Research on Optimization of Delivery and Pickup Vehicle Routing Problems Considering Cargo Loading

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Abstract: ***The VRP is a well-known combinatorial optimization problem in transport and logistics distribution. Customers require simultaneous pickup of goods from their location and the delivery of goods to their place in some cases. The cargo loading problem plays an essential role in physical distribution. The weight and volume of the vehicle are effectively used so that freight is reasonably loaded with as many goods as possible. A reasonable loading plan can improve the load and space utilization ratio of cars, reduce the logistics cost of distribution enterprises, and increase their competitive capacity. Therefore, the vehicle routing problem and cargo loading have gotten the great attention of logistics scholars and enterprises, and both belong to NP-hard problems. This paper presents a mathematical formulation and genetic algorithm method for solving a vehicle routing problem with simultaneous pickup and delivery and cargo loading (VRPSPD-CL), was analyzed the theory of logistics distribution optimization problem as a case study. The calculation example data was selected to analyze the actual problem of VRPSPD with cargo loading. The paper selected the genetic algorithm to solve the problem and improved GA and the basic genetic algorithm to get the optimal solution for the simulation experiment. Then, the paper concretely designs every step in the algorithm to make the algorithm compact, efficient, and fit, to solve the VRPSPD with cargo loading optimization, and a mathematical model was established. At the same time, MATLAB software is adopted to solve a related practical problem. Finally, the results obtained show the optimal objective function iteration value of the simulation experiment was satisfactory by the improved GA compared with the basic GA for the VRPSPD cargo loading with the simulation.***

Keywords: Vehicle Routing Problem, Cargo loading and unloading,Logistics Distribution, Improved Genetic Algorithm

1. Introduction

With the rapid economic development today, logistics has become the Third Source of Profit[1]. In recent years, transportation costs are becoming the primary concern of logistics companies, especially companies in the developing logistics industry, such as in China. Companies have recognized the modern logistics sector, driven by globalization and information technology. Logistics plays a more critical role in developing the social economy, attracting more and more attention from people. A principal component of logistics; is that logistics distribution has gradually increased due to its distribution cost**.** As a result, optimizing logistics, distribution, and transportation and reducing transportation costs are important ways for companies,especially logistics and distribution companies, to improve their competitiveness [2].

The vehicle routing problem with delivery and pickup (VRPDP) has been a vital optimization problem in transport and logistics distribution. Choosing an effective distribution route under constrained conditions will help logistics companies increase their profits and help to reduce distribution costs also urban traffic congestion. Vehicle routing and cargo loading are among the most studied combinatorial optimization problems in transport and logistics. Optimizing vehicle routes for deliveries and pickups with cargo loads is a complex task that requires the consideration of different aspects and constraints [3]. Many activities in freight transportation involve two fundamental optimization issues that have been intensively studied in the last decades: finding the optimal routes to deliver goods and determining the best way to load such goods on the vehicles used for transportation. This research is motivated by a real-life application pickup and delivery problem. Since the classical VRP-PDP and cargo loading are NP-hard optimization problems, the combination of these three variants is certainly NP-hard [4]. Therefore, the main contribution of this paper is the development of a fast and straightforward heuristic to solve the VRP and cargo loading.The combination of vehicle loading and routing problems is a relatively recent research domain. Although there are many research papers on loading problems, there remain many new topics regarding practical aspects of the problem.

We consider complex combinatorial optimization problems arising in transportation logistics when one is interested in optimizing vehicles' routing and the loading of goods into them. The different problems (Routing, Loading, Delivery, and Pickup) are already NP-hard and very difficult to solve in practice. Some exact methodologies have also been developed to solve small-sized problems [5].

The objective of this study was to findthe best possible loading configuration to minimize cargo volume and mass capacity to maintain space utilization inside the vehicle and know the total number of goods needed to be loaded and unloaded at each demand point. In simultaneously picking up and delivering, the vehicle picks up the goods from the distribution center and delivers them to customers; after the vehicle finishes the delivery, simultaneously vehicle returns with a specific demand of volume and mass of cargo. To resolve VRPDP with cargo loading problem, a heuristic algorithm is proposed.Therefore, a mathematical model proposed by Toth and Vigo (2002) was adapted for the VRPDP with cargo loading from the inherent problem's characteristics

2. Literature Review

In recent years, environmental issues have beenintegrated into combinatorial optimization problems, such as the Vehicle Routing Problem with simultaneous delivery and pickup with cargo loading (VRPDP-CL). The VRP was first introduced by Dantzig and Ramser (1959)[6].The goal is to find the minimum cost of travel (e.g., distance or time). Each customer is visited and serviced once by a vehicle.The VRP is related to one of the most extensively studied combinatorial optimization problems, the Travelling Salesman Problem (TSP), which was first considered by Menger (1932).Cargo loading problem, which means that under certain constraints, load the goods required by different customers in a reasonable single layer in the vehicle under the premise of not exceeding the vehicle loading limit (load capacity, volume, compartment size) to maximize the load capacity and volume utilization of the vehicle. The loading space of each vehicle is embedded in the first octant of acartesian coordinate system so that the length, width, and height of the loading space lie parallel to the $x-$, $y-$, $z-$ axis, respectively.

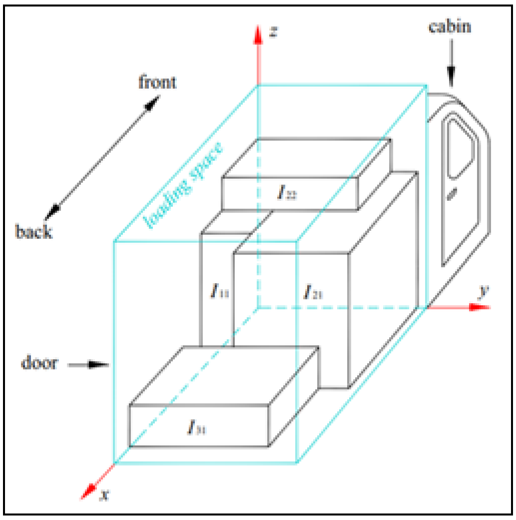

Figure 1: Loading space of a vehicle with placed boxes

The cargo loading problem in distribution centers should consider several factors such as vehicles, distribution centers, customers, constraints, weights and dimensions of each piece of cargo, and the loading and unloading location.

This paper analyzed the cargo loading and unloading problems, which refers to loading a batch of goods into the carriages suitable for the model according to the appropriate loading method under some constraints. Products are loaded and unloaded at a certain point. The vehicle loading rate can be maximized to meet the distribution requirements.Due to the different proportions of cargo, volumes, and mass of the goods to be distributed, the volume and mass of cargo should be considered when loading the vehicle so that vehicle space can be effectively utilized. The main problem is to increase the vehicles' loading capacity in terms of volume and mass of cargo as much as possible under the premise of thoroughly ensuring the quality and quantity of goods in good condition to improve the utilization rate of vehicles, save transportation capacity and reduce distribution costs.Generally, when the delivery quantity of a single customer cannot meet the effective load of the vehicle, the delivery goods of other customers on the unified distribution route should be loaded together to improve the utilization rate of vehicle capacity. This way can improve distribution efficiency and reduce the distribution cost through practical stowage.

1) Optimal pickup and delivery with two-dimensional loading/unloading constraints

In recent years, cargo loading and routing problems have received some attention. A review on the combination of routing problems and loading/unloading constraints was introduced by Iori and Martello and, more recently, by Polaris et al.[7].In-vehicle routing problems with two-dimensional loading constraints, the items are stackable 2D rectangular boxes that must be placed inside a vehicle's 2D loading space. The restrictions related to the container refer to the container or vehicle in which the items are placed. The restrictions related to the load are related to the result of the packaging process. Examine the value of integrating the loading decisions instead of solving routine and loading sequentially.

The loading/unloading constraint is the following: (1) while loading/delivering items of customers, there must not exist items of other clients blocking the way in/out of the items of the current client[7]; (2) the loaded cargo can be mixed; (3) the center of gravity of the loaded cargo is the geometric center; (4) The goods to be loaded cannot be suspended in the express vehicle compartment;(5) The capacities (weight and volume) of vehicles need to be respected; (6) *Unloading sequence constraint.* When a customer $i\ (i=1,\ldots n)$ is visited, it must be possible to unload all his boxes $I_{ik}(k=1,\ldots,m_i)$ exclusively using movements parallel to the longitudinal axis of the loading space[8]. According to the determined pickup and delivery route, all products' unloading or loading sequence in a truck is known in advance.*(7) Weight limits constraint;* Each box I_{ik} has a positive weight $d_{ik}(i=1,\ldots n\ \ k=1,\ldots m_i)$ The total weight of all the boxes placed in a vehicle must not exceed the maximum load weight of the vehicle.

2) Model assumptions of vehicle loading

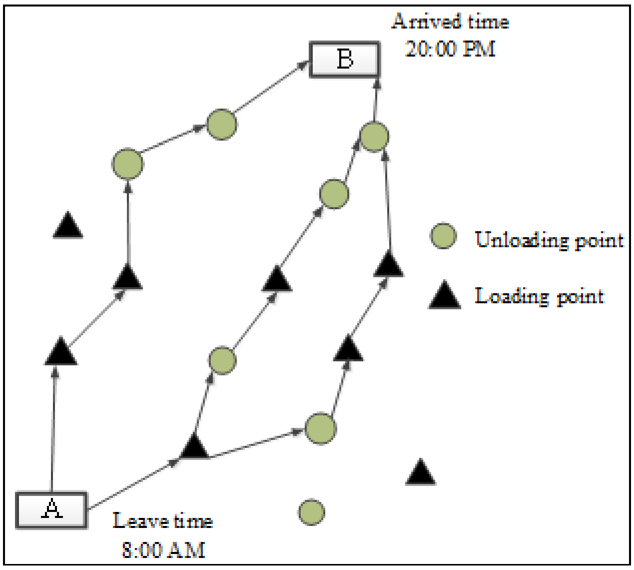

Figure 2: Vehicle loading model

1) Defined the city where the vehicle is located at depot A and also defined the resource-based city to be returned to depot B;
2) A freight vehicle is leaving depot A with no load, and there are several customer points with their cargo on the road network;
3) Each customer has a specific amount of cargo and a specific time window for receiving services;
4) Consider the cost of fuel, tolls, and time penalties;
5) After going through all the customer points, earning a profit, and completing the delivery tasks, the empty car returns to the final deposit B;

Unlike the traditional vehicle routingproblem, not all customer points are suppliedby freight vehicles from depot A to B. Some customer locations are too far away or have insufficient cargo volume, and they will not be selected for completion. However, not all freight vehicles complete their transportation jobs through clientlocations, its transportation tasks do not. Some vehicles may return to depot B when they are empty to maximize the transportation enterprise's total benefits.

3) Vehicle routing problem with simultaneous pickup and delivery with cargo loading

This paper describes a vehicle routing problem with simultaneous pickup and delivery—cargo loading.Customers require simultaneous pickup of goods from their location. In addition, the goods first need to be loaded into the vehicle before delivery to their location, and each vehicle can load and unload products simultaneously; the vehicles have a maximum load cargo mass capacity and maximum volume capacity, which must be monitored with fluctuating loads, as pickups and deliveries are performed by the exact vehicle during a single route as illustrated in Fig 3. Some routes are sought for v number of vehicles with C units' homogenous capacity, which minimizes the total transportation cost of routes while simultaneously satisfying the pickup and delivery demands of the n number of customer nodes.This illustration of VRPSPD with cargo loading involves eight customers and one depot. A total of three vehicles travel along the routes to service customers. Each customer has two different types of cargo demands of mass:delivery and pickup. Each type of demand mass consists of five different products. Red arrows represent pickup; green arrows represent deliveries in customer nodes; Each vehicle has to depart and return with a specific demand of volume of cargo to the depot. Each customer node has to be visited exactly once by one vehicle. As an example of a route, a vehicle starts loading at the depot, delivers products 1., 5, with a mass of 155 kg, and picks up products 1., 5 as shown amounts at the node for customer 5. The vehicle continues its route to service customer 4 by delivering products 1., 5, the mass of products 103 kg. It picks up products 2, 4, and 5 as shown, and the vehicle will end the route at the depot. Some points will only consider it pick up and not deliver. In contrast, others will only consider delivering, not picking up, so they will not complete the service, as shown in figure 3.

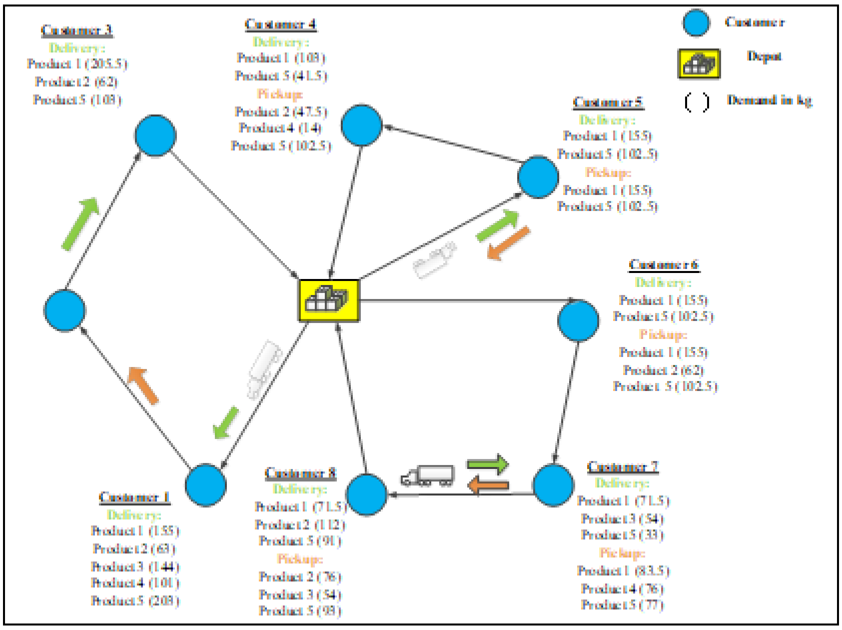

Figure 3: Illustration of VRPSPD and loading eight with customers and five products

4) Problem description of VRPSPD with cargo loading and model foundation

a) Problem description

According to the combined optimization of the vehicle routing problem simultaneous pickup and delivery with cargo loading established in this paper, the problem is selected: A distribution center has 30 customer nodes andis served with simultaneous pickup and deliveries,loading, and unloading at locations. There are currently 6 trucks that can be dispatched. The types of vehicles are different, with the same maximum load capacity of 100 units. The rated load mass capacity and rated maximum volume of each vehicle are shown in table 1.Coordinate demand of pickup and delivery cargo loading and unloading for 30 customer points is shown in tables 2 and 3 of 30 customers and is distributed in the two-dimensional coordinate plane of (-100, 100). The distribution center is located at the coordinate origin (0, 0). The transportation network between each customer is completely connected. The specific distribution positions of the customers can be seen in figure5**;** the positions of two customers, i and j, are divided into (x_i, y_i) and (x_j, y_j). The distance between the two customers $d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$ d_{ij} represents the vehicle travel distance between customers i and j. The MATLAB program solves the exact test data for the calculation example, and the appropriate vehicle must be selected to determine the vehicle's route so that the loading utilization rate of the vehicle and driving route is comprehensively optimized. The values of the model's relevant parameters are as follows: the traveling cost per unit distance is C=2.5 yuan/km, and the value per unit cargo is C_k = yuan/unit.

b) Model assumption

In addition, to establish a mathematical model to describe VRPSPD with cargo loading, the following assumptions:

1) Only one distribution center
2) The location coordinates of distribution centers and customer points are known.
3) Each vehicle can load/unload several materials simultaneously in any plant as soon as they arrive.
4) Vehicles have different volumes and load capacities, and the maximum load capacity and maximum volume are known.
5) If a customer has both delivery and pickup requirements, the customer will be unloaded first and then loaded.
6) All client nodes have the qualifications of simultaneous delivery and pickup;
7) The vehicle will not serve all nodes.
8) Each car can only serve one route.
9) All vehicles run at a standard speed.
10) Not all customers are satisfied
11) The demand for goods of each customer node is known.
12) The distribution distance of each vehicle is not more than the maximum travel distance;
13) Load/unloading pickup and delivery tasks can be simultaneously completed at the customer node.
14) Each vehicle will not exceed the entire load or the maximum load and loading capacity.
15) Each delivery vehicle must return to the depot after unloading the vehicle.
16) Products must be delivered within the specified time window.
17) The unloading time and the rest time of drivers are not considered.
18) All roads are smooth, regardless of exceptional circumstances such as traffic jams and congestion.

c) Parametersof VRPSPD with cargo loading

K - The total number of cargos to be loaded;
Q -The maximum load of the delivery vehicle;
G_k - Represents the rated load capacity of vehicle k;
H -Set of nodes (pick-up and delivery), {1,2…, n};
q_v - Capacity of the vehicle v, $q_v \in R^+$
g_h - Indicates the weight of the cargo h;
C_k – The transportation cost per unit mass or volume of cargo of vehicle K;
C: The traveling cost per unit distance of the distribution vehicle;
p_i – Pickup number of customers $j \in J$, $p_j \in Z^+$;
q_i - Delivery demand in the client node i;
N- Set of customersnodes;N= {N =0,1,2…, N};
h - Indicates the number of the goods h=1,2…H;
D_{ij} – Euclidean distance between two nodes costumers i=1, 2,..N, j=1,2,..N;
V_i - The total volume of goods required by each customer $i = 1, 2, ..., N$;
y_i^k - The load of vehicle k before leaving the node i;
T_{ij} - Travel time from node i to node j (excluding loading and unloading times);
L_j - Remaining load of a vehicle after having served customer;
T_{ki} – Arrival time at the customeri of k vehicle

$$IN_i = \begin{cases} 1 & \text{Cargo } i \text{ load into the Vehicle} \\ 0 & \text{Otherwise} \end{cases}$$

$$a_{ih} = \begin{cases} 1, & \text{Customer } i \text{ has demand for goods h;} \\ 0 & \text{Otherwise} \end{cases}$$

$$x_{ijk} = \begin{cases} 1, & \text{Vehicle k travels from customer i to j} \\ 0 & \text{Otherwise} \end{cases}$$

d) A mathematical model of VRPSPD considering cargo loading

The mathematical model explains a vehicle routing problem that combines pickup and delivery with cargo loading. VRPSPD and cargo loading can be set up for a single product distribution location. Only one distribution center existed.To establish a better VRPSPD with a cargo loading mathematical model, as shown below:

$$\min Z_1 = \sum_{i=0}^{L}\sum_{j=0}^{L}\sum_{k=1}^{k} dij\, X_{ijk} \quad (1)$$

$$\max Z_2 = \sum_{k=1}^{k}\left(\sum_{i=1}^{L}\sum_{h=1}^{H} a_{ih} g_h y_{ki} / \sum_{j=1}^{L} X_{ojk} G_k\right) \quad (2)$$

$$\max Z_3 = \sum_{k=1}^{k}\left(\sum_{i=1}^{L}\sum_{h=1}^{H} a_{ih} v_h y_{ki} / \sum_{j=1}^{L} X_{ojk} V_k\right) \quad (3)$$

$$L_{0v} = \sum_{i\in J_v}\sum_{j\in J} d_j X_{ijv} \forall v \in V \quad (4)$$

$$L_j \geq L_{0v} - d_j + p_j - M(1 - x_{0jv}) \forall j \in J, \forall v \in V \quad (5)$$

$$\sum_{k=0}^{k}\sum_{j=0}^{N} X_{ijk} \leq k, i = 0 \quad (6)$$

$$\sum_{i=1}^{N} X_{ki} V_1 \leq V, \quad \forall k \quad (7)$$

$$F_i \geq F_j \quad (8)$$

$$t_0 \geq e_0 \quad (9)$$

$$t_{ij} = d_{ij}, \forall i, j = 1, 2 \ldots, N, i \neq j \quad (10)$$

$$t_{kj} = \sum\sum X_{ijk}(t_{ki} + w_i + s_i + t_{ij}), j = 1, 2 .. N \quad (11)$$

$$w_i = \max\left[0, (e_i - t_{ki})\right], i = 1, 2 \ldots N \quad (12)$$

$$e_i \leq t_{ki} \leq l_i, i = 1, 2, \ldots N \quad (13)$$

$$\sum_{k=1}^{k} y_{ki} = 1, \quad i = 1, \ldots, N \quad (14)$$

$$p_i \geq 0, d_i \geq 0, Q \geq 0 \quad i \in R \quad (15)$$

$$\sum_{i=1}^{n} y_{i0}{}^{k} \leq Q . x_{i0}{}^{k}, \quad i, j \in R, k \in V, i \neq j \quad (16)$$

The various descriptions of the above models are as follows: (1) is the objective function, which means that the total distance of the vehicle is the shortest; (2) is the objective function, which means that the load utilization rate of the vehicle is the largest and indicating that the total mass of goods loaded on each vehicle does not exceed the carrying maximum load capacity of the vehicle; (3) is the objective function, which means that the volume utilization rate of the vehicle is the largest. The constraint (4) Initial vehicle loads; The constraint (5) Vehicle loads the after first customer; The constraint (6) Specifies that the number of vehicles starting from the distribution center cannot be exceeded k, showing that the number of routes selected from the distribution center should be returned to the distribution center. The constraint (7) means that the sum of the volume of cargo loaded by each customer on each route does not exceed the volume capacity; Formula (8) Boxes are classified into fragile and non-fragile boxes. The constraint (9) indicates that the delivery vehicle should start at 0 or later; constraint (10) is expressed by using Euclidean distance to calculate the customer's time to reach the customer point of the vehicle running time, the constraint (11) indicates that the time at which the customer arrives is equal to when the delivery vehicle leaves the customer from the last time plus the time it takes to arrive at the customer's point from the customer's point. Constraint (12) means that the customer has not yet appeared if the delivery vehicle arrives on time, the delivery vehicle will need to wait until the customer appears. Constraints (13) indicate that the time window constraints of the model should meet the needs of each customer. Constraints (14) mean that the goods of the same customer are loaded on the same express truck. Constraints (15) indicate that any customer point's pickup and delivery volume are non-negative, and the vehicle's maximum load capacity is not exceeded. Formula (16) suggests that the loading cargo volume of the distribution vehicle returning to the distribution center cannot exceed its maximum loading capacity.volume are non-negative, and the vehicle's maximum load capacity is not exceeded.

Model Processing

The three objective functions are directly applied for calculation. It will greatly increase the difficulty and complexity of the calculation. In order to improve the convergence and efficiency, the objective function is now processed, and the multi-objective problem is transformed into a single-objective problem for solution. The dimensions of these three objective functions are different.Toconvert them into a single objective problem, they must be normalized. Each objective functionmust be converted to less than 1, the objective function, then consider the weight of each sub-objective.

$$\max Z = \lambda_1 \frac{\sum_{i=0}^{L} d_{0i} + \sum_{i=0}^{L} d_{i0} - \sum_{i=0}^{N}\sum_{j=0, j\neq i}^{N}\sum_{k=1}^{k}(cd_{ij} + s_i c_u) X_{ijk}}{\sum_{i=0}^{L} d_{0i} + \sum_{i=o}^{L} d_{i0}} +$$

$$\lambda_2\left[\lambda_3\left(\sum_{k=1}^{k}\frac{\sum_{i=1}^{L}\sum_{h=1}^{H} a_{ih} g_h y_{ki}}{\sum_{j=1}^{L} X_{0jk} G_k} \div \sum_{k=1}^{k}\sum_{j=1}^{L} X_{0jk}\right) + \lambda_4\left(\sum_{k=1}^{k}\frac{\sum_{i=1}^{L}\sum_{h=1}^{H} a_{ih} v_h y_{ki}}{\sum_{j=1}^{L} X_{0jk} V_k} \div \sum_{k=1}^{k}\sum_{j=1}^{L} X_{0jk}\right)\right] \quad (17)$$

$\sum_{i=0}^{L} d_{0i} + \sum_{i=o}^{L} d_{i0}$ Indicates the total round-trip distance between the distribution center and all customers; $\sum_{i=0}^{N}\sum_{j=0, j\neq i}^{N}\sum_{k=1}^{k}(cd_{ij} + s_i c_u) X_{ijk}$ Indicates the total distance traveled and the total travel cost of vehicles participating in the delivery; $\sum_{k=1}^{k}\frac{\sum_{i=1}^{L}\sum_{h=1}^{H} a_{ih} g_h y_{ki}}{\sum_{j=1}^{L} X_{0jk} G_k}$ and

$\sum_{k=1}^{k} \frac{\sum_{i=1}^{L}\sum_{h=1}^{H} a_{ih} v_h y_{ki}}{\sum_{j=1}^{L} X_{0jk} V_k}$ Indicates that the total load utilization rate and the total volume utilization rate of the vehicle are the largest; $\sum_{k=1}^{k}\sum_{j=1}^{L} X_{ojk}$ Indicates the number of vehicles used in the delivery. λ_1 Represents the importance of the vehicle path in the combined optimization objective function, λ_2 represents the importance of cargo loading in the combined optimization objective function, λ_3 Indicates the importance of vehicle load utilization, λ_4 and indicates the importance of vehicle volume utilization. Then we have $\lambda_1 + \lambda_2 = 1, \lambda_3 + \lambda_4 = 1$. For λ_1 and λ_2 it can be seen from the objective function that $\sum_{i=0}^{L} d_{0i} + \sum_{i=o}^{L} d_{i0}$ compares with $\sum_{i=0}^{N}\sum_{j=0, j\neq i}^{N}\sum_{k=1}^{k}(cd_{ij} + s_i c_u) X_{ijk}$ much more significant, of which $\sum_{i=0}^{L} d_{0i} + \sum_{i=o}^{L} d_{i0}$ is definite $\sum_{i=0}^{N}\sum_{j=0, j\neq i}^{N}\sum_{k=1}^{k}(cd_{ij} + s_i c_u) X_{ijk}$ is our goal, $\frac{\sum_{i=0}^{L}\sum_{i=0}^{L}\sum_{i=0}^{N}\sum_{j=0, j\neq i}^{N}\sum_{k=1}^{k}(cd_{ij} + s_i c_u) X_{ijk}}{\sum_{i=0}^{L} d_{0i} + \sum_{i=o}^{L} d_{i0}}$ the value is small, so tobalance the importance of the vehicle path in the whole target, λ_1 and λ_2 to be big, for λ_1 and λ_2 The determination of the specific value can be continuously changed by experimental methods λ_1 and λ_2 value to determine the optimal parameter. For λ_3 and λ_4 the determination, the load can be determined according to the texture of the loaded goods. If the density of the goods is high, the load utilization rate of the vehicle should be improved. The value λ_3 is more significant; if the cargo density is smaller, the volume utilization rate of the vehicle should be improved, λ_4 value is more significant.

3. Research Methodology

The Genetic Algorithm (GA) was first proposed by Holland (1975). Due to its global search mechanism, GA has shown its capability to find suitable solutions for complex mathematical problems, like the VRP and other NP-hard problems, in a reasonable amount of time.

We selected GA as widely used to solve the problem because the genetic algorithm can effectively solve the combinational optimization problem, has good searching performance, and is easy to implement. The genetic algorithm is widely used in the optimization calculation of complex systems because of its unique intelligence and essential parallelism; It is a reliable search algorithm. These methods do not guarantee finding the optimal solution but offer an acceptable approximate solution in a reasonable time.This paper implemented appropriate software to write the program that can realize the algorithm quickly and accurately. Many software can be used torealize genetic algorithms, such as MATLAB, VC++, C, and Delphi. However, MATLAB has apparent advantages, considering the need to use many random numbers to implement the genetic algorithm. After analyzing and comparing this software, we finally used MATLAB software to write the genetic algorithm program. The heuristic algorithm does not require that an exact optimal solution must be obtained in the problem's solution, but rather an acceptable and better solution is expected to meet the requirements of solving practical problems. Therefore, this paper uses a heuristic algorithm to solve complex optimization problems

3.1The specific design of the genetic algorithm

GA is a simple, random-search, and general-purposeoptimization tool, which is motivated by the law of thenatural evaluation processes.The specific design of the genetic algorithmconsists of several stages: chromosomal encoding, initial population, fitness function, selection operator, crossover operator, and mutation operator elements' design.

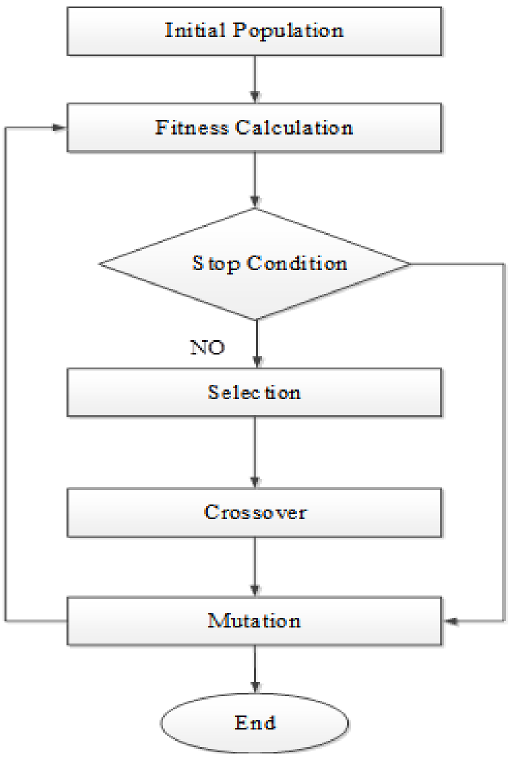

Figure 4: Flowchart of the genetic algorithm

Table 1: Rated load mass and rated volume of vehicles

Vehicle number	Maximum load cargomass capacity (kg)	C_k (kg)	Maximum cargo volume m^3	The total quantity of cargo Pickup/ Delivery
1	3000	5 yuan	16	5
2	3500	10 yuan	18	
3	4000	7.5 yuan	20	
4	4500	8 yuan	22	
5	5000	15 yuan	24	
6	5500	20 yuan	26	

Table 2: Coordinate delivery cargo loading demand required by 30 customer nodes (Unit: mass kg, volume m3)

Loading sequence	Customers	Coordinate		Good A		Good B		Good C		Good D		Good E		Total mass	Total volume
		X	Y	Mass	Volume	Mass	Volume	Mass	Volume	Mass	Volume	Mass	Volume		
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	81.205	−2.045	155	1.5	47.5	0.2	31	0.2	14	0.1	102.5	0.5	350	2.5
2	2	−68.68	−10.55	103	0.5	62	0.3	105	0.7	75.5	0.5	41.5	0.2	387	2.2
3	3	−34.615	−79.26	205.5	1	152	0.6	150.5	1	51.5	0.3	103	0.4	662.5	3.3
4	4	−88.765	41.87	29	0.1	153	0.6	77	0.5	101	0.6	52.5	0.2	412.5	2
5	5	−30.57	80.935	101	0.5	103.5	0.4	52	0.3	39.5	0.3	154.5	0.7	450.5	2.2
6	6	−72.69	−69.795	162.5	0.8	137	0.6	144	0.9	162	1	203	0.9	808.5	4.2
7	7	38.965	35.94	62	0.3	63	0.3	72.5	0.5	153.5	1	91	0.4	442	2.5
8	8	−36.58	31.015	71.5	0.3	104	0.4	121.5	0.8	72	0.4	122.5	0.5	491.5	2.4
9	9	90.04	−62.475	128	0.6	112	0.5	93	0.6	62.5	0.4	93	0.4	488.5	2.5
10	10	43.11	−76.2	62	0.3	76	0.3	54	0.3	41	0.3	72.5	0.3	305.5	1.5
11	11	17.25	61.825	78.5	0.4	82.5	0.3	62	0.4	103	0.6	93	0.4	419	2.1
12	12	−23.685	91.945	102.5	0.5	62	0.3	43	0.3	53.5	0.6	81.5	0.4	342.5	2.1
13	13	58.1	−31.92	51.5	0.2	53	0.2	32.5	0.2	79	0.5	62.5	0.3	278.5	1.4
14	14	59.04	67.05	83.5	0.4	103	0.4	157	1.3	76	0.5	33	0.1	452.5	2.7
15	15	−7.625	−55.285	93	0.4	62.5	0.3	103.5	0.7	38	0.2	77	0.3	374	1.9
16	16	33.63	−14.62	170.5	1.6	52.3	0.2	34.1	0.2	15.4	0.1	112.8	0.5	385.1	2.6
17	17	−45.57	−0.32	92.7	0.5	55.8	0.2	94.5	0.6	68	0.5	37.4	0.2	348.4	2
18	18	−18.99	−72.135	164.4	0.8	121.6	0.5	120.4	0.8	41.2	0.3	82.4	0.4	530	2.8
19	19	−77.625	86.51	40.6	0.2	214.2	0.9	107.8	0.7	141.4	0.9	73.5	0.3	577.5	3
20	20	−94.64	56.865	111.1	0.6	113.9	0.5	57.2	0.4	43.5	0.3	170	0.7	495.7	2.5
21	21	−53.07	−53.175	130	0.6	109.6	0.4	115.2	0.7	129.6	0.8	162.4	0.7	646.8	3.2
22	22	27.89	20.865	80.6	0.4	98.8	0.4	70.2	0.4	53.3	0.3	94.3	0.4	397.2	1.9
23	23	−30.71	17.885	57.2	0.3	83.2	0.4	97.2	0.6	57.6	0.4	98	0.4	393.2	2.1
24	24	81.695	−70.82	76.8	0.4	67.2	0.3	55.8	0.3	37.5	0.2	55.8	0.2	293.1	1.4
25	25	35.44	−68.87	80.6	0.4	98.8	0.4	70.2	0.4	53.3	0.3	94.3	0.4	397.2	1.9
26	26	13.32	42.895	62.8	0.3	66	0.3	49.6	0.3	82.4	0.5	74.4	0.3	335.2	1.7
27	27	−13.125	85.005	123	0.6	74.4	0.3	51.6	0.3	64.2	0.8	97.8	0.4	411	2.4
28	28	42.54	−27.48	56.7	0.3	58.3	0.2	35.8	0.2	86.9	0.5	68.8	0.3	306.5	1.5
29	29	48.97	91.98	91.9	0.4	113.3	0.5	172.7	1.4	83.6	0.5	36.3	0.1	497.8	2.9
30	30	−0.055	−47.165	74.4	0.3	50	0.2	82.8	0.5	30.4	0.2	61.6	0.3	299.2	1.5

Table 3: Coordinates cargo unloading demand required by 30 customer nodes

Loading sequence	Customers	Coordinate		Good A		Good B		Good C		Good D		Good E		Total mass kg	Total Volume m^3
		X	Y	Mass	Volume	Mass	Volume	Mass	Volume	Mass	Volume	Mass	Volume		
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	81.205	–2.045	15.5	0.15	4.75	0.02	3.1	0.02	1.4	0.01	10.25	0.05	35	0.25
2	2	–68.68	–10.55	10.3	0.05	6.2	0.03	10.5	0.07	7.55	0.05	4.15	0.02	38.7	0.22
3	3	–34.62	–79.26	20.55	0.1	15.2	0.06	15.05	0.1	5.15	0.03	10.3	0.04	66.25	0.33
4	4	–83.77	41.87	2.9	0.01	15.3	0.06	7.7	0.05	10.1	0.06	5.25	0.02	41.25	0.2
5	5	–50.57	80.935	10.1	0.05	10.35	0.04	5.2	0.03	3.95	0.03	15.45	0.07	45.05	0.22
6	6	–72.69	–69.8	16.25	0.08	13.7	0.06	14.4	0.09	16.2	0.1	20.3	0.09	80.85	0.42
7	7	38.965	35.94	6.2	0.03	6.3	0.03	7.25	0.05	15.35	0.1	9.1	0.04	44.2	0.25
8	8	–36.58	31.015	7.15	0.03	10.4	0.04	12.15	0.08	7.2	0.04	12.25	0.05	49.15	0.24
9	9	90.04	–62.48	12.8	0.06	11.2	0.05	9.3	0.06	6.25	0.04	9.3	0.04	48.85	0.25
10	10	43.11	–76.2	6.2	0.03	7.6	0.03	5.4	0.03	4.1	0.03	7.25	0.03	30.55	0.15
11	11	17.25	61.825	7.85	0.04	8.25	0.03	6.2	0.04	10.3	0.06	9.3	0.04	41.9	0.21
12	12	–23.69	91.945	10.25	0.05	6.2	0.03	4.3	0.03	5.35	0.06	8.15	0.04	34.25	0.21
13	13	58.1	–31.92	5.15	0.02	5.3	0.02	3.25	0.02	7.9	0.05	6.25	0.03	27.85	0.14
14	14	59.04	67.05	8.35	0.04	10.3	0.04	15.7	0.13	7.6	0.05	3.3	0.01	45.25	0.27
15	15	–7.625	–55.24	9.3	0.04	6.25	0.03	10.35	0.07	3.8	0.02	7.7	0.03	37.4	0.19
16	16	33.63	–14.62	17.05	0.16	5.23	0.02	3.41	0.02	1.54	0.01	11.28	0.05	38.51	0.26
17	17	–45.57	–0.32	9.27	0.05	5.58	0.02	9.45	0.06	6.8	0.05	3.74	0.02	34.84	0.2
18	18	–18.99	–72.14	16.44	0.08	12.16	0.05	12.04	0.08	4.12	0.03	8.24	0.04	53	0.28
19	19	–77.68	86.51	4.06	0.02	21.42	0.09	10.78	0.07	14.14	0.09	7.35	0.03	57.75	0.3
20	20	–94.64	56.865	11.11	0.06	11.39	0.05	5.72	0.04	4.35	0.03	17	0.07	49.57	0.25
21	21	–53.07	–53.18	13	0.06	10.96	0.04	11.52	0.07	12.96	0.08	16.24	0.07	64.68	0.32
22	22	27.89	29.865	8.06	0.04	9.88	0.04	7.02	0.04	5.33	0.03	9.43	0.04	39.72	0.19
23	23	–29.71	17.885	5.72	0.03	8.32	0.04	9.72	0.06	5.76	0.04	9.8	0.04	39.32	0.21
24	24	81.695	–70.82	7.68	0.04	6.72	0.03	5.58	0.03	3.75	0.02	5.58	0.02	29.31	0.14
25	25	35.44	–68.87	8.06	0.04	9.88	0.04	7.02	0.04	5.33	0.03	9.43	0.04	39.72	0.19
26	26	13.32	42.895	6.28	0.03	6.6	0.03	4.96	0.03	8.24	0.05	7.44	0.03	33.52	0.17
27	27	–13.13	85.005	12.3	0.06	7.44	0.03	5.16	0.03	6.42	0.08	9.78	0.04	41.1	0.24
28	28	42.54	–27.48	5.67	0.03	5.83	0.02	3.58	0.02	8.69	0.05	6.88	0.03	30.65	0.15
29	29	48.97	91.98	9.19	0.04	11.33	0.05	17.27	0.14	8.36	0.05	3.63	0.01	49.78	0.29
30	30	–0.055	–47.17	7.44	0.03	5	0.02	8.28	0.05	3.04	0.02	6.16	0.03	29.92	0.15

(Unit: mass kg, volume m^3)

3.2 Randomly generate pickup and delivery demand

The pickup demand of the node is randomly generated based on the scope of the node's delivery demand and the maximum load weight of the vehicle for the specified customer's node, with both pickup and delivery considering the unloading procedure. This paper's VRPSPD and cargo loading/unloading test case data are specially generated and distributed according to the above principles. **0** represents the distribution center.

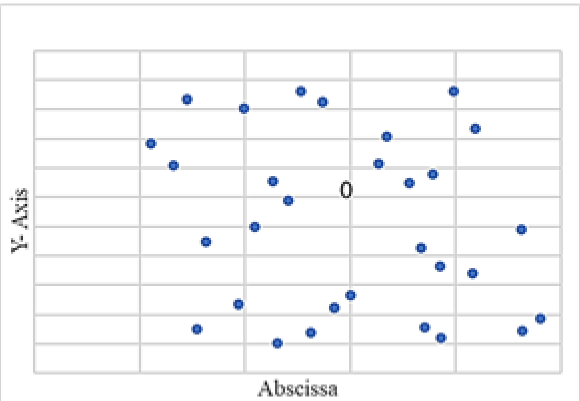

Figure 5: Scattergram of locations for 30 customers nodes

3.3 Model and genetic algorithm parameter settings

MATLAB is used to write an example program to measure the established model and the algorithm used in this paper. The measurement results illustrate the feasibility of the model and algorithm. As a result, the model to solve the problem and the genetic algorithm parameters are specified asfollows, based on the actual condition of the calculation example. The genetic algorithm's parameter settings are based on varying five parameters, and the specific parameter values are shown in Table 4.

Table 4: Genetic Algorithm parameter

Name of parameter	Value
Chromosome length	L= 100
Population size	Ps= 1200
Number of generations	Gn= 500
Crossover probability	Cp= 0.7 and 0.9
Mutation probability	Mp=0.005 and 0.01

4. Analysis of test results

According to the improved genetic algorithm designed in chapter 5, MATLAB 9.0 runs on a computer with an Intel Core i7-4800 CPU 2.70 GHz and 8GB of RAM of memory, windows 10 XP operating system. The optimal solution value and corresponding vehicle route can be obtained by solving the VRPSPD and cargo loading model established in this research. This paper conducted five simulation experiments for the example calculation to make the result more scientific and practical. The program quickly obtained the optimization results and finally generated four distribution routes. The main optimization results of the program are shown inTable 5.

Table 5: The optimal solution for **GA**instance of 30 customers

Vehicle numbers	Number customers	Delivery volumes	Return volume	Delivery of mass	Return mass	Maximum loading capacity	Maximum cargo volume	Distance travelled (Km)	Departure time (Hours)
2	7	15.10m^3	1.51m^3	2838.40kg	283.84kg	3500 kg	18 m^3	271.964815	10:00
6	8	23.20m^3	2.32m^3	4584.00kg	458.40kg	5500 kg	26 m^3	488.547590	10:00
4	9	19.10m^3	1.91m^3	3416.50kg	341.65kg	4500 kg	22 m^3	562.008147	20:00
3	6	11.50m^3	1.15m^3	2140,00kg	214.00kg	5000 kg	20 m^3	389.165936	15:00
Total	30	68.9 m^3	6.89 m^3	12,978.9kg	1,297.89	18,500	86 m^3	1711.6865	

Table 6: Results of each delivery vehicle cargo loading of demand locations (Mass kg, volume m^3)

Vehicle	Product A		Product B		Product C		Product D		Product E	
	m	v	m	v	m	v	m	v	m	v
2	580.9	2.8	550.7	2.3	470.4	3	581.9	4.2	654.5	2.8
6	944.1	4.6	1104.8	4.5	824.1	5.3	709.7	4.5	1001.3	3.1
4	956.8	6.2	641.3	2.8	864.3	4.3	421.8	2.7	712.3	3.1
3	420	1.9	453.6	1.8	534.4	3.9	386.9	2.5	334.7	1.4

Table 7: Results of unloading cargo in-demand locations (mass kg, volume m^3)

Vehicle	Product A		Product B		Product C		Product D		Product E	
	m	v	m	v	m	v	m	v	m	v
2	58.09	0.28	55.07	0.23	47.04	0.3	58.19	0.42	65.45	0.28
6	94.41	0.46	110.48	0.45	82.41	0.53	70.97	0.45	100.13	0.43
4	95.68	0.62	64.13	0.28	68.43	0.43	42.18	0.27	71.23	0.31
3	42	0.19	45.36	0.18	53.48	0.39	39.69	0.25	33.47	0.14

Tables (5), (6), and (7) above show 30 customers' calculation optimization results of pickup and delivery cargo loading and unloading of demand locations obtained.Moreover, the experiment used four vehicles to serve 30 customers, and the speed for each vehicle was 60 min/h. The four optimal delivery distribution routes result(Vehicle 2 route1)0—>8—>12—>27—>11—>7—>22—>26—>0 (Vehicle 6 route 2) 0—>18—>3—>6—>21—>19—>5—>20—>4—>0 (Vehicle 4 route 3)0—>2—>15—>16—>25—>24—>9—>1—>17—>23—>0 (Vehicle 3 route 4) 0—>30—>10—>13—>28—>14—>29—>0. The total travelling cost of 4 vehicles is 4,279.1 yuan/km, transportation cost of 5 cargo per mass is 67.85 yuan/kg. The total distribution cost is 4,346.95 yuan, and the average distribution cost for each vehicle is 1,086.7 yuan. The optimal distribution solution route is shown in figure 6.

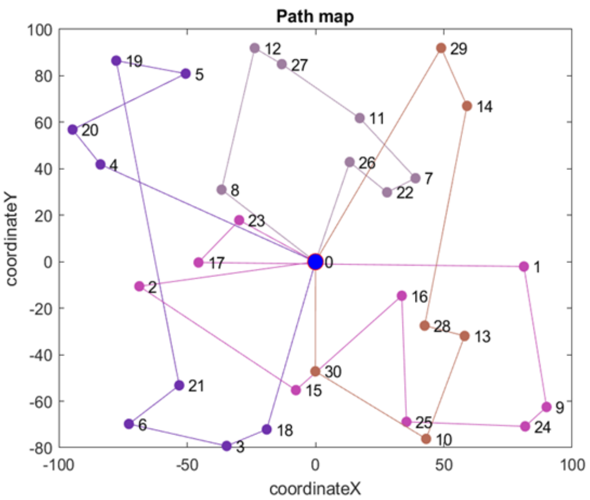

Figure 6: Path Diagram Optimal Solution for Vehicle Routing Delivery Based on the Improved GA

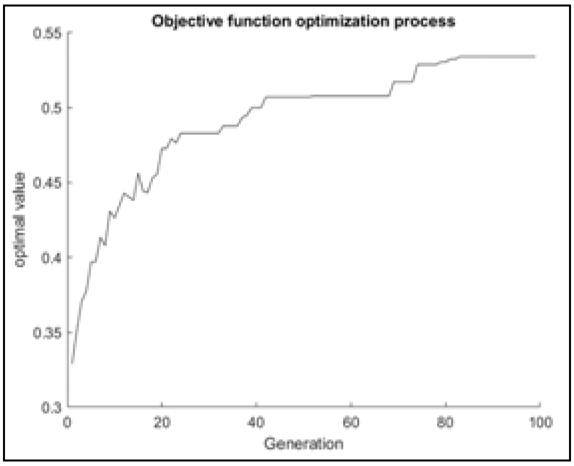

Figure 7: Graph of Iterative Process of the Optimal Soluion based on the improved GA

The above figure 7the trend shows that the objective function fitness increases with the number of iterations; between the 20th generation and the 43th generation, the function fluctuates slightly, but it is generally stable. The optimization curve is a straight line after the number of iterations reaches 48. The system's objective remains unchanged, the algorithm has converged, the system is stable, and the overall result of the objective function optimization value is 0.53404. The change of the objective function in the figure shows that the algorithm has converged well. The convergence of the fitness function shows the feasibility of the improved genetic algorithm.

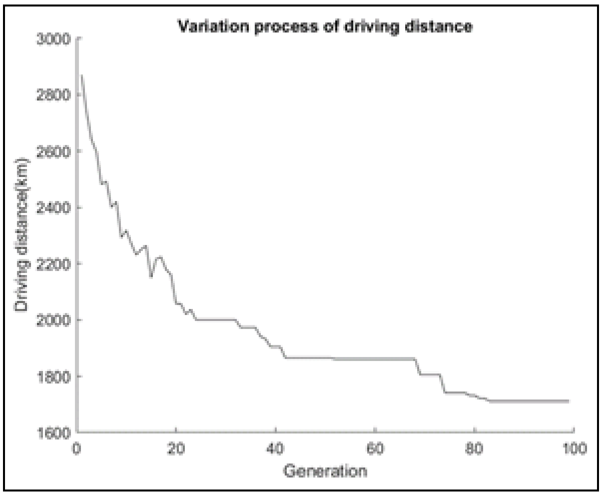

Figure 8: Diagram of the total travel distance and generation of the vehicle based on the improved GA

As shown in figure 8 above, the optimization curve changes relatively slowly in the graph at the beginning process. As the optimization process proceeds, the change of the optimization curve starts to become relatively stable after 44 generations. It converges to the optimal solution to the problem in the 85th generation. Since the initial population is randomly generated, the population fitness at the initial stage of the optimization process is good, so the obtained solution is relatively good.The optimization result of the total driving distance is 1711.6865km.

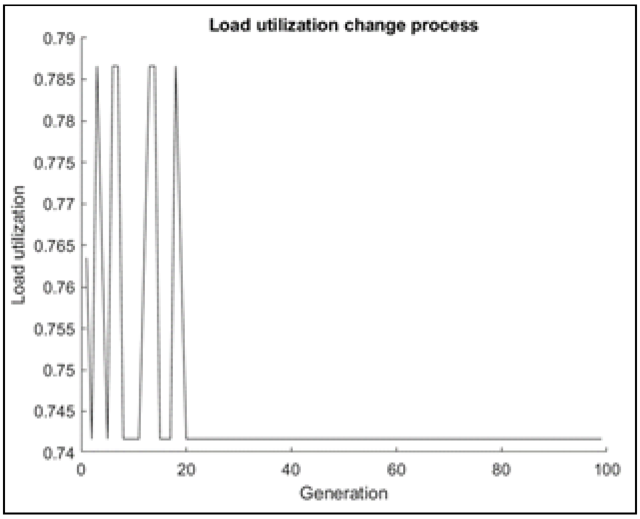

Figure 9: Variation trend graph of total cargo load utilization rate based on the improved GA

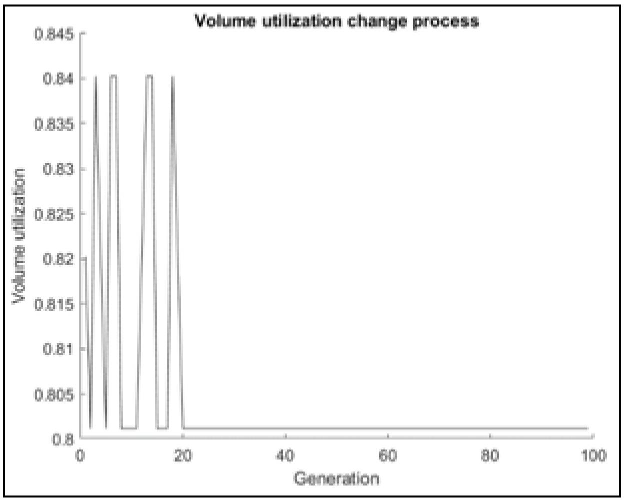

Figure 10: Graph of the change trend of total vehicle volume utilization rate based on the improved GA

Figure 9 and figure 10 have very similar trends. In the early 20th generation, the quality of the solution was compared to good, the total vehicle load utilization ratio fluctuated between 0.8 and 0.84, and the total vehicle volume utilization ratio fluctuated between 0.75 and 0.785; when iterating to generations 0 to 20, the total vehicle load utilization ratio fluctuates around 0.785, the total volume utilization rate of the vehicle fluctuates around 0.84; the curve has a significant leap in the 100th generation. From the 20th generation, the fluctuation of the solution tends to be stable and reaches the optimum in the 100th generation. The total vehicle cargo load utilization rate curve and the total vehicle volume utilization rate curve leapt in the 100th generation. With the increase in vehicle load utilization and volume utilization rates, fewer vehicles will decrease. The optimization result of the total vehicle load utilization rate is 0.74165, and the optimization result of the total vehicle volume utilization rate is 0.80116.

5. Comparison with genetic algorithm and improved genetic algorithm

To verify the superiority of the improved genetic algorithm designed in this paper, the basic genetic algorithm is used to solve the above example on the same computer and with the same calculation example to compare and analyze the solution results of the two algorithms. To ensure the comparability of the algorithms, the model parameters and genetic algorithm parameter settings in the basic genetic algorithm solution process are consistent with the parameter settings in the improved genetic algorithm solution process, as described in table 4.Under the same conditions, the optimal value solution of the basic genetic algorithm and the path allocation scheme obtained from the five simulation experiments are shown in figures (11), (12),(13) and (14) respectively. The comparison of the convergence process of the optimal value solutions of the two algorithms is shown in figure 14 Show.

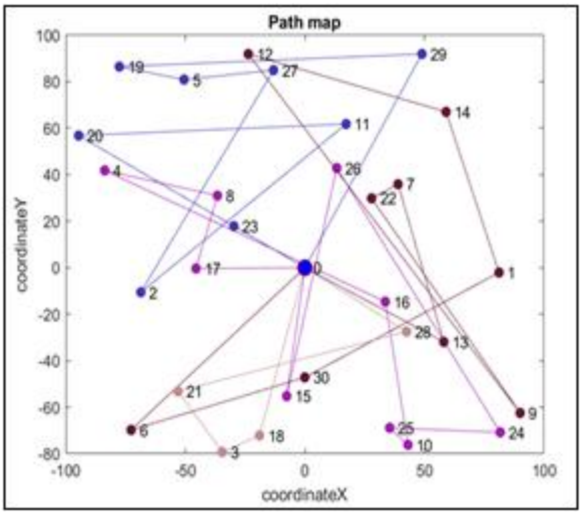

Figure 11: Path Diagram Optimal Solution for Vehicle Routing Delivery Based on the

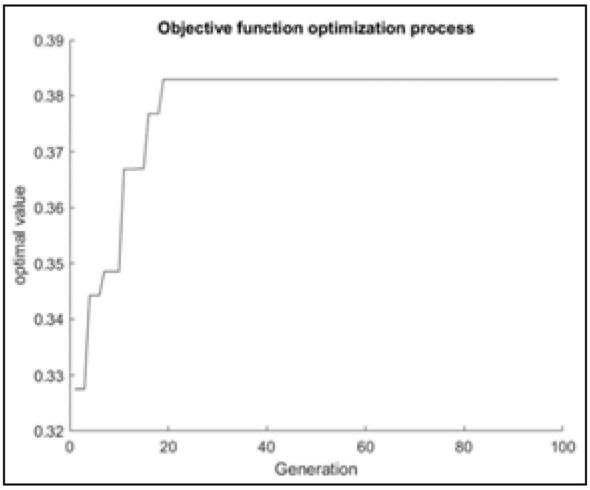

Figure 13: Graph of Iterative Process of the Optimal Solution based on Genetic Algorithm1

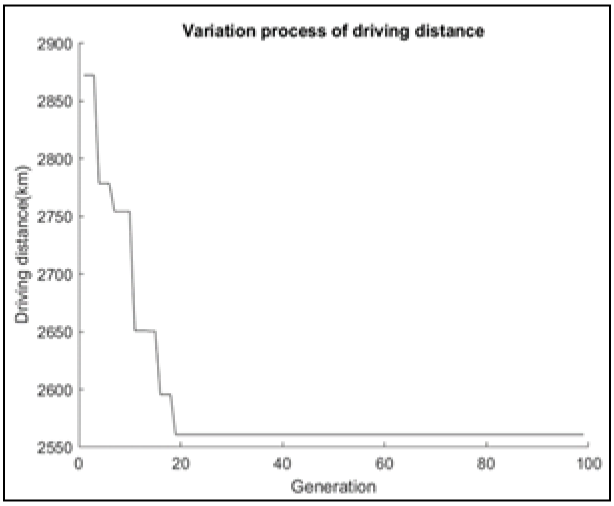

Figure 12: Diagram of the total travel distance and generation of the vehicle based on Genetic Algorithm

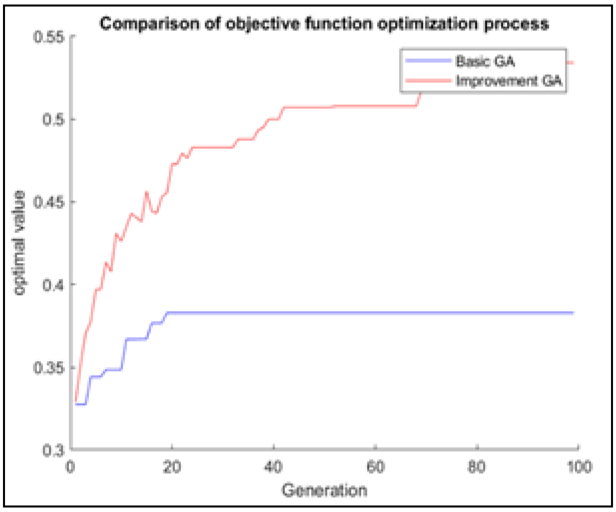

Figure 14: Graph of Comparison of the Optimal Solution on the Basic GA and the Improved GA

It can be seen from figure 14 that the algorithm based on the traditional roulette selection operator has relatively large fluctuations and a slow convergence speed, and it begins to become relatively stable after about 43 generations. However, the sorting-based multi-round roulette selection operator used in this paper has improved the performance of the algorithm. Compared with the basic roulette operator, the convergence speed is faster, and it tends to be relatively convergent at about 28 generations.

Table 8: Optimal Solution Based on Genetic Algorithm Instance of 30 Customers

Vehicle numbers	Number customers	Delivery volume	Return volume	Delivery of mass (kg)	Return of mass (kg)	Maximum loading capacity	Maximum cargo volume	Distance travelled (km)	Departure time (Hours)
3	9	17.40 m^3	1.74m^3	3342.50	334.25	4000 kg	20 m^3	664.865634	15:00
6	9	21.30m^3	2.13m^3	3858.90	385.89	5500 kg	26 m^3	881.265127	10:00
5	8	19.30m^3	1.94m^3	3631.70	363.17	5000 kg	24 m^3	741.431345	8:00
1	4	10.80m^3	1.08m^3	2145.80	214.58	3000 kg	16 m^3	273.365323	20:00
Total	30	68.9 m^3	6.89m^3	12,978.9	1,297.89	17.500	86 m^3	2560.9274	

The four optimal delivery distribution routes result of genetic algorithm; (Vehicle 3 route 1) 0—>17—>8—>4—>16—>10—>25—>24—>26—>15—>0(Vehicle 6 route 2) 0—>13—>7—>22—>9—>12—>14—>1—>30—>6—>0(Vehicle 5 route 3) 0—>29—>19—>5—>27—>2—>11—>20—>23—>0(Vehicle 1 route 4) 0—>18—>3—>21—>28—>0. The total travelling cost of 4 vehicles is 6,402.1 yuan/km, transportation cost of 5 cargo per mass is 2,205.72 yuan/kg. The total distribution cost is 8,607.82 yuan, and the average distribution cost for each vehicle is 2,151.955 yuan.

Table 9: Results camparison of two methods

	Genetic Algorithm	Improved GA
Objective function value	0.38295	0.53404
Iteration	20	48
Distance	2560.9274 km	1711.6865 km
Traveling Cost	6,402.1yuan/km	4,279.1 yuan/km
Transportation cost of cargo	2,205.72	67.85 yuan/cargo

The result of the optimal objective function value obtained by the improved genetic algorithm designed is also more ideal, which meets the actual demand for low transportation costs, and low traveling cost. Therefore, the improved genetic algorithm designed in this paper solves the problem of VRPPD and cargo loading, and has beer performance than the basic genetic algorithm, and the algorithm is effective and feasible but is not firmly proved.

6. Conclusion

This paper investigated two problems considered combinatorial optimization problems arising in transportation logistics. The combined optimization problem of VRPSPD with cargo loading in this paper is based on the classical laden vehicle routing and two-dimensional cargo loading stowage problems, and the two are successfully unified. Therefore, this combinatorial optimization problem has strong pertinence, different from the existing similar integrated optimization problems. A heuristic algorithm is currently a widespread method for solving vehicle routing problems and cargo loading. It is also a relatively effective method. The crossed parameters, variables, and case studies in VRPSPD with cargo loading models are unified in this model, making the model concise and clear.The primary constraint of VRPSPD with cargo loading, as described in this paper, the objective was to find enough space load utilization to load items into the vehicle and volume utilization and find optimal distribution routes. Therefore, the vehicle can transport a specific demand of products todeliver at different locations. After delivery, the vehicle returns with a specific volume and mass of cargo.We developed a genetic algorithm, and a mathematical model of VRPSPD with cargo loading was designed to solve the actual problem. The algorithm design was realized by MATLAB programming.The result of the optimal objective function value obtained by the improved genetic algorithm designed is also more feasible and effective, which meets the actual demand for low transportation costs, and low traveling cost than based on GA.

Finally, the algorithm was applied in solving the actual case; a satisfactory result was obtained, and GA has better performance and is not strongly proved.However, this paper has studied the combination optimization problem of vehicle routing with cargo loading stowage pickup and delivery in the design process of the solution algorithm to make the algorithm concise, efficient, easy to implement, and suitable for solving the integration problem.

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Data Availability: The datasets/materials used and analyzed for the present paper are available from the corresponding author on reasonable request.

Declarations
The authors declare that they have no known competing financialinterests or personal relationships that could have appeared to influencethe work reported in this paper.

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