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The Study on Hybrid Scheduling Optimizing of Industrial Solid Waste Recycling Vehicle Routing with Time Window

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Abstract: Industrial Solid Waste Recycling Vehicle Routing problem with Time Window is studied. Based on the characteristics of industrial solid waste recycling and reusing, a vehicle hybrid scheduling optimization model is proposed. In which, Vehicle Routing problem with full load and Vehicle Routing problem with not-full load are combined. The sum of employed vehicle cost, travel cost, handling cost and time penalty cost for waiting or delaying is took as the objective function in the model. Two constraints of time window and maximal vehicle travel length are presented. Finally, an improved ant colony optimization algorithm is proposed for solving the problem. Dalian industrial solid waste recycling network is token as case to verify effective of the proposed model and algorithm. . The result shows that the proposed ant colony algorithm can search the satisfactory solution quickly and efficiently with small error and proposed model can save the number of employed vehicles and total cost.

Key words: Industrial solid waste, vehicle scheduling, hybrid scheduling optimizing, time window, ant colony algorithm

INTRODUCTION

Industrial solid waste is the solid waste produced in Industrial activity. In 2012, the production of industrial solid waste in China is about 19 times of urban garbage output, accounted for 94% of the total solid waste production, becoming the main form of solid waste. In the recycling economy of 21 century, how to achieve the industrial circular economy (Mbuligwe and Kaseva, 2006) attract a great number of scholars' attention and research. Industrial solid waste collection and transportation, as the important part of cycle economy, not only can effectively alleviate the resources and environment problems caused by the rapid economic growth, at the same time, it can increase the speed of industrial waste recycling, reduce the cost of recycling solution (Nuortio *et al*., 2006).

Theoretically, recycling of solid waste transportation problem belongs to optimization of the car scheduling problem in reverse logistics, foreign scholars separate the problem into route problem, scheduling problem and multipath traveling salesman problem. It is generally believed that it becomes a vehicle route problem when we only consider about spatial location arrangement vehicle routes, namely the VRP (Vehicle Routing Problem); Taking time into consideration is known as the Vehicle Scheduling Problem, namely the VSP (Vehicle Scheduling Problem). At present, the research on industrial waste recycling transportation or other wastes recycling transportation is less, such as (Kirca and Erkip, 1988; Ni-Bin and Lin, 1997) studied the waste recycling station location problem; Angelelli (2002) studied the periodic vehicle routing problem with transit; Lia *et al*. (2008) introduced fixed cost and minimize the total cost as objective function. They proposed waste recycling vehicle scheduling problem as a NP scheduling problem, then built the NP model of vehicle scheduling. Vu Tung and Pinnoi (2000) introduced constraint of the arrival time window problems on the basis of studies, pointing out that the waste collection vehicle scheduling should be problem of time window and vehicle loading and unloading of arrival time window constraints. Lv *et al*. (2005) studied the waste recycling logistics, such as the location-route problem. Dai and Huang (2010) studied the route optimization problem of hazardous waste. He and Mao (2007) studied the regional solid waste site-transportation optimization problems; Shi *et al*. (2010) studied the urban medical waste recycling and vehicle route problem. However, these may only used in waste recycling transportation research because they are not applicable to industrial solid waste recycling transport. For: (1) At present the base number of industrial solid waste processed in our country for one year is generally about more than ten tons, average hourly capacity can reach dozens of tons. But industrial solid waste recycling

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vehicles' capacity is about 15 tons by using large trucks, in order to guarantee the urban traffic flow. And most cities limit the passage time of these vehicles which only allows them to pass within a certain period of time. (2) Different from other waste characteristics, industrial solid waste produced from industrial enterprises and industrial zone, usually with the characteristics of large quantity or large scale and vehicles transport among waste and recycling companies for point-to-point line transportation. Due to production of point can't be the integer time of vehicle's capacity, the last car would appear to be non-full load when it returned back to recycling companies and that will waste the vehicle volume. Therefore, the vehicle scheduling problem of industrial solid wastes recycling transportation is problem with time window constraints, loaded with direct return and non-full loaded with cycle. And it is vehicle scheduling problem with mixed characteristics.

In order to avoid the volume of waste of non-full loaded transport vehicles, the article assumes that the transport vehicles will continue to visit other wastes generated points in the case of non-full, in addition. In order to ensure that the vehicle will not unlimited access to other points under the capacity limits, the article also introduce in the vehicle's mileage limit, that is, when the truck is not full load, vehicle return to recycling companies if the vehicle mileage reached the maximum. Based on the above statement, the study establish sum cost as objective function above the vehicles dispatch cost, transportation cost, handling cost and waiting cost for time window limit. And the study also construct the vehicle scheduling model of industrial solid waste recycling with time windows and mileage limit of vehicles load that combined full and non full load together. On the choice of methods, most scholars use the saving algorithm, the network flow algorithm, genetic algorithm and ant colony algorithm. Because the saving algorithm is not suitable for solving the problem of large-scale (Song *et al.*, 2006), network flow algorithm for determining the solution need to continue to get after modification, calculation is more complicated (Zhang and Tang, 2002) the genetic algorithm is mainly used in the location selection problem (Gao and Chen, 2005). So the study selects a model of ant colony algorithm, the algorithm on the vehicle optimization scheduling has been well applied, showing a good search performance (Yang and Gong, 2009). Finally, we provide an example to verify the validity of the model and algorithm.

PROBLEM DESCRIPTION AND MODEL ESTABLISHMENT

Industrial solid waste vehicle scheduling problem can be described as the recycling network that involves resources recycling enterprises, m cars and n recovery point. Recycling companies cover each collection point in the network and they have the same kind of vehicles, Vehicles scheduling network topology is shown in Fig. 1 which the transport vehicles return to recycling companies directly when a recycling point can meet the constrain of full load and if the transport vehicles can't load fully, then it will go to the next industrial collection until the truck load constrain or time window, path length restrictions is matched. In Fig.1, implementing line shows the full load vehicle routing, dashed lines show the non-full load vehicle routing.

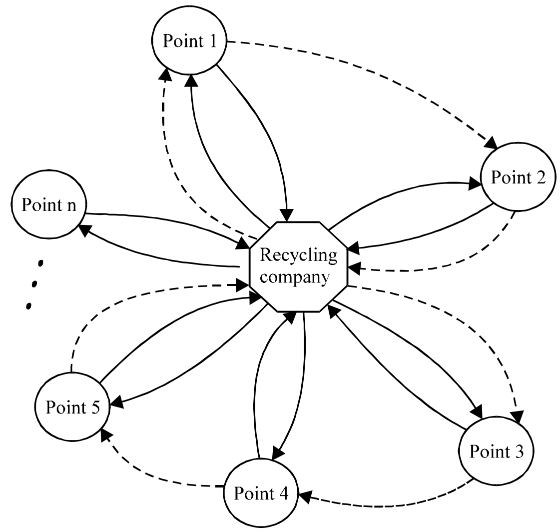

Fig. 1: Vehicles scheduling network topology for industrial wastes' recalling

In order to establish model, the study make the following assumptions: (1) The motion of the vehicle is limited by the vehicle mileage, service time and the load of vehicle capacity; (2) Vehicles start from recycling enterprise yard and after the transportation it must be returned to the recycling enterprise yard; (3) When production of recycling waste is bigger than the vehicle's capacity, the transportation of point-to-point is the priority arrangement, only in the case that the production of left waste is less than the vehicle's capacity, the vehicle will consider to transport non-full loaded and determine whether to continue to visit other points; (4) When the vehicle is fully loaded, it must be returned to the recycling companies, until it does not meet the constraint of mileage or service time; (5) when vehicles is not fully loaded, it can visit the next point according to the vehicle's capacity, or choose to return back to plant yard again after unloading for next visit. If it accesses to the next point directly, the vehicle capacity is recorded as last point. And if it returns back to the plant, vehicle capacity should be zero.

Symbols used in the article shows as follows: We assume that o stands for the recycling company, it has its own fleets which include the same vehicle type, industrial area covered by the company are represented by i(i = 1, 2, 4, …, n) and q_i stand for the total amount of waste generated. The dispatch cost of each vehicle is denoted by c_0 and the unit running cost of vehicles is denoted by c_1 and c_2 is the unit cost of loading and unloading operations and d_{ij} is the distance between the industrial zone i and industrial zone j, the number of fleet vehicles is m, the total vehicle trips departing from 0 is R, each vehicle's maximum load is Q, vehicle speed is v, each vehicle's allowable maximum distance as L. the time that vehicles reach the industrial area i is t_i, the operating time is s_i, the service time window is $[Et_i, LT_i]$, a is the allowable maximum value of time error, c_3 is the time window of out of service, but the cost of the unit should be bearded in the allowable error range penalty. The distance between two points is $d_{ij}(i, j = 0, 1, 2, \dots n)$, the transport time between two points is t_{ij}, the longest travel mileage of vehicles is L.

Decision variable $t^r_{ik}, x^r_{ijk}, y^r_{ik}$ are:

t^r_{ik} means the reaching time that trip r of vehicle k arrived at point i

$$x^r_{ijk} = \begin{cases} 1, \text{ the trip r of vehicle k travel from i to j} \\ 0, \text{ otherwise} \end{cases}$$

$$y^r_{ik} = \begin{cases} 1, \text{ the point i is served by the vehicle k's trip} \\ 0, \text{ otherwise} \end{cases}$$

The objective function is:

$$\begin{aligned} \min Z = c_0 \sum_{k=1}^{m} \sum_{j=1}^{n} x^1_{0jk} + \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{m} \sum_{r=1}^{R} c_1 d_{ij} x^r_{ijk} + c_2 \sum_{i=0}^{n} q_i \\ + \sum_{i=1}^{n} c_3 \left(\max\{(ET_i - t_i), 0\} + \max\{(t_i - LT_i), 0\} \right) \end{aligned} \quad (1)$$

s.t.:

$$\sum_{k=1}^{m} \sum_{r=1}^{R} y^r_{ik} = \begin{cases} \frac{q_i}{Q}, \text{ when } \frac{q_i}{Q} \text{ is integer} \\ [\frac{q_i}{Q}]+1, \text{ otherwise} \end{cases} \quad i = 1, 2, \dots, n \quad (2)$$

$$\sum_{i=0}^{n} x^r_{ijk} = \sum_{i=0}^{n} x^r_{jik} \quad ; \quad j = 1, 2, \dots n, \quad k = 1, 2, \dots m, \quad r = 1, 2, \dots R \quad (3)$$

$$\sum_{j=1}^{m} x^r_{0jk} \le 1; \quad k = 1, 2, \dots m, \quad r = 1, 2, \dots R \quad (4)$$

$$\sum_{i=0}^{m} x^r_{ijk} = 1; \quad j = 1, 2, \dots n, \quad k = 1, 2, \dots m, \quad r = 1, 2, \dots R \quad (5)$$

$$\sum_{i \in s} \sum_{j \in s} x^r_{ijk} \le |s| - 1; \quad k = 1, 2, \dots m, \quad r = 1, 2, \dots R \quad (6)$$

$$y^r_{ik} = \sum_{j=0}^{n} x^r_{jik}; \quad i = 1, 2, \dots n, \quad k = 1, 2, \dots m, \quad r = 1, 2, \dots R \quad (7)$$

$$t^r_{ik} = \sum_{j=0}^{n} x^r_{jik} \times (t^r_{jk} + s_j + t_{ji}); \quad i = 1, 2, \dots n, \quad k = 1, 2, \dots m, \quad r = 1, 2, \dots R \quad (8)$$

$$ET_i - a \le t^r_{ik} \le LT_i + a; \quad i = 1, 2, \dots n, \quad k = 1, 2, \dots m, \quad r = 1, 2, \dots R \quad (9)$$

$$\sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{r=1}^{R} x^r_{ijk} d_{ij} \le L; \quad k = 1, 2, \dots, m \quad (10)$$

Objective function (1) is set to minimize the whole cost to recycle, the first item related to dispatch cost, the second item related to transportation cost and the third item related to handling cost. The fourth item related to waiting cost for time window limit; Constraint (2) guarantee the actual service number of vehicles is equal to the number of cars that it needs and according to the insufficient approximation rule the number is rounded; Constraint (3) restricts for balance of in and out, ensures that the number of vehicle that arrive and departure from the point is the same car; Constraint (4) ensure that each car come from the recycling companies; Constraint (5) ensure that each node has one service path. Constraint (6) is a standard branch to eliminate constraints that works for customer collection of vehicle service route. Constraint (7) tells the relationship between the two decision variables; Constraint (8) is the arrival time of the trip r of vehicle k when it arrived point i; Constraint (9) is the time window constraints, when the vehicle arrives at industrial zone in the time window, or in the permissible time range of the vehicle can service for industrial zone, it can make the service; Constraint (10) ensure that each vehicle road length can not exceed the maximum permissible distance L.

THE DESIGN AND IMPLEMENTATION OF ANT COLONY ALGORITHM

Assuming the number of ants in the ant colony algorithm is m, the maximum number of iterations is

NcMax, $b_i(t)$ stands for the number of ants in time t of demand point i:

$$m = \sum_{i=1}^{N} b_i(t)$$

Vehicle scheduling algorithms require two steps: Firstly, the set of points satisfying the constraints should be found before selecting the access point; secondly, points that meet probability conditions can be visited based on the previously selected set of points:

$$p_{ij}^k(t) = \begin{cases} \dfrac{[\tau_{ij}]^\alpha [\eta_{ij}]^\beta}{\sum_{j \notin tabuk} [\tau_{ij}]^\alpha [\eta_{ij}]^\beta}, j \notin tabuk \\ 0, \text{otherwise} \end{cases} \quad (11)$$

τ_{ij} Stands for the residual pheromone in the connection e(i, j) of demand points i and j in time t. In the initial time, pheromone τ_{ij} = C and C is a constant; in the process of motion, the updated formula is:

$$\tau_{ij}(t+1) = (1-\rho) \times \tau_{ij}(t) + \Delta\tau \quad (12)$$

$$\Delta\tau = \sum_{k=1}^{m} \Delta\tau_{ij}^k \quad (13)$$

$$\Delta\tau_{ij}^k = \begin{cases} \dfrac{Q}{L_k} & \text{the ant k goes through e(i, j) in this circle} \\ 0 & \text{otherwise} \end{cases} \quad (14)$$

In the formula, ρ is the residual factor pheromone, $0 \le \rho \le 1$; $\Delta\tau_{ij}^k$ stands for the pheromone that the ant k left in the side of path e(i, j) of this cycle (Δt time); Δτ indicates the sum of pheromone that all of the m ants left in the side of path e(i, j) of this cycle (Ät time); Q is a constant; η_{ij} is a heuristic function, its expression is:

$$\eta_{ij}(t) = \frac{1}{d_{ij}}$$

tabuk denotes the taboo tables of ant k which records the demand points that the ant k has gone through; α, β is variable.

When selecting the path, the roulette strategy is used to generate the current point to meet the requirements of each point's probability (p_1, p_2, ..., p_n), then calculating the cumulative probability (pp_1, pp_2, ..., pp_n):

$$pp_i = \sum_{j=1}^{i} p_j$$

generating a random number, if the random number can meet r>0 and $r \le pp_1$, the first individual will be selected; if $r > pp_i$ and $r \le pp_{i+1}$, then the individual i +1 will be selected. When the pheromone updates, based on the total recovery cost the ants' touring path, including its transport costs, handling costs, soft time windows penalty fees, etc., the pheromone updates according different feasible path constructed by the ants, during the process of updating, the total cost will be compared with the optimal solution currently, the pheromone evaporation relates to the size of costs. This algorithm designed in this study is as follows:

- **Step 1:** Initialize each parameter Q, ρ, α, β dynamically, setting the maximum number of cycles NcMax, calculating τ_{ij} and η_{ij}, then deposited them in the appropriate array
- **Step 2:** The number of iterations has been set by Nc, judging whether Nc <= NcMax, if so, then Ant = 0, turning to Step 3, end the task
- **Step 3:** The number of ants which are already visited is Ant, determining whether Ant <= m and if so, calculating the next step, otherwise turning to Step 9
- **Step 4:** Putting the m ants on the initial point (recycling business) and the initial point should be stored in the current solutions
- **Step 5:** For each ant, selecting randomly any optional node in addition to the current solutions stored in the current solutions
- **Step 6:** For each ant, transition probabilities should be calculated, using the roulette method, combining with the constraints of vehicles' capacity, time window and the path length, then the next node should be selected to place in the current solutions; if the next node can't be found, then returning to the recycling business
- **Step 7:** Repeat step 5 and step 6, until all the nodes are visited by ants or the ant is constrained by conditions, when there are constraints, if the ants are constrained by the time window and the path length, then returning to the initial point directly and stopping the ant's task; if ants are constrained by vehicles' capacity, then the ants return to the initial point, after emptying the capacity, step 7 will be repeated, until all the nodes are visited or constrained by the time window and the path length.Every ant can get a loop starting with an initial point and ending with the same one
- **Step 8:** Iterating the number of ants Ant+1 and returning to step 3
- **Step 9:** Saving the shortest path of iteration, minimum cost and other information
- **Step10:** Emptying the taboo list and returning to step 2

ANALYSIS OF EXAMPLES

In Dalian of northeast Liaoning province, the study takes the industrial solid waste recycling system as an example. The system involves an industrial solid waste recycling company and 12 industrial zones and each industrial zone is regarded as a recycling point. By using Google earth the study locates the coordinates of different zones and after researching industrial solid waste production of the collection points, all the related data are shown in Table 1. Among them, the operation time and time window limit between Recovery Company and recycling point are estimated in combination with experience and the survey data. Assuming that the distance between the nodes are expressed as:

$$d_{ij} = 1.3 \cdot \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

and the coordinates are expressed as: (x_i, y_i); The transport time between two points are expressed as:

$$t_{ij} = \frac{d_{ij}}{v}$$

v is the vehicle speed; Dispatch cost for unit vehicle is fixed as c_0 = 300;Unit mileage transportation cost is c_1 = 10; Handling operation cost is c_2 = 10; Unit penalty cost for time window is c_3 = 50; Permissible value of the maximum error of the time is shown as a = 2. The maximum of vehicle load is shown as Q = 30, driving route restrictions is L = 300.

To solving these problems, the ant colony algorithm program is operated on Matlab7.0. Set MaxNc = 200, AntNum = 100, through the test, take the Q = 1; ρ = 0.5; α = 1; β = 5.

The algorithm convergence is shown in Table 2. The total costs is 783250 and travel length is 65177.The worst of ten total costs is 785780 and corresponding travel length is 65387. The average of ten total cost is 784887, the average of ten travel length is 65234.2. The error is 0.2 and 0.11%, respectively which is rather small which can be ignored.

Figure 2 and 3 are the variation of the best total cost and best travel length with ant colony algorithm for the 7th running experiment. Seen from the Fig. 2, the algorithm is rather stable and the designed algorithm can get the optimal solution for the problem. Moreover, in the Fig. 3, we can see that the pheromone in ant colony algorithm update rather rational. Therefore, that the designed algorithm is stable and effective for solving such problems.

Figure 4 shows that the optimal scheduling scheme of recovery vehicle for the 7th running experiment. The number of employed vehicles is 84 and 24 routes are travelled. Table 3 shows the detailed route and arrival time of every vehicle.

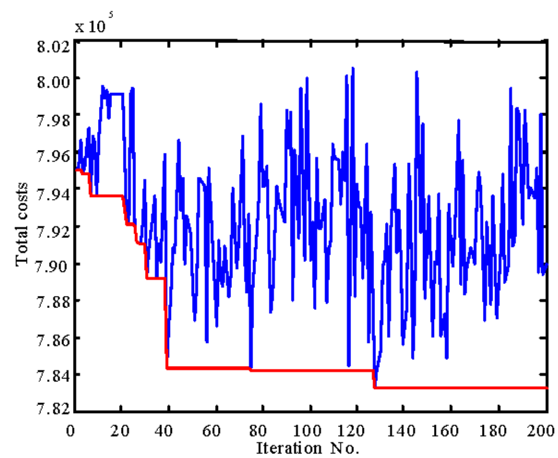

Fig. 2: The variation of the best total cost with ant colony algorithm for the 7th running experiment

Table 1: The related information of industry zone locations and time windows

No.	Industrial zone	Production (ton/day)	Location x	Location y	Working time (h)	Time window ET_i	Time window Lt_i
1	Recycling company	0	4364.10	-87.88	0	6.0	24
2	Bay	666.67	4362.35	-88.50	0.9	6.0	10
3	Changing island	1416.67	4386.58	-132.41	1.2	7.0	16.5
4	Dengsha river	1444.44	4344.29	-81.51	0.8	6.0	11.5
5	Huayuankou	1416.67	4396.14	-1.07	1.5	8.0	15.0
6	Wafangdian	416.67	4386.29	-91.66	0.5	6.0	16.5
7	Yingchengzi	277.78	4317.49	-142.36	1	7.5	16.5
8	Lvshun	833.33	4299.49	-151.54	0.5	7.5	14.5
9	Shuangdaowan	166.67	4304.28	-160.06	2	8.0	14.0
10	Sanshilibao	1527.78	4355.95	109.27	1.2	10.0	20.0
11	Piyanglu island	805.56	4363.07	-56.33	1.8	6.0	15.5
12	Songmu island	1027.78	4363.54	-137.36	0.6	7.0	15.0
13	The north sea economic development zone 16.5		277.78	4324.76	-113.50	0.8	7 . 0

Table 2: The experimental result after running 10 times

No.	Total cost	Travel length
1	7.8524×105	6.5286×104
2	7.8532×105	6.5184×104
3	7.8490×105	6.5242×104
4	7.8550×105	6.5332×104
5	7.8442×105	6.5057×104
6	7.8459×105	6.5362×104
7	7.8325×10^5	6.5177×10^4
8	7.8472×10^5	6.5154×10^4
9	7.8515×10^5	6.5387×10^4
10	7.8578×10^5	6.5161×10^4
Average	7.8489×10^5	6.5234×10^4

Table 3: Detailed route and arrival time of every vehicle

Vehicle 1-5	Route	1-2-1-4-1-12-1-3-1-10-1
	Arrival time	6.00-6.05-6.14-6.67-7.24-8.52-9.83-11.12-12.45-17.58-22.73
Vehicle 6-15	Route	1-2-1-4-1-11-1-5-1-10-1
	Arrival time	6.00-6.04-6.14-6.68-7.24-8.06-8.94-11.35-13.79-18.92-24.07
Vehicle 16-22	Route	1-2-1-4-1-12-1-3-1-7-1-13-1
	Arrival time	6.00-6.04-6.14-6.68-7.24-8.52-9.83-11.12-12.45-14.31-16.28-17.50-18.81
Vehicle 23	Route	1-2-4-1-12-1-3-1-7-1-13-1
	Arrival time	6.00-6.04-6.56-7.11-8.40-9.71-11.00-12.33-14.19-16.16-17.38-18.69
Vehicle 24-32	Route	1-4-1-12-1-3-1-10-1
	Arrival time	6.00-6.54-7.10-8.39-9.69-10.99-12.31-17.44-22.60
Vehicle 33-43	Route	1-4-1-11-1-5-1-10-1
	Arrival time	6.00-6.54-7.10-7.92-8.81-11.21-13.65-18.78-23.93
Vehicle 44-56	Route	1-6-1-5-1-10-1
	Arrival time	6.00-6.59-7.21-9.61-12.05-17.18-22.33
Vehicle 57	Route	1-4-1-12-1-3-1-7-1-13-1
	Arrival time	6.00-6.54-7.10-8.39-9.69-10.99-12.31-14.17-16.15-17.37-18.67
Vehicle 58	Route	1-4-1-12-1-3-1-7-13-8-1
	Arrival time	6.00-6.54-7.10-8.39-9.69-10.99-12.31-14.17-14.97-16.18-18.55
Vehicle 59-61	Route	1-4-1-12-1-3-1-12-1-3-1-3-1
	Arrival time	6.00-6.54-7.10-8.39-9.69-10.99-12.31-13.60-14.90-16.20-17.52-18.82-20.14
Vehicle 62	Route	1-6-5-1-10-1
	Arrival time	6.00-6.59-8.99-11.40-16.53-21.68
Vehicle 63	Route	1-11-1-5-1-10-1
	Arrival time	6.00-6.82-7.71-10.11-12.55-17.68-22.84
Vehicle 64	Route	1-4-12-1-3-1-10-1
	Arrival time	6.00-6.54-8.08-9.38-10.68-12.00-17.13-22.28
Vehicle 65	Route	1-3-1-12-1-3-1-12-1-3-1
	Arrival time	6.00-7.30-8.62-9.91-11.21-12.51-13.83-15.12-16.42-17.72-19.04
Vehicle 66	Route	1-3-1-12-1-3-1-12-3-1-3-1
	Arrival time	6.00-7.30-8.62-9.91-11.21-12.51-13.83-15.12-15.74-17.05-18.34-19.67
Vehicle 67-68	Route	1-3-1-8-1-3-1-3-1
	Arrival time	6.00-7.30-8.62-10.98-13.35-14.65-15.97-17.27-18.59
Vehicle 69	Route	1-11-1-5-1-3-1-11-1-11-1
	Arrival time	6.00-6.82-7.71-10.11-12.55-13.85-15.17-15.99-16.88-17.70-18.59
Vehicle 70	Route	1-11-1-5-1-11-5-1
	Arrival time	6.00-6.82-7.71-10.11-12.55-13.37-15.10-17.51
Vehicle 71	Route	1-8-1-9-1-8-1
	Arrival time	6.00-8.36-10.73-13.17-15.97-18.33-20.70
Vehicle 72-75	Route	1-5-1-9-1-8-1
	Arrival time	6.00-8.41-10.84-13.28-16.08-18.44-20.81
Vehicle 76	Route	1-5-1-9-8-1-8-1
	Arrival time	6.00-8.41-10.84-13.28-13.73-16.10-18.46-20.84
Vehicle 77	Route	1-5-1-5-1-5-1
	Arrival time	6.00-8.41-10.84-13.25-15.69-18.09-20.53
Vehicle 78	Route	1-5-1-5-1
	Arrival time	6.00-8.41-10.84-13.25-15.69
Vehicle 79-84	Route	1-8-1-8-1-8-1
	Arrival time	6.00-8.36-10.73-13.09-15.47-17.83-20.20

Cost before and after optimization scheduling is presented in Table 4. Before the optimization, the scheme indicates that fixed employed vehicles for each collection points on astraight-there-and-back- again route. The number of employed vehicles is 349, the cost of employed vehicles is 104700, travel cost is 653892.6, handling cost is 102778 and time penalty cost is 0, the total cost is 861370.6. After the optimization, the number of employed

Table 4: The comparison before and after optimization

Costs	Vehicle Num	Total	Dispatch	Travel	Handling	Delay
Traditional	349	861370.6	104700	653892.6	102778	0
Optimization	84	783251.2	25200	651773.2	102778	3500
Save	265	78119.4	79500	2119.4	0	-3500

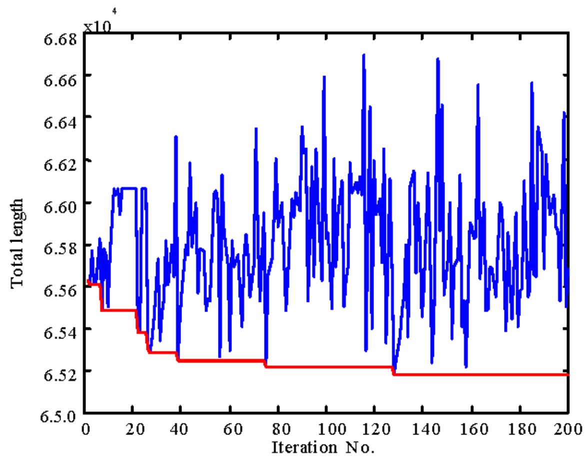

Fig. 3: The variation of the best travel length with ant colony algorithm for the 7th running experim

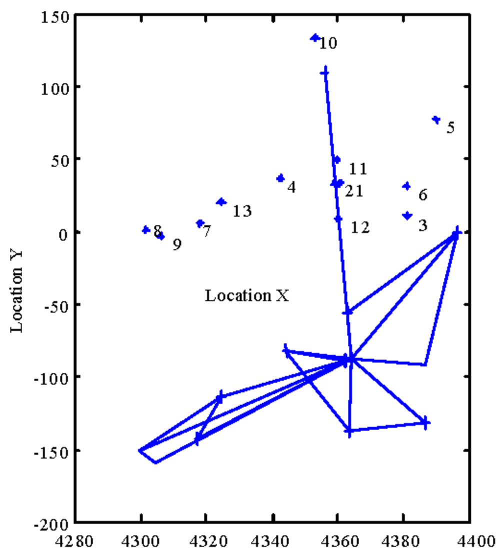

Fig. 4: The optimal scheduling scheme of recovery vehicle for the 7th running experiment

vehicles is 84, the cost of employed vehicles is 25200, travel cost is 651773.2, handling costs is 102778, time penalty cost is 3500 and the total cost is 783251.2. The number of employed vehicles reduces about 265, the cost of employed vehicles falls by 79500, travel cost reduces about 2119.4,and the total cost decreases by 78119.4. The reason for decreasing is the decreasing amplitude of cost of employed vehicles and travel cost is bigger than the growth of the time penalty cost. Thus, the established model is effective.

CONCLUSIONS

The study shows: (1) the article analyzes the transportation characteristics of industrial solid waste recycling. Considering the constraints of vehicles arrival time and the total time for handling, conditions of non-full load combined with full load of total operation time limit of recovery that vehicles take can be converted to total mileage limit. The established model is suitable for solving vehicle scheduling optimization problem of industrial solid waste recycling after introducing the vehicle dispatch cost, transportation cost, handling cost and time penalty cost as the objection function. After optimization, the number of vehicles needed and transportation cost reduced significantly. At the same time, time penalty cost increase and the handling cost remains the same. (2) the results error and operation time of the proposed ant colony algorithm is small after running 10 time which shows that the algorithm can search the satisfactory solution quickly and efficiently and it is an effective algorithm to solve the problem.

Based on the above conclusions, the article has obtained the following results: (1) The study enrich the theory research about VRP, VSP and it provides solutions and cases for the hybrid vehicle scheduling problem that with time window constraint and different conditions of load; (2) it provides the theory basis for resource recycling enterprise to optimize the path, reduce logistics cost and it is also can be used for the government when planning to build the ecological industrial park or to promote the development of industrial circular economy.

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