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Research of Oil Product Secondary Distribution Optimization Based on Collaborative Distribution

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Abstract

During peak seasons, the petrol company's oil supply capacity is insufficient, therefore, with limited trucks, adjusting the distribution quantity of petrol station and formulating an effective distribution route can minimize the total cost and maximize the vehicle utilization. In this paper we observe the extension of the multi-depot half open vehicle routing problem with time windows (MDHOVRPTW) in oil product secondary distribution. Based on the characteristics of secondary distribution and MDHOVRPTW problem, this paper formulates oil distribution model intra-area with distribution quantity and distribution routing as decision variables. A proposed algorithm is applied to solve this model and result compared with the traditional non-cooperative method to verify the effectiveness of collaborative distribution.

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Keywords: Oil product secondary distribution, MDHOVRPTW, collaborative distribution;

1. Introduction

Secondary distribution is located at the end of oil product supply chain. It's the core link to improve logistics efficiency and reduce operation costs for oil enterprises. Tank truck scheduling is the key problem of secondary distribution, and it reflects the rationalization degree of secondary distribution. Distribution center needs to meet the demand of multiple petrol stations in time with limited vehicles. Choose the appropriate vehicle, make the most

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reasonable vehicle routing and ensure vehicle fully-loaded as soon as possible are crucial to reducing oil product distribution (OPD) costs, especially in the oil product sales season.

Secondary Distribution can be abstracted as vehicle routing problem (VRP). In addition to the complexity of VRP, it has the complexity of oil distribution as well which includes multiple yards, multiple warehouses, multiple products, multiple shipping spaces, multiple vehicle types, cargo stowage plan, return empty, carrying the load balance and nonlinear discontinuous cost function and so on.

Oil product distribution has high risk according to its liquidity and volatility. It has very strict technical requirements to its transportation facilities and needs special tank truck to be transported. In order to reduce the loss during secondary distribution, bin type large capacity tank truck is accepted. So far poor vehicle structure, lack of capacity, inefficient and unloaded ratio and some other problems make transport optimization unachievable. According to petrol stations' cycle demand rule, using large capacity tankers on the line back and forth to provide the same or different products can reduce the wastage of products and save distribution costs at the same time.

In general, in traditional oil distribution, different depots are responsible for petrol stations in different areas because of administrative division and distances. This distribution mechanism always leads to tension distribution tasks of some depots, whose day turns is much higher than its affordable range, and too low day turns and idle assets to some other depots. Thus, collaborative optimization distribution of multiple depots and multiple petrol stations in a relative large area can improve the average vehicle capacity utilization rate and decline delivery costs to a large extent.

Traveling salesman problem (TSP) and vehicle routing problem (VRP) are two more mature models in distribution optimization models up to now. Compared to TSP, VRP is more complex and more difficult to solve, but it fits the actuality better. Based on the secondary distribution characteristics, combined with multi-depot half open vehicle routing problem with time windows, this paper formulates oil distribution model intra-area with distribution quantity and distribution routing as decision variables. Genetic algorithm is applied to solve this model.

The rest of the paper is organized as follows. In section 2, literature review of oil secondary distribution is introduced briefly. In section 3, oil distribution problem is described in detail and the relevant mathematical model is formulated. Solution of the model and the suitable algorithm is put forward in section 4. In section 5, the specific experiment is conducted and compared with the traditional non-cooperative method. At last, the conclusions are drawn.

2. Literature review

Some studies have addressed various transportation routing and scheduling problems, with an emphasis on the petroleum products distribution problem. In this section, we present a brief review of the published literature dealing with these versions of petroleum products distribution problem.

Brandão et al. [2] developed a novel tabu search heuristic for the multi-trip vehicle routing and scheduling problem (MTVRSP) to tackle real distribution problems, considering most of the constraints that appear in practice. Jiang S et al. [5] developed a stochastic model for the combined location-inventory problem (LIP) in a single-product multi-depot oil distribution system. Wang Xuping et al. [6-7] studied the vehicle routing problem, in the first article, improved a mathematical model with time windows where a limited number of vehicles is given, designed a genetic algorithm and proved the validity of the algorithm by the experiments. In another one, to tackle the disruption caused by the requests of the customers in the logistics, a disruption recovery strategies and the methods of deviation measurement are given, which is the basis of the disruption management modeling for the vehicle routing problem. Boctor et al. [8] provided a mathematical formulation of the problem and proposes some construction, improvement and neighborhood search solution heuristics, with a set of benchmark problem instances is created in a way that reflects real-life situations and used to analyse the performance of the proposed heuristics. Surjandari et al. [12] proposed a kind of Petrol Station Replenishment Problem (PRSP) model with the multi-depot, multi-product, time windows and split deliveries and completed it by the Tabu Search algorithm (TS). Cornillier et al. [13] proposed a mathematical model that selects among a set of feasible trips, the subset that allows the delivery of all the demands while maximizing the overall daily net revenue. This heuristic outperforms a previously published solution method for the special case of only one depot. Izuno et al. [15] apply a column generation algorithm to present an optimal assignment of requests to a fleet of tankers, sequence of visiting places, and loading and unloading volume of demand simultaneously in order to minimize the total cost with the capacity of the tankers.

The present paper is slightly different from the above studies as it deals with the multi-depot version of the problem based on the collaborative distribution. In addition, two objectives are considered: to maximize the average vehicle capacity utilization rate， to minimize the transportation costs.

3. Problem statement and Mathematical model

3.1. Problem statement

Based on multi-depot half open vehicle routing problem and the features of oil product distribution, the research questions are described as follows:

In the season of oil, the petrol company's oil supply capacity is insufficient. And we assume that the distribution of daily oil product sales follows the $f(t)$ function. Every petrol station has an established distribution time window, a maximum and minimum distribution quantity ($q_{i\max}, q_{i\min}$). The maximum distribution quantity ($q_{i\max}$) is equal to the storage capacity of petrol station ($G_{i\max}$) minus the stock quantity when the tank truck arrives. The minimum distribution quantity ($q_{i\min}$) is the product of average daily sales times the contribution rate of petrol station. Distribution network is composed of N depots and M petrol stations, which is responsible for one kind of oil product distribution. A depot is a distribution center with limited numbers of tank trucks. Each truck has a work time constrain, the work beyond working hours need to be paid and overtime has a limit. Trucks start from depots and return to any petrol station of this area after completing all distribution tasks. Each truck can conduct oil supplement from any petrol station midway and this implies that vehicles can be reused in each delivery cycle to perform multiple tasks. In addition, considering the oil product distribution capabilities of the next period, we require the quantity of tank truck at each depot have a lower boundary, namely after completion of this period distribution, the number of tank trucks returned to the depot cannot under a certain standard.

Multi-depot half open vehicle routing problem with time windows and distribution quantity constrain aimed to minimize delivery costs and maximize the average vehicle capacity utilization rate. Namely under constrain of vehicle number, determine the distribution quantity and delivery routes to minimize delivery costs and maximize the average vehicle capacity utilization rate. According to the starting node in the process of oil tank truck driving, delivery routes can be divided into the following three categories: (1) from a depot to a petrol station; (2) from a petrol station to a petrol station; (3) from a petrol station to a depot.

To formulate the mathematical model, the assumptions are as follows:

1. In consideration of the vehicle purchase cost and the basic wage of driver in the normal working hours, vehicles have a fixed dispatch cost.
2. In distribution network, the location of the distribution center and customer is known, the distribution time window of petrol station is known.
3. Distribution trucks are homogeneous with the same maximum load and fuel consumption, regardless of the loading and unloading oil time.
4. Every vehicle should not load more than its maximum capacity at any time.
5. Each customer is served only once during single period, namely one distribution can satisfy customer's demand.

3.2. Mathematical model of collaborative distribution

A. Notation Description of the Model

The following notations will be used to formulate the problem considered in this paper.

Parameters:

N : A set of depots, $N\{\mathrm{n}\vert\mathrm{n}=1,2....,\vert\mathrm{N}\vert\}$;	M : A set of petrol stations, $M\{\mathrm{m}\vert\mathrm{m}=1,2....,\vert\mathrm{M}\vert\}$;
K : A set of tank trucks, $K\{k\vert k=1,2....,\vert\mathrm{K}\vert\}$;	a_i : The initial tank truck number of depot i , $\forall i\in N$;
b_i : The lower bound of vehicle quantity in depot i ;	d_{ij} : The distance between node i and node j ;
$[ET_i, LT_i]$: The time window of petrol station i , $i\in M$;	C : The tank truck cost in unit distance;
J : The upper bound of overtime;	r : The upper bound of truck regular working hours;
Q : The maximum capacity of each vehicle;	s : The drivers' overtime fee (per hour);
u_k : The overtime of vehicle k , $k\in K$;	V : The average speed of vehicle;
$W(T_{ik})$: Delivery time penalty function, $k\in K$, $i\in M$;	p : The average daily sales of the petrol station;
G_{i0} : The storage amount of petrol station i at initial time;	F : The fixed dispatch cost per vehicle;
g_i : The contribution rate of petrol station i to depot;	m_1 : The waiting cost;
m_2 : The cost for petrol station preference time window;	m_3 : The delay cost;
L_k : A set of total distribution routes by truck k , $L_i\{l\vert l=1,2....,\vert L_i\vert\}$;	
L : A set of total distribution routes, $\vert L\vert=\vert L_1\vert+\ldots\vert L_{\vert K\vert}\vert$;	
$CT_i\in[ET_i, LT_i]$: The preference time for unloading of petrol station i , $i\in M$;	
T_{ik} : The time vehicle k arriving petrol station i , $k\in K$, $i\in M$;	
t_{kl} : The initial time of the l th route by truck k , $k\in K$, $i\in N$.	

Decision variables:

x_{ij}^{kl} : binary that takes the value 1 if arc (i,j) belongs to the l th route of truck k , $i,j\in N\cup M$; $l\in L_k$;

q_i : The distribution quantity of petrol station i , $i\in M$.

B. Penalty function

Soft time windows can reflect the degree of customer's preference to time window. Considering the basic characteristic of the petrol station distribution time, we use the soft time windows to depict penalty function. The time window of petrol station is $[ET_i, LT_i]$, in which there is a preference time point $CT_i\in[ET_i, LT_i]$. When tank truck arrives during $[ET_i, CT_i]$, it won't produce penalty cost; when tank truck arrives during $[CT_i, LT_i]$, it will cause time window preference cost; if the arriving time is more than LT_i or less than ET_i , it will produce delay cost and waiting cost. The established penalty function is as follow:

$$W(T_{ik})=\begin{cases} m_1(ET_i-T_{ik}) & T_{ik}<ET_i \\ 0 & ET_i\leq T_{ik}<CT_i \\ m_2(T_{ik}-CT_i)\big/(LT_i-CT_i) & CT_i\leq T_{ik}<LT_i \\ m_3(T_{ik}-LT_i) & T_{ik}>LT_i \end{cases}$$

The mathematical model is:

$$Min\quad Z_1=\sum_{i\in N\cup M}\sum_{j\in N\cup M}\sum_{k\in K}\sum_{l\in L_k}x_{ij}^{kl}d_{ij}C+\sum_{k\in K}u_k s+\sum_{i\in M}\sum_{k\in K}W(T_{ik})+\sum_{i\in N}\sum_{j\in M}\sum_{k\in K}x_{ij}^{k1}F \tag{1}$$

$$Max\quad Z_2=\sum_{i\in N\cup M}\sum_{j\in M}\sum_{k\in K}\sum_{l\in L_k}x_{ij}^{kl}q_j\Big/\sum_{i\in N\cup M}\sum_{j\in M}\sum_{k\in K}\sum_{l\in L_k}x_{ij}^{kl}Q \tag{2}$$

$$\sum_{i\in N\cup M}\sum_{k\in K}x_{ij}^{kl}=\sum_{i\in N\cup M}\sum_{k\in K}x_{ji}^{kl}=1\qquad\forall j\in M,\ \forall l\in L_k \tag{3}$$

$$\sum_{i\in N\cup M}\sum_{j\in M}x_{ij}^{kl}q_j\leq Q\qquad\forall k\in K\ \forall l\in L_k \tag{4}$$

$$\sum_{i\in N}\sum_{j\in M}\sum_{l\in L_k} x_{ij}^{kl} = \sum_{i\in M}\sum_{j\in N}\sum_{l\in L_k} x_{ij}^{kl} \qquad \forall k\in K \tag{5}$$

$$T_{jk} = \sum_{k\in K}\sum_{i\in N}\sum_{l\in L_k}\left(t_{kl} + \frac{d_{ij}}{V}\right)x_{ij}^{kl} + \sum_{k\in K}\sum_{i\in M}\sum_{l\in L_k}\left(T_{ik} + \frac{d_{ij}}{V}\right)x_{ij}^{kl} \quad \forall j\in M \tag{6}$$

$$u_k = \max\left\{\max_{\forall i\in M}\left(T_{ik} + \sum_{j\in N} x_{ij}^{kl}\frac{d_{ij}}{V}\right) - t_{k1} - r,\ 0\right\}\ , \quad l = | L_k | \tag{7}$$

$$u_k \le J \tag{8}$$

$$\sum_{i\in N}\sum_{j\in M} x_{ij}^{kl} = \sum_{i\in M}\sum_{j\in N} x_{ij}^{kl} = 1 \qquad \forall k\in K, \forall l\in L_k \tag{9}$$

$$\sum_{i\in M}\sum_{k\in K} x_{ij}^{kl} \ge b_j \qquad \forall j\in N, l = | L_k | \tag{10}$$

$$\sum_{j\in M}\sum_{k\in K} x_{ij}^{kl} \le a_i \qquad \forall i\in N, l = 1 \tag{11}$$

$$q_j \in [q_{j\min}, q_{j\max}]\ \forall j\in M \tag{12}$$

$$x_{ij}^{kl}\ \ 1 - x_{ij}^{kl}\ \ = 0 \quad \forall i,j\in N\cup M, \forall k\in K, \forall l\in L_k \tag{13}$$

Where the objective function (1) is minimizing total cost which is composed of delivery cost, penalty cost, overtime cost and fixed dispatch cost; The objective function (2) is maximizing the average vehicle capacity utilization rate; Constrains (3) ensure that each petrol station is served only once; Constrain (4) represents that the total demand on a route cannot exceed vehicle capacity; Constrains (5) is flow conservation constrains that describe the individual routes; Constrains (6)-(8) define that the arrival time at petrol station i and the driver's overtime of vehicle k cannot exceed the upper bound; Constrains (9) state that each vehicle should leave and return to one depot; Constrains (10) and (11) ensure the vehicle number leave and return to depot i ; Constrains (12) represent the value range of decision variable q_i ; Constraint (13) ensures the decision variable which states the corresponding situation between vehicles and customer nodes.

4. Solution of the Model

The vehicle routing problem (VRP) has been studied by researches for many years. Recently VRP models have been more and more comprehensive and exact algorithms become fairly complex. Although exact algorithms can find optimal solutions for the model, it is merely suitable for relatively smaller problem. With the increase of problem scale, calculation time grow exponentially. Therefore heuristic solutions are much more effective to provide efficient results under larger VRP problem. Currently heuristic solutions for VRP include simulated annealing algorithm, Tabu search algorithm, genetic algorithm, ant colony algorithm et al. In this work, as genetic algorithm (GA) presents good performance in combination optimization problem, GA is chosen to solve oil product distribution (OPD) problem.

4.1. Lower and upper bound of distribution quantity

The upper bound of station i 's distribution quantity is:

$$q_{i\max} = G_{i\max} - \max(G_{i0}(i) - f(ET_i),\ 0) \tag{14}$$

The lower bound of station i 's distribution quantity is:

$$q_{i\min} = p\cdot g_i \tag{15}$$

Oil sale volume follows $f(t)$ distributed and p is the average daily sales. Time window of petrol station i is $[ET_i, LT_i]$. At start time, the stock of station i is G_{i0}. Maximal storage capacity of station i is $G_{i\max}$. Contribution rate of station i is g_i.

4.2. Proposed algorithms

In this work, we try to solve the OPD problem with GA and heuristic vehicle assigning algorithm proposed in [8]. Firstly, oil distributions and visiting sequence are constructed by GA. Secondly, visiting sequence is separated into several feasible trips. After that the trips are assigned to trucks based on heuristic algorithm in [8]. Lastly we choose efficient chromosome through crossover-mutation operation until the iteration termination.

A. Fitness function

The fitness function is formulated as follows:

$$F(X) = \frac{Z_2}{Z_1} = \frac{\sum_{i\in N\cup M}\sum_{j\in M}\sum_{k\in K}\sum_{l\in L_k} x_{ij}^{kl} q_j}{\left(\sum_{i\in N\cup M}\sum_{j\in M}\sum_{k\in K}\sum_{l\in L_k} x_{ij}^{kl} Q\right)\left(\sum_{i\in N\cup M}\sum_{j\in N\cup M}\sum_{k\in K}\sum_{l\in L_k} x_{ij}^{kl} d_{ij} C + \sum_{k\in K} u_k s + \sum_{i\in M}\sum_{k\in K} W(T_{ik}) + \sum_{i\in N}\sum_{j\in M}\sum_{k\in K} x_{ij}^{k1} F\right)} \tag{16}$$

Z_1 is minimal cost function and Z_2 is maximal vehicle capacity utilization rate. As we can see, larger $F(X)$ is, the greater probability the chromosome X evolves to the next generation.

B. Encoding

VRP with time window is a combination problem based on distribution order. In this work, we use the natural number coding method to improve search efficiency effectively. A chromosome, also called individual, contains several gene segments in which each segment consists of the same type of items.

As the OPD problem contains two decision variables, the chromosome contains two segments: distribution quantity sequence and visiting sequence. Suppose there are l petrol stations, the length of a chromosome is $2l$. Therefore a feasible chromosome encoding is $(i_{11}\ i_{12}\cdots i_{1l}\ , i_{21}\ i_{22}\cdots i_{2l})$. As we can see, depot sequence is not taken into account. Although depots can be used to separate trips, crossover-mutation operators would generate many illegal solutions. $(i_{11}\ i_{12}\cdots i_{1l})$ presents the quantity of each station and $(i_{21}\ i_{22}\cdots i_{2l})$ presents a feasible sequence of visiting station.

C. Decoding

Step1: Initialize an empty new route. Insert each gene of the chromosome $(i_{21}\ i_{22}\cdots i_{2l})$ into the new route.

Step2: Evaluate the capacities and distribution time of the new route.

Step3: If the capacities are full or the distribution time cannot meet time window constraint, construct one distribution route and initialize another new route. Else go back to Step 1, delete the gene from the chromosome.

Step 4: If there are no more gene in the chromosome, stop.

D. Assigning depot and vehicle

Through decoding process, feasible routes of each chromosome are generated. Furthermore, we should assign depots and vehicles to each route. Through shortest Euclidean distance approach, we choose the nearest depots from the starting point and ending point of each route. Vehicle assigning algorithms are based on the literature [8].

E. Crossover- mutation operation

As there are two segments of the chromosome, we choose single-point crossover operation and simple mutation operation to calculate the distribution quantity sequence segment, but for the visiting sequence segment, we use the partially matched crossover operation (PMX) and uniform mutation. It is worth noting that we should fix the crossover result based on the formulation as follows to avoid exceeding distribution quantity constraint.

$$i_{1k} = \begin{cases} i_{1k} & if \ i_{1k} \in \left[q_{k\min} \ \ q_{k\max} \right] \\ q_{k\min} & if \ i_{1k} < q_{k\min} \\ q_{k\max} & if \ i_{1k} > q_{k\max} \end{cases}$$

4.3. Algorithmic framework of the proposed algorithm

The general framework of the proposed algorithms is:

Repeat the following steps R times and retain the best solution obtained, and the value of the parameter R is chosen by the user.

Step1: Start with a randomly generated population of n (even number) $2l$-bit chromosomes (candidate solutions).

Step2: Calculate the fitness $F(X)$ of each chromosome X in the population. But before this, we must construct a set of optimal trips (a truck is only used in one trip) for each chromosome by using the proposed heuristics in literature [8] with limited tank trucks. At the same time, this optimal set must make sure the lower bound of vehicle quantity in each depot. Therefore, for each optimal set we must perform the following test and adjustment. Repeat the following steps until a feasible solution have been created:

Step2.1: Set $s_i = 0, \ \forall i \in N$, s_i is the number of truck returns to depot *i* when all tasks are finished. Check each trip in this set, if there is a trip return returns to depot i, set $s_i = s_i + 1$.

Step2.2: If $s_i \geq b_i, \ \forall i \in N$, it is a feasible solution, stop. Else, this solution is infeasible, let another second-best solution obtained by the heuristics in literature [8] replace it, and go to step 2.1.

Step3: Repeat the following steps until n offspring have been created:

Step3.1: Select a parent chromosome from the current population, and the probability of selection depend on the fitness function.

Step3.2: With probability p_c, for each pair use the corresponding crossover operation at a randomly chosen point to form two offspring.

Step3.3: Mutate the two offspring at each locus with probability p_m, and place the resulting chromosomes in the new population.

Step4: Replace the current population with the new population.

Step5: Go to step 2.

5. Computational results

5.1. Test instances

Our test instances data is generated from a real-life VRPTW with 100 customers and 10 depots. The original instance's depot is chosen as the oil depot and all the customers in this instance are chosen as the petrol-stations. Furthermore, the data of distance matrix and time window are unchanged, finally 40 customers and three depots (named as A, B, C) are chosen as our experimental instances.

we assume in the distribution network, the daily sales of the product oil is normal distribution, therefore, the bound of each petrol-station's delivery quantity can be obtained with the time window by formulas 14-15. We assume the number of the tank truck in each depot is 4, 1, 2 in initial time, and upon completion of all tasks, the lower boundary of tank truck at each depot is 1. In addition, the following parameters are used for all instances:

capacity of a truck is 60t; fixed dispatch cost is ¥400 per truck; average travel speed is 50 km per hour; variable travel costs is ¥3 per kilometer; regular working hours per day is 5 h; maximum overtime is 3 h per day; overtime hour wage is ¥30 per hour; start work time of any oil depot is 6 am; the waiting cost is ¥10 per hour; the cost for petrol station preference time window is ¥15 per hour; the delay cost is ¥30 per hour.

The algorithm was implemented in MATLAB 7.0 on a PC with a 2.66GHz CPU and 4GB RAM. First, the collaborative distribution model was solved using the algorithm proposed in section 4. Second, after we obtained an optimal solution, we solved this problem with non-cooperative based on the same delivery quantity. Finally, the comparison between the two transportation modes was given.

5.2. Results for the collaborative distribution model

The proposed algorithm in section 4 has been applied in this mode, for the reported result we used: $R = 200$, $n = 100$, $l = 40$, $p_c = 0.6$, $p_m = 0.01$, we can obtain a better solution when the iterations reached 171 times,Table1 presents the detailed results, and the corresponding abbreviations is as follows:

$D[i]$: The distribution quantity of petrol station i; $T[i]$: The time truck arriving petrol station i;
R: The distribution trip; Z1: Total cost;
Z2: The average vehicle capacity utilization rate; Z3: Total quantity of delivery;
Z4: Truck usage amount; Z5: Maximum overtime; Z6: Total working time;
U[A,B,C]: Truck number(from depot A, B, C); Y[A,B,C]:Truck number (return to depot A, B, C);

Table 1. The optimal distribution scheme.

Truck1	R	C—29—35—30—A—19—28—A	Z1: ¥10415.11 Z2: 0.82 Z3: 883 t Z4: 7 Z5: 9.85 h Z6: 44.85 h U[A,B,C]: [4,1,2] Y[A,B,C]: [3,3,1]
	D	D[29]=16 D[35]=22 D[30]=22 D[19]=19 D[28]=22	
	T	T[29]=6.72 T[35]=7.98 T[30]=8.51 T[19]=9.69 T[28]=10.82	
Truck2	R	A—38—32—8—C—37—5—B	
	D	D[38]=20 D[32]=22 D[8]=16 D[37]=24 D[5]=18	
	T	T[38]=7.2 T[32]=7.7 T[8]=8.67 T[37]=10 T[5]=10.75	
Truck3	R	A—9—27—25—A	
	D	D[9]=22 D[27]=16 D[25]=17	
	T	T[9]=6.94 T[27]=7.9 T[25]=9.3	
Truck4	R	A—3—18—4—C—34—6—A	
	D	D[3]=19 D[18]=20 D[4]=21 D[34]=32 D[6]=21	
	T	T[3]=6.56 T[18]=8.31 T[4]=10.26 T[34]=11.71 T[6]=12.57	
Truck5	R	B—21—16—40—C—13—39—B—7—12—B	
	D	D[21]=19 D[16]=26 D[40]=15 D[13]=21 D[39]=20 D[7]=30 D[12]=19	
	T	T[21]=6.82 T[16]=7.3 T[40]=8.79 T[13]=10 T[39]=10.64 T[7]=12.14 T[12]=13.44	
Truck6	R	C—22—11—C—20—17—C—33—24—15—C	
	D	D[22]=32 D[11]=23 D[20]=35 D[17]=17 D[33]=21 D[24]=18 D[15]=16	
	T	T[22]=6.4 T[11]=6.75 T[20]=7.92 T[17]=8.46 T[33]=10.42 T[24]=11.16 T[15]=12.22	
Truck7	R	A—10—14—B—31—B—2—B—23—36—A—26—1—B	
	D	D[10]=23 D[14]=19 D[31]=31 D[2]=33 D[23]=29 D[36]=16 D[26]=16 D[1]=35	
	T	T[10]= 6.6 T[14]=6.98 T[31]=8 T[2]=8.95 T[23]= 10 T[36]=10.66 T[26]=12T[1]=14.5	

Table1 presents the results that all available trucks (7 tank trucks) are used, and each truck from a depot can back to any depots after completing all tasks as long as the truck return number is greater than or equal to 1. In addition, during the distribution, each truck can conduct oil supplement from any petrol stations. For example, the distribution trip of truck 2 is A—38—32—8—C—37—5—B, it implies that this truck have two distribution tasks. First, the truck starts at depot A with the quantity 20, 22 and 26 to the corresponding petrol stations marked as 38, 32 and 8. After that, it conducts oil supplement in depot C, and continues the tasks for petrol station 37 and 5 with the quantity 24 and 18 immediately, finally, truck 2 comes back to depot B. The arrival time of each petrol station is 7.2, 7.7, 8.67, 10 and 10.75. Truck number return to depot A, B, C is 3, 3 and 1.

5.3. *Optimization distribution with non-cooperative*

In order to verify the feasibility of regional collaborative delivery, traditional delivery was used based on the distribution quantity obtained by the above model. And related results could be obtained.

First of all, the monolithic deliver region need to be divided to simulate the reality, therefore, according to the petrol station and depot location coordinates, through the k means clustering algorithm, finally, each depot is just responsible for a part of those petrol stations, which implies that each truck must leave and return to a same depot, and only service for the petrol stations in this region.

The proposed algorithm in section 4 is also used to solve this problem except that we should do three modifications as follows:

First, distribution quantity sequence of each chromosome must be always same as the corresponding optimal delivery quantity obtained by the above model. Second, the step 2 is without the test and adjustment operation, and each truck only can leave and return to a corresponding depot. Thirdly, we assume that the number of the tank truck is unlimited, which makes sure that the problem can have a feasible solution.

We use this algorithm to optimize the distribution for each discrete region, and the optimization results in Table2 show that for the same delivery quantity, we need 9 trucks with total cost: ¥11664.244 and average vehicle capacity utilization rate: 0.90 to realize.

Table 2. The optimal distribution scheme with non-cooperative

Depot A	Truck 1	R	A—27—10—25—A	Z1：¥11664.244 Z2：0.90 Z3：883 t Z4：9 U[A,B,C]: [3,3,3] Y[A,B,C]: [3,3,3]
	Truck 2	R	A—35—12—19—A—3—14—28—A	
	Truck 3	R	A—36—9—30—A	
Depot B	Truck 1	R	B—7—13—B—23—31—B—21—39—B	
	Truck 2	R	B—1—24—B	
	Truck 3	R	B—16—2—40—37—5—B	
Depot C	Truck 1	R	C—11—4—15—C—20—17—C	
	Truck 2	R	C—8—26—38—C—32—22—C	
	Truck 3	R	C—18—34—C—6—29—33—C	

To compare the result from two kinds of distribution mode, firstly, the total cost of collaborative distribution (¥10415.11) is less than non-cooperative (¥11664.244), although the non-cooperative mode can obtain more optimal distribution in some local regions (eg. for the petrol station 1 and 24, the truck arrival time with cooperative mode is 14.5 and 11.16, however those nodes can be supplied more timely with the non-cooperative mode), and the local optimal does not represent the overall optimal, especially for some fringe nodes. Secondly, the average vehicle capacity utilization rate of collaborative distribution is 0.82 slightly lower than 0.90 obtained by non-cooperative mode, but within the regular working time, the collaborative distribution can obtain a higher time usage amount (35h). Thirdly, the collaborative distribution just uses 7 trucks and another one uses 9 to deliver the same quantity, which implies that the collaborative distribution just need part trucks and the rest can be used in other tasks, then the total revenue could be increased. Fourthly, collaborative distribution can strengthen the communication between oil depots and once an oil depot is out of supply, it can obtain timely supplement from the nearest oil depot which has extra inventory instead of the oil refinery.

Based on the optimal comparison of the two distribution modes, collaborative distribution can effectively reduce logistics cost of the entire distribution system, improve the efficiency of distribution, reduce the number of vehicles using.

6. Conclusion

This paper has studied optimization problem of oil product secondary distribution. A MDHOVRPTW-based collaborative distribution model has been established. A transportation assignment scheme in which cost and vehicle utilization can be optimized has been obtained by the proposed algorithm. In addition, a numerical example that includes 40 petrol stations and three oil depots is given to verify the effectiveness of algorithm and Collaborative distribution.

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