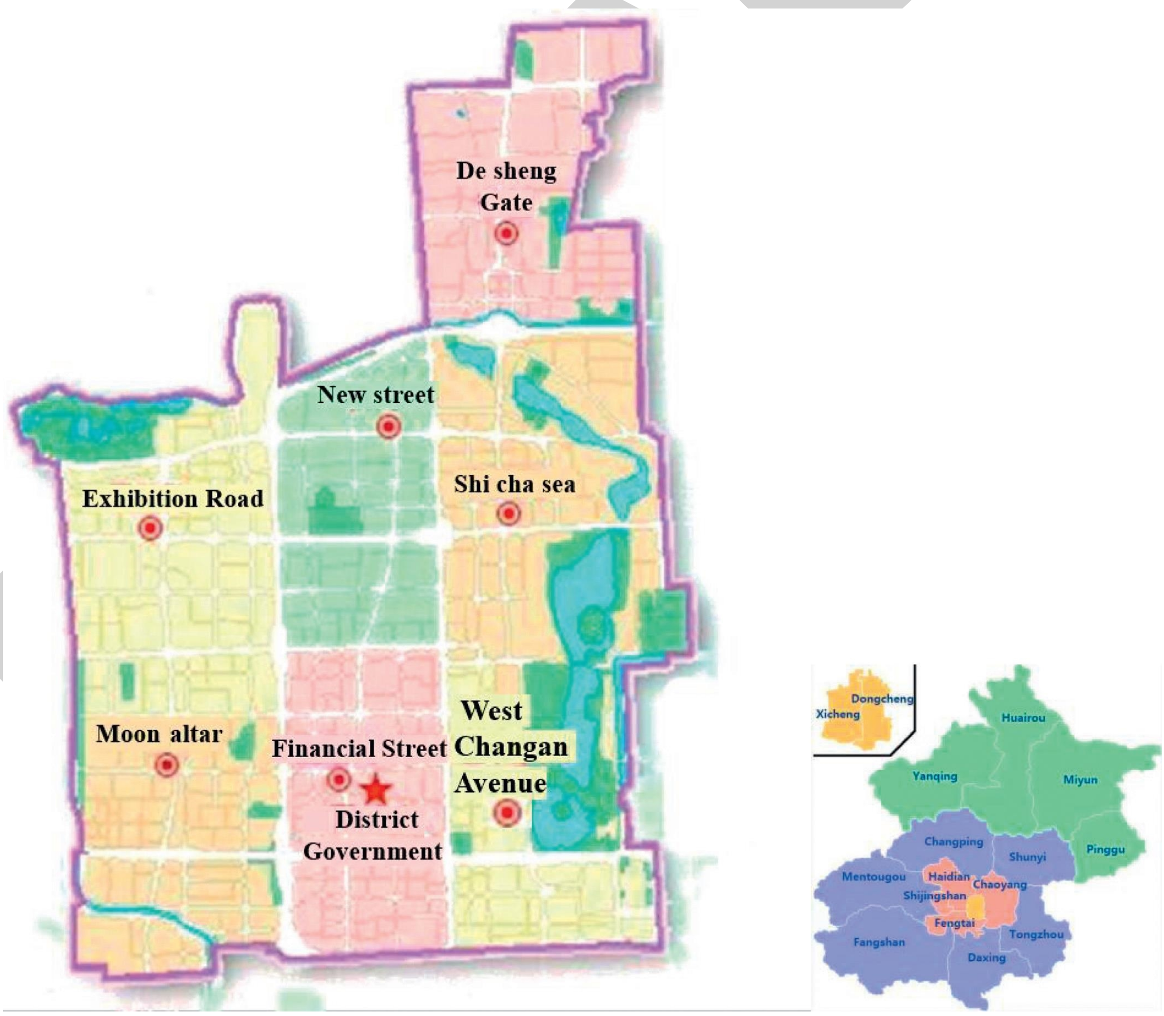


Figure 4: Map of Xicheng District, Beijing.


Figure 5: Location map of solid waste collection points in Xicheng District, Beijing.

When calculating fuel consumption in this paper, in addition to the influence of vehicle and engine models and related parameters, the influence of factors such as slope, load, distance, and speed is considered. Based on Beijing's geographical location and actual topography (see Table 6), the road slopes are set to 0 in this example. The load is the cumulative load of the vehicle during a cruise, which is determined by the transportation route and the amount of solid waste at each collection point. Distance is calculated based on the position coordinates of each point, and Baidu Map is used to calculate the shortest distance in the feasible route. For the speed setting, the real time is calculated according to the real-time traffic flow. See Table 7 for specific parameter settings.

*4.3. Results.* In this example, the population size is set to 100, the maximum evolutionary iteration is 700, crossover is performed with a probability of 0.8, and mutation is performed with a probability of 0.1. After the program runs, a green transportation scheme with minimum fuel consumption as the goal is obtained. The corresponding iterative curve, the fuel consumption of each vehicle, the driving distance, and the corresponding optimal route arrangement are shown in Figure 6 and Table 8. For the shortest path scheme with the goal of minimizing the driving distance, the corresponding iterative curve, the fuel consumption of each vehicle, the driving distance, and the corresponding optimal route arrangement are shown in Figure 7 and Table 9.

*4.3.1. Green Transportation Plan.* Under the minimum fuel consumption target, the total fuel consumption of the optimized path is 186.36 liters, and the total distance is 561,213 meters. The solution results show that each vehicle has completed the cleaning and transportation of 105 solid waste collection points within the prescribed seven-hour working time and finally returned to the parking lot. In the model with the goal of minimum fuel consumption (green transportation scheme), a total of 13 vehicles participate in transportation activities, of which one vehicle cruises five times, four vehicles cruise four times, seven vehicles cruise three times, and one vehicle cruises once. Because of the limitation of the longest working hours of vehicles, most vehicles will not carry out the fourth patrol clearance after the maximum working time of seven hours after three patrols. The order of visits to the collection points follows the principle of minimum fuel consumption; vehicles preferentially choose unobstructed road sections with large speeds and short distances. The collection points with large amounts of solid waste are arranged close to the transfer station for collection and transportation to avoid heavy driving and excessive fuel consumption (Figure 7).

*4.3.2. Shortest Path Scheme.* Under the shortest distance target, the total fuel consumption of the optimized path is 200.49 liters, and the total distance is 537,813 meters. It can be seen from the solution results that each vehicle has completed the cleaning and transportation of 105 solid waste collection points within the prescribed seven-hour working time and finally returned to the parking lot. In the model with the smallest distance as the goal (shortest path scheme), a total of 12 vehicles participate in transportation activities, of which one vehicle cruises five times, three vehicles cruise four times, and eight vehicles cruise three times. In this scheme, the number of patrols of the vehicle is still determined by the maximum working time of the vehicle, and the visiting order of each collection point follows the principle of distance priority. The shortest route arrangement for the total distance of the vehicle is selected (Figure 6).

Table 6: Information on location, quantity, and time of solid waste collection and transportation in Xicheng District.

| Serial number | Community name | Longitude | Latitude | Solid waste removal volume (tons) |
|---|---|---|---|---|
| 0 | Depot | 116.391169 | 39.904897 | 0 |
| 1 | Yanshou street | 116.39514 | 39.903563 | 4.26 |
| 2 | Tieshu Xiejie | 116.393764 | 39.899568 | 4.69 |
| 3 | Da'an lanying | 116.394064 | 39.900235 | 5.03 |
| 4 | Mitsui | 116.396543 | 39.901669 | 6.23 |
| 5 | Dashilan west street | 116.399109 | 39.901717 | 4.91 |
| 6 | Stone | 116.399166 | 39.897915 | 7.28 |
| 7 | Baishun | 116.395762 | 39.896955 | 5.35 |
| 8 | Meishi street east | 116.403817 | 39.898118 | 6.32 |
| 9 | Tianqiao community | 116.400733 | 39.890224 | 9.6 |
| 10 | Hufang road | 116.393778 | 39.890524 | 9.71 |
| 11 | Yongan road | 116.394222 | 39.893147 | 7.15 |
| 12 | Xiangchang Lu | 116.397841 | 39.893317 | 9.04 |
| 13 | Study abroad | 116.401622 | 39.893538 | 11.96 |
| 14 | Luchang street | 116.397159 | 39.888833 | 9.43 |
| 15 | Xiannongtan | 116.402725 | 39.88626 | 6.66 |
| 16 | Taiping street | 116.397433 | 39.879554 | 6.65 |
| 17 | Xuanwumen Waidong street | 116.384318 | 39.905526 | 3.2 |
| 18 | Liulichang west street | 116.390259 | 39.899287 | 4.36 |
| 19 | Liang Jiayuan | 116.389064 | 39.898596 | 3.98 |
| 20 | Red line | 116.387669 | 39.897711 | 3.42 |
| 21 | Sichuan camp | 116.386539 | 39.89685 | 5.74 |
| 22 | Chunshu garden | 116.384653 | 39.900102 | 5.58 |
| 23 | Incense camp | 116.387548 | 39.904597 | 3.42 |
| 24 | Longquan | 116.385959 | 39.883912 | 2.08 |
| 25 | Black kiln factory | 116.384773 | 39.887577 | 3.37 |
| 26 | Red clay shop | 116.384404 | 39.886989 | 2.72 |
| 27 | Fenfang liuli street | 116.387757 | 39.891855 | 2.56 |
| 28 | Fruit lane | 116.382257 | 39.891557 | 2.08 |
| 29 | Rice city | 116.381759 | 39.891565 | 4.64 |
| 30 | Fuzhou pavilion | 116.389348 | 39.892055 | 2.08 |
| 31 | Xinxingli | 116.390961 | 39.886478 | 2.08 |
| 32 | Changchunli | 116.368944 | 39.895846 | 3.29 |
| 33 | Changchun street | 116.370337 | 39.903082 | 3.18 |
| 34 | Changchun street west | 116.368836 | 39.904413 | 4.26 |
| 35 | Kangle | 116.373306 | 39.901044 | 2.21 |
| 36 | Shangxiejie | 116.376281 | 39.903758 | 4.61 |
| 37 | Old wall root | 116.37451 | 39.899763 | 4.4 |
| 38 | Gwangan Dongli | 116.37619 | 39.895664 | 5.24 |
| 39 | Xiaoliujo | 116.378447 | 39.90235 | 6.71 |
| 40 | Xibianmen Dongli | 116.361617 | 39.905474 | 0.69 |
| 41 | Xibianmen Siri | 116.358473 | 39.904392 | 0.69 |
| 42 | Xibianmen inner street | 116.359283 | 39.90207 | 4.49 |
| 43 | Huaibaishu street South | 116.360188 | 39.901443 | 3.68 |
| 44 | North of Huaibaishu street | 116.365552 | 39.90333 | 3.59 |
| 45 | Xuanwumen west street | 116.377248 | 39.905067 | 3 |
| 46 | Guangnei avenue east | 116.373968 | 39.896069 | 1.47 |
| 47 | Walnut garden | 116.360158 | 39.89576 | 4.58 |
| 48 | Sanmiao street | 116.370322 | 39.903919 | 3.37 |
| 49 | Baoguo temple | 116.367126 | 39.898393 | 5.34 |
| 50 | Fenghua | 116.378062 | 39.892945 | 4.44 |
| 51 | Fayuan temple | 116.377268 | 39.88987 | 5.86 |
| 52 | Niujie Dongli | 116.372565 | 39.89359 | 7.54 |
| 53 | Baiguang road | 116.362948 | 39.891109 | 4.71 |
| 54 | South line court | 116.358815 | 39.893745 | 4.31 |
| 55 | Caiyuan Beili | 116.357684 | 39.88942 | 2.76 |
| 56 | Spring breeze | 116.371824 | 39.890263 | 6.2 |
| 57 | Niujie Xili first District | 116.368875 | 39.89405 | 3.26 |
| 58 | Niujie Xili second District | 116.369033 | 39.890198 | 3.35 |
| 59 | Steel institute | 116.366486 | 39.891719 | 3.46 |

Table 6: Continued.

| Serial number | Community name | Longitude | Latitude | Solid waste removal volume (tons) |
|---|---|---|---|---|
| 60 | In the plain | 116.37823 | 39.888735 | 5.19 |
| 61 | Shuanghuaili | 116.377118 | 39.887928 | 2.02 |
| 62 | Youbei avenue | 116.37157 | 39.888624 | 1.32 |
| 63 | Cherry orchard | 116.368339 | 39.885945 | 2.91 |
| 64 | Caiyuan street | 116.361844 | 39.887384 | 2.45 |
| 65 | Chongxiao temple | 116.363277 | 39.884632 | 3.71 |
| 66 | Jiangong Beili | 116.357848 | 39.883933 | 3.02 |
| 67 | Jiangong nanli | 116.359957 | 39.880931 | 2.44 |
| 68 | Xin'an zhongli | 116.363235 | 39.88337 | 2.37 |
| 69 | Xin'an nanli | 116.36792 | 39.880821 | 2 |
| 70 | Right inner back | 116.367066 | 39.879039 | 1.81 |
| 71 | Right inner west street | 116.369465 | 39.878726 | 2.84 |
| 72 | Confident road | 116.374547 | 39.883018 | 2.56 |
| 73 | In the light source | 116.374082 | 39.883791 | 2.05 |
| 74 | Half-step bridge | 116.37454 | 39.877581 | 2.2 |
| 75 | Wanboyuan | 116.374751 | 39.877506 | 0.77 |
| 76 | Liren street | 116.376383 | 39.881408 | 2.22 |
| 77 | Qingzhiyuan | 116.377889 | 39.878455 | 4.03 |
| 78 | Duck bridge | 116.353641 | 39.880591 | 3.85 |
| 79 | Youth lake | 116.354865 | 39.885148 | 4.62 |
| 80 | Chunshukan | 116.351703 | 39.887713 | 5.77 |
| 81 | Cabbage bay | 116.354195 | 39.892115 | 6.87 |
| 82 | Station east street | 116.351315 | 39.894692 | 5.05 |
| 83 | Station west street | 116.348216 | 39.884298 | 3.95 |
| 84 | Hongju South street | 116.345071 | 39.890248 | 7.16 |
| 85 | Hongju street | 116.346099 | 39.892002 | 7.91 |
| 86 | Handkerchief South street | 116.349028 | 39.884229 | 2.84 |
| 87 | Handkerchief north street | 116.34674 | 39.896735 | 5.01 |
| 88 | Honglian north lane | 116.341094 | 39.891127 | 3.93 |
| 89 | Honglian zhongli | 116.342122 | 39.887696 | 14.82 |
| 90 | Honglian nanli | 116.341231 | 39.884684 | 10.71 |
| 91 | Sanyi Dongli | 116.33876 | 39.893495 | 6.18 |
| 92 | Longqin garden | 116.348616 | 39.891697 | 7.8 |
| 93 | Sanyili | 116.336333 | 39.89466 | 3.99 |
| 94 | Tianning temple south | 116.351541 | 39.897228 | 5.83 |
| 95 | Tianning temple north | 116.351523 | 39.898724 | 7.48 |
| 96 | Rongfeng | 116.343634 | 39.900955 | 5.86 |
| 97 | Yilianxuan | 116.335069 | 39.891395 | 5.16 |
| 98 | Lecheng | 116.351421 | 39.888557 | 5.93 |
| 99 | No. 15 station west street | 116.34519 | 39.883288 | 5.93 |
| 100 | Wanzi street | 116.330503 | 39.890604 | 5.4 |
| 101 | Lotus river | 116.335515 | 39.89836 | 3.43 |
| 102 | Pony factory | 116.343925 | 39.903792 | 14.16 |
| 103 | Malian Daozhongli | 116.338684 | 39.8935 | 3.95 |
| 104 | Maliandao | 116.331987 | 39.894123 | 3.63 |
| 105 | Butterfly garden | 116.339219 | 39.898948 | 2.96 |
| 106 | Majialou transit station | 116.35728 | 39.840239 | 0 |

Table 7: Parameters related to fuel consumption.

| g—acceleration of gravity | 9.8 | V—engine capacity | 5 |
|---|---|---|---|
| Cd—coefficient of air resistance | 0.7 | $\xi$—mass ratio of fuel to air | 1 |
| Cr—rolling resistance coefficient | 0.01 | $\eta$—engine efficiency | 0.9 |
| $\rho$—air density | 1.2 | $K$—heat value of diesel | 44 |
| $\eta_{tf}$—vehicle transmission efficiency | 0.4 | $\Psi$—fuel conversion factor | 737 |
| $P_{acc}$—other energy requirements of vehicles | 0 | $A$—windward area of vehicles | 3.912 |
| $kf$—engine friction factor | 0.2 | $W$—empty vehicle mass (t) | 6 |
| $N$—engine speed | 33 | $Q$—maximum vehicle load (t) | 15 |
| $a$—vehicle acceleration | 0 | $\theta_{ij}$—road gradient | 0 |

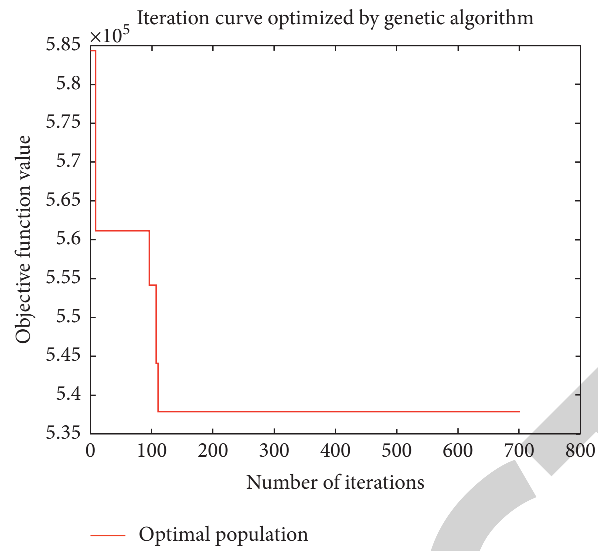


Figure 6: Iterative curve of the shortest distance scheme.

*4.3.3. Comparative Analysis of the Two Optimization Schemes.* In this paper, we propose two objective functions, one is to minimize fuel consumption, the other is to minimize cruise path. We use genetic algorithm to solve these two objective functions. It can be seen from Tables 8 and 9 that under different optimization goals, both the number of vehicles participating in transportation and the route arrangement are different, and the total distance and total fuel consumption are also different. The analysis results in Table 10 show that the green transportation scheme uses one additional vehicle than the shortest path scheme.

Because genetic algorithm is a heuristic search algorithm, it cannot obtain the exact solution. Therefore, we solve these two objective functions and obtain 50 approximate solutions, respectively (see Table 11).

First of all, according to Table 11, the original hypothesis $H0$ is established: there is no difference between the detection data of the total fuel consumption with total fuel consumption as the target value and the detection data of the total fuel consumption with total distance as the target value. The alternative hypothesis $H1$ is that there is a difference between the detection data of total fuel consumption with total fuel consumption as the target value and the detection data of total fuel consumption with total distance as the target value. The test method is the Mann–Whitney test, and the results are given in Table 12.

Form the test results, the $Z$ value was −4.500, and the bilateral $p$ value was 0.000. According to the significance level $\alpha = 0.05$, rejecting the original hypothesis $H0$, it can be seen that there is a difference between the detection data of total fuel consumption with total fuel consumption as the target value and the detection data of total fuel consumption with total distance as the target value.

Secondly, according to Table 11, the original hypothesis $H0$ is established: there is no difference between the detection data of the total distance with total fuel consumption as the target value and the detection data of the total distance with total distance as the target value. The alternative hypothesis $H1$ is that there is a difference between the detection data of total distance with total fuel consumption as the target value and the detection data of total distance with total distance as the target value. The test method is the Mann–Whitney test, and the results are given in Table 13.

From the test results, the $Z$ value was −4.640, and the bilateral $p$ value was 0.000. According to the significance level $\alpha = 0.05$, rejecting the original hypothesis $H0$, it can be seen that there is a difference between the detection data of total distance with total fuel consumption as the target value and the detection data of total distance with total distance as the target value.

Although the use of genetic algorithm to solve the optimization problems has certain uncertainty, but at the same time has a certain stability, it still can be used to repeat the calculation and then take the average method and improve the reliability of the calculation results [21]. Converting the objective function from the shortest distance to minimum fuel consumption saves 7.74% of fuel (from 182.16 to 197.44 liters) and increases the distance by 2.63% (from 533296 to 547346 meters). This shows that when the shortest distance is used as the objective function, the lowest fuel consumption cannot be obtained. The minimum fuel consumption objective function increases the transportation distance, but it can also reduce the fuel consumption to an extent. In general, the shortest route is not the most fuel-efficient route, and the green transportation plan has better fuel-saving potential than the shortest route.

## 5. Discussion

In social practice, for different roles of transportation undertakers, the preferred optimization goals will be different. When the garbage transportation task is undertaken by a third-party logistics company, the company will pay more

Table 8: Vehicle route optimization arrangement of the green transportation plan.

| Vehicle | Number of cruises | Route arrangement | Fuel consumption (L) | Distance (m) |
|---|---|---|---|---|
| 1 | 4 | 0⟶50⟶45⟶93⟶106⟶39⟶74⟶28⟶106⟶85⟶81⟶106⟶70⟶106⟶0 | 14.60 | 38754 |
| 2 | 5 | 0⟶68⟶106⟶89⟶106⟶100⟶92⟶106⟶47⟶58⟶60⟶106⟶69⟶55⟶106⟶0 | 16.15 | 41267 |
| 3 | 3 | 0⟶20⟶27⟶82⟶44⟶106⟶91⟶40⟶35⟶36⟶106⟶56⟶106⟶0 | 12.69 | 36904 |
| 4 | 3 | 0⟶14⟶54⟶106⟶105⟶41⟶34⟶1⟶106⟶63⟶84⟶17⟶106⟶0 | 13.96 | 42703 |
| 5 | 4 | 0⟶9⟶23⟶106⟶59⟶48⟶106⟶10⟶18⟶106⟶71⟶33⟶106⟶0 | 20.33 | 61432 |
| 6 | 4 | 0⟶12⟶104⟶106⟶52⟶51⟶106⟶79⟶38⟶78⟶106⟶6⟶4⟶106⟶0 | 17.39 | 48846 |
| 7 | 3 | 0⟶5⟶7⟶106⟶80⟶83⟶72⟶106⟶103⟶61⟶87⟶106⟶0 | 10.94 | 31343 |
| 8 | 3 | 0⟶11⟶25⟶106⟶42⟶32⟶76⟶31⟶106⟶2⟶75⟶64⟶106⟶0 | 15.33 | 49348 |
| 9 | 3 | 0⟶21⟶97⟶88⟶106⟶99⟶86⟶73⟶106⟶29⟶37⟶96⟶106⟶0 | 14.92 | 39023 |
| 10 | 3 | 0⟶3⟶16⟶46⟶106⟶67⟶22⟶24⟶43⟶106⟶15⟶106⟶0 | 15.01 | 48409 |
| 11 | 4 | 0⟶53⟶65⟶106⟶95⟶106⟶90⟶106⟶102⟶106⟶19⟶26⟶62⟶8⟶106⟶0 | 16.88 | 42329 |
| 12 | 3 | 0⟶98⟶94⟶106⟶77⟶57⟶49⟶106⟶101⟶30⟶66⟶106⟶0 | 10.94 | 34524 |
| 13 | 1 | 0⟶13⟶106⟶0 | 7.22 | 46331 |
| | | Sum | 186.36 | 561213 |

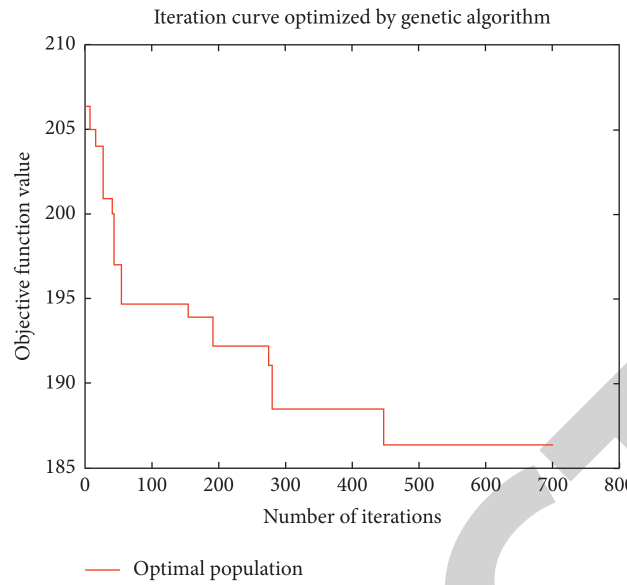


Figure 7: Iterative curve of the green transportation scheme.

Table 9: The optimal arrangement of the vehicle route of the shortest route plan.

| Vehicle | Number of cruises | Route arrangement | Fuel consumption (L) | Distance (m) |
|---|---|---|---|---|
| 1 | 3 | 0⟶94⟶63⟶21⟶106⟶44⟶70⟶58⟶27⟶106⟶65⟶32⟶106⟶0 | 15.29 | 44755 |
| 2 | 3 | 0⟶79⟶35⟶29⟶106⟶54⟶50⟶49⟶106⟶97⟶19⟶30⟶55⟶106⟶0 | 17.44 | 45570 |
| 3 | 4 | 0⟶2⟶96⟶106⟶99⟶37⟶106⟶84⟶45⟶101⟶106⟶33⟶95⟶106⟶0 | 18.56 | 47776 |
| 4 | 5 | 0⟶81⟶106⟶90⟶103⟶106⟶12⟶106⟶102⟶106⟶15⟶8⟶41⟶106⟶0 | 19.34 | 46324 |
| 5 | 3 | 0⟶17⟶3⟶98⟶106⟶78⟶51⟶46⟶106⟶36⟶1⟶48⟶106⟶0 | 14.74 | 37962 |
| 6 | 3 | 0⟶5⟶52⟶106⟶100⟶93⟶105⟶106⟶14⟶64⟶106⟶0 | 11.69 | 32815 |
| 7 | 3 | 0⟶13⟶106⟶87⟶61⟶23⟶67⟶106⟶86⟶82⟶16⟶106⟶0 | 29.09 | 79801 |
| 8 | 3 | 0⟶25⟶20⟶28⟶80⟶106⟶38⟶59⟶66⟶106⟶91⟶62⟶18⟶106⟶0 | 14.15 | 38646 |
| 9 | 4 | 0⟶11⟶43⟶68⟶106⟶6⟶83⟶106⟶85⟶104⟶106⟶92⟶106⟶0 | 17.66 | 41805 |
| 10 | 4 | 0⟶10⟶72⟶106⟶56⟶57⟶74⟶26⟶106⟶9⟶7⟶106⟶77⟶106⟶0 | 16.70 | 48126 |
| 11 | 3 | 0⟶22⟶24⟶40⟶34⟶106⟶47⟶53⟶73⟶106⟶88⟶42⟶75⟶106⟶0 | 13.38 | 39629 |
| 12 | 3 | 0⟶89⟶106⟶71⟶39⟶60⟶106⟶69⟶76⟶31⟶4⟶106⟶0 | 12.45 | 34604 |
| | | Sum | 200.49 | 537813 |

Table 10: Comparative analysis of the results of the two optimizations.

| Schemes plan | Target | Vehicle numbers | Total fuel consumption (L) | Total distance (m) | Fuel consumption deviation (%) | Distance deviation (%) | Fuel consumption deviation per hundred kilometers (%) |
|---|---|---|---|---|---|---|---|
| Green transportation plan | Minimum fuel consumption | 13 | 186.36 | 561213 | 7.05 | 4.36 | 11.48 |
| Shortest path plan | Shortest distance | 12 | 200.49 | 537813 | | | |

Table 11: Statistical analysis on two different objective functions (sum of fuel or distance).

| Id | Objective: Sum of fuel (L) | Sum of distance (m) | id | Sum of fuel (L) | Objective: Sum of distance (m) |
|---|---|---|---|---|---|
| 1 | 183.01 | 553738 | 1 | 187.62 | 526310 |
| 2 | 174.28 | 530501 | 2 | 201.65 | 534376 |
| 3 | 185.89 | 587954 | 3 | 193.44 | 541241 |
| 4 | 182.47 | 547886 | 4 | 198.15 | 541764 |
| 5 | 183.83 | 558686 | 5 | 187.32 | 538639 |

Table 11: Continued.

| Id | Objective: Sum of fuel (L) | Sum of distance (m) | id | Sum of fuel (L) | Objective: Sum of distance (m) |
|---|---|---|---|---|---|
| 6 | 178.56 | 537604 | 6 | 200.62 | 533044 |
| 7 | 182.02 | 557908 | 7 | 201.38 | 535553 |
| 8 | 183.32 | 574010 | 8 | 196.82 | 527420 |
| 9 | 187.19 | 553213 | 9 | 192.71 | 533423 |
| 10 | 184.09 | 546983 | 10 | 199.66 | 532241 |
| 11 | 189.62 | 573262 | 11 | 197.03 | 535059 |
| 12 | 185.46 | 554350 | 12 | 203.30 | 534417 |
| 13 | 188.57 | 569537 | 13 | 200.54 | 530908 |
| 14 | 176.58 | 526252 | 14 | 197.02 | 537491 |
| 15 | 181.65 | 538266 | 15 | 201.53 | 541765 |
| 16 | 187.36 | 567655 | 16 | 201.28 | 530415 |
| 17 | 188.67 | 561465 | 17 | 188.96 | 526099 |
| 18 | 173.59 | 523843 | 18 | 193.48 | 534122 |
| 19 | 182.38 | 541316 | 19 | 199.76 | 528513 |
| 20 | 182.27 | 554189 | 20 | 191.44 | 534847 |
| 21 | 178.15 | 538485 | 21 | 201.98 | 532297 |
| 22 | 180.38 | 541132 | 22 | 201.81 | 531752 |
| 23 | 184.27 | 582981 | 23 | 192.03 | 524258 |
| 24 | 186.93 | 535791 | 24 | 204.53 | 535826 |
| 25 | 178.81 | 540387 | 25 | 197.79 | 539388 |
| 26 | 183.73 | 542983 | 26 | 193.69 | 538075 |
| 27 | 183.03 | 562584 | 27 | 195.28 | 524074 |
| 28 | 182.30 | 542961 | 28 | 196.41 | 536585 |
| 29 | 181.76 | 541701 | 29 | 196.42 | 538051 |
| 30 | 177.19 | 541777 | 30 | 191.83 | 527618 |
| 31 | 182.92 | 562494 | 31 | 205.38 | 538680 |
| 32 | 183.36 | 546080 | 32 | 195.08 | 525461 |
| 33 | 172.72 | 526787 | 33 | 200.67 | 531061 |
| 34 | 181.36 | 536851 | 34 | 195.64 | 534138 |
| 35 | 185.60 | 552890 | 35 | 202.12 | 543037 |
| 36 | 184.92 | 529095 | 36 | 198.47 | 532438 |
| 37 | 174.94 | 513997 | 37 | 196.37 | 539892 |
| 38 | 188.10 | 568893 | 38 | 198.78 | 534104 |
| 39 | 180.08 | 523048 | 39 | 197.60 | 526767 |
| 40 | 182.47 | 568281 | 40 | 195.35 | 541615 |
| 41 | 179.14 | 512244 | 41 | 188.65 | 517027 |
| 42 | 177.63 | 531452 | 42 | 192.89 | 522591 |
| 43 | 181.21 | 538053 | 43 | 196.55 | 531794 |
| 44 | 189.76 | 561161 | 44 | 197.90 | 534372 |
| 45 | 176.23 | 520766 | 45 | 201.63 | 535379 |
| 46 | 173.38 | 532377 | 46 | 198.43 | 533628 |
| 47 | 183.51 | 552349 | 47 | 198.50 | 529449 |
| 48 | 183.43 | 558262 | 48 | 196.74 | 529055 |
| 49 | 182.08 | 538385 | 49 | 203.16 | 534879 |
| 50 | 187.88 | 564450 | 50 | 206.57 | 543894 |
| AV | 182.16 | 547346.3 | AV | 197.44 | 533296.64 |
| | Saving of fuel consumption | Increasing of distance | | | |
| Percentage | −7.74% | 2.63% | | | |

Table 12: The detection data difference of the total fuel consumption test statistics.

| Statistic | Statistic value |
|---|---|
| Mann–Whitney U | 4.000 |
| Wilcoxon W | 124.000 |
| $Z$ | −4.500 |
| Progressive significance | 0.000 |

Table 13: The detection data difference of the total distance test statistics.

| Statistic | Statistic value |
|---|---|
| Mann–Whitney U | 577.000 |
| Wilcoxon W | 1852.000 |
| $Z$ | −4.640 |
| Progressive significance | 0.000 |

attention to economic costs from the perspective of the company's profitability. The optimal solution generally uses a smaller number of vehicles and a shorter driving distance, which can reduce the logistics company's vehicle purchase cost and operating costs. If you make a decision as an environmental protection agency, you may pursue a solution with low energy consumption, less emissions, and lower environmental costs, and choose the solution with the least fuel consumption. The job responsibility of the environmental protection department is to create a good living environment, and vehicle exhaust emissions will cause a lot of air pollution, so this is its key optimization goal. In different situations, different decision-making bodies will form different target preferences due to the nature of work and the content of their focus, which will affect the choice of the plan. This article provides decision-making basis for different subjects and has certain guiding significance for the actual transportation of garbage collection and transportation.

## 6. Conclusion

How to solve the increasingly serious urban solid waste and air pollution is one of major problems in modern urban management. This paper considers green WSM transportation plan and aims at minimizing fuel consumption, which uses a big data platform to obtain real-time road condition information of urban roads.

Firstly, compared with other relative literatures, this paper established a green WSM transportation VRP model with cruise constraints, which considers distance, load, speed, and slope. This paper adopts a genetic algorithm to solve this NP-completed problem.

Secondly, the models with the shortest distance and the minimum fuel consumption as targets are analyzed. From above, it can be seen that the route with the shortest distance as the goal is generally not the most fuel-efficient route. In the route arrangement considering fuel consumption, the collection distance will be higher compared to the shortest route, but it can significantly reduce fuel consumption. Furthermore, it will not increase the operating cost of the enterprise and still deliver a better performance in energy saving, emission reduction, and environment protection.

Finally, this paper uses a big data platform for energy consumption calculation and obtains real-time speed based on the actual urban road conditions by Baidu Maps. However, facing increasingly complex transportation networks and rapidly changing traffic conditions, congestion should be considered in speed prediction when calculating energy consumption, which makes our models more valuable for application.

## Data Availability

All data are included within the paper.

## Conflicts of Interest

The authors declare no conflicts of interest.

## Acknowledgments

This study was supported by the National Key Technology Research and Development Program of the Ministry of Science and Technology of China (Grant Nos. 2019YFC1906100 and 2015BAK39B00) and the Funds for First-Class Discipline Construction (Grant No. NXK1802-5).

## References

[1] A. Sulemana, E. A. Donkor, E. K. Forkuo, and S. Oduro-Kwarteng, "Effect of optimal routing on travel distance, travel time and fuel consumption of waste collection trucks," *Management of Environmental Quality: An International Journal*, vol. 30, no. 4, p. 803, 2019.

[2] D. He and Y. Li, "Optimization model of multi-vehicle green vehicle routing problem," *Computer Applications*, vol. 38, no. 12, pp. 3618–3624+3637, 2018.

[3] L. Jin and P. Fu, "Modeling and simulation of vehicle routing problem with time windows based on energy consumption," *Journal of System Simulation*, vol. 25, no. 6, pp. 1147–1154, 2013.

[4] G. Laporte, "Fifty years of vehicle routing," *Transportation Science*, vol. 43, no. 4, p. 408, 2009.

[5] S. Faiz, S. Krichen, and W. Inoubli, "A DSS based on GIS and Tabu search for solving the CVRP: the Tunisian case," *The Egyptian Journal of Remote Sensing and Space Science*, vol. 17, no. 1, p. 105, 2014.

[6] M. A. Hannan, M. Akhtar, R. A. Begum, H. Basri, A. Hussain, and E. Scavino, "Capacitated vehicle-routing problem model for scheduled solid waste collection and route optimization using PSO algorithm," *Waste Management*, vol. 71, pp. 31–41, 2018.

[7] Y. Wang, H. Zhou, and Y. Wang, "Research and application of genetic algorithm in path planning of logistics distribution vehicle," *AIP Conference Proceedings*, vol. 1864, 2017.

[8] A. Asghar and R. Hosseinabadi, "An ameliorative hybrid algorithm for solving the capacitated vehicle routing problem," *IEEE Access*, vol. 7, 2020.

[9] E. B. Tirkolaee, I. Mahdavi, and M. Mehdi Seyyed Esfahani, "A robust periodic capacitated arc routing problem for urban waste collection considering drivers and crew's working time," *Waste Manag.*vol. 76, 2018.

[10] S. Chaudhary, C. Nidhi, and N. R. Rawal, "Gis-based model for optimal collection and transportation system for solid waste in Allahabad city," *Advances in Intelligent Systems and Computing*, vol. 3, 2019.

[11] E. Demir, T. Bektaş, and G. Laporte, "The bi-objective pollution-routing problem," *European Journal of Operational Research*, vol. 232, no. 3, p. 464, 2014.

[12] M. R. Jabbarpour, R. M. Noor, and R. H. Khokhar, "Green vehicle traffic routing system using ant-based algorithm," *Journal of Network and Computer Applications*, vol. 58, p. 294, 2015.

[13] Y. Suzuki, "A dual-objective metaheuristic approach to solve practical pollution routing problem," *International Journal of Production Economics*, vol. 176, p. 143, 2016.

[14] Y. Xiao, Q. Zhao, I. Kaku, and Y. Xu, "Development of a fuel consumption optimization model for the capacitated vehicle routing problem," *Computers & Operations Research*, vol. 39, no. 7, p. 1419, 2012.

[15] C. Z. Li, Y. Zhang, Z. H. Liu, X. Meng, and J. Du, "Optimization of MSW collection routing system to reduce fuel

consumption and pollutant emissions," *Nature Environment and Pollution Technology*, vol. 13, 2014.
[16] Z. Zsigraiova, V. Semiao, and F. Beijoco, "Operation costs and pollutant emissions reduction by definition of new collection scheduling and optimization of MSW collection routes using GIS. The case study of Barreiro, Portugal," *Waste Management*, vol. 33, no. 4, p. 793, 2013.
[17] G. Tavares, Z. Zsigraiova, V. Semiao, and M. Da Graça Carvalho, "A case study of fuel savings through optimisation of MSW transportation routes," *Management of Environmental Quality: An International Journal*, vol. 19, no. 4, p. 444, 2008.
[18] E. Demir, T. Bektaş, and G. Laporte, "An adaptive large neighborhood search heuristic for the pollution-routing problem," *European Journal of Operational Research*, vol. 223, no. 2, p. 346, 2012.
[19] S. N. Sivanandam and S. N. Deepa, *Introduction to Genetic Algorithm*, Springer, New York, NY, USA, 2007.
[20] A. T. Mulloorakam and N. Mathew Nidhiry, "Combined objective optimization for vehicle routing using genetic algorithm," *Materials Today: Proceedings*, vol. 11, pp. 891–902, 2019.
[21] Y. Qin and F. Shan, "The statistical analyses for computational performance of the genetic algorithms," *Chinese Journal of Computers*, vol. 32, no. 12, pp. 2389–2392, 2009.