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The Transportation Mode Distribution of Multimodal Transportation in Automotive Logistics

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Abstract

Currently, road transportation is still the main part of China's automotive logistics. Railway and waterway traffic are increasing in recent years, but are still small in the proportion of China's automotive logistics. Therefore, the automotive logistics of multimodal transportation and the distribution of the mode of transport are paid more and more attention. This paper focuses on the transport allocation problem of the commodity car. When the route and demand are fixed, considering the transportation cost, transportation time and the mode of transportation capacity constraints, establish a model to solve the road, railway and waterway transportation allocation problem. And design a genetic algorithm to solve the mode of transportation allocation problem to minimize the logistics cost. Finally, a case study is given to verify it.

Keywords: Automotive logistics; Multimodal transportation; Transportation mode distribution; Genetic algorithm

1. Introduction

Recent years, with the rapid development of the China's national economy and the continuous improvement of people's living standards, the automobile industry has entered into a rapid development track. According to the China Automobile Association statistics, China's auto production and sales have been ranked first in the world, which has a very important position in the international automobile market. The vehicle output of China from 2000 to 2011 is shown in Table 1.

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Table 1. Vehicle Output of China from 2000 to 2011

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Output	207	273	325	444	507	571	728	904	935	1379	1806	1841

* Units: ten thousand

China has become the world's largest automobile producer and consumer, and our country's automobile industry is still in high sustainable development. On one hand, such a large domestic car market in China brought the huge market demand for the automotive logistics industry. Domestic vehicle logistics started in the 1990 s, and with the development of China's automobile industry, it developed and promoted gradually. On the other hand, China's "wide land, Multiplant monopoly, wide distribute" characteristics provide the objective market conditions for the Chinese vehicle logistics development. Figure 1 is Chinese Mainland's major auto companies' distribution.

As the last step to achieve the ultimate sales for the automobile manufacturers, the automotive logistics not only play a role in rapid response to market and distribute commodity cars on time and in high quality, but also carry the responsibilities to reduce costs and enhance the competitiveness of their products.

At present, the railway, waterway traffic in the share of China's automotive logistics respectively 7% and 8%(The data from "Anji cup" the fourth national college students logistics design competition case), while road transport is still the main part of China's automotive logistics. But in recent years, the development of railway transportation is speed up, and the waterway transportation volume is also rising. Highway, railway, waterway, etc, the multimodal transport gradually tend to be perfect. On the railway transport, due to the cost advantages of itself as well as the support of the national railway development, making railway transport gradually increased in the proportion of automotive logistics. Water transport is concerned, in the field of vehicle logistics, water costs are typically 20% to 30% lower than the cost of road transport. With the development of China's ro-ro manufacturing and port construction propulsion, a large part vehicle logistics will transit to the waterway. Of course, the cost advantage of rail and waterway transport is limited within a certain range, such as in short and small batch sporadic transportation, road transportation still has incomparable advantages.

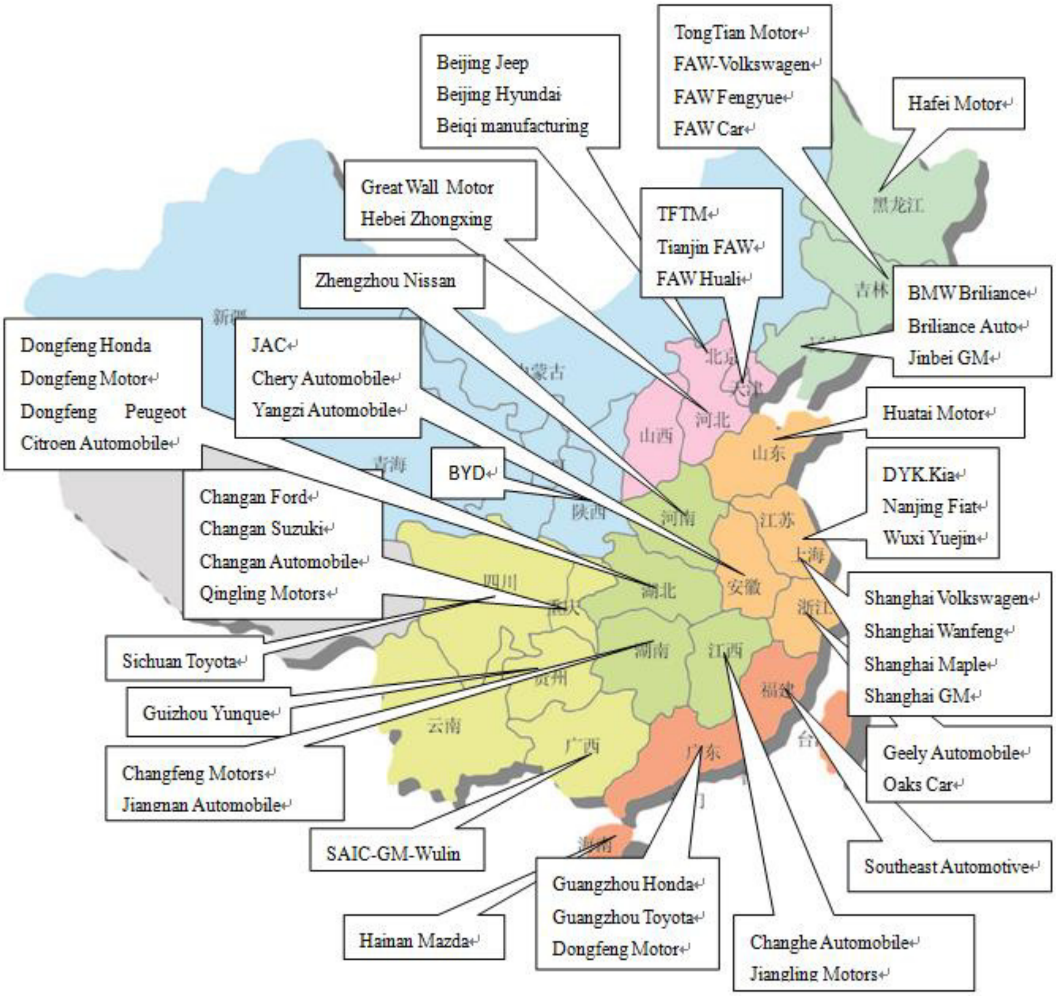

Fig.1 Chinese mainland's major auto companies' distribution

For a modern automotive logistics enterprise, the reasonable mode of transportation and resource matching can easily make the enterprise to reduce the cost, and gain more market share and economic benefit. This paper focuses on the research of the transport allocation problem of the commodity car. When the transport route and traffic volume are confirmed, comprehensively considered the transportation cost, transportation time and the mode of transportation capacity constraints, determine the highway, railway, waterway transport mode selection and the traffic volume distribution.

2. Domestic Automotive Logistics Operation Overview

At present, the domestic automotive logistics industry generally followed the "two stage distribution shipment" system. Namely: the finished vehicle of each production base shipped to each Vehicle Storage Center (VSC) from Vehicle Distribution Center (VDC), and then delivery to authorized dealer or direct sales to customers (see Fig.2). Among them, the VDC's main function is responsible for commodity inspection of the car after off the production line and planned delivery to each VSC in all over the country; or directly distribute to the surrounding area distributor. The main function of the VSC is to receive the commodity cars which shipped from the VDC, and then shipped the car to the dealer according to the plan.

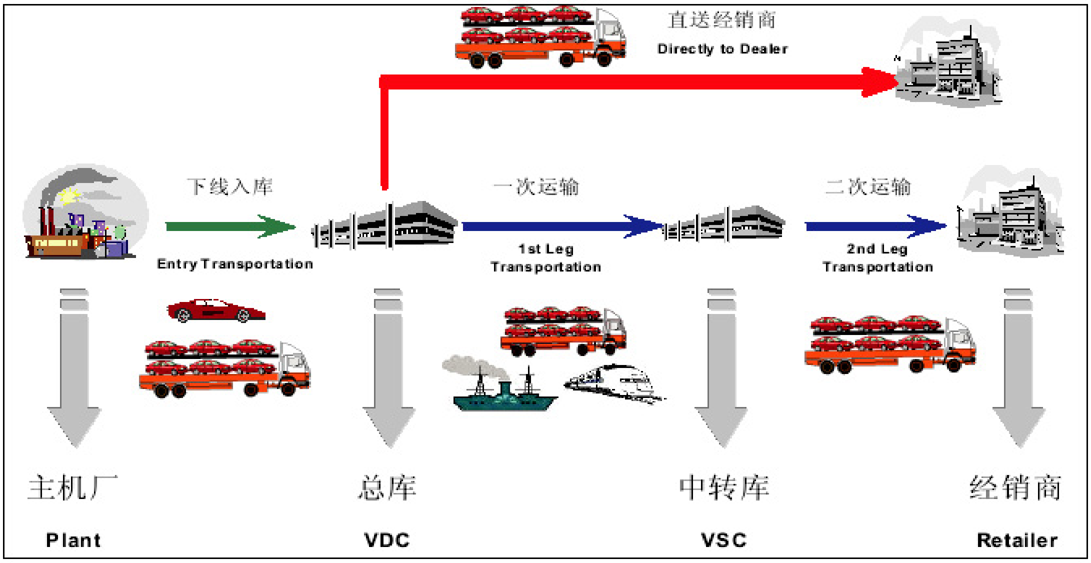

Fig.2 The automotive logistics business model

See Fig 2. "1st Leg Transportation" means the commodity cars are shipped from VDC to VSC; "2nd Leg Transportation" means goods delivered from the VSC to the dealer. Commodity cars may move between warehouses of the VDC and VSC in the same city, as well as the short distance transportation transfer between the warehouse and rail yard and between the docks, which referred to as short barge.

The automotive logistics business applied three kinds of modes of transport: highway, railway and waterway, the present situation of the transportation use is shown in Fig 3.

- Plant →VDC (Entry Transportation): Given priority to road transportation. In most cases, the Plant and the VDC is a one-to-one relationship, and the location is adjacent.
- VDC→VSC (1st Leg Transportation): There are three kinds of modes of transportation: road, waterway, and railway. So "multimodal transport" as well as the proportion of the various modes of transport become one of the factors that must be considered.
- VSC→Retailer (2nd Leg Transportation): All through the road transportation and provide home delivery service.
- VDC→Retailer (Directly to dealer): Mainly road transportation and provide a door-to-door delivery.
- Short barge: all for road transportation.

To sum up, this paper mainly studies the choice of mode of transportation and their ratio in the VDC→VSC (1st Leg Transportation).

3. Target Factors

In the case of ensure on time delivery, taking full advantage of multimodal transportation which connected the high-volume, low-cost waterway and railway transport and the fast, flexible road transport, balancing regulation, fully enhancing the carrying vehicle turnover rate, and reducing logistics costs, are the guiding ideology of the road, railway, waterway distribution. Therefore, road, railway, waterway transportation mode selection and traffic volume distribution need to consider the cost target, time goals and the mode of transport capacity limit.

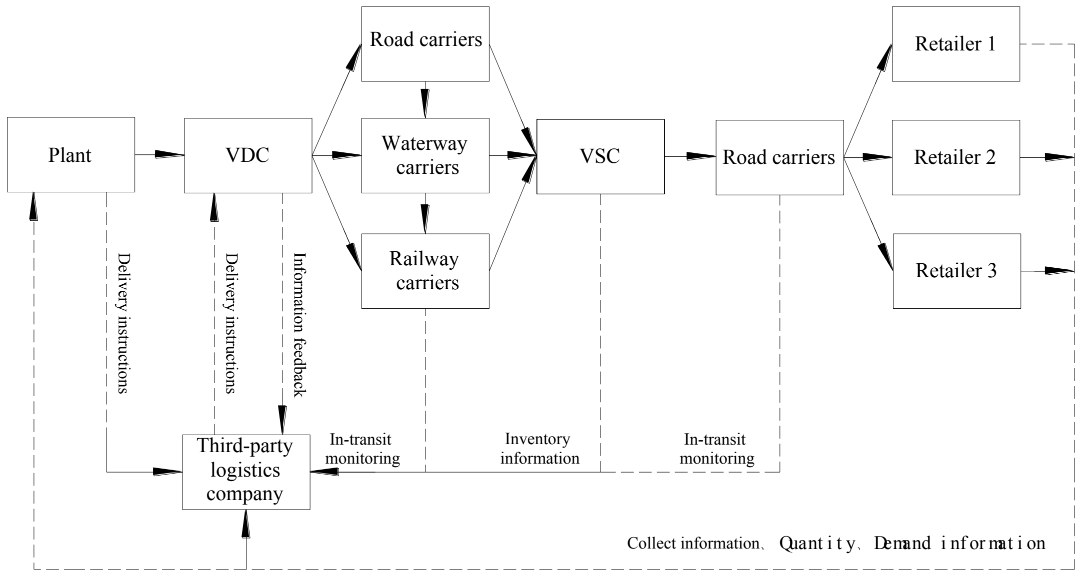

Fig.3 The vehicle logistic transportation mode

● Transportation Costs z

Transportation cost mainly refers to the cost generated in Plant→VDC、VDC→VSC、VDC→Retailer and VSC→Retailer, as well as all kinds of short barge cost in these processes. Short barge cost mainly generated in VDC→VSC when commodity car are transferred from warehouse to dock or between stations by water or railway transportations. Different modes of transport rate is different, the rate is generally related to the transport mode, transport mileage and the cost price which changes with the market price of oil.

Transportation cost accounting process need to know the optimal path and distance between the place of departure and destination (not the study area of this paper). In the complicated transport network, obtain the optimal path have greater difficulty, generally use a simplified solution at present: First, according to the existing business data, such as transport distance is determined by the mileage in the service contract or the mileage produced by the actual operation etc, and then take its minimum value. The second is to transfer the node location information (latitude and longitude) into the actual distance, and then adjust according to the human experience.

● Transportation Time t

The transportation time refers to the time the commodity car from the shipment to the destination, that is to say the time in transit, including transportation time between the nodes, travel modes conversion time occurring at the nodes, and the waiting time due to the influence of the shipping date or the training divisions. For example: some water transportation route, the sailing time only Tuesday and Saturday, and then the car arrived on Wednesday will need to wait for three days. Usually, the owner seen the shorten or extended time of commodity car transit as a loss. Transit time shortened, it will generate an additional storage cost, and prolong the transit time, it can increase the cost of turnover and other links or reduce customer satisfaction, etc.

- Capacity constraints w

Temporary procurement of road capacity is relatively flexible, so it can be said that there is no restrictions in road capacity. As to railway and waterway, due to the frequency of trains, sailing restrictions, there are annual maximum transport capacity constraints, such as: railway transport trains 2 times a week, the loading capacity are 290/column, etc.

4. Establishment of the Model

As shown in Fig 2, the finished vehicle of each production base shipped to each VSC from VDC, and then delivery to authorized dealer or direct sales to customers. In the 1st Leg Transportation, the road, railway and waterway transportation are available (some routes are limited by the geographical conditions or customer requirements), and the cost, time and capacity of each mode of transportation are different. There need a certain transfer time and transfer fee when a transport mode conversion happened in VDC and VSC. Different transport modes and at different time to reach the vehicle sales center, the cost are different. When arrive prematurely, it will generate additional storage cost, while too late will produce the penalty cost (default compensation or reduce customer satisfaction, etc)

4.1 Model Assumptions:

- The transportation costs of a certain mode only associated with the relevant transportation distance and the cost price a;
- Does not consider the possibility of improving transportation prices in the case of the means of transport is not fully loaded;
- There need a certain transfer time and transfer fee when a transport mode conversion happened in VDC and VSC;
- Not consider the cost of damage.

4.2 Parametric Description

$x_{i,i+1}^{j}$: The mode of transportation between nodes i and $i+1$, $x_{i,i+1}^{j} \in \{0,1\}$, 1 means that the mode j is selected between i and $i+1$, while 0 means not.

Make $j=1$: road transportation;

$j=2$: railway transportation;

$j=3$: waterway transportation;

$y_i^{j,k}$: $y_i^{j,k} \in \{0,1\}$, 1 means that the mode shift from j to k in node i, 0 means there is no mode shift in node i;

$c_{i,i+1}^{j}$: The unit price of mode j between nodes i and $i+1$;

$\alpha_{i,i+1}^{j}$: The proportion of the total transport volume in mode j between nodes i and $i+1$, if there is only one transportation mode, $\alpha_{i,i+1}^{j}=1$;

$e_i^{j,k}$: The transfer fees of the mode shift from mode j to k in node i, including loading and unloading costs, carrying costs and the warehouse cost which proportional to the waiting time, etc;

$h_{i,i+1}^{j}$: The transportation time of mode j between nodes i and $i+1$;

d_i: The additional storage costs produced by the goods car which are arrived early according to the contract;

f_i: The penalty costs produced by the goods car which are arrived late according to the contract;

Q: The total amount of goods car to be transported;

$o_i^{j,k}$: The transfer time of the mode shift from mode j to k in node i, including loading and unloading time, carrying time and the waiting time;

t^j: The transportation time of the mode j for the transport of commodity cars;

s: The unit inventory cost;

f: The penalty value of unit time;

$w_{i,i+1}^{j}$: The transportation capacity of mode j between node i and node $i+1$;

t_{wait}^{j}: The waiting time to send the commodity car in mode j due to the shipping schedules or the frequency of trains impacts;

t_m: The moment the goods car arrived, it is corresponding to t^j, the transport time is shorter, it will arrive at an earlier time;

$[a,b]$: The arrival time window according to the contract.

4.3 Model Formulation:

Minimize $$z=\sum_{i=1}^{m}\sum_{j=1}^{n}x_{i,i+1}^{j}*c_{i,i+1}^{j}*Q*\alpha_{i,i+1}^{j}+\sum_{i=1}^{m}\sum_{k\in n}y_i^{j,k}*e_i^{j,k}*Q*\alpha_{i,i+1}^{j}+d_i+f_i \quad (1)$$

Subject to $$\sum_{i=1}^{m}(x_{i,i+1}^{j}*h_{i,i+1}^{j}+y_i^{j,k}*o_i^{j,k})+x_{i,i+1}^{j}*t_{wait}^{j}=t^j \qquad j\in(1,2,3),k\in n \quad (2)$$

$$d_i=\begin{cases}(a-t_m)*s & (\min t_m<a)\\ 0 & (a\le \min t_m\le b)\end{cases} \quad (3)$$

$$f_i=\begin{cases}0 & (a\le \max t_m\le b)\\ (t_m-b)*f & (\max t_m>b)\end{cases} \quad (4)$$

$$Q*\alpha_{i,i+1}^{j}*x_{i,i+1}^{j}\le w_{i,i+1}^{j} \qquad i\in m,j\in n \quad (5)$$

$$\sum_{j=1}^{n}\alpha_{i,i+1}^{j}=1 \quad (6)$$

$$0\le \alpha_{i,i+1}^{j}\le 1 \quad (7)$$

$$y_i^{j,k}=x_{i-1,i}^{j}*x_{i,i+1}^{k} \quad (8)$$

$$1\le \sum_{j=1}^{n}x_{i,i+1}^{j}\le n \quad (9)$$

$$x_{i,i+1}^{j} \in \{0,1\} \tag{10}$$

$$y_{i}^{j,k} \in \{0,1\} \tag{11}$$

In the above modal, the formula (1) is objective function; formula (2)-(11) are the constraint conditions. The objective function takes the least transportation costs and the conversion costs throughout the transport process as a target. Formula (2) refers to the transport time the commodity car shipped from the starting point to the destination by various modes of transportation. Equation (3)-(4) for the transportation time limit, i.e. the arrival time of first arrive batch must be greater than the time window lower bound, while the slowest arrival time must be less than the time window upper bound. Equation (5) for the capacity constraints, i.e., the number of commodity car in transit between two nodes must not be greater than the transport capacity between the two nodes. (6)- (7) mean that all commodity cars between two nodes can shipped with a variety of transportation modes, and the ratio of various modes of transport accounted for 1. Formula (8) said that the mode shift from j to k in node i. (9) said that there is at least one mode of transportation to transport all goods cars between two nodes.

LINGO verified the model as an Integer Nonlinear Programming model (INLP), and can find out a global optimal solution, thus the accuracy of the model is proved.

5. Model Solution

Lingo focuses on solving linear problems or simple nonlinear problems, and genetic algorithm in solving nonlinear function or strong nonlinear constraint model has more advantages. According to the model, this paper design a genetic algorithm solving process, the specific steps are shown as follows:

(1) Code design. Convert the parameters of the practical solution of the problem into a standard binary bit string. The encoding length determining method: assuming the change interval of the variable is $[a,b]$, the desired accuracy is m decimal places, that is to say each variable should be divided into at least $(b-a)*10^{m}$ section. A variable's binary string digit (represented by n) is calculated using the following formula:

$$2^{n-1} < (b-a)*10^{m} \leq 2^{n} - 1$$

Due to the influence of capacity constraints in railway and waterway, we express the traffic parameters of these two transportation modes with a length of $n = 23$ (railway with 12, waterway 11) chromosome. Road transport has no capacity restrictions, and the total amount of transportation tasks is known, that is to say remove water and railway traffic volume, the rest is Road transport.

(2) Initial population set. Without any prior knowledge of the solution of solving problem, we use a completely random way to produce initial generation, i.e. the first generation. Randomly generated NIND chromosomes, NIND are the number of the initial solution and the size of NIND general choice for 30 to 100.

(3) Fitness evaluation. Calculate the objective function values in accordance with the time window conditions, and then Rank-based fitness assignment. This rating algorithm using linear assessment, select 2 as the equal differences, give the best adapted individual the fitness value of 2, and the worst individual fitness value of 0.

(4) Selected operation. The selection is to use the advanced function calls lower random ergodic sampling function, the selection process used the generation gap (Generation gap referred GGAP) 0.9.

(5) Crossover operation. After the selection operation, the GGAP*NIND individuals from the original chromosome using the crossover probability $Px = 0.7$ to single point cross ($Px = 0.7$ is an empirical value from a large number of experiments based on genetic algorithm, it can ensure the search capabilities and search speed of the algorithm at the same time). The schematic diagram of single point cross shown as Fig.4.

Fig.4 Single point cross schematic diagram

(6) Mutation operation. Variation is a mutation operation to the crossed population used a discrete mutation operator. The mutation probability $PM = Px / Lind$, $Lind$ is the length of the individual, in this paper, $PM = 0.03043$. It can effectively improve the global search ability of genetic algorithm, prevent premature phenomenon, and also can increase the diversity of the population.

(7) Recovery operation. Due to the use of generation gap, the number of offspring is smaller than the current population. So we use the re-insertion based on the fitness to restore the population quantity. This will ensure that 10% of the most adapted individuals in the previous generation always be continuously propagated to the next generation.

Thus produced a new generation of population and a cycle is over and repeat the above operation. Stop the cycle according to the generation number (MAXGEN) and output the final result. Fig 5 shows the genetic algorithm flow chart.

6. Model Validation

A batch of a certain brand of vehicle produced by a vehicle manufacturing enterprise (Quantity：1000)，transferred from the VDC in the local place A to the VSC in place B (about 1949 kilometers), and then transported to the various distributors. Due to the geographical location adjacent, road transport is used from the Plant to the VDC. There are three kinds of transport mode (road, waterway and railway) available from the VDC to the VSC, but to the waterway and railway, not only influenced by capacity constraints, but also by the voyage and the schedules. The VCD to the distributor, use the road transport. The target factors are as follows:

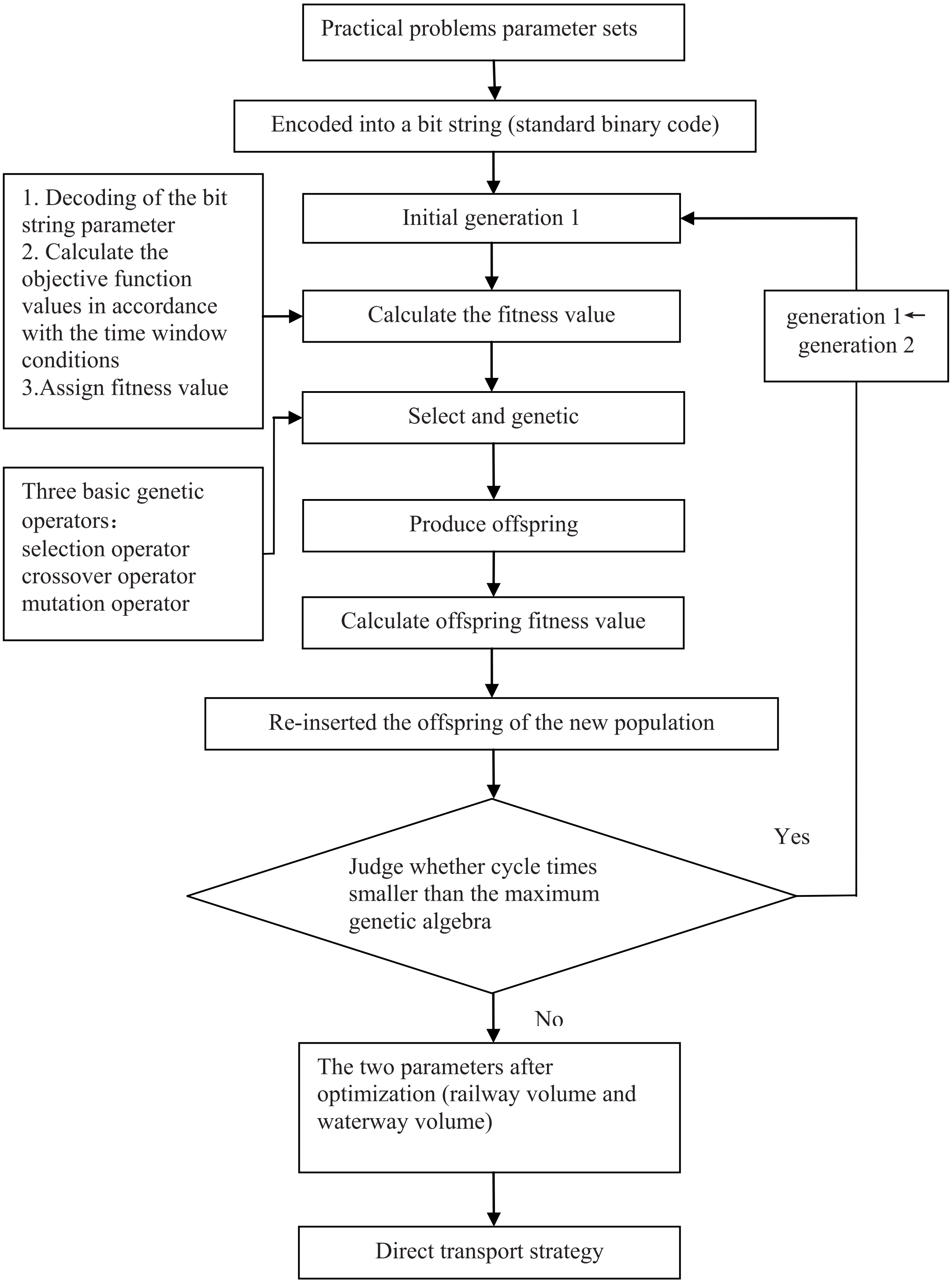

Fig.5 Genetic algorithm flow chart

Table 2. Transport rates

Mode of transportation		Rate (Yuan/car.km)
Road	≤100 kilometers	2.0 a
	≤200 kilometers	1.7 a
	≤500 kilometers	1.5 a
	≤1000 kilometers	1.3 a
	>1000 kilometers	1.2 a
waterway		1.0 a
railway		1.1 a

*The cost price a changes with the market prices.

Table 3. Transportation time

Mode of transportation		Transportation time Description
Road		The time the vehicle loading and unloading commodity car were 0.5days,day driving 500 km
Waterway		Every Tuesday and Saturday sailing once, day sailing 400 km
Railway	Shanghai→Deyang（Sichuan）	Nine days
	Shanghai→Dongguan（Guangdong）	Eight days
	Shanghai→Kunming（Yunnan）	Ten days
	Shanghai→Tianjin	Seven days
	Shanghai→Xianyang（Xi'an）	Nine days
	Shanghai→Yantai（Shandong）	Nine days

Table 4. Capacity constraints

Transportation modes	Capacity restrictions introductions
Railway	2 times a week, loading capacity:290/column
Waterway（sea transportation、inland water transportation）	Every Tuesday, Saturday sailing once (freight space: ship:300/ship; riverboat: 200/boat)

The transport costs, transport time and transport capacity of the various modes of transport between each node are shown in Table 5, different modes of transport conversion cost and time as shown in table 6. The sailing time of waterway on Monday and Thursday, and the railway with a shift time on Tuesday and Friday. The waiting time after the arrival of the commodity car as shown in table 7. The sales center's constraints: a single vehicle storage cost and single cars penalty cost both are fifty Yuan/day, requiring that less than half a day do not calculated as a day, and more than half a day by day calculation. Shipping deadline is 4.5-7.5 days.

Table 5. The transport unit price $c_{i,i+1}^{j}$ 、 time $h_{i,i+1}^{j}$ and capacity $w_{i,i+1}^{j}$ between each nodes

Node i	Road			railway			waterway		
	$c_{i,i+1}^{j}$	$h_{i,i+1}^{j}$	$w_{i,i+1}^{j}$	$c_{i,i+1}^{j}$	$h_{i,i+1}^{j}$	$w_{i,i+1}^{j}$	$c_{i,i+1}^{j}$	$h_{i,i+1}^{j}$	$w_{i,i+1}^{j}$
Plant—VDC	2.0 a	0.5	∞	0	0	0	0	0	0
VDC—VSC	1.2 a	4	∞	1.1 a	5	290	1.0 a	6	200
VSC—Retailer	2.0 a	0.5	∞	0	0	0	0	0	0

*Transport cost unit for one thousand Yuan, transport time unit in days, and the transport capacity of the unit vehicle.

Table 6. The cost $e_i^{j,k}$ and the time $o_i^{j,k}$ of the transportation modes conversion

Mode of transportation	Road		Railway		Waterway	
	$e_i^{j,k}$	$o_i^{j,k}$	$e_i^{j,k}$	$o_i^{j,k}$	$e_i^{j,k}$	$o_i^{j,k}$
Road	0	0	0.04	0.04	0.08	0.08
Railway	0.04	0.04	0	0	0.12	0.12
Waterway	0.08	0.08	0.12	0.12	0	0

*Transfer cost unit for one thousand Yuan, transfer time unit for days

Table 7. The waiting time t_{wait}^{j} of the commodity car in waterway and railway

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Railway	1	0	2	1	0	3	2
Waterway	0	2	1	0	3	2	1

*Assume that the sailing time of waterway on Monday and Thursday, the railway with a shift time on Tuesday and Friday. The waiting time unit is day.

The optimization program's running environment is Windows XP + Mat lab 7.9.0(R2009b). Assume that the commodity cars arrived on Wednesday there needs to wait two days by railway and one day by waterway. The operation results as shown in figure.6.

The algorithm has converged nearby the 26th generations. With a large number of operations, we found that more than 95% of the operation result is that in 1000 commodity cars, 800 quantity in road transportation and 200 with water transportation, i.e., roads, railways, waterways transport ratio is 4:0:1. The logistics cost is optimal, namely $\min z = 5198.6$ thousand Yuan.

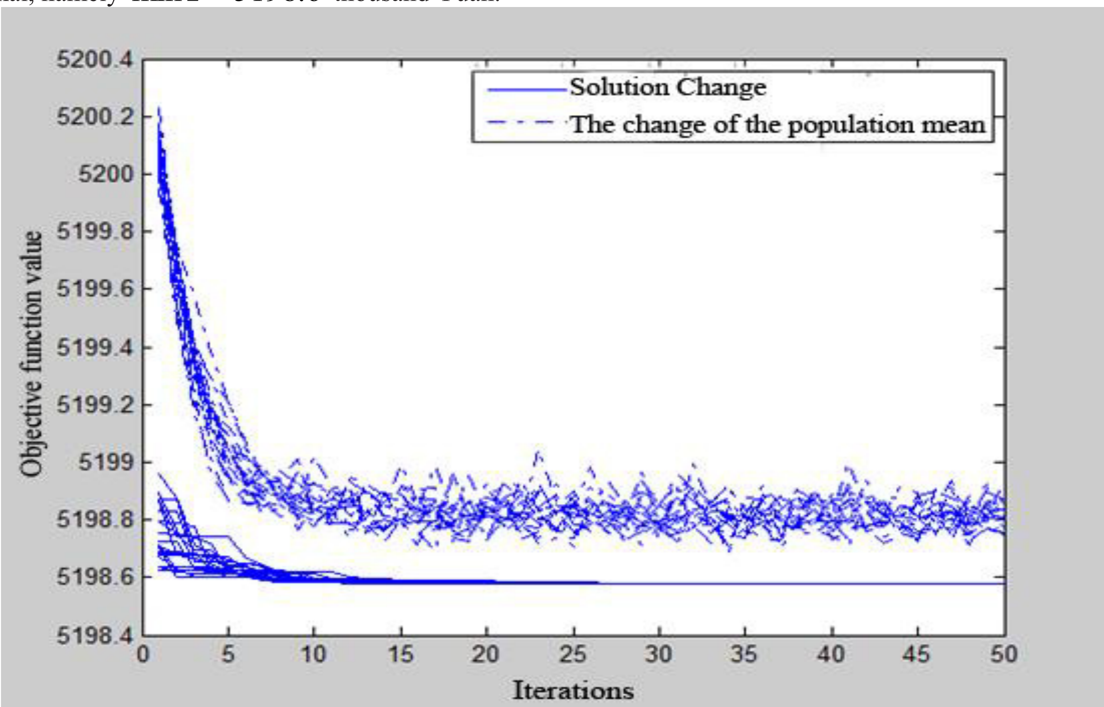

Fig.6 Evolution Process

7. Conclusions

This paper from the view of transportation cost on the optimal, comprehensively considered the transportation time and the modes of transportation capacity constraints, solve the problem of the ratio of three kinds of transportation modes, i.e., road, waterway and railway with time windows. According to the transportation time limits and capacity status, arranging transportation task with a minimum of logistics cost balance, was the basic requirement to successful complete the task on time. This study also has some practical significance in reality vehicle transport operation, the data of the algorithm is not static, and we can modify the corresponding parameters according to the actual situation in practice, so as to guide the practical operation.

This paper only study the four nodes, namely Plant, VDC, VSC and distributor, between Plant and VDC, VSC and distributor are road transport, in fact, we solve the allocation problem between the VDC and VSC. The actual situation may be more complicated, because there may need transfer through the transfer point between VDC and VSC, and even many times of transshipment, which requires to study more nodes to be further study.

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