Research on vehicle routing problem of automobile part Milk-Run with time windows constrained

Jiahui Yang1,a, Zaijin You1,b*, Wanying Li1,c, Yu Zhao1,d, Zhe Ji2,e
1Transportation Engineering College, Dalian Maritime University, Dalian 116026, China
2Navigation College, Dalian Maritime University, Dalian 116026, China

Abstract—Based on the parts inbound logistics as the research object, this thesis introduces Milk-run of third party logistics enterprise mode. Establish mathematical model under the premise of time window, through genetic algorithm optimize the distribution route, and using MATLAB to simulation, the results show that distribution vehicles reduced from 18 to 6. Transportation costs were reduced by 30.05%. Though the research on the circular pick-up mode of incoming logistics of parts and components, this thesis explores the strategy of optimizing its transportation path. On the one hand, it can solve the contradiction of reducing inventory cost but increasing transportation cost to a certain extent, and effectively reduce the cost of the nodes of the whole supply chain, which has certain theoretical value and significance for the research of vehicle path optimization; On the other hand, a reasonable distribution route can reduce driving distance and alleviate urban traffic pressure, while reducing distribution vehicles can reduce urban noise and automobile exhaust emissions, and contribute to the realization of low-carbon environmental protection.

1. Introduction

In recent years, the automobile manufacturing industry is affected by a variety of factors such as demand changes and environmental protection requirements, and its market sales have declined significantly. Therefore, the automobile industry urgently needs to reduce costs and explore new profit margins to ensure development, so many automobile companies begin to pay attention to the logistics link of auto parts entering the factory with higher costs and explore strategies to reduce its transportation costs. At present, there are many types of logistics supply models adopted by major domestic automobile enterprises, and two common models are the traditional auto parts supply model and the outsourcing model of third-party logistics enterprises[1]. From a global perspective, although the inventory cost and the time of parts in the warehouse are decreasing, the cost of the entire supply chain is not fundamentally reduced because the transportation cost is also rising at the same time, which results in the realistic contradiction of JIT supply[2].

Gillett and Miller proposed a scanning algorithm, which represented distribution points with position coordinates and took any distribution point as the starting point to scan other distribution points in a fixed sequence, thus realizing the planning of vehicle distribution paths[3]. In 2000, Steven A Samaras analyzed the inbound operation mode of auto parts and concluded that the inbound and outbound logistics operation level is related to the competitive advantage of auto manufacturers in the industry[4]. In 2000, Luiz Fernando Pesce conducted a study on the circular pickup method adopted by Mercedes-Benz in Germany, and the results showed that the inventory could be effectively reduced by nearly 80% through circular pickup. The most important step of circular pickup was to determine the parts involved in the process and cooperate with suppliers to complete route planning and vehicle scheduling[5]. Dethloff J concluded through research in 2002 that the heuristic algorithm for the routing problem of vehicles with mixed load for return pick-up and delivery can effectively solve the problem of the routing of vehicles with simultaneous pick-up and delivery under a specified time[6]. By introducing the circular pickup method of Shanghai General Motors, QingSong Lan designed the circular pickup route, established the circular pickup route network, and proved by using software that circular pickup can make up for the defects of traditional transportation methods, effectively improve cargo handling efficiency, reduce suppliers’ inventory costs, and respond quickly to market demand[7]. ShuangJin Wang took into account the influence of time window and inventory on circular pickup path, built a relevant model of circular pickup path planning, solved it by using the improved ant colony algorithm, and verified the feasibility of the algorithm through examples[8].

To sum up, this paper takes the inbound logistics of auto parts as the research object, compares various distribution modes of inbound logistics of auto parts, mainly including the traditional direct delivery mode of suppliers and the circular pickup mode led by third-party logistics enterprises, and finally chooses the circular pickup mode, and explores the theories related to the circular pickup path of inbound logistics of parts. A cyclic
path optimization model with time window constraint was established, solved by genetic algorithm, combined with simulation examples, and the optimal path was obtained by adjusting model parameters.

2. Model construction

This paper addresses the vehicle routing problem of automobile part Milk-Run with time windows constrained, focusing on optimizing the driving routes of vehicles starting from a fixed distribution center, serving specified suppliers within known time windows, and returning to the distribution center. The objective is to minimize the number of vehicles and transportation costs by pre-planning routes to meet vehicle capacity and distance constraints. The study simplifies real-world complexities by assuming a single fixed distribution center, known supplier time requirements, consistent vehicle models, constant driving speed, one-cycle pickup, and constant transport cost per unit distance. The constructed model incorporates parameters outlined in Tab.1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Meanings</th>
</tr>
</thead>
<tbody>
<tr>
<td>i, j</td>
<td>j ∈ V, V = {0, 1, ..., n}, Distribution center</td>
</tr>
<tr>
<td>k</td>
<td>Vehicle number, k ∈ {1, 2, ..., m}</td>
</tr>
<tr>
<td>t&lt;sub&gt;i&lt;/sub&gt;, t&lt;sub&gt;j&lt;/sub&gt;</td>
<td>Arrival time of the vehicle at each demand point i (h), Latest arrival time of the vehicle at each demand point j (h)</td>
</tr>
<tr>
<td>v</td>
<td>Average driving speed of the vehicle (km/h)</td>
</tr>
<tr>
<td>Q</td>
<td>Maximum loading capacity of vehicles (m&lt;sup&gt;3&lt;/sup&gt;)</td>
</tr>
<tr>
<td>p</td>
<td>Cost per kilometer for vehicle delivery (RMB/km)</td>
</tr>
<tr>
<td>v&lt;sub&gt;ijk&lt;/sub&gt;</td>
<td>1, Vehicle k delivers from demand point i to j, 0, otherwise</td>
</tr>
<tr>
<td>y&lt;sub&gt;ijk&lt;/sub&gt;</td>
<td>1, Vehicle k delivers to demand point i, 0, otherwise</td>
</tr>
</tbody>
</table>

Tab.1 Model parameters and meanings

In this paper, a mathematical model is designed to minimize the transportation cost and time window penalty cost of parts distribution. The model is shown below.

(1) Minimum distribution and transportation costs.

\[
\min f_1 = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij} x_{ijk}
\]

(2) The time window penalty cost is the lowest.

\[
\min f_2 = \sum_{i=1}^{m} \sum_{j=1}^{n} \left[ C_\alpha \max(0, t_{ei} - t_{ik}) + C_\beta \max(0, t_{ik} - t_{li}) \right]
\]

The penalty cost of the time window refers to whether the material can arrive within the expected time of the demand point. If the material arrives earlier, it will be punished by the early arrival penalty coefficient. The formula of the early arrival penalty coefficient is shown in Formula 2; if the material arrives later, it will be punished by setting the late arrival penalty coefficient, specifically shown in Formula 3. Formula 4 represents the set penalty coefficient, where M is a large positive value, and imposes strict penalties on delivery vehicles that arrive later than the latest time window. Formula 5 represents the objective function with the lowest penalty cost.

(3) Constraints of the model are as follows.

\[
\sum_{k=1}^{m} y_{ok} = m
\]

\[
\sum_{k=1}^{m} y_{ik} = 1, (i = 1, 2, ..., n)
\]
\[
\sum_{j=0}^{n} \sum_{k=1}^{m} x_{ijk} = 1, (i = 0, 1, ..., n)
\]

\[
\sum_{i=1}^{n} q_i y_{ik} \leq Q, (k = 1, 2, ..., m)
\]

\[
x_{ijk} (t_{ik} + s_i + t_{ij} - t_{jk}) \leq 0, (i \neq j, k = 1, 2, ..., m)
\]

Formula 6 indicates that all m vehicles exit from the same distribution center. Formula 7 indicates that each supplier is picked up by only one vehicle; Formula 8 and Formula 9 indicate that each supplier is visited only once and the vehicle starts from the distribution center after a cycle of picking up goods, without loading on the way; Formula 10 indicates that the total load of goods does not exceed the maximum volume limit of the vehicle; Formula 11 indicates that the second number of vehicles arriving and departing from each demand point; Formula 12 represents the number of paths between two consecutive demand points on the same distribution path, the time for the vehicle to arrive at the previous demand point does not exceed the time to arrive at the next demand point.

### 3. Algorithm Design

The methodology involves the following steps:

1. **Coding.** The problem is coded, combining distribution center and supplier numbers using natural number coding. The order of each path significantly impacts the objective function, and random changes are not allowed.

2. **Initial group selection.** The size and selection of the initial population are crucial for optimization. In this example with 18 supply points, the initial population size is set to 100.

3. **Calculating individual fitness.** The fitness function is set as the objective function of the model, aiming to minimize transportation costs.

4. **Selection operator.** The operator is based on fitness values, favoring larger values. This helps the algorithm approach the optimal solution through continuous iteration.

5. **Crossover operator.** The crossover method involves crossing two genes with a specified probability to generate a new population. In this paper, the crossover probability is set at 0.9.

6. **Mutation operator.** The mutation probability is set to 0.1, using the reversal mutation method. If the mutated child is better than the parent, it replaces the parent; otherwise, the parent continues to iterate.

7. **Termination conditions.** When solving the optimal path problem, if the predetermined stopping conditions are reached, such as finding a satisfactory solution or reaching the maximum number of iterations, the algorithm is terminated. Otherwise, the fourth step operation is returned.

### 4. Test Results and Discussions

#### 4.1. A Logistics Company Introduction and Distribution Status

Company A, a third-party logistics provider specializing in services for automobile manufacturing enterprises, particularly handling significant parts logistics volumes, has observed high operational costs. This paper proposes adopting the Milk-run path optimization method to reduce the company’s operating expenses. Notably, all vehicles in Company A’s distribution center are of the same model, ensuring that loading goods won’t exceed maximum capacity. Delivery vehicles can be mixed, and deliveries primarily occur between 8 am and 4 pm daily. The focus of this paper is solely on optimizing vehicle delivery routes during this timeframe, without considering service for individual customers in other periods. See Tab.2 for details on the specific distribution of vehicles.

<table>
<thead>
<tr>
<th>Total Number of Vehicles (units)</th>
<th>Speed (km/h)</th>
<th>Capacity (m³)</th>
<th>Unit Transportation Cost (RMB/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>50</td>
<td>80</td>
<td>10</td>
</tr>
</tbody>
</table>

#### 4.2. Model Solving and Comparative Analysis of Optimization Results

Through genetic algorithm and MATLAB programming, it runs for 51.5 seconds and iterates 500 times for convergence, as shown in Fig.1.

The optimal solution was obtained through genetic algorithm optimization, using 6 vehicles with a total driving distance of 314.86 km. The optimal delivery path obtained by genetic algorithm is shown in Fig.1.(a), and the total delivery cost is 3148.6 yuan. By observing the iterative graph of the algorithm, it can be seen that after 150 group iterations, the optimal value basically remains unchanged, and the obtained value is the optimal solution of the model. According to the distribution route of each vehicle, the total distribution cost, travel time and actual load of each vehicle can be obtained.

The optimization result is compared with the previous route of Company A, and the comparative analysis is carried out from the aspects of total travel distance, total cost, total time and vehicle loading rate of vehicle distribution. The distribution before and after optimization is shown in Tab.3. The solution results are compared with the distribution situation without optimization, as shown in Tab.4.
Tab.3 Optimized distribution information

<table>
<thead>
<tr>
<th>NO.</th>
<th>Distribution Order</th>
<th>Distance (km)</th>
<th>Time (h)</th>
<th>Actual Capacity (m³)</th>
<th>Rated Capacity (m³)</th>
<th>Loading Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0→2→5→0</td>
<td>40.72</td>
<td>0.81</td>
<td>63</td>
<td>80</td>
<td>78.75</td>
</tr>
<tr>
<td>2</td>
<td>0→3→1→0</td>
<td>35.11</td>
<td>0.70</td>
<td>66</td>
<td>80</td>
<td>82.50</td>
</tr>
<tr>
<td>3</td>
<td>0→4→6→0</td>
<td>38.45</td>
<td>0.77</td>
<td>60</td>
<td>80</td>
<td>75.00</td>
</tr>
<tr>
<td>4</td>
<td>0→16→17→12→13→0</td>
<td>70.23</td>
<td>1.40</td>
<td>76</td>
<td>80</td>
<td>95.00</td>
</tr>
<tr>
<td>5</td>
<td>0→7→9→11→10→15→0</td>
<td>83.21</td>
<td>1.66</td>
<td>70</td>
<td>80</td>
<td>87.50</td>
</tr>
<tr>
<td>6</td>
<td>0→18→14→8→0</td>
<td>47.14</td>
<td>0.94</td>
<td>71</td>
<td>80</td>
<td>88.75</td>
</tr>
</tbody>
</table>

Tab.4 The result of genetic algorithm is compared with that before optimization

<table>
<thead>
<tr>
<th>Vehicle(unit)</th>
<th>Original Plan</th>
<th>Optimum Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td>Total Distance(km)</td>
<td>450.13</td>
<td>314.86</td>
</tr>
<tr>
<td>Total Cost(RMB)</td>
<td>4501.3</td>
<td>3148.6</td>
</tr>
<tr>
<td>Total Time(h)</td>
<td>9.00</td>
<td>6.30</td>
</tr>
<tr>
<td>Average Loading Rate(%)</td>
<td>28.33</td>
<td>84.58</td>
</tr>
</tbody>
</table>

(a)Convergence diagram of genetic algorithm

(b)Optimized path diagram

Fig.1 Construction and geometrical dimensions of specimens

Through the comparative analysis of the results, it can be found that the total distribution cost after optimization is 1352.7 yuan, and the overall reduction is 30.05%; The optimized distance is reduced by 30.05%; 30% reduction in delivery time; The average load factor of the optimized vehicles of A logistics company is 84.58%, which is 66.5% higher than that before optimization. According to the total distribution vehicles, a total of 18 vehicles are required before optimization. After optimization, fewer distribution vehicles are required, which is more convenient for enterprise scheduling and management, and reduces the operating costs of vehicles. Improve the transportation efficiency and quality of A logistics company and enhance its market competitiveness.

5. Conclusion

This paper expects that the proposal and application of optimization scheme can effectively improve the current situation of parts distribution. By establishing a vehicle routing model with plasticity, the known quantities in the model can be changed, such as the number of target customers, location information and demand changes, and the optimal path information can be updated to obtain the updated distribution path. This is conducive to scientific and efficient planning. It is of great significance to improve service level and distribution quality. For third-party logistics companies, a reasonable distribution route can complete the pickup task with fewer vehicles, reduce costs and improve profits. For automobile manufacturing enterprises, it is helpful to save production costs and achieve lean production. At the same time, from the perspective of social benefits, reducing transport vehicles is conducive to easing traffic pressure, reducing vehicle exhaust emissions, and thus boosting the greening of logistics.

Areas that can be further improved:

1. In terms of constructing a vehicle path optimization model, this article only involves one type of vehicle and does not consider multiple different vehicle models for delivery.
2. Not considering the impact of driving environment on the speed and time of delivery vehicles.
3. The method used in this article to solve the optimization model for constructing vehicle delivery routes is genetic algorithm, without using other algorithms for comparison.

As China’s automotive industry becomes increasingly mature, automotive logistics, as a link in various links of this industry chain, has great development space. With the deepening of a new round of industrial transformation, automotive logistics will respond to the increasing
demand for higher quality automotive logistics services from customers with a trend of high-quality, information-based, intelligent, and digital development. In turn, it also ensures the smooth flow of value flow in the automotive industry.

References


