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ROUTE OPTIMIZATION AND SCHEDULING FOR WASTE SORTING TRANSPORTATION BASED ON PARTICLE SWARM ALGORITHM

Yan Zhang*, ZeYu Pan, SiChao Zhu
School of Automation, Nanjing University of Science and Technology, Nanjing 210094, Jiangsu, China.
**Corresponding Author: Yan Zhang*

Abstract: Aiming at the low efficiency and high cost of classified municipal solid waste transportation in urban China, this paper proposes a constrained vehicle routing optimization model. The particle swarm optimization (PSO) algorithm with greedy initialization is adopted to solve routing and scheduling problems under single-vehicle, multi-vehicle coordination, transfer station and time-window scenarios. The single-vehicle scheme achieves a minimum daily travel distance of 1101 km with 15 vehicles. For classified multi-vehicle transportation, the optimized fleet allocation yields a minimum daily cost of 2869 yuan. This study integrates classification characteristics, load and time constraints to bridge the gap between traditional VRP and real-world waste logistics. It provides a quantitative decision support tool for urban sanitation management to reduce costs and improve efficiency.

Keywords: PSO algorithm; Route planning; CVRP; Greedy strategy; Waste sorting transportation

1 INTRODUCTION

Rapid urbanization in China has triggered a continuous surge in municipal solid waste generation. To pursue sustainable development and eco-friendly urban governance, efficient waste collection, classification, transportation and disposal have become imperative. As a core segment of waste management, classified waste transportation needs to accommodate four waste categories (kitchen waste, recyclables, hazardous waste and other waste), while satisfying vehicle load and volume limits, transfer station capacity, and operating time-window constraints. A reasonable transportation scheme is expected to cut logistics costs, reduce carbon emissions and improve overall operational efficiency.

Worldwide scholars have carried out abundant studies on waste collection and transportation route optimization. Singh et al. (2021) explored route optimization for municipal solid waste collection and transportation under fuzzy stochastic demand with collection failure compensation mechanisms [1]. Kapadia and Mehta (2023) designed dynamic route optimization for IoT-based intelligent waste collection vehicle routing systems [2]. Olalo et al. (2022) constructed a full-process integrated recycling network for classified waste collection, transportation and treatment in accordance with local mandatory waste management policies [3]. Liang Xiaoru and Fan Jing (2026) adopted deep reinforcement learning to solve the capacitated vehicle routing problem (CVRP) [4]. Baral et al. (2024) evaluated the economic and environmental benefits of route optimization, yet only focused on conventional waste collection and transportation [5]. Hao Jiang et al. (2025) combined evolutionary algorithms and neighborhood search to solve the vehicle routing problem with soft time windows (VRPSTW) [6].

However, existing research is still incompatible with the actual needs of urban classified waste transportation. Most studies focus on single-type waste or traditional collection scenarios and fail to systematically consider the differentiated collection and transportation requirements of four types of classified waste, which cannot support the refined management of classified waste. Many models only set basic load constraints while ignoring vehicle volume limits, transfer station processing capacity and operation time window constraints that are critical in actual operation, resulting in poor practicability of the scheme. In addition, few studies involve multi-vehicle collaborative scheduling for classified transportation and cannot realize the coordinated configuration of special vehicles for different waste, making it difficult to match the real operation logic of urban waste logistics.

In view of the above deficiencies, this paper takes the route optimization and scheduling of urban classified waste transportation as the research core and puts forward targeted improvements and innovations. A multi-constraint vehicle routing model is constructed by integrating waste classification attributes, load capacity, volume limits, transfer station capacity, and time-window constraints, which highly conforms to real-world classified waste transportation scenarios. A greedy-initialized particle swarm optimization (PSO) algorithm is employed to solve routing and scheduling problems under single-vehicle, multi-vehicle coordination, transfer station, and time-window conditions, enhancing solution efficiency and robustness. Meanwhile, refined fleet allocation for four types of special waste collection vehicles is realized, and an operable classified transportation scheduling scheme is formed with the objective of minimizing total cost.

This study connects the traditional vehicle routing problem with the actual demand of classified waste logistics, fills the gap of multi-constraint and multi-vehicle collaborative optimization in the field of waste classification transportation, and provides a quantitative decision-making tool for urban sanitation departments to reduce costs, improve efficiency and promote green development.

2 BASIC ROUTE OPTIMIZATION AND SCHEDULING FOR A SINGLE VEHICLE TYPE

2.1 Model Establishment

For the capacitated vehicle routing problem(CVRP)under a single vehicle type, Yu Chen et al. also established an optimization model aimed at minimizing the total travel distance and designed a corresponding solution algorithm, providing an important methodological reference for the model construction in this section[7]. It is assumed that each collection point generates only one type of waste per day:kitchen waste. Therefore, only vehicles used for transporting kitchen waste are required. It is also assumed that transportation vehicles encounter no traffic congestion, and differences in vehicle speeds are ignored. Furthermore, it is assumed that the transportation network formed by the 30 collection points and the waste treatment plant is a symmetric road network, and that the route connecting any two collection points is unobstructed, allowing vehicles to pass without hindrance. Thus, the Euclidean distance can be used to represent the distance between two points, with distances rounded to integers.

The basic route optimization and scheduling for a single vehicle type involves using only one type of vehicle for waste transportation, subject to certain constraints, with the goal of minimizing the total travel distance. This problem falls under the capacitated vehicle routing problem(CVRP)category within the broader vehicle routing problem(VRP). The CVRP has the following basic characteristics:one-way, single depot, single vehicle type, closed routes(vehicles return to the depot), sufficient vehicles, and single route per vehicle.

This paper aims to minimize the total daily travel distance, determining the number of transport vehicles, the transportation route for each vehicle, and task assignment.

Optimization objective:Minimize the total daily travel distance.

Constraints:Waste treatment plant flow constraint, vehicle quantity constraint, load capacity constraint, collection frequency constraint for each collection point, and required number of vehicles constraint.

Given conditions:**Locations of the waste treatment plant and collection points, waste generation amount, and maximum load capacity of transport vehicles(Data source: https://shumo.neepu.edu.cn/).

Vehicles may make multiple trips, i. e. , the same vehicle is allowed to perform batch transportation. However, batch transportation is not cost-effective, as multiple trips by the same vehicle would result in a longer total distance. This paper arranges for vehicles to complete waste collection without batching, while simultaneously optimizing the number of vehicles and the total distance.

$$x_{ijt} = \begin{cases} 1, \text{Vehicle t travels from collection point i to collection point j} \\ 0, \text{other} \end{cases} \tag{1}$$

Among them, it represents whether the vehicle travels the path from i to j.

Objective function:minimize the total daily travel distance.

$$MinD = \sum_{i=0}^{N}\sum_{j=0}^{N}\sum_{t=1}^{T} d_{ij}x_{ijt} \tag{2}$$

Among them, d_{ij} represents the Euclidean distance from i to j, in km; T represents the total number of vehicles.

Constraints:

(1) Waste treatment plant flow constraint:All vehicles depart from the waste treatment plant and return to the waste treatment plant after completing their tasks.

$$\sum_{t=1}^{T}\sum_{j=1}^{N} x_{0jt} = \sum_{t=1}^{T}\sum_{j=1}^{N} x_{j0t} = T \tag{3}$$

(2) Vehicle quantity constraint:The number of vehicles entering each collection point should be equal to the number of vehicles leaving it.

$$\sum_{i=1}^{N} x_{ijt} = \sum_{i=1}^{N} x_{jit} (t \in L, \forall j = 1,2,...,N) \tag{4}$$

(3) Load capacity constraint:The weight of waste collected by a vehicle cannot exceed the vehicle's load capacity limit.

$$\sum_{i=0}^{N}\sum_{j=0}^{N} x_{ijt}w_j \le Q \ (t \in L) \tag{5}$$

where w represents the weight of the waste.

(4) Collection frequency constraint:The waste at each collection point is collected only once per day.

$$\sum_{t=1}^{T}\sum_{i=0}^{N} x_{ijt} = 1 (j = 1,2,...,N) \tag{6}$$

(5) Required number of vehicles constraint:The number of vehicles used cannot be less than the number of vehicles required to transport all the waste from all collection points in a single trip.

$$T \geq \left[\frac{\sum_{j=1}^{N} w_j}{Q} \right] (T = 1,2,\ldots,N) \tag{7}$$

where Q represents the vehicle load capacity limit.

2.2 Model Solution

VRP is an NP-hard problem whose solution difficulty increases exponentially with the scale of the problem, and few algorithms can obtain exact solutions. Therefore, this paper introduces PSO to solve this problem. It is worth noting that traditional PSO algorithms are prone to premature convergence and getting stuck in local optima when solving route optimization problems. Zhang Delong et al[8]. Pointed out that if the convergence speed of PSO is too fast, the algorithm may stagnate near local optima; if it is too slow, the search efficiency decreases. Therefore, in subsequent research, adaptive adjustment strategies for inertia weight or dynamic learning factors could be considered to further enhance the global search capability of route optimization.

PSO initializes a swarm of random particles(initial solutions). The optimal solution is then found through iteration. In each iteration, particles update themselves by tracking two"extreme values"(pbest, gbest). After finding these two optimal values, the particle updates its velocity and position using the following formulas.

$$v_i = v_i + c_1 \times rand() \times (pbest_i - x_i) + c_2 \times rand() \times (gbest_i - x_i) \tag{8}$$

$$x_i = x_i + v_i \tag{9}$$

Where i=1, 2, . . . , N, and N is the total number of particles in the swarm; v_i is the velocity of the particle, with a maximum value of $v_{\max}$. If $v_i > v_{\max}$, then $v_i = v_{\max}$; $rand()$ are random numbers between 0 and 1; x_i is the current position of the particle; c_1 and c_2 are learning factors. In Equation(1), the term representing memory v_i indicates the influence of the previous velocity's magnitude and direction; the self-cognitive term $c_1 \times rand() \times (pbest_i - x_i)$ represents the part of the particle's action derived from its own experience; the social term $c_2 \times rand() \times (gbest_i - x_i)$ reflects the cooperative collaboration and knowledge sharing among particles.

The algorithm was coded, and the data were input to obtain the results shown in Figures 1 and 2 below.

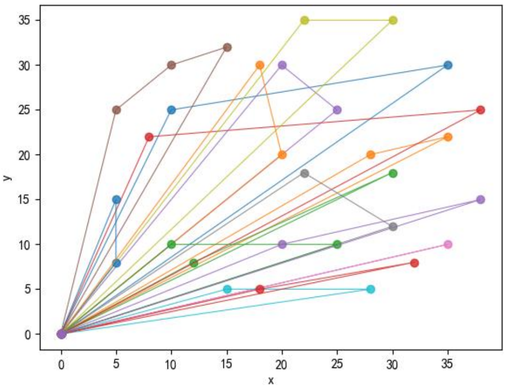

Figure 1 Route Diagram of the First Vehicle Transportation

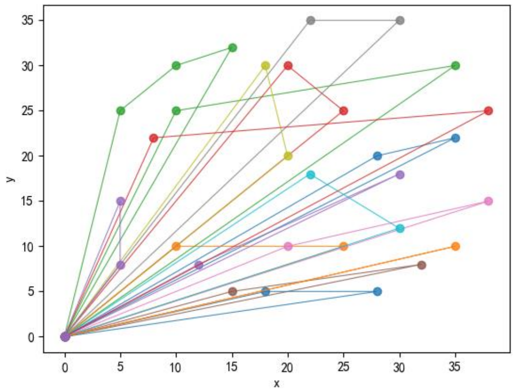

Figure 2 Route Diagram of the Second Vehicle Transportation

After thousands of particle iterations, this paper obtained two sets of optimal solutions. Both have a daily travel distance of 1101 km, but the routes taken are different.
The vehicle transportation routes shown in Figure 1:
Vehicle 1:[0, 8, 17, 0]; Vehicle 2:[0, 22, 5, 0]; Vehicle 3:[0, 1, 26, 0];
Vehicle 4:[0, 18, 23, 0]; Vehicle 5:[0, 3, 19, 0]; Vehicle 6:[0, 12, 24, 27, 0];
Vehicle 7:[0, 29, 0]; Vehicle 8:[0, 9, 14, 0]; Vehicle 9:[0, 30, 7, 0];
Vehicle 10:[0, 21, 13, 0]; Vehicle 11:[0, 2, 11, 0]; Vehicle 12:[0, 16, 28, 0];
Vehicle 13:[0, 4, 15, 0]; Vehicle 14:[0, 20, 6, 0]; Vehicle 15:[0, 25, 10, 0].
The vehicle transportation routes shown in Figure 2:
Vehicle 1:[0, 8, 17, 0]; Vehicle 2:[0, 22, 5, 0]; Vehicle 3:[0, 1, 26, 0];
Vehicle 4:[0, 18, 23, 0]; Vehicle 5:[0, 3, 19, 0]; Vehicle 6:[0, 12, 24, 27, 0];
Vehicle 7:[0, 29, 0]; Vehicle 8:[0, 9, 14, 0]; Vehicle 9:[0, 30, 7, 0];
Vehicle 10:[0, 21, 20, 0]; Vehicle 11:[0, 2, 11, 0]; Vehicle 12:[0, 16, 28, 0];
Vehicle 13:[0, 4, 15, 0]; Vehicle 14:[0, 6, 13, 0]; Vehicle 15:[0, 25, 10, 0].
The difference between the two lies in the routes of Vehicle 10 and Vehicle 14. According to calculation, $d_{21,13}+d_{20,6}=13+14=27km$, $d_{21,13}+d_{20,6}=13+14=27km$. So, $d_{21,13}+d_{20,6}$, $d_{21,20}+d_{6,13}$ Verification is correct.
For simplicity of calculation, the results based on the route shown in Figure 2 are presented below. The conclusion requires 15 transport vehicles. The specific routes and travel distances are shown in Table 1 below, and the minimum total daily travel distance is 1101 km.

Table 1 Vehicle Transportation Routes

Vehicle Number	Route	Travel distance(km)	Payload(t)
1	0→8→17→0	98	4. 4
2	0→22→5→0	82	4. 9
3	0→1→26→0	70	4. 8
4	0→18→23→0	98	4. 6
5	0→3→19→0	78	4. 6
6	0→12→24→27→0	72	4. 5
7	0→29→0	72	3. 7
8	0→9→14→0	70	5. 0
9	0→30→7→0	95	4. 8
10	0→21→13→0	57	5. 0
11	0→2→11→0	32	4. 0
12	0→16→28→0	73	4. 8
13	0→4→15→0	56	5. 0
14	0→20→6→0	66	4. 9
15	0→25→10→0	82	5. 0
Total	/	1101	70

3 MULTI-VEHICLE COORDINATED ROUTING AND SCHEDULING FOR SORTED WASTE

3.1 Model Establishment

Given that the single-vehicle model cannot fully cover the complex demands of waste sorting transportation in practice, this section introduces multi-vehicle type coordinated scheduling. Considering the actual collection and transportation scenario:each type of waste needs to be transported by a dedicated vehicle, and the types and quantities of waste generated at different collection points vary. This paper combines the constraints of various transport vehicles in terms of load capacity, volume, and number of vehicles, and establishes a mixed-integer programming model with the objective of minimizing the total transportation cost. The model is specifically defined as follows:

$$x_{ijt}=\begin{cases}1,\text{Vehicle t travels from collection point i to collection point j}\\0,\text{other}\end{cases} \tag{10}$$

Objective function:minimize the total daily transportation cost.

$$MinP=\sum_{k=1}^{4}C_k\sum_{i=0}^{N}\sum_{j=0}^{N}\sum_{t=1}^{T_k}d_{ij}x_{ijt} \tag{11}$$

Among them, C represents the vehicle distance cost.
Actual parameter constraints:
Waste treatment plant flow constraint:All vehicles of each type depart from the waste treatment plant and return to the waste treatment plant after completing the collection of the same type of waste.

$$\sum_{t=1}^{T_k}\sum_{j=1}^{N} x_{0jt} = \sum_{t=1}^{T_k}\sum_{j=1}^{N} x_{j0t} = T_k (k=1,2,3,4) \tag{12}$$

Vehicle quantity constraint:The number of vehicles entering each collection point should be equal to the number of vehicles leaving it.

$$\sum_{i=1}^{N} x_{ijt} = \sum_{i=1}^{N} x_{jit} (t \in L, \forall j = 1,2,...,N) \tag{13}$$

Load capacity constraint:The waste carried by each type of vehicle cannot exceed its load capacity limit.

$$\sum_{i=0}^{N}\sum_{j=0}^{N} x_{ijt} w_{j,k} \le Q_k (t \in L, k = 1,2,3,4) \tag{14}$$

Collection frequency constraint:For each collection point, each different type of waste is collected only once per day.

$$\sum_{t=1}^{T_k}\sum_{i=0}^{N} x_{ijt} = 1(k = 1,2,3,4; j = 1,2,...,N) \tag{15}$$

Required number of vehicles constraint:For each waste type, the number of vehicles used cannot be less than the number of vehicles required to transport all waste of that type from all collection points in a single trip.

$$T_k \ge \left[\frac{\sum_{j=1}^{N}\sum_{k}^{4} w_{j,k}}{Q_k} \right] (T_k = 1,2,...,N) \tag{16}$$

Constraint on the sum of waste by type:The sum of all types of waste at each collection point equals the total waste at that collection point.

$$\sum_{k=1}^{4} w_{j,k} = w_j (j = 1,2,...,N) \tag{17}$$

Volume constraint:The volume of waste carried by each type of vehicle cannot exceed its volume capacity limit.

$$\sum_{i=0}^{N}\sum_{j=0}^{N} x_{ijt} v_{j,k} \le V_k (t \in L, k = 1,2,3,4) \tag{18}$$

where V represents the vehicle's volume capacity limit.

3.2 Model Solution

3.2.1 Solution algorithm design

To solve the multi-vehicle type coordinated scheduling model for sorted waste constructed above, this paper adopts PSO algorithm. Considering the independent nature that different types of waste must be collected by dedicated vehicles, the solution process of this model can essentially be decomposed into a set of sub-processes that optimize the transportation routes for the four types of waste separately. To solve the multi-vehicle type/multi-compartment coordinated scheduling model for sorted waste constructed above, this paper adopts PSO algorithm. Chen Zhiwei et al. used the Non-dominated Sorting Genetic Algorithm II(NSGA-II) to solve the multi-objective optimization problem of waste sorting transportation[9], obtaining a Pareto optimal solution set under the dual objectives of cost and risk. This paper focuses on single-objective optimization, using the PSO algorithm combined with a greedy strategy for initialization, which achieves higher solution efficiency and is more suitable for the route optimization scenario in this study.

Compared with the route planning problem for a single vehicle type, the model in this section introduces multiple complex constraints. These newly added constraints require that during the algorithm iteration process, the legality of the route solutions must be dynamically checked. For example, the global load constraint needs to be refined and mapped to the load capacity limits of the four specific vehicle types, thereby ensuring that the generated scheduling scheme conforms to actual physical conditions.

To further improve the quality of the solution, this paper can draw on the variable neighborhood search strategy adopted by Zhou Luhui et al. [10], performing 2-opt, sequential insertion, and swap operations on the global optimal route after each iteration. If a better solution is generated, it is accepted. This method can effectively escape local optima and is particularly suitable for CVRP scenarios with strict load constraints.

3.2.2 Optimization results of kitchen waste collection and transportation routes

Based on the Python programming language, this paper implements the above PSO algorithm and performs the solution calculation. The optimized route results for kitchen waste collection and transportation planning are shown in Figure 3:

According to the simulation results, the minimum total transportation cost to complete the collection and transportation of kitchen waste from all collection points is 1065. 00 yuan. To meet this scheduling plan, a total of 5 dedicated kitchen waste transport vehicles are required. The specific route plans for each vehicle are as follows:

Vehicle 1 is responsible for collecting from collection points No. 1, 4, 13, 14, 20, and 29. Its specific route is:[0, 1, 4, 14,

20, 29, 13, 0].
Vehicle 2 is responsible for collecting from collection points No. 3, 12, 16, 19, and 28. Its specific route is:[0, 12, 28, 3, 19, 16, 0].
Vehicle 3 is responsible for collecting from collection points No. 8, 11, 15, 18, 24, and 27. Its specific route is:[0, 11, 15, 27, 24, 8, 18, 0].
Vehicle 4 is responsible for collecting from collection points No. 6, 9, 21, 22, 25, and 26. Its specific route is:[0, 25, 9, 22, 26, 21, 6, 0].
Vehicle 5 is responsible for collecting from collection points No. 2, 5, 7, 10, 17, 23, and 30. Its specific route is:[0, 10, 5, 23, 17, 7, 30, 2, 0].

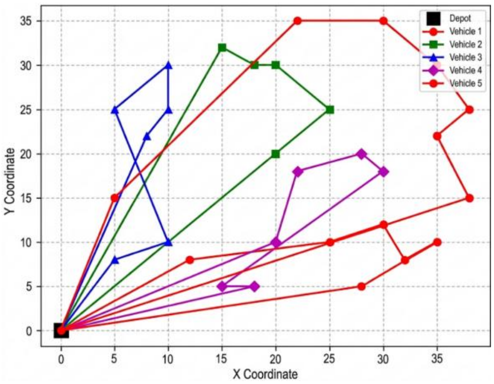

Figure 3 Optimal Collection and Transportation Route for Kitchen Waste Dedicated Vehicles

3.2.3 Optimization results of recyclable waste collection and transportation routes

The optimized route results for recyclable waste collection and transportation planning are shown in Figure 4:

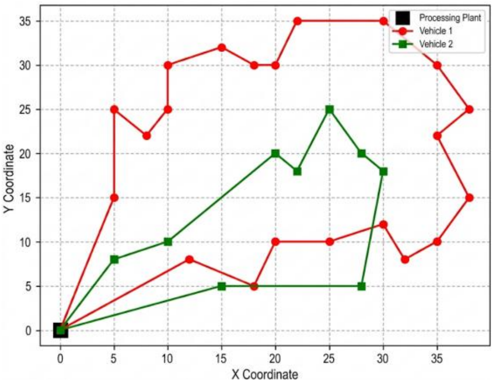

Figure 4 Optimal Collection and Transportation Route for Recyclable Waste Dedicated Vehicles

According to the simulation results, the minimum total transportation cost to complete the collection and transportation of recyclable waste from all collection points is 456. 00 yuan. To meet this scheduling plan, a total of 2 dedicated recyclable waste transport vehicles are required. The specific route plans for each vehicle are as follows:
Vehicle 1 is responsible for collecting from collection points No. 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 14, 17, 18, 20, 23, 24, 25, 27, 28, 29, and 30. Its specific route is:[0, 1, 6, 25, 4, 14, 20, 29, 10, 5, 23, 17, 7, 30, 3, 28, 12, 24, 8, 18, 27, 2, 0].
Vehicle 2 is responsible for collecting from collection points No. 9, 11, 13, 15, 16, 19, 21, 22, and 26. Its specific route is:[0, 11, 15, 16, 9, 19, 22, 26, 13, 21, 0].

3.2.4 Optimization results of hazardous waste collection and transportation routes

The optimized route results for hazardous waste collection and transportation planning are shown in Figure 5:

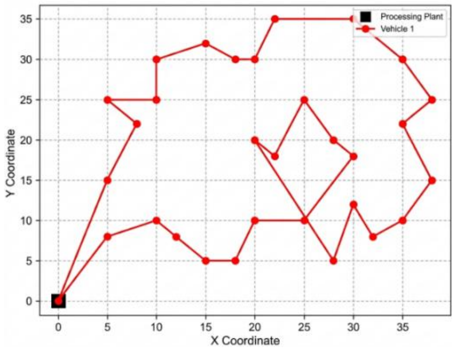

Figure 5 Optimal Collection and Transportation Route for Hazardous Waste Dedicated Vehicles

According to the simulation results, the minimum total transportation cost to complete the collection and transportation of hazardous waste from all collection points is 940. 00 yuan. To meet this scheduling plan, a total of 1 dedicated hazardous waste transport vehicle is required. The specific route plan for the vehicle is:[0, 11, 15, 1, 21, 6, 25, 4, 26, 22, 19, 9, 16, 13, 14, 20, 29, 10, 5, 23, 17, 7, 30, 3, 28, 12, 24, 8, 27, 18, 2, 0].

3.2.5 Optimization results of other waste collection and transportation routes

The optimized route results for other waste collection and transportation planning are shown in Figure 6:

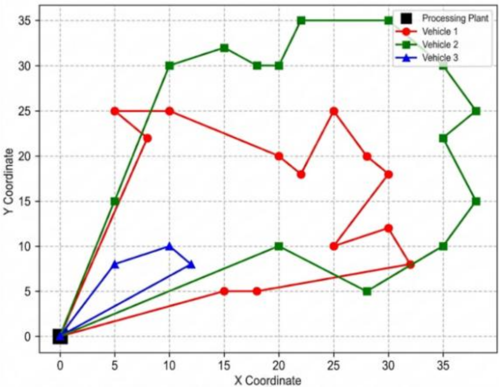

Figure 6 Optimal Collection and Transportation Route for Other Waste Dedicated Vehicles

According to the simulation results, the minimum total transportation cost to complete the collection and transportation of other waste from all collection points is 408. 00 yuan. To meet this scheduling plan, a total of 3 dedicated other waste transport vehicles are required. The specific route plans for each vehicle are as follows:

Vehicle 1 is responsible for collecting from collection points No. 4, 6, 8, 9, 14, 16, 18, 19, 20, 21, 22, 26, and 27. Its specific route is:[0, 18, 27, 8, 16, 9, 19, 22, 26, 4, 14, 20, 6, 21, 0].

Vehicle 2 is responsible for collecting from collection points No. 2, 3, 5, 7, 10, 12, 13, 17, 23, 24, 25, 28, 29, and 30. Its specific route is:[0, 25, 13, 29, 10, 5, 23, 17, 7, 30, 3, 28, 12, 24, 2, 0].

Vehicle 3 is responsible for collecting from collection points No. 1, 11, and 15. Its specific route is:[0, 11, 15, 1, 0].

Combining the independent scheduling schemes for the above four types of waste, the global optimal solution of this model under the basic constraints is obtained. Substituting into the formula, the total daily transportation cost for all types of dedicated vehicles is 2, 869 yuan.

3.3 Model Extension Considering Maximum Travel Time Constraint

In the basic model above, the working hours of a single vehicle are not limited. However, in actual sanitation operations, due to constraints such as the driver's working time, road traffic conditions, and the actual operating condition of the vehicle, there is usually a strict upper limit on the continuous daily travel time of a single vehicle. Therefore, it is necessary to introduce a"maximum daily travel time per vehicle"constraint into the original model.

Let the maximum daily travel time per vehicle be H. Then the following formula must be satisfied,

$$\frac{\sum_{i=0}^{N}\sum_{j=0}^{N} x_{ijt} d_{ij}}{40km/h} \le H(t \in L) \tag{19}$$

To verify the feasibility of the scheduling scheme derived above under time constraints, this paper takes the most complex hazardous waste collection route operated by a single vehicle as an example for verification. This route traverses all collection points in the area, with the specific node sequence as follows:[0, 11, 15, 1, 21, 6, 25, 4, 26, 22, 19, 9, 16, 13, 14, 20, 29, 10, 5, 23, 17, 7, 30, 3, 28, 12, 24, 8, 27, 18, 2, 0]. Assuming a constant speed of 40 km/h, the single-trip travel distances between nodes and the cumulative distances for this vehicle are shown in Table 2 below:

Table 2 Cost of Hazardous Waste Collection and Transportation by a Single Vehicle under Maximum Travel Time Constraint

ID	Driving route	Route（km）	Total distance （km）	Cost(yuan)	Total cost(yuan)
1	0→11	9	188	45	940
2	11→15	5		25	
3	15→1	3		15	
4	1→21	4		20	
5	21→6	3		15	
…	…	…		…	
27	24→8	5		25	

28	8→27	5	25
29	27→18	4	20
30	18→2	8	40
31	2→0	16	80

Based on the average operating speed of 40 km/h set above, it can be deduced that the maximum theoretical daily travel distance for a single vehicle is limited to 40H. According to the calculation results in Table 2, the total travel distance of this vehicle for collecting all hazardous waste in the original scheduling scheme is 188 km, which is very likely to exceed the travel distance threshold. Therefore, after introducing the strict time constraint, the original hazardous waste collection and transportation network must be decoupled by region and the sub-routes must be split. Specifically, the system needs to increase the total number of vehicles deployed and reallocate the overall collection task through multi-vehicle coordinated operation.

“After introducing the maximum travel time constraint, how to reasonably arrange the tasks of a single vehicle to avoid overtime becomes critical. Fang Kan et al. added a latest delivery time constraint to their model and precisely handled the time window limit using a branch-and-price algorithm [11], providing a feasible modeling and solution path for the time constraint extension proposed in this section. ”

4 CONCLUSION

This paper investigates the route optimization and scheduling problem in urban waste sorting transportation. For the single-vehicle type scenario, a CVRP model aimed at minimizing the total daily travel distance is solved using a PSO algorithm initialized with a greedy strategy, achieving an optimal route of 1,101 km with 15 vehicles. To better align with real-world sanitation practices, the model is extended to multi-vehicle type coordinated scheduling under load, volume, and maximum travel time constraints. The decomposed PSO optimization yields a type-differentiated fleet allocation (5 kitchen, 2 recyclable, 1 hazardous, and 3 other waste vehicles) with a minimized daily transportation cost of 2,869 yuan. The primary contribution of this study lies in the formulation of a comprehensive mathematical model that accurately reflects the heterogeneous and independent characteristics of multi-category waste collection, bridging the gap between conventional Vehicle Routing Problems (VRP) and the practical demands of urban waste sorting. This research holds significant application value for urban sanitation management, providing a quantitative decision-making solution for optimizing fleet configuration, reducing operational expenditures, and enhancing logistics efficiency.

Despite the achieved results, this study still possesses certain limitations that warrant further investigation. First, the current optimization model relies on a single-objective approach centered on economic costs and travel distance. Future work should expand this into multi-objective optimization to concurrently account for environmental impacts, such as carbon emissions and weather conditions. Second, the assumption of a static and unobstructed road network ignores real-world traffic congestion; therefore, incorporating dynamic road conditions and time-varying travel speeds will significantly enhance the robustness of the scheduling scheme. Finally, although the greedy-initialized PSO algorithm demonstrates high solution efficiency, the integration of multiple intelligent algorithms—such as hybridizing PSO with local search operators or genetic algorithms—should be explored to further improve global search capabilities.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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