Research on The Vehicle Routing Problem with Simultaneous Pick-up and Delivery with Time Windows

Bo Wang

International Chinese College, MBA, Rangsit University, Pathum Thani, Thailand
Corresponding author, E-mail: bowang0722@163.com

Abstract

Vehicle Routing Problem refers to the vehicle routing problem, which is an important issue in the research of modern logistics management. It is the most important issue at present to effectively dispatch vehicles of logistics transportation in a limited time, to reasonably arrange the distribution routes and travel time, and to complete the distribution task with the minimum distribution cost. The pros and cons of the VRP scheme directly affect the customer's satisfaction and the logistics cost, which makes the VRP scheme becomes an important part of "the third profit source-logistics". By interviewing the employees of A Company, it is found out that the existing VRP in A Company has strict requirements for time window with simultaneous pick-up and delivery. Targeted at the existing problems, this paper makes an arrangement and analysis, and based on which a mathematical model is established. Furthermore, it makes an optimization of A Company's existing VRP scheme by using genetic algorithm. The optimized scheme obtained by the algorithm is compared with the existing scheme, The transportation cost of the enterprise is successfully reduced, while the profitability of the enterprise is improved, which verifies the validity of the mathematical model and algorithm.

Keywords: *VRP, Time Windows ,Genetic Algorithm*

1. Introduction

Logistics refers to the flowing process of the actual objects from the upstream supplier to the downstream receiver, which produces the logistics cost in the process of the flow of goods. Since the logistics cost accounts for part of the operation cost of the enterprise, the level of the operation cost directly affects the profitability of the enterprise. In order to effectively reduce logistics cost and optimize logistics distribution system, the study of VRP in logistics distribution system came into being. Moreover, because it has a strong practical application background in the academic world, the research of it has still been a hotspot.

VRP was first put forward by the western scholar (Min, 1989). At first, the factor that VRP once concerned was relatively single. However, with the diversification of transportation mode, the improvement of information, the popularization of punctuality and the increasing demand of customers, the vehicle routing problem with simultaneous pick-up and delivery and time windows came into being. Zhao-geng, Geng-jian, and Shi-dong (2006) generalized this kind of problem as Vehicle Routing Problem with Simultaneous Pick-up and Delivery with Time Windows(VRPSPDTW), and uses an improved genetic algorithm to solve it. Compared to the classic vehicle routing problem, the Vehicle Routing Problem with Time Windows(VRPTW) only considering the time window and the Vehicle Routing Problem with Simultaneous Pick-up and Delivery (VRPSPD) only considering the simultaneous pick-up and delivery, the problems that VRPSPDTW faced (with the time window and the simultaneous pick-up and delivery with the time window) is undoubtedly more complicated.

At present, most of the research on VRP remains constrained by the single condition, such as Fan, Liu, Xu, and Geng (2018) that only considers the time window when carrying out vehicle routing and Chun-lin, Chun-hua, and Hong (2008) that also only considered the issue of simultaneous delivery and pick-up, while the research on VRPSPDTW is relatively less concerned. Generally speaking, when companies optimize their vehicle routing, the VRPTW with time window will be taken into consideration. The enterprise that this paper chooses for research, that is, A Company, is different from the general enterprise in term of operation mode. When carrying on the routing optimization, it not only has to consider the time window, but also has to consider the pick-up and delivery operated in the supplier side, that is to say, the constraint condition is more complex.

VRPSPDTW is a more complex problem derived from the VRP problem, which adds such a condition that the customer needs to pick up and deliver at the same time compared with the VRPTW, and increases the requirement for the time window compared with the VRPSPD. Thus it makes the VRPSPDTW much more complex in computation than that of the former. On the one hand, it needs to consider the demand of the service point and the limitation of vehicle loading capacity; on the other hand, it needs to consider the limitation of delivery time. In the literature, this problem is often referred to as the simultaneous delivery and pick-up as well as the vehicle routing problem with time window. The VRPSPDTW problem is a difficulty for NP that has always been a hot topic in academic world. In general, such problems cover a lot and are much more difficult to solve under the different constraints and conditions in the actual operation.

Based on the actual situation of the A Company that the author explored, the VPRSPDTW in this paper is defined as follows: a set of trucks with the same model complete the scheduled transportation task, each delivery point is composed of delivery point and pick-up point and each delivery point has a time window limit. The delivery volume and the pick-up volume can be the same but not greater than the loading capacity of the vehicle. Each service point can only be served by one vehicle, that is, the relationship between the vehicle and the service point is one-to-many.

2. Objectives

This paper aims to make an optimized vehicle transportation scheme from the point of view of VRPSPDTW by constructing a mathematical model and designing an optimized routing algorithm under the premise of meeting the needs of customers. On this basis, it contributes to make the total transportation cost minimized, thus enriching the research and application of relevant theories.

3. Materials and Methods

3.1 Vehicle Routing Problem

This paper takes A Company as the research object. In the context of the actual business of the company, it makes an exploration of the VRPSPDTW problem. It has its own operation center and the most advanced factory that Honda Group established in the world. In order to meet the needs of daily production, the company has adopted a "Convenient Production" mode. That is to say, it has developed a number of suppliers to provide semi-finished products to the production base in the vicinity of the main engine plant. In the plan of daily transportation and distribution, the delivery vehicle starts from the depot, carrying the spare and accessory parts required by the suppliers along the road and then simultaneously loading the semi-finished products to the production base when finished unloading. With the popularity of the concept of JIT (Just In Time) production, A Company has formed a strict time window with its suppliers, and its vehicles must send spare and accessory parts to suppliers within the specified time, or else it will bear high compensation cost. Although the existing transportation and distribution plan of A Company can meet the strict requirements of suppliers, but there still are such problems as high frequency of departure and low loading rate. It results in a waste of capacity and increases the transportation cost. This is the problem that companies often encounter in the actual promotion of JIT production mode. How to meet the needs of customers while minimizing transport costs is an important issue that A Company needs to solve.

3.1.1 Cumbersome transportation mode

In the existing transportation plan of A Company, the relationship between the vehicles and the suppliers is many-to-many, that is, one supplier can be serviced by multiple vehicles and one vehicle can also serve multiple suppliers. Superficially, many-to-many relationships can make full use of the vehicles to increase the loading rate, but there is a situation of route repetition for the vehicles, which increases the variable cost of the vehicles. The current procurement model of A Company is characterized by the small-batch, multi-frequency, and many-to-many relationship between suppliers and vehicles, which will not only make it more difficult for the transportation department to carry out vehicle routing arrangements, but also increase the uncertainty of vehicles in transportation arrangements, resulting in unnecessary waste of resources.

3.1.2 Excessive strictness in the constraints of time windows

The current procurement model of A Company is characterized by the small-batch, multi-frequency, and many-to-many relationship between suppliers and vehicles. The production mode determines the procurement mode. Because the Just In Time (JIT) production model has strict control over the time consumed in production line, the restriction on the delivery time to suppliers is caused to be strict too. It is clearly stated in the contract with the supplier that if the supplier is unable to provide services within the specified time, the supplier will face a problem of high penalty.

3.1.3 Low loading rate

The current transportation mode of A Company is a many-to-many relationship, which seems to make the most of the vehicles and increases the loading rate, but in practice, there will be situations of repeated delivery or empty transportation. It is because the material quality and products quality have different requirements for loading, which will affect the loading rate of the vehicle, and the order of pick-up and delivery to the supplier will also have an impact on the overall vehicle loading rate. At present, the vehicle loading rate of A Company has not reached the optimal situation, which there is room for improvement.

3.1.4 Disordered arrangement of suppliers

In recent years, A Company has grown rapidly, which has made the number of cooperating suppliers increased, with the suppliers who it has been cooperated now covering the surrounding neighboring cities and provinces. As the number of suppliers increase gradually, the vehicle routing arrangements of the transportation department become more complex. At present, there is no classified management of the suppliers in the vehicle transportation arrangement, which results in such a chaos that some vehicles and manpower will be responsible for transportation both in the province and outside the province. There is a risk of management confusion in the current vehicle arrangements.

3.2 Mathematical modeling

In this paper, the VPRSPDTW is defined as follows: a set of trucks with the same model complete the scheduled transportation task, each delivery point is composed of delivery point and pick-up point and each delivery point has a time window limit. The delivery volume and the pick-up volume can be the same but not greater than the loading capacity of the vehicle. Each service point can only be served by one vehicle, that is, the relationship between the vehicle and the service point is one-to-many. Combining with the research purpose of this paper, the author put forward some reasonable assumptions. I under the premise of hypothesis, the mathematical model adapted to the goal is established, which is expected to solve the problem of vehicle distribution in the best way, so as to improve the vehicle loading rate, and make the total cost of vehicle transportation minimized. The specific assumptions are as follows:

Firstly, supplier's delivery and pick-up requirements are both known;

Secondly, all transport vehicles are of the same type;

Thirdly, there are smooth traffic, regardless of traffic congestion, etc;

Fourthly, there is no transportation with several dumping trailers in the arrangement of vehicles, unified into one vehicle one trailer.

Fifthly, all vehicles are self-owned, neglecting the situation of outsourcing;

Sixthly, the deadweight of the vehicle has no effect on the transport cost of the vehicle per unit, and shall be the constant.

To facilitate the description of the problem, the parameters are set as follows:

Q: vehicle loading capacity, $Q = 50\text{m}^3$, the number of boxes converted to $Q = 50$;

c_f : departure costs per vehicle;

c_v : transport cost of the vehicle per unit, unit: RMB/km;

d_{ij} : distance between transportation nodes, $i \in V_0;\ j \in V_0; i \neq j$,

d_i : number of the boxes picked up from the supplier i , $i \in V_0$;

b_i : number of the turnover boxes that the vehicle given to the supplier i , $i \in V$;

ET_i : time that the supplier i specified for starting the service, $i \in V$;

LT_i : deadline that the supplier i specified for starting the service, $i \in V$;

t_i : time that the vehicle needed at the transportation node i , $i \in V_0, t_1 = 0, t_n = 0$;

t_{ij} : traveling time that the vehicle taken between two nodes, $i \in V_0;\ j \in V_0; i \neq j$;

α : parameters for weighing the departure and traveling costs, $\alpha \in [0,1]$;

M : a constant for judgement without limitation;

x_{ijk} : traveling variables of the vehicle k $(k \in K)$, $x_{ijk} \in [0,1]$, if the vehicle k is responsible for the transportation form node i to node j , then $x_{ijk} = 1$, or else $x_{ijk} = 0$, in which $i \in V_0;\ j \in V_0; i \neq j$;

y_{ik} : delivery service variables of the vehicle k $(k \in K)$, $y_{ik} \in [0,1]$, if the vehicle k is responsible for

F L_{ik} : number of boxes that the vehicle k $(k \in K)$ carried when departing the node i , the carrying capacity of the vehicle shall not exceed the maximum carrying capacity at any time, in which $i \in V_0$;

S_{ik} : time that the vehicle k $(k \in K)$ arrive at the node i , $i \in V_0$, $S_{1k} = 0$;

The corresponding mathematical models are set up as follows:

$$\min Z = \alpha \sum_{j \in V} \sum_{k \in K} c_f x_{1jk} + (1-\alpha) \sum_{i \in V_0} \sum_{j \in V_0} \sum_{k \in K} c_v d_{ij} xijk \tag{1}$$

$$\sum_{j \in V} x_{1jk} = \sum_{i \in V} x_{ink} \qquad \forall k \in K \tag{2}$$

$$\sum_{k \in K} y_{ik} = 1 \qquad \forall i \in V \tag{3}$$

$$\sum_{i \in V_0} X_{ijk} = y_{jk} \qquad \forall j \in V;\ k \in K; i \neq j \tag{4}$$

$$\sum_{j \in V_0} X_{ijk} = y_{ij} \qquad \forall i \in V;\ k \in K; i \neq j \tag{5}$$

$$L_{0k} = \sum_{i \in V} b_i y_{ik} \qquad \forall k \in K \tag{6}$$

$$L_{jk} = L_{ik} + \sum_{j \in V} x_{ijk}(d_j - bj) - M(1 - y_{jk}) \quad \forall k \in K; \forall_i \in V_0 \tag{7}$$

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$$0 \le L_{ik} \le Q \qquad \forall k \in K; \forall_i \in V_0 \tag{8}$$

$$s_{jk} = s_{ik} + \sum_{j \in V} x_{ijk}(t_i + t_{ij}) - M(1 - y_{ij}) \qquad \forall k \in K; \forall_i \in V_0 \tag{9}$$

$$ET_i \le s_{ik} \le LT_i \qquad \forall k \in K; \forall_i \in V_0 \tag{10}$$

$$x_{ijk} \in \{0,1\} \qquad \forall k \in K; \forall_i \in V_0; \quad \forall j \in V_{0;} i \ne j \tag{11}$$

$$y_{ik} \in \{0,1\} \qquad \forall k \in K; \forall_i \in V_0 \tag{12}$$

Formula (1) refers to the objective function, which is the departure cost of the vehicle combined with the variable cost caused by the vehicle traveling; formula (2) is the vehicle returns from node 1 to node n; formula (3) means that a supplier is only served by one vehicle; formula (4) and (5) refers to the traveling route of the vehicle; formula (6) means the volume of goods carried by the vehicle departed from the depot; formula (7) refers to the loading capacity of the vehicle departed from node i; formula (8) means that the actual loading capacity of the vehicle does not exceed the maximum carrying capacity of the vehicle; formula (9) and formula (10) refer to the time limitation; formula (11) and formula (12) refer to the limitation of the variables attributes.

3.3 Algorithm setup

Potvin and Bengio (1996) put forward the concept of genetic path system when studying the VRPTW problem. Genetic Algorithm (GA) is an intelligent heuristic algorithm to simulate the biological evolution process in natural evolution. The basic idea of GA is to first set the rules for genetic coding, and then through different methods produce the initial population——a set of solutions. According to the principle of survival of the fittest stated in "evolutionism" and based on the crossover and variation of chromosome segments (between coding), a new and optimal solution is formed through the evolution from generation to generation.

Compared with the accurate algorithm, the genetic algorithm can calculate the optimal solution continuously through the crossover and variation of its own chromosome on the basis of calculating the generally feasible solution. Qing and Jun (2016) used hybrid genetic algorithm to solve the vehicle routing problem and got the optimized result. Complex problems such as NP-hard can also find a satisfactory solution under the condition of qualified parameter by setting the parameters. According to the actual situation of A Company, this paper makes use of genetic algorithm to solve the problem. The genetic algorithm steps are shown in the following figure:

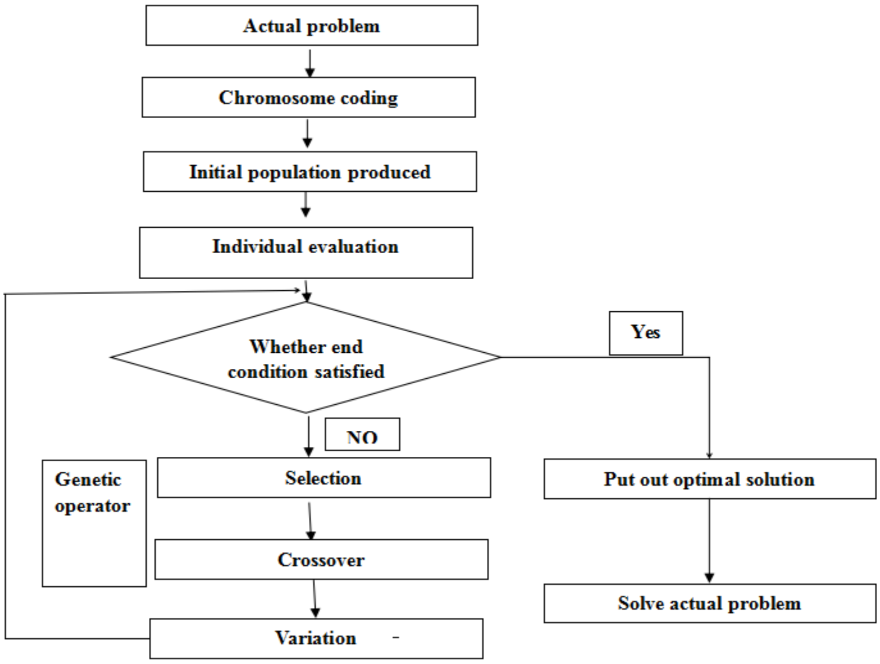

Figure 1 Genetic algorithm steps

4. Results and Discussion

In order to verify the feasibility and effectiveness of the genetic algorithm, the actual data of A Company is substituted into the calculation. The algorithm designed in this paper operates on the MATLAB R2019b of PC end. Final scheme is obtained as shown in Table 1:

Table 1

Vehicles	Suppliers passed by	Traveling distance	Departure loading rate	Return loading rate
1	7	60	88%	60%
2	4-13	54	70%	86%
3	2-12	41	96%	74%
4	14	56	68%	94%
5	9	86	66%	86%
6	15-16	69	78%	52%
7	10-11	54	68%	90%
8	6-8-17	58	96%	96%
9	3-5	48	48%	70%

From the optimal solution mentioned above, we can know that there are different degrees of traveling distance between different vehicles. The main cause of it is that the demand of some suppliers is too large, which makes the vehicle can no longer provide service to other suppliers after satisfying this very supplier, and the vehicle can only provide service to one supplier; so if the demand of some suppliers is smaller, the solution is to integrate nearby suppliers and serve them uniformly by one vehicle, so as to reduce the cost of departure.

In terms of loading rate, it can be seen that there is a big gap between the departure loading rate and the return loading rate of some vehicles. It is caused by the asymmetry of the volume of pick-up and delivery by the supplier. Some suppliers are in large demand for delivery, and small demand for picking up; some are in large demand for picking up, and small demand for delivery. Theoretically, the vehicle loading rate can be improved to some extent through the VRP plan. Based on the investigation, it can be seen that due to the strict requirements for the time window, some vehicles cannot provide service to other suppliers though there is spare capacity available, just like what happened to No.9 vehicle. This is also the biggest difference between the VRPSPDTW problem and VRP, VRPSPD and VRPTW problems. Due to the increase of constraints, the vehicle cannot improve the loading rate by minimizing the frequency of departures.

The average vehicle loading rate in the optimal scheme is 77%, which is 7 percent higher than the average loading rate in the enterprise's original transportation scheme; the total traveling distance of the vehicle is 526 km, which is about 10 percent lower than the total traveling distance of the original vehicle; and the number of vehicle departures is reduced to 9 times from the original 12 times.

Through the above comparative analysis of the optimal solution obtained by genetic algorithm and company A's existing vehicle distribution routes, it can be seen that by using the genetic algorithm and the mathematical model established in this paper, the number of departures on the basis of satisfying customer satisfaction is successfully reduced, and the average loading rate of vehicles is improved. It not only meets the needs of all suppliers but also reduces the total transportation cost. The feasibility and effectiveness of the algorithm is proved. Therefore, it can be inferred that the rationality and validity of the mathematical model constructed according to the actual situation of Company A in this paper have certain scientific basis for the selection of genetic algorithm. The above mathematical model and genetic algorithm can be used to optimize the vehicle routing problem with time windows and simultaneous delivery and retrieval.

5. Conclusion

First, through the understanding of the actual operation and the simple analysis of the vehicle transportation plan of Company A, it is found that Company A has problems such as complicated transportation mode and too strict time window. In order to optimize the vehicle routing problem of Company A, this paper puts forward corresponding solutions to the above problems. According to the actual situation of Company A, this paper expands the traditional VRP problem, increases the restriction conditions, and generalizes the problem into The Vehicle Routing Problem with Simultaneous Pick-up and Delivery with Time Windows, namely VRPSPDTW. On this basis, assumptions are made; parameters are set; and mathematical models are established to reduce the total vehicle transportation cost of the enterprise under the condition of satisfying customer satisfaction. The mathematical model is constructed according to the situation of Company A, and the real data of Company A are used in the calculation, thus ensuring the feasibility of genetic algorithm.

The results obtained by genetic algorithm show that, on the premise of ensuring the vehicles to complete the service within the time window, for the enterprises, the loading rate of the vehicles is improved, while the departure times are reduced, and the total transportation cost is reduced. The results prove the effectiveness of genetic algorithm in vehicle route planning.

This paper can also be optimized in the following two aspects in future research. First, when selecting the data, the data quoted in this article are all from a certain procurement cycle of company A, only covering the data of several suppliers near the production base. Overall, the selected data is small in scale. Then there is the choice of algorithm: this paper adopts the genetic algorithm of modern heuristic algorithm. In the following research, we can focus on combining various heuristic algorithms to form a unique hybrid algorithm to solve practical problems.

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