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Research on Vehicle Routing Problem in Auto Parts Inbound Logistics Based on Milk Run Mode

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Abstract: The application of milk run in domestic automobile parts supply was studied. A mathematical model for routing a milk run system was formulated by minimizing the transportation and inventory cost under the restriction of tiered storage pricing scheme and multiple vehicle types. In solving the model, a modified genetic algorithm was developed, which is suitable for realistic sized problems. The utility of the approach was demonstrated through a computational experiment.

Keywords: Inbound logistics, Milk run, Genetic algorithm, Inventory routing problem, Supply hub.

1. Introduction

As the first phase of automotive logistics, the inbound logistics of parts has attracted the attention of researchers due to its complexity, management challenges, and high costs. Considering the Milk Run inbound logistics model in the consolidation center, which involves multiple pickups, can not only reduce transportation costs by increasing vehicle load capacity and reducing empty return trips, but also meet the just-in-time (JIT) delivery requirements of the assembly plant through frequent and small-batch supplies, thereby reducing inventory costs. This approach has gradually gained favor among automotive manufacturing companies.

Transportation and warehousing are the two main cost sources in inbound logistics. Designing optimal delivery routes and transport frequencies is of significant practical importance in reducing loading time, decreasing vehicle empty rates, saving vehicle resources, and lowering transportation costs. Vehicle routing optimization has been a focal point in research on cost control in inbound logistics, but real-world considerations often neglect tiered warehousing price ranges and the use of multiple vehicle types for transportation. In 2008, Ohlmann et al. [1] proposed a two-stage algorithm to solve the cyclic pickup problem with time windows and demand partitioning characteristics. In 2009, Wang Jinlian and Jiang Zuhua introduced the concept of maximum line-side inventory into Milk Run, transforming the problem into a common frequency routing problem. In 2013, Zhu Ling and Wu Di presented a cyclic pickup model with time window constraints and demand partitioning. In 2014, Chen et al. [2] proposed a new method for computing transportation costs and improved the ant colony algorithm for solution. In 2017, Guner et al. [3] considered vehicle locations and real-time congestion, utilizing dynamic stochastic programming to derive dynamic paths. In 2021, Li Tong et al. studied the cooperative optimization of paths and 3D loading in cyclic pickup transportation problems under demand uncertainty. In 2022, Zheng Renrong et al. made decisions based on multi-stage inventory levels of parts and pickup sequencing of transport vehicles, considering the dynamic demand of production lines and the characteristics of bulk transportation for parts.

Based on the aforementioned research background, it can be observed that current studies on inbound logistics of automotive parts primarily focus on pickup modes and vehicle routing optimization, often emphasizing rigid inventory control and single-vehicle type solutions. Research on multi-vehicle cyclic pickup path optimization considering inventory costs is relatively scarce. This study takes a well-known domestic automotive company as the background and conducts route optimization design. A mathematical model is established based on the cyclic pickup operation mode, with the objective of minimizing transportation and inventory costs. A genetic algorithm is employed for solving the model. Finally, numerical experiments are conducted to validate the effectiveness and optimization capabilities of the proposed method.

2. Consideration of Inventory Costs in The Optimization Model for Multi-vehicle Cyclic Pickup Routing

2.1. Problem Description

This study defines the problem of multi-vehicle cyclic pickup with consideration of inventory costs as follows: In an inbound logistics process with a supply-demand balance, with the assembly plant as the demand point, multiple vehicles of different types, without quantity restrictions, depart from the consolidation center. Following the material requirements of the assembly plant within a designated operational cycle (typically one day), pickups are made from corresponding suppliers according to predetermined routes and pickup frequencies, and ultimately return to the consolidation center. The consolidation center then delivers the goods at a uniform speed based on the production requirements of the assembly plant.

2.2. Model Assumptions

Based on the analysis above, the following assumptions and definitions can be made for the cyclic pickup routing optimization problem studied in this paper:

(1) Consolidation Center: There is a unique consolidation center with a known geographical location.

(2) Vehicles: There are multiple vehicle types, each with different capacity, fixed costs, and variable costs. The number of vehicles is not limited.

(3) Suppliers: The geographical locations of all suppliers are known. The daily volume for each supplier is known. Each supplier provides only one type of component.

(4) Components: Each component is consumed evenly over

time, and the synchronization of pickup frequencies with the production schedule is not considered.

(5) Paths: Each path can only be used by one vehicle type. Each supplier has only one pickup path passing through it. The pickup frequencies for all supplier points on a single path can be different, but they are the same for all suppliers on that particular path. The consolidation center serves as the origin and destination of the paths.

(6) Inventory Tiers: The storage prices at the consolidation center increase in gradient with the growth of inventory tiers. The price for each inventory tier is known.

2.3. Page Numbers.

2.3.1. Related parameters

V: $V=\{i \mid i=0,1,2,\text{B} \;,n\}$ is the set of n supplier points and distribution centers, where i=0 represents the distribution cent

U: $U=\{u \mid u=0,1,2,\text{B} \;,a\}$ represents a type of vehicle, and the volume of u type of vehicle is q_u

R: $R=\{r \mid r=0,1,\text{B} \;,e\}$ represents e inventory level

K: $K=\{k \mid k=1,2,\text{B} \;,m\}$ is a collection of m path

c_{ij}: The distance from supplier i to j, specifically cii=0

v: The average driving speed of the vehicle

d_i: Daily cargo volume of supplier i

t_i: Average loading time for supplier i

t_{ij}: Upplier i to j transportation time, $t_{ij}=\frac{c_{ij}}{v}$

T: The maximum allowable time for a single cycle per path

J: Maximum number of suppliers accessed per path

G: Maximum frequency per path

$S_{max,r}$: The maximum frequency corresponding to the r inventory interval

$S_{min,r}$: The minimum frequency corresponding to the r inventory interval

α : Unit distance transportation cost

β_r : The storage price per cubic meter corresponding to the inventory level of category r

γ_u: Fixed single departure cost for u vehicles

m: Total number of scheduled paths

F_k: Pickup frequency of path k

P_i: Single pickup quantity at supplier i

2.3.2. Model building

Based on the above parameter symbols and decision variables, a mathematical model is constructed as follows:

Objective function:

$$\min Z=\sum_{i\in V}\sum_{j\in V}\sum_{k\in K}\sum_{u\in U}\alpha f_k c_{ij}x_{ijku}+\sum_{i\in V}\sum_{k\in K}\sum_{u\in U}\sum_{r\in R}y_{iku}Z_{kr}P_i\beta_r+\sum_{k\in K}\sum_{u\in U}\gamma_u b_{ku}f_k \quad (1)$$

Formula (1) represents the objective function, Z represents the total logistics cost incurred during a cycle of picking up operations, Where $\sum_{i\in V}\sum_{j\in V}\sum_{k\in K}\sum_{u\in U}\alpha f_k c_{ij}x_{ijku}$ represents transportation cost, $\sum_{i\in V}\sum_{k\in K}\sum_{u\in U}\sum_{r\in R}y_{iku}Z_{kr}P_i\beta_r$ represents inventory cost, and $\sum_{k\in K}\sum_{u\in U}\gamma_u b_{ku}f_k$ represents total fixed departure cost;

Constraint condition:

$$\sum_{j\in V}x_{ijku}-\sum_{j\in V}x_{ijku}=0, \quad \forall i\in V,k\in K,u\in U \quad (2)$$

$$\sum_{i\in V}x_{0iku}=1, \quad \forall k\in K,u\in U \quad (3)$$

$$\sum_{i\in V}x_{i0ku}=1, \quad \forall k\in K,u\in U \quad (4)$$

$$\sum_{j\in V}\sum_{u\in U}x_{ijku}=\sum_{u\in U}y_{iku}, \quad \forall i\in V,i\neq 0,k\in K \quad (5)$$

$$\sum_{i\in V}\sum_{u\in U}x_{ijku}=\sum_{u\in U}y_{jku}, \quad \forall j\in V,j\neq 0,k\in K \quad (6)$$

$$\sum_{k\in K}\sum_{u\in U}y_{iku}=1, \quad \forall i\in V,i\neq 0 \quad (7)$$

$$\sum_{u\in U}\sum_{i\in M}\sum_{j\in M}x_{ijku}\leq |W|-1, \quad \forall W\subseteq V,0\notin W,|W|\geq 2 \quad (8)$$

$$f_k=\left\lceil\sum_{i\in V}\sum_{u\in U}\frac{y_{iku}d_i}{q_u}\right\rceil\leq G, \quad \forall k\in K \quad (9)$$

$$P_i=\left(\sum_{k\in K}\sum_{u\in U}\frac{y_{iku}}{f_k}\right)d_i, \quad \forall i\in V,i\neq 0 \quad (10)$$

$$\sum_{r\in R}Z_{kr}=1, \quad \forall k\in K \quad (11)$$

$$f_k\geq\sum_{r\in R}Z_{kr}S_{\min,r}, \quad \forall k\in K \quad (12)$$

$$f_k\leq\sum_{r\in R}Z_{kr}S_{\max,r}, \quad \forall k\in K \quad (13)$$

$$\sum_{u\in U}b_{ku}=1, \quad \forall k\in K \quad (14)$$

$$\sum_{i\in V}\sum_{u\in U}P_i y_{iku}\leq\sum_{u\in U}q_u b_{ku}, \quad \forall k\in K \quad (15)$$

$$\sum_{u\in U}\sum_{i\in V,i\neq 0}t_i y_{iku}+\sum_{i\in V}\sum_{j\in V}\sum_{u\in U}t_{ij}x_{ijku}\leq T, \quad \forall k\in K \quad (16)$$

$$\sum_{i\in V}\sum_{u\in U}y_{iku}b_{ku}\leq J, \quad \forall k\in K \quad (17)$$

Formula (2) indicates that the number of vehicles entering and leaving each supplier is equal, ensuring that the vehicles leave after the pickup is completed;

Formulas (3) and (4) indicate that the starting and ending points of the pickup path are the distribution centers, ensuring that a complete loop can be formed;

Formulas (5), (6), and (7) indicate that each supplier is only assigned to one path;

Formula (8) is famous for eliminating constraints in sub circuits.

Formula (9) indicates that the pickup frequency of route k does not exceed the maximum pickup frequency limit for each path;

Formula (10) represents the single pickup quantity of supplier i;

Formula (11) indicates that each path can only select one inventory interval;

Formulas (12) and (13) indicate that the picking frequency of this path should be within the picking frequency range of the inventory interval in which it is located;

Formula (14) indicates that only one vehicle type can be used for each path;

Formula (15) indicates that the total single pickup volume of all suppliers on a pickup path cannot exceed the maximum loading capacity of the corresponding vehicle model on that path;

The formula (16) indicates that the total loading time of each supplier on a path and the transportation time between suppliers should not exceed the maximum time of the circular pickup order;

The formula (17) indicates that the total number of suppliers on each path cannot exceed the maximum number of suppliers accessed per path.

3. Improved Genetic Algorithm Design

To effectively and quickly solve problems, this article adopts genetic algorithm, which has good convergence and search efficiency.

3.1. Chromosome coding

This article adopts integer encoding and designs a three-layer encoding format to describe the complete transportation scheme. The first layer uses integer encoding to describe the arrangement order of suppliers in chromosomes, the second layer uses integer encoding to describe the position of separation points on chromosomes to determine the supplier number on each path, and the third layer uses integer encoding to describe the selected vehicle type on each path.

3.2. Initial population

The initial population size is usually set based on experience, and the number of individuals is generally between 20 and 200.

3.3. Fitness function

Take the reciprocal of the objective function as the fitness function of the genetic algorithm, namely:

$$F=\frac{1}{\sum_{i\in V}\sum_{j\in V}\sum_{k\in K}\sum_{u\in U}\alpha f_k c_{ij} x_{ijku}+\sum_{i\in V}\sum_{k\in K}\sum_{u\in U}\sum_{r\in R} y_{iku} Z_{kr} P_i \beta_r+\sum_{k\in K}\sum_{u\in U}\gamma_u b_{ku} f_k} \quad (18)$$

3.4. Selection Operator

This article combines the championship operator and elite selection operator to design the selection operator, and the specific process is as follows:

(1) Calculate the fitness function values of each chromosome in the current population;

(2) Set the number of championship groups to p and randomly divide the chromosomes in the current population into p groups;

(3) Select the chromosome with the best fitness function value in each group and directly replicate it to the next generation.

3.5. Mutation operator

This article presents a total of seven different mutation operators:

(1) Inversion Mutation: This operator targets the first-tier supplier encoding. It randomly selects two gene positions, i and j, in the chromosome encoding. It reverses the gene segment between the two positions and inserts it back in its original location.

(2) Swap Mutation: This operator targets the first-tier supplier encoding. It randomly selects two gene positions, i and j, in the chromosome encoding. It swaps the values at the two positions while keeping the rest of the gene positions unchanged.

(3) Insertion Mutation: This operator targets the first-tier supplier encoding. It randomly selects two gene positions, i and j, in the chromosome encoding. It shifts the values between positions i+1 and j forward by one position in their original order and inserts the value at position i into the original position of gene position j.

(4) Breakpoint Mutation: This operator applies to the second-tier breakpoint encoding and the third-tier vehicle type encoding. It generates new second-tier breakpoint encoding and third-tier vehicle type encoding according to the encoding rules, replacing the original encoding for the second and third tiers.

(5) Reverse-Mix Breakpoint Mutation: This operator simultaneously targets the first-tier supplier encoding, the second-tier breakpoint encoding, and the third-tier vehicle type encoding. It combines the inversion mutation and breakpoint mutation simultaneously.

(6) Swap-Mix Breakpoint Mutation: This operator simultaneously targets the first-tier supplier encoding, the second-tier breakpoint encoding, and the third-tier vehicle type encoding. It combines the swap mutation and breakpoint mutation simultaneously.

(7) Insert-Mix Breakpoint Mutation: This operator simultaneously targets the first-tier supplier encoding, the second-tier breakpoint encoding, and the third-tier vehicle type encoding. It combines the insertion mutation and breakpoint mutation simultaneously.

3.6. Mutation operator

Because the Rate of convergence of different population sizes is different, the algorithm uses the maximum number of fitness function calculations as the termination condition.

4. Numerical Experiment

4.1. Data preparation

This article randomly generated 18 suppliers to be included in the circular pickup operation system, numbered 1-18, where 0 represents the centralized distribution center.

(1) Transportation distance

See Table 1 of the Distance matrix for the distance between each supplier and the gathering and distribution center, in kilometers (km):

Table 1. Distance matrix(a)

	0	1	2	3	4	5	6	7	8	9
0	0.0	66.1	65.3	78.4	66.0	125.8	91.7	100.8	72.8	40.1
1	66.1	0.0	38.8	49.1	36.9	59.7	38.5	51.1	29.5	41.6
2	65.3	38.8	0.0	14.1	2.4	81.8	31.9	37.3	67.6	64.7
3	78.4	49.1	14.1	0.0	14.6	82.2	28.9	29.2	78.6	78.6
4	66.0	36.9	2.4	14.6	0.0	79.5	29.9	35.9	65.8	63.9
5	125.8	59.7	81.8	82.2	79.5	0.0	53.5	59.0	65.3	96.2
6	91.7	38.5	31.9	28.9	29.9	53.5	0.0	12.7	65.5	78.3
7	100.8	51.1	37.3	29.2	35.9	59.0	12.7	0.0	78.3	90.3
8	72.8	29.5	67.6	78.6	65.8	65.3	65.5	78.3	0.0	34.8
9	40.1	41.6	64.7	78.6	63.9	96.2	78.3	90.3	34.8	0.0
10	13.6	52.5	54.3	67.9	54.7	112.2	79.0	88.7	60.8	30.7
11	127.2	64.1	71.1	66.8	69.1	29.0	39.3	38.6	80.7	105.3
12	41.5	61.2	36.1	45.0	38.0	115.1	67.9	72.9	82.9	63.2
13	44.4	30.9	23.3	37.4	23.3	87.3	47.4	56.6	53.7	42.5
14	23.7	69.0	54.2	65.1	55.7	127.1	84.8	91.5	84.2	56.8
15	31.8	34.7	46.1	60.2	45.8	94.3	65.2	76.1	43.6	20.6
16	63.8	44.1	6.1	14.6	8.4	87.8	37.1	41.3	72.4	67.0
17	81.3	22.1	31.9	36.1	29.5	50.5	16.7	29.4	49.0	63.0
18	123.3	82.6	58.4	44.9	58.1	84.2	45.0	32.4	110.5	119.6

Table 2. Distance matrix(b)

	10	11	12	13	14	15	16	17	18
0	13.6	127.2	41.5	44.4	23.7	31.8	63.8	81.3	123.3
1	52.5	64.1	61.2	30.9	69.0	34.7	44.1	22.1	82.6
2	54.3	71.1	36.1	23.3	54.2	46.1	6.1	31.9	58.4
3	67.9	66.8	45.0	37.4	65.1	60.2	14.6	36.1	44.9
4	54.7	69.1	38.0	23.3	55.7	45.8	8.4	29.5	58.1
5	112.2	29.0	115.1	87.3	127.1	94.3	87.8	50.5	84.2
6	79.0	39.3	67.9	47.4	84.8	65.2	37.1	16.7	45.0
7	88.7	38.6	72.9	56.6	91.5	76.1	41.3	29.4	32.4
8	60.8	80.7	82.9	53.7	84.2	43.6	72.4	49.0	110.5
9	30.7	105.3	63.2	42.5	56.8	20.6	67.0	63.0	119.6
10	0.0	113.8	37.3	32.1	26.2	18.4	53.7	68.0	112.7
11	113.8	0.0	107.1	84.1	123.1	97.6	76.4	45.9	57.2
12	37.3	107.1	0.0	30.4	21.5	43.2	31.6	64.7	88.0
13	32.1	84.1	30.4	0.0	39.9	23.0	24.6	38.6	81.3
14	26.2	123.1	21.5	39.9	0.0	40.6	50.8	78.3	109.0
15	18.4	97.6	43.2	23.0	40.6	0.0	47.6	52.3	103.2
16	53.7	76.4	31.6	24.6	50.8	47.6	0.0	38.0	59.5
17	68.0	45.9	64.7	38.6	78.3	52.3	38.0	0.0	61.5
18	112.7	57.2	88.0	81.3	109.0	103.2	59.5	61.5	0.0

From the Distance matrix, it can be seen that the maximum distance between each supplier and the distribution center does not exceed 130km, and the distribution among suppliers is uniform, which is conducive to the design of recycling routes.

(2) Daily inventory of components

After summarizing the past daily supply times and quantities of 18 suppliers participating in the circular pickup project, the daily pickup volume data of each supplier is shown in Table 3. Based on past loading and unloading experience, this article takes the average loading and unloading time at each supplier as 0.5 hours, which is convenient for subsequent calculations.

Table 3. Supplier Daily Quantity Table

Supplier Number	Daily cargo volume (m^3)	Average layday (h)	Supplier Number	Daily cargo volume (m^3)	Average layday (h)
1	106.9	0.5h	10	48.6	0.5h
2	74.2	0.5h	11	187.8	0.5h
3	100.4	0.5h	12	43.6	0.5h
4	70.1	0.5h	13	38.2	0.5h
5	183.3	0.5h	14	43.8	0.5h
6	140.8	0.5h	15	40.6	0.5h
7	145.5	0.5h	16	78.8	0.5h
8	146.4	0.5h	17	142.8	0.5h
9	102.6	0.5h	18	187.5	0.5h

(3) Vehicle model information

Three types of vehicle models are used for circular pickup, each with different sizes, volumes, speeds, fixed departure costs, transportation costs, and single cycle time. The specific information is shown in Table 4.

Table 4. Vehicle Model Information Table

Vehicle model number	Size(m)	Volume (m^3)	Average speed per hour (km/h)	Fixed cost (RMB/time)	Transport cost (RMB/km)	Single maximum cycle time (h)
1	17.5×3×2.7	120	70	700	8	8
2	15.5×2.7×2.4	100	70	550	7	8
3	12.5×2.7×2.4	80	70	450	6	8

According to the driver's working hours, set the maximum single cycle time for each vehicle to not exceed 8 hours. Assuming that each vehicle type is traveling at a constant speed, with an average speed of 70km/h.

(4) Warehouse tiered price

The picking frequency of each route has a certain impact on the management cost of the warehouse. The warehouse has set tiered prices based on the frequency of circular picking routes, and different frequency intervals correspond to different prices. The specific prices are shown in Table 5.

Table 5. Warehouse Ladder Price List

Type	Maximum frequency of the line (times)	Minimum frequency of the line (times)	Warehouse price（RMB/m^3）
1	-	6	7
2	6	3	6.8
3	3	2	6.3
4	2	1	6

(5) Operational restrictions

In order to reduce the difficulty of supplier management during operation and reduce operational risks, the number of suppliers visited per route is set to not exceed 6, and the maximum number of daily cycles per route is not more than 8.

4.2. Algorithm implementation

Through extensive computational verification, this article sets the main parameters of the genetic algorithm as follows: the population size is 40, the number of championship groups is set to 5, each group has 8 chromosomes, and the maximum number of fitness function calculations is 8000 times. The algorithm iteration results are basically convergent.

When using multiple vehicle models for cyclic pickup, the solution results in 5 routes, with each route picking frequency ranging from 3 to 6 times. The average loading rate calculated by vehicle model and frequency is 98%. The solution results are shown in Table 6, and the route planning is shown in Figure 1.

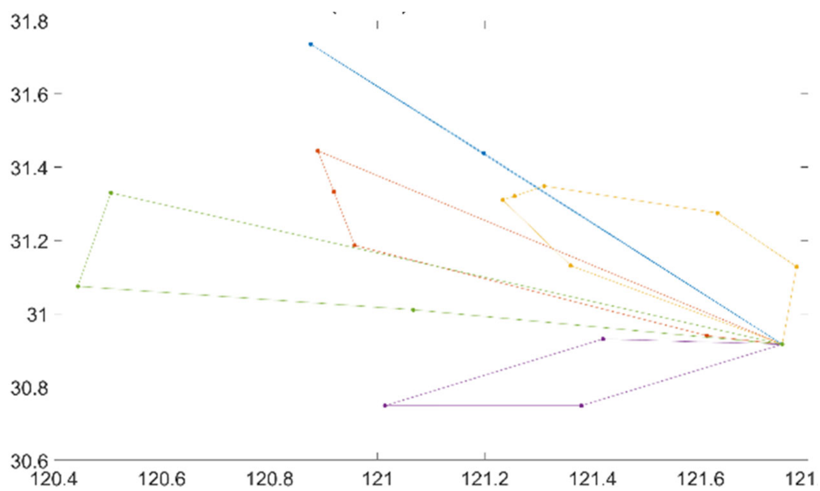

Figure 1. Hybrid vehicle cycle pickup roadmap

Table 6. Hybrid vehicle cycle pickup route information

Line number	Pickup sequence	Vehicle model	Pickup frequency	Inventory Price (RMB/m³)	Loading rate
1	0-18-3-0	2	3	6.3	96%
2	0-10-17-6-7-0	3	6	6.8	99.5%
3	0-14-12-16-2-4-13-0	1	3	6.3	96.9%
4	0-15-8-9-0	2	3	6.3	96.5%
5	0-11-5-1-0	1	4	6.8	99.6%

4.3. Result analysis

In the supplier direct delivery mode, each route is delivered by a single vehicle model. The vehicle model, loading rate, and inventory price information for each route are shown in Table 7, and the transportation route is shown in Figure 2.

Table 7. Supplier Direct Delivery Line Information

Line number	Pickup sequence	Vehicle model	Pickup frequency	Inventory Price (RMB/m³)	Loading rate
1	0-1-0	3	2	6	66.8%
2	0-2-0	3	1	6	92.8%
3	0-3-0	1	1	6	83.7%
4	0-4-0	3	1	6	87.6%
5	0-5-0	2	2	6	91.7%
6	0-6-0	3	2	6	88%
7	0-7-0	3	2	6	90.9%
8	0-8-0	3	2	6	91.5%
9	0-9-0	3	2	6	64.1%
10	0-10-0	2	1	6	48.6%
11	0-11-0	2	2	6	93.9%
12	0-12-0	3	1	6	54.5%
13	0-13-0	3	1	6	47.8%
14	0-14-0	3	1	6	54.8%
15	0-15-0	3	1	6	50.8%
16	0-16-0	3	1	6	98.5%
17	0-17-0	3	2	6	89.2%
18	0-18-0	2	2	6	93.8%

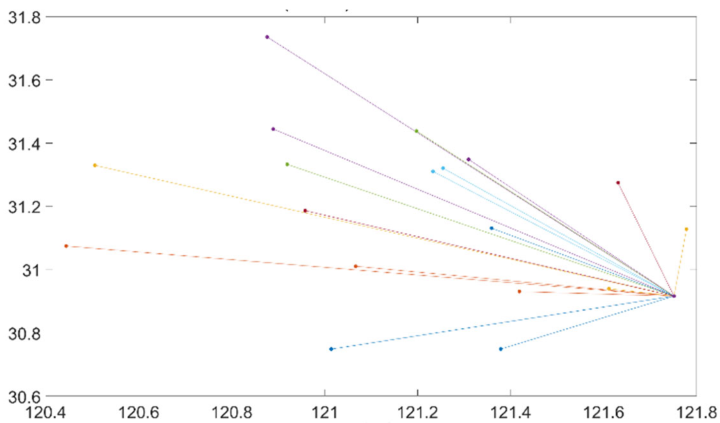

Figure 2. Supplier Direct Delivery Route Map

The comparison of key indicators for each project between the supplier direct delivery mode and the circular pickup mode is shown in Table 8.

Table 8. Comparison of key indicators under two modes

Supply mode	Number of transportation vehicles (vehicles)	Average loading rate (%)	Transport mileage (km)	Total rental volume of warehouse (m³)	Total cost (RMB)
Direct delivery	26	80.4%	2515	1210.1	42933
Milk run	19	98.0%	1043.6	507.9	34936
Optimization amplitude (%)	26.9%	17.6%	58.5%	58.0%	18.6%

Note: Average loading rate=total cargo volume of all suppliers/total volume of all operating vehicles

Total rental volume of the warehouse=total single pickup volume of all routes

From the above table, it can be seen that compared to the supplier direct delivery mode, the circular pickup mode greatly improves transportation efficiency and reduces logistics costs, which is reflected in the following aspects: the average loading rate of the fleet has increased from 80.4% to 98%, an increase of 17.6%; The total transportation mileage decreased from 2515km to 1043.6km, a reduction of 58.5%; The total cost decreased from 42933 yuan to 34936 yuan, saving 18.6%. The total rental volume of the warehouse has increased from the original 1210.1 m^3 Lowering to 507.9 m^3, Reduced by 58%. The number of transportation vehicles decreased from 26 to 19, a decrease of 26.9%.

5. Summary

Many existing studies on the optimization of cyclic picking paths only consider rigid inventory costs and single vehicle types, often overlooking the impact of tiered warehousing prices and multiple vehicle types on transportation schemes. This study investigates the vehicle path optimization problem for cyclic picking, taking into account inventory costs and multiple vehicle types. A genetic algorithm is designed and employed to solve the problem, and the effectiveness of the method is validated using real-world data. The experimental results demonstrate that compared to the direct delivery mode, the cyclic picking mode can optimize the automotive parts inbound logistics in terms of operational efficiency and cost. Additionally, considering tiered warehousing prices and multiple vehicle types enhances the feasibility of the cyclic picking scheme.

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