

Vehicle Routing Problem with Simultaneous Delivery and Pickup for Cold-chain Logistics

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Abstract — In View of the vehicle routing problem with simultaneous delivery and pickup (VRPSDP) for cold-chain logistics, this paper analyzed the cost structure of vehicle fixed cost, running cost, refrigerating cost and cold-chain goods deteriorating cost in the process of delivery and pickup. By minimizing the total cost and integrating the delivery and pickup operation in cold chain logistics, an optimization model of VRPSDP for cold-chain logistics with a single distribution center and multiple client nodes was established. A genetic algorithm was designed to solve the problem. The results of empirical analysis verify that the established model and its algorithms are feasible and effective.

Keywords—cold-chain logistics; simultaneous delivery and pickup; vehicle routing problem; genetic algorithm

I. INTRODUCTION

Distribution is an important link in cold-chain logistics. It takes over 80% of the time of cold-chain products transferred from manufacturers to final consumers. Vehicle Routing Problem with Simultaneous Delivery and Pickup (VRPSDP) in a closed-loop cold-chain logistics system has turned to be a key optimization decision issue in cold-chain product distribution so as to meet customers' service requirement, enhance the efficiency of cold-chain logistics distribution vehicles, and reduce the damage and cold-chain operation cost.

Dell'Amico et al decomposed the VRPSDP into a MP problem and a pricing problem through Dantzig-Wolfe decomposition approach, and solved the pricing problem by using dynamic programming state-space relaxation and dynamic programming respectively. Nicola et al solved the VRPSDP through neighborhood search, construction algorithm and taboo search respectively and provided numerical examples accordingly. Ai T. J. et al examined the VRPSDP on the basis of the known information of vehicle model standard configuration, distribution route maximum service time and client node delivery volume, and proposed a particle swarm optimization algorithm for solving it. Christos et al examined the results of the numerical example resolved by hybrid neighborhood search and taboo search respectively, showing

that these two algorithms both have high efficiency and quality when resolving the VRPSDP with about 50-400 client nodes. Subramanian et al developed the undirected and directed two-commodity flow formulations for VRPSDP and solved by branch-and-cut scheme, while the undirected two-commodity flow formulation obtaining consistently better results. Julia et al presented two mixed-integer linear model formulations for the VRPSDP, and resolved the model by domain-reducing preprocessing techniques and effective cutting planes.

The previous research major focuses on the VRPSDP at room temperature. However, the damage cost and cooling cost have not been considered in terms of the cold-chain logistics distribution. Therefore, this paper integrates the cold-chain delivery and pickup into each client node through analyzing the relevant costs in cold-chain distribution and accordingly establishes the cold-chain VRPSDP model, aiming at providing a valuable decision-making reference for cold-chain distribution.

II. PROBLEM DESCRIPTION

It is assumed that several sales terminals (client nodes) for cold-chain products are located within a city, with requirements for delivery and pickup in every delivery cycle. The distribution center dispatches several refrigerated trucks with certain loading capacity participating in the delivery and pickup services of sales terminals. In other words, cargos in distribution center are delivered to client nodes with delivery needs, and cargos in client nodes with return needs are brought back to distribution center to be handled. Once failed to meet the requirement of delivery and pickup or failed to meet the constraint of loading, vehicles would return to the distribution center, till meeting the demand of all customers. Each customer can only be served by one vehicle and by one time. The optimization goal is to discover the optimal route of the minimum delivery and pickup cost under the constraints of vehicle loading capacity while meeting the delivery and pickup requirements of all customers (See Figure 1):

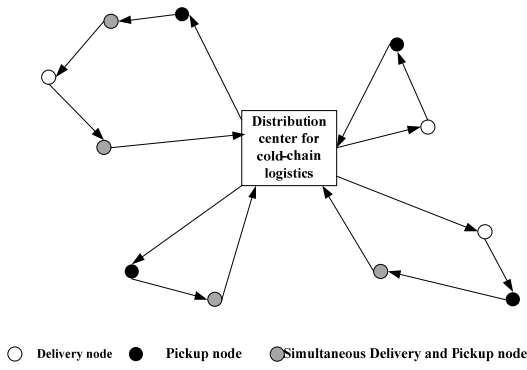


FIGURE 1. VRPSDP IN COLD CHAIN

According to Figure 1, we have the following hypotheses of VRPSDP for cold-chain logistics:

- Only a single original position, that is, a single distribution center for cold-chain logistics, all distribution vehicles departing from the original position and returning to the original position after completing mission;
- the cargos delivered to client nodes and recycled from client nodes can be mixed loaded;
- the demand (including delivery and pickup) in each client node is known;
- each client node should be served, and only be served once;
- the loading capacity of each distribution vehicle is equal and known;
- the specific location of each client node is known, i.e., the distances among nodes and between each node and distribution center are known;
- the delivery time among nodes and between each node and distribution center is known;
- one distribution vehicle can only serve one distribution route;
- all client nodes have the qualifications of simultaneous delivery and pickup;
- the shipment (delivery plus pickup) of a single customer cannot exceed the maximum load of the distribution vehicle.

III. MODEL DEVELOPMENT

This paper introduces the following symbols:

U : a collection of nodes, $U = \{i\}$, $i = 0$ suggests the distribution center for cold-chain logistics, $i = 1, 2, \dots, n$ is the client node;

R : a collection of client nodes, $U = R \cup \{0\}$;

V : a collection of distribution vehicles,
 $V = \{k\}, k = 1, 2, \dots, m$;

C : the travelling cost per unit distance of the distribution vehicle;

c : the value of unit cargo;

f_k : the fixed cost of distribution vehicle k ;

Q : the maximum load of the distribution vehicle;

d_{ij} : the distance between node i and j ;

t_{ij} : the vehicle travelling time between node i and j ;

t_i : the loading and unloading time in the client node i ;

α_1 : the cooling cost per unit time of refrigerated vehicles in travelling;

α_2 : the cooling cost per unit time of refrigerated vehicles in loading and unloading;

β_1 : the loss ratio per unit cargo per unit cargo in travelling;

β_2 : the loss ratio per unit cargo per unit cargo in loading and unloading;

p_i : the pickup (return) demand in client node i ;

q_i : the delivery demand in client node i ;

$X_{ij}^k =$

$$\begin{cases} 1, & \text{if the vehicle } k \text{ serves the directed arc } (i, j) \\ 0, & \text{if the vehicle } k \text{ does not serve the directed arc} \end{cases}$$

y_{ij}^k : the loading volume of distribution vehicle k in the directed arc (i, j) ;

Synthesizing the description of VRPSDP and the relevant cost of distribution for cold-chain logistics, the following optimization model can be established.

$$\min F(i, j, k) = C \cdot \sum_{i=0}^n \sum_{j=0}^n \sum_{k=1}^m d_{ij} \cdot x_{ij}^k + \alpha_1 \cdot \sum_{i=0}^n \sum_{j=0}^n \sum_{k=1}^m t_{ij} \cdot x_{ij}^k + \alpha_2 \cdot \sum_{j=0}^n \sum_{k=1}^m t_j \quad (1)$$

$$+ c \cdot \left(\beta_1 \cdot \sum_{i=0}^n \sum_{j=0}^n \sum_{k=1}^m t_{ij} \cdot y_{ij}^k \cdot x_{ij}^k + \beta_2 \cdot \sum_{j=0}^n \sum_{k=1}^m t_j \cdot (y_{ij}^k + p_j) \right) + \sum_{k=1}^m f_k$$

s.t.

$$\sum_{k=1}^m \sum_{i=0}^n x_{ij}^k = 1, \quad j \in R, i \neq j \quad (2)$$

$$y_{ij}^k \leq Q \cdot x_{ij}^k, \quad i, j \in U, k \in V, i \neq j \quad (3)$$

$$\sum_{j=1}^n y_{0j}^k = \sum_{i=0}^n \sum_{j=0}^n q_i \cdot x_{ij}^k, \quad i, j \in R, k \in V, i \neq j \quad (4)$$

$$\sum_{i=1}^n y_{i0}^k = \sum_{i=0}^n \sum_{j=0}^n p_i \cdot x_{ij}^k, \quad i, j \in R, k \in V, i \neq j \quad (5)$$

$$\sum_{i=0}^n y_{ij}^k + (p_i - q_i) \cdot \sum_{i=0}^n x_{ij}^k = \sum_{i=0}^n y_{ji}^k, \quad i, j \in R, k \in V, i \neq j \quad (6)$$

$$\sum_{j=1}^n y_{0j}^k \leq Q \cdot x_{0j}^k, \quad i, j \in R, k \in V, i \neq j \quad (7)$$

$$\sum_{i=1}^n y_{i0}^k \leq Q \cdot x_{i0}^k, \quad i, j \in R, k \in V, i \neq j \quad (8)$$

$$y_{ij}^k \geq 0, \quad i, j \in U, k \in V, i \neq j \quad (9)$$

$$p_i \geq 0, q_i \geq 0, Q > 0, \quad i \in R \quad (10)$$

In objective function (1), $\sum_{k=1}^m f_k z$ is the total fixed cost for m vehicles; $C \cdot \sum_{i=0}^n \sum_{j=0}^n \sum_{k=1}^m d_{ij} \cdot x_{ij}^k$ is the total travelling cost for distribution vehicles; $\sum_{i=0}^n \sum_{j=0}^n \sum_{k=1}^m \alpha_1 \cdot t_{ij} \cdot x_{ij}^k$ is the vehicle cooling cost; $\sum_{j=0}^n \sum_{k=1}^m \alpha_2 \cdot t_j$ is the extra cooling cost; $c \cdot \left((\beta_1 \cdot \sum_{i=0}^n \sum_{j=0}^n \sum_{k=1}^m t_{ij} \cdot y_{ij}^k \cdot x_{ij}^k + \beta_2 \cdot \sum_{j=0}^n \sum_{k=1}^m t_j \cdot (y_{ij}^k + p_j)) \right)$ is the cost of damage in cumulative delivering time for distribution and door-opening time for loading and unloading. Formula (2) suggests every client node should be served, and be served only once; Formula (3) suggests the loading volume of distribution vehicle in any node cannot exceed the its maximum loading capacity; Formula (4) suggests the loading volume of any distribution vehicle departed from distribution center should equal to the sum of the delivery demand in each node in the delivery route; Formula (5) suggests the loading volume of each distribution vehicle returning to distribution center should equal to the sum of the pickup demand in each node in the delivery route; Formula (6) suggests the loading

volume of distribution vehicles in any node should obey the identical equations of delivery demand and pickup demand in the node; Formula (7) suggests the loading volume of distribution vehicle departing from the distribution center cannot exceed its maximum loading capacity; Formula(8) suggests the loading volume of distribution vehicle returning to the distribution center cannot exceed its maximum loading capacity; Formula (9) suggests the loading volume of vehicle k from node i to node j should be positive; the constraint (10) suggests the pickup and delivery volume in any client node should be non-negative, and the maximum loading capacity of vehicles should be positive.

IV. ALGORITHM DESIGN

The above-established VRPSDP model for cold-chain logistics is a nonlinear programming model, therefore, genetic algorithm is used to resolve the model accordingly. Genetic algorithm is a kind of “creation + detection” iterative search algorithm, taking all individuals in the species as operation targets, each individual corresponding to a solution to the problem. Selection, crossover and mutation are the three major operations of it. This paper suggests the following procedure of genetic algorithm.

Step1: population initialization, population size: L , the length of chromosomes: n , the current generation: 0 ;

Step2: inserting the element “0” into each chromosome, calculating and marking the fitness value of individual chromosome;

Step3: selecting M chromosomes to enter the crossness-pools using Monte-Carlo selection policy;

Step4: crossover operation at the crossover probability P_c , the cross genes from the parent chromosomes form new chromosome and enter new population, and the non-crossed chromosomes directly enter the new population;

Step5: mutation operation at the mutation probability P_m , the mutated chromosomes, replacing the original chromosomes, enter the new population, and the non-mutated chromosomes directly enter the new population;

Step6: if the new generation of population astrings, then stop, else go Step2.

V. EXAMPLE ANALYSIS

This paper takes the cold-chain logistics of HX Co. Ltd. in each store in Zhengzhou as an example to examine the rationality of the model and the effectiveness of the algorithm. The number, geographical position, delivery and pickup demand and inventory time of distribution center and client nodes are shown in Table 1.

TABLE I. INFORMATION OF CLIENT GEOGRAPHICAL POSITION DEMAND AND INVENTORY TIME

No.	Client	Coordinate (X,Y)	Delivery (unit)	Pickup (unit)	Inventory time (minute)
0	Sinian Food distribution center	(0, 0)	0	0	0
1	New-mart (Guomao)	(1.2, -3.3)	72	12	15
2	New-mart (Jianshe Road)	(-5, -6.7)	65	23	20
3	New-mart (Jinboda)	(-0.4, -6.6)	34	0	15
4	Dennis department store (Renmin Road)	(0.7, -6.7)	23	9	17
5	Dennis department store (University Road)	(-2.1, -8.4)	41	14	22
6	Dennis department store (Fengle Road)	(-2.5, -2.7)	32	7	16
7	Dennis department store (Hanghai Road)	(6.6, -10.4)	25	20	18
8	Dennis department store (Renmin Road)	(1.2, -1.7)	62	24	20
9	CR Vanguard (Hanghai East Road)	(2.7, -10.7)	29	0	25
10	CR Vanguard (Songsan Road)	(-3.9, -8.8)	57	23	15
11	CR Vanguard (Hanghai West Road)	(-4.9, -10.6)	42	13	16

The values of the relevant parameters in the model are as followings: the maximum loading capacity of a refrigerated vehicle is 200 units; the fixed cost of a vehicle is $f_k = 150$ Yuan/time; the travelling cost per unit distance is $c = 2.5$ Yuan/kilometer; the value of per unit cargo is $c = 100$ Yuan/unit; the cooling cost per unit time of refrigerated vehicles in travelling is $\alpha_1 = 0.05$ Yuan/min; the extra cooling cost per unit time of refrigerated vehicles in loading and

unloading is $\alpha_2 = 0.1$ Yuan/min; the loss ratio per unit cargo per unit cargo in travelling is $\beta_1 = 0.0015$; the loss ratio per unit cargo per unit cargo in loading and unloading is $\beta_2 = 0.025$.

Considering the road conditions in the actual distribution, this paper adopts the actual data of distribution distance and time among client nodes acquired from the previous distribution of HX Logistics Co. Ltd. (See Table II)

TABLE II. DISTANCE MATRIX OF DISTRIBUTION NODES (UNIT: KM/MIN)

(d_{ij} / t_{ij})	0	1	2	3	4	5	6	7	8	9	10	11
0	(0/0)	(5.8/11)	(11.3/20)	(9.7/17)	(8.9/15)	(12/23)	(5.3/11)	(15.9/20)	(3.6/7)	(16.6/22)	(12.8/22)	(15.8/27)
1	(5.8/11)	(0/0)	(9/15)	(6.1/10)	(5.3/9)	(9.8/18)	(4.1/8)	(12.3/16)	(2.9/5)	(13/18)	(10.5/18)	(13.6/22)
2	(11.3/20)	(9/15)	(0/0)	(5.9/11)	(6.6/12)	(5.5/11)	(5.9/11)	(15.5/25)	(11.5/19)	(13/21)	(3.7/7)	(5.3/9)
3	(9.7/17)	(6.1/10)	(5.9/11)	(0/0)	(2.3/5)	(4.7/11)	(5.1/10)	(10.8/17)	(7.7/13)	(8.7/15)	(6.3/11)	(10/17)
4	(8.9/15)	(5.3/9)	(6.6/12)	(2.3/5)	(0/0)	(4.9/11)	(5.9/11)	(9.6/16)	(6.5/11)	(7.4/13)	(6/11)	(10.2/17)
5	(12/23)	(9.8/18)	(5.5/11)	(4.7/11)	(4.9/11)	(0/0)	(7.3/13)	(11.6/19)	(11.1/18)	(9/16)	(2.1/5)	(5.1/11)
6	(5.3/11)	(4.1/8)	(5.9/11)	(5.1/10)	(5.9/11)	(7.3/13)	(0/0)	(15.3/21)	(6.5/11)	(14.3/21)	(7.7/13)	(10.7/18)
7	(15.9/20)	(12.3/16)	(15.5/25)	(10.8/17)	(9.6/16)	(11.6/19)	(15.3/21)	(0/0)	(16.1/20)	(3.8/7)	(12.4/21)	(11.7/19)
8	(3.6/7)	(2.9/5)	(11.5/19)	(7.7/13)	(6.5/11)	(11.1/18)	(6.5/11)	(16.1/20)	(0/0)	(13.3/18)	(11.2/19)	(15.2/24)
9	(16.6/22)	(13/18)	(13/21)	(8.7/15)	(7.4/13)	(9/16)	(14.3/21)	(3.8/7)	(13.3/18)	(0/0)	(8.7/15)	(8/14)
10	(12.8/22)	(10.5/18)	(3.7/7)	(6.3/11)	(6/11)	(2.1/5)	(7.7/13)	(12.4/21)	(11.2/19)	(8.7/15)	(0/0)	(3/6)
11	(15.8/27)	(13.6/22)	(5.3/9)	(10/17)	(10.2/17)	(5.1/11)	(10.7/18)	(11.7/19)	(15.2/24)	(8/14)	(3/6)	(0/0)

According to the genetic algorithm designed in this paper, relevant parameters are set as followings: population size $N=200$, number of iterations $Gen=200$, crossover probability $P_c=0.85$, mutation probability $P_m=0.01$. The optimal delivery route can be get via Matlab2012a: $0 \rightarrow 2 \rightarrow 3 \rightarrow 7 \rightarrow 4 \rightarrow 11 \rightarrow 0$, $0 \rightarrow 8 \rightarrow 5 \rightarrow 10 \rightarrow 0$, $0 \rightarrow 1 \rightarrow 9 \rightarrow 6 \rightarrow 0$. The total distribution cost is 935.6Yuan, and the average distribution cost for each vehicle is 311.9Yuan.

The first ten iterations in the optimization process show a fast convergence rate, and the convergent curve declines

sharply, reaching the target value in the fiftieth generation. See Figure2 for the convergence process and the optimal arrangements of vehicle routing respectively.

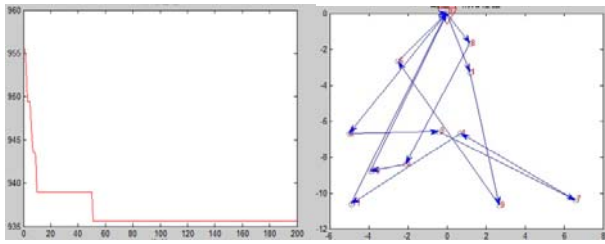


FIGURE II. CONVERGENCE PROCESS AND OPTIMAL ARRANGEMENTS OF VEHICLE ROUTING

VI. CONCLUSION

This paper studies the VRPSDP in the context of cold-chain logistics, analyzing the relevant cost in the distribution of cold-chain logistics, including vehicle fixed cost, vehicle travelling cost, cooling cost and loss cost, establishing the VRPSDP model for cold-chain logistics, total cost minimum as the goal, and accordingly designing genetic algorithm to solve the model. The actual distance and transportation time among client nodes, rather than the linear distances among coordinates, are collected in the numerical example to gain better accordance with practice. The results indicate that the VRPSDP model and the genetic algorithm designed in this paper would effectively get the optimal routes of distribution, reducing the distribution cost while improving the distribution efficiency, providing a reference, both theoretical and practical, for the systematic optimization of cold-chain distribution.

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