Uncertainty and Operations Research

Xiang Li
Xiaofeng Xu *Editors*

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Uncertainty and Operations Research

Decision analysis based on uncertain data is natural in many real-world applications, and sometimes such an analysis is inevitable. In the past years, researchers have proposed many efficient operations research models and methods, which have been widely applied to real-life problems, such as finance, management, manufacturing, supply chain, transportation, among others. This book series aims to provide a global forum for advancing the analysis, understanding, development, and practice of uncertainty theory and operations research for solving economic, engineering, management, and social problems.

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The Optimization of the Location-Allocation Problem of Pallet Pooling Centers

Bowen Miao, Xiaoting Shang, and Hao Sun

1 Introduction

Pallet, as an important equipment for loading /unloading, storage and transportation in logistics, has been widely used in various fields, including production, transportation, warehousing, circulation. According to its attribution, pallets can be divided into self-owned pallets and shared pallets: self-owned pallets are the ownership of pallets obtained by enterprises through procurement, limited to the internal turnover circulation; shared pallets are the right to use pallets obtained by enterprises through leasing, which are used as a transport carrier to achieve the circulation of goods between enterprises. Compared with self-owned pallets, shared pallets not only can significantly enhance logistics efficiency, reduce logistics costs, improve logistics service quality, but also promote the low-carbon development of logistics industry, save social and economic resources and promote the modernization reform of logistics on a large scale.

Recently, pallet industry in China has developed rapidly, and many enterprises such as LOSCAM and CHEP (Commonwealth Handing Equipment Pool) have entered the field of pallet pooling. As an important tool for integrating the supply chain and improving logistics efficiency, the number of pallets has become one of the indicators for measuring the level of logistics modernization in a country [1]. The total number of pallets in China's market reached 1.7 billion by 2022, with a

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year-on-year growth of 2.41%. However, the number of shared pallets is only around 37 million, accounting for merely 2.2% of the total pallet inventory [2]. Currently, shared pallets in China are at a disadvantageous position in international market competition and have yet to establish a smooth and rational circulation mechanism for pallet pooling.

The pallet pooling centers serve as key nodes in the pallet pooling system and play an important role in improving logistics transportation efficiency and promoting resource recycling. The location and allocation optimization for pallet pooling centers are important steps in the construction of the pallet pooling system, playing a significant role in improving logistics transportation efficiency and promoting resource recycling.

This paper studies the optimization of the location-allocation problem of pallet pooling centers. The main contributions include:

1. Filling the blank of location problem in the field of pallet sharing. The existing research mainly focuses on the theoretical research on the construction of the pallet pooling center system, the mathematical model of the pallet sharing scheduling, etc., and lacks the research on the location of the pallet pooling center;
2. The multi-allocation location optimization model of pallet pooling operation center is established, where a demand node can be assigned to many centers, aiming to balance the pallet demand distribution and improve the utilization efficiency of the pallet pooling center.

The remainder of this article is organized as follows: A brief review of *p*-median problem, multiple allocation problem and pallet pooling literature is given in Sect. 2. In Sect. 3, the problem is formally described and presents a linear mathematical programming model. Sect. 4 describes the computational experience, analyses the obtained numerical results and performs sensitivity analysis on the number of pallet pooling centers. The paper concludes in Sect. 5 with some comments and suggestions for further research.

2 Literature Review

The location-allocation problem of pallet pooling centers fundamentally belongs to the location problem. As early as 1909, Weber studied the geographical location of a warehouse within a given area, aiming to minimize the total distance while satisfying customer demands, which laid the foundation for the location problem [3]. Subsequently, this issue attracted numerous scholars to conduct relevant research, finding wide applications in transportation, electronic communications, and computer networks [4–6].

According to the objective function, facility location problem can be classified into covering problem [7–9], *p*-median problem [10], and *p*-center problem [11]. The *p*-median model is commonly used in warehouse and factory location problem.

In 1964, Hakimi [12] first proposed the *p*-median model, which selects *p* locations from a given set of n potential locations, minimizing the sum of the distances between demand nodes and facility points multiplied by the demand. In 2004, Correa et al. [13] introduced a capacity-constrained *p*-median model for the application of college entrance examination location problem. They solved the model using a Genetic algorithm (GA) with a hypermutation operator and compared it with the Tabu search algorithm, validating the algorithm's effectiveness. In 2007, Mladenovic et al. [14] summarized algorithms for solving the *p*-median model, dividing them into classical heuristic algorithms and metaheuristic algorithms, demonstrating that metaheuristic algorithms are more efficient and time-saving for solving large-scale problems. In 2012, Fagueye et al. [15] addressed the students allocation problem for further education, constructing a *p*-median model with the objective of minimizing the total distance between their homes and schools. In 2019, Karatas and Yakici [16] studied the emergency service facility location problem, considering backup service levels and establishing a capacity-constrained *p*-median model for simulation experiments, providing decision support for emergency service system planners. In 2021, Rios-Mercado et al. [17] tackled the practical problem of dividing regions for a beverage distribution company and developed a *p*-median model.

The allocation problem can be classified into single-allocation and multi-allocation problems. In 2012, Shariff et al. [18] studied the location problem for healthcare facilities in a certain region of Malaysia, developing a single-allocation maximum coverage facility location model and proposing an improved GA. In 2018, Li and Mao [19] addressed the location-allocation problem for self-pickup points and formulated a single-allocation mixed-integer programming model with the objective of minimizing total costs. Compared to single-allocation problems, multi-allocation problems can effectively improve the utilization efficiency of network nodes. In 2011, Albareda-Sambola et al. [20] studied the location problem under uncertain customer demands, considering two types of recourse actions if customer demands are not satisfied and established a multi-allocation stochastic programming model. In 2018, Du and Zhou [21] applied robust optimization to solve a multi-allocation *p*-center problem with three types of uncertainty sets. In 2020, Lin et al. [22] focused on the location problem for low-carbon logistics distribution centers under demand uncertainty and established a multi-allocation model using stochastic programming theory, providing reference for companies' site selection decisions under market demand fluctuations. In 2021, Panteli et al. [23] proposed a heuristic algorithm based on a clustering framework in data mining for the multi-allocation *p*-median problem. Through numerical simulations, the algorithm demonstrated not only computational superiority over CPLEX but also improved solution quality as the problem size increased. In 2021, Shi [24] extended the capacity-constrained facility location problems by considering multiple uncertainties, presenting two-stage multi-allocation stochastic programming models and multi-allocation robust programming models. In 2022, Shang et al. [25] studied the dynamic location-allocation problem for fixed-location hospitals during the COVID-19 pandemic, establishing a multi-allocation optimization model.

In recent years, there is significant progress in China at the theoretical research of pallet pooling systems. In 2006, Li [26] analyzed the pallet logistics development system and related theories of developed western countries, and proposed the enterprise alliance approach for pallet leasing and exchange in China, aiming to enhance information exchange between enterprises. In 2009, Zhang and Fu [27] studied the current situation of pallet transportation by railways and explored the possibility of establishing a pallet pooling system. They made suggestions from three aspects: pallet standards, system exchange nodes and networks, and pallet joint venture companies. In addition, some scholars have also explored issues such as dynamic allocation of pallets and scheduling in pallet pooling operations. In 2013, Liu [28] constructed a two-level pallet operation system consisting of operational centers and business outlets and established location models for each level. You [29] researched the problem of empty pallet transportation by railways and built a multi-objective scheduling optimization model considering factors such as priority and call cost. In 2017, Zhang [30] studied the scheduling and transportation problem of pallet pooling systems, taking into account LTL (less-than-truckload) transportation and multi-vehicle types, developed a constrained planning model under random conditions, and designed a GA to solve it. In 2020, Hu [31] studied the scheduling problem of pallet recycling in a flexible supply chain environment, built a pallet scheduling model, and designed an improved quantum ant colony algorithm for solving it. Li [32] addressed the inventory routing problem in a packaging leasing system and established a delivery and retrieval inventory routing model. Li et al. [33] focused on the issue of delay in pallet picking and established a mathematical model with the total delay time as the optimization objective. In 2021, Xiong [34] researched the path planning problem of multi-pallet service centers under the condition of pallet reassignment and designed an ant colony algorithm to solve the established bi-objective mixed-integer programming model.

In summary, scholars have conducted extensive research on *p*-median problem and multiple allocation problem. Many scholars have also explored the optimization models for scheduling pallet pooling systems. However, the research on the optimization of location for pallet pooling operation centers is very limited.

3 Problem Formulation

3.1 Problem Description

The pallets are transported from the pallet manufacturer to pallet pooling centers (centers for short below), where the centers are responsible for leasing and recovery of pallets to meet the demands of users. Considering the difference of demands for pallets, different-scale centers are built for this purpose. Given a pallet manufacturer, a set of demand nodes, a set of candidate locations for centers, and a set of construction scales for centers, some nodes are selected from the potential centers set to establish

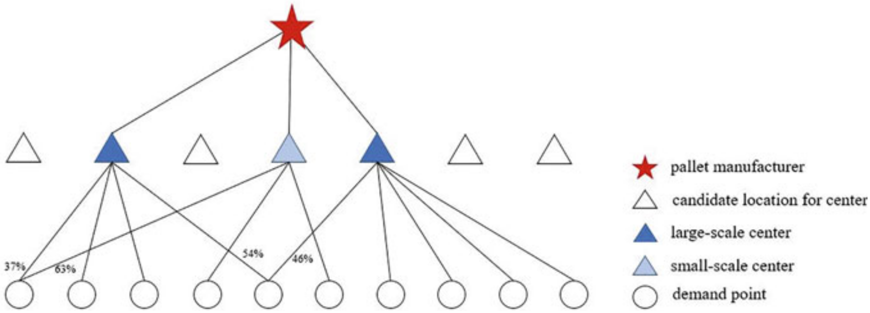

Fig. 1 An example of the location-allocation problem of pallet pooling centers

centers and assign demand nodes to the selected centers. Besides, determining the proportion of demand shared by each center is determined to ensure that the demand and the capacity of centers are met.

Figure 1 provides an example of the location-allocation problem of pallet pooling center, which includes 1 pallet manufacturer, 7 candidate locations for centers, and 10 user demand nodes. To meet users' demand, 2 large-scale and 1 small-scale centers are selected. And 2 user demand node present multiple distribution results.

3.2 *Model Assumptions and Parameter Descriptions*

The location-allocation problem of pallet pooling center is modelled with the following assumption:

1. The number of centers to be constructed is known.
2. Each demand node can be assigned to up to r centers ($r \geq 1$), i.e., a p-median multiple location- allocation problem.
3. The capacity of centers must be satisfied, i.e., a capacitated p-median problem.
4. The transportation of pallets between the manufacturer and centers is using large trucks, whose capacity is big enough.
5. Two scales of centers are considered: large-scale and small-scale.

The parameters and variables used in the model are explained as follows:

		Notion
Sets	D	Set of demand nodes
	N	Set of potential centers
	L	Set of the scale of centers
Input parameters	c_l	Pallet capacity of a center of scale $l, \forall l \in L$
	w_j	Pallet demand of node $j, \forall j \in D$

(continued)

(continued)

		Notion
	$c1_{ij}$	Unit transportation cost from center i to demand node j,$\forall i \in N,\ j \in D$
	$c0_i$	Transportation cost from pallet manufacture to center i,$\forall i \in N$
	z_{il}	The cost of building a center with a scale of l at node i,$\forall i \in N, l \in L$
	p	The total number of centers to be constructed
	r	The maximum number of a demand node is assigned ($r \geq 1$)
Decision variables	x_{il}	Binary, equal to 1 if node i is selected to construct a center of scale l, and 0 otherwise,$\forall i \in N,\ l \in L$
	y_{ij}	Binary, equal to 1 if center i provide pallets for demand node j, and 0 otherwise, $\forall i \in N,\ j \in D$
	t_{ij}	Real number, the proportion of demands shared by center i for demand node j, $0 \leq t_{ij} \leq 1$,$\forall i \in N,\ j \in D$

3.3 Linear Programming Model

The linear mathematical optimization model for the location-allocation problem of pallets is established below:

$$\textbf{min}\ f(x,\ y,\ t) = \sum_{l\in L}\sum_{i\in N} z_{il} \bullet x_{il} + \sum_{i\in N} c0_i \bullet \sum_{l\in L} x_{il} + \sum_{i\in N}\sum_{j\in D} c1_{ij} \bullet t_{ij} \bullet w_j \tag{1}$$

$$\textbf{s.t.} \sum_{l\in L} x_{il} \leq 1,\ \forall i \in N \tag{2}$$

$$\sum_{i\in N}\sum_{l\in L} x_{il} = p \tag{3}$$

$$t_{ij} \leq \sum_{l\in L} x_{il}, \forall i \in N,\ \forall j \in D \tag{4}$$

$$\sum_{i\in N} t_{ij} = 1,\ \forall j \in D \tag{5}$$

$$\sum_{j\in D} y_{ij} \leq r,\ \forall i \in N \tag{6}$$

$$\sum_{j\in D} t_{ij} \bullet w_j \leq \sum_{l\in L} c_l \bullet x_{il},\ \forall i \in N \tag{7}$$

$$x_{il},\ y_{ij} \in \{0,\ 1\},\ \forall i \in N,\ \forall j \in D \tag{8}$$

$$0 \le t_{ij} \le 1, \forall i \in N,\ \forall j \in D \tag{9}$$

The objective function (1) minimizes the total cost, including construction costs and transportation costs: the first part is the total construction cost of the selected centers; the second part is the transportation cost between the pallet manufacturer and centers; the third part is the transportation cost between the centers and the demand nodes. Constraint (2) indicates that the construction scale of each center is uniquely determined. Constraint (3) restricts p centers to be established. Constraint (4) states that only selected center can serve demand nodes. Constraint (5) ensures that the demands of each demand node must be satisfied. Constraint (6) indicates that each demand node can be assigned to at most r centers ($r \ge 1$). Constraint (7) guarantees that the number of pallets provided by each center should not exceed its capacity. Constraints (8)–(9) represent the domain of variables.

4 Case Study

The pallet manufacturer in Changzhou, Jiangsu Province, China is selected, and 15 cities have been selected as potential locations for centers and demand nodes, ($|N| = |D| = 15$), as shown in Fig. 2. Based on the freight volume of highway transportation, Table 1 provides the demand for pallets in each demand node. The capacity constraints and construction costs of different scale centers are shown in Table 2.

The numerical experiments were conducted using a personal laptop with an *Intel(R) Core(TM) i5-5350U CPU @ 1.80 GHz* processor. The hardware environment was *CPLEX Studio IDE 12.10.0.*

We explore the space distribution of the location selected and demand allocation, and the impact of main parameters on the objective function. Figure 3 shows the space distribution of location and allocation results when $p = 3$ and $r = 2$, with a total cost of 11.483 million RMB. Chongqing (node 5) and Suzhou (node 6) are selected to establish large-scale centers, while Guangzhou (node 4) is chosen for a small-scale center. The reasons for this location are as follows: Chongqing has the highest demand for pallets and is located at a moderate distance from Chengdu, Wuhan, and Changsha. Moreover, there is a large demand for pallets in the Jiangsu-Zhejiang region, and Suzhou is centrally located among densely populated cities. Therefore, Chongqing and Suzhou are chosen for large-scale centers. Guangzhou and its nearby cities have lower demand for pallets, and they are geographically located in the southern region, so a small-scale center is established there. Due to capacity limitations of the centers, multiple allocations occur in Changsha and Wuhan: 80% of demands in Changsha is satisfied by Guangzhou, and 20% is met by Chongqing; 63% demands in Wuhan is satisfied by Suzhou, and 37% is met by

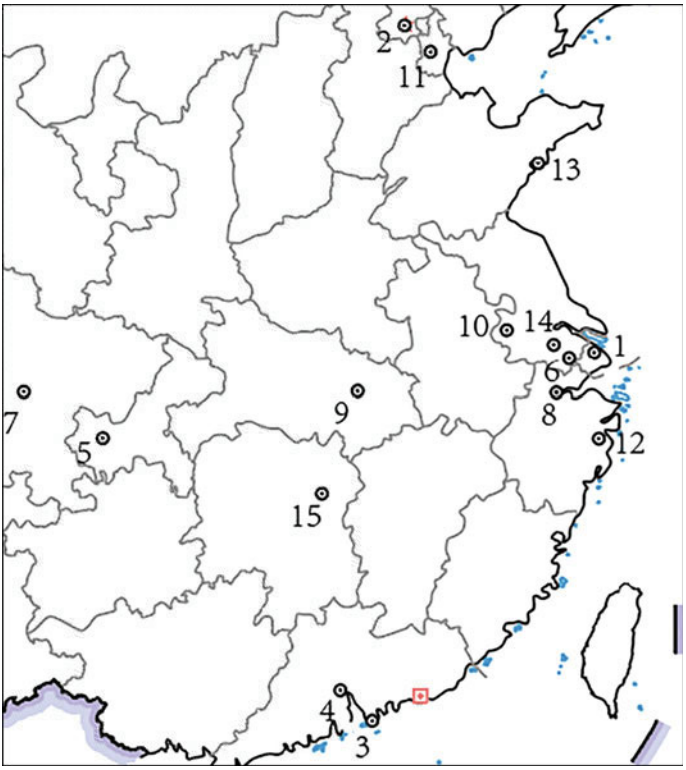

Fig. 2 Urban spatial distribution map

Chongqing. This shows that the location and allocation model for centers can provide theoretical support for decision-makers in choosing the location of pallet centers.

The number of centers (p) is an important parameter that affects the objective function in the location and allocation model for centers. Figure 4 shows the sensitivity of the objective function value to the number of centers (p). It can be seen that as the number of centers (p) increases, the objective function value initially decreases and then increases. This is consistent with the actual situation: when the number of centers is small, the transportation cost accounts for a larger proportion of the total cost, resulting in higher total costs. As the number of centers (p) increases, the reduction in transportation costs exceeds the increase in construction costs, resulting in lower total costs. However, when the number of operation centers (p) continues to increase, the increase in construction costs exceeds the reduction in transportation costs, leading to an upward trend in total costs. In other words, when the number of centers reaches a certain point, the total cost reaches its minimum, i.e., the optimal number of centers. Decision-makers can make use of this characteristic to determine a reasonable total number of pallet centers.

Table 1 The demand for pallets in each demand node

Num	Demand node	Cargo carrying capacity (million tons)	Pallet demand (million)
1	Shanghai	4210	281
2	Beijing	1277	86
3	Shenzhen	2985	199
4	Guangzhou	4091	273
5	Chongqing	9929	662
6	Suzhou	2184	146
7	Chengdu	2791	187
8	Hangzhou	3000	200
9	Wuhan	3760	251
10	Nanjing	1455	97
11	Tianjin	2493	167
12	Ningbo	4304	287
13	Qingdao	2103	141
14	Wuxi	1764	118
15	Changsha	3875	259

Table 2 The construction costs of different scale centers

Different scale centers	Cargo carrying capacity (million tons)	Pallet demand (million)
Small-scale ($l = 1$)	680	150
Big-scale ($l = 2$)	1680	250

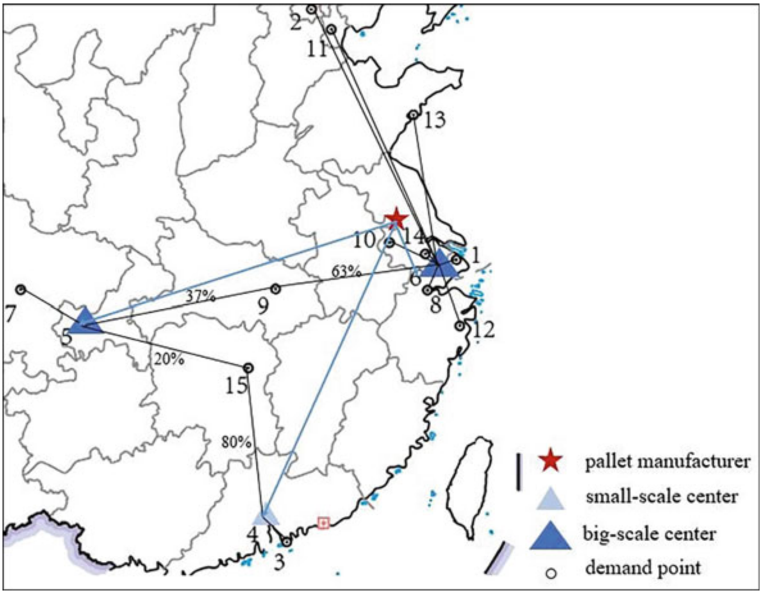

Fig. 3 The space distribution location and allocation results when $p = 3$ and $r = 2$

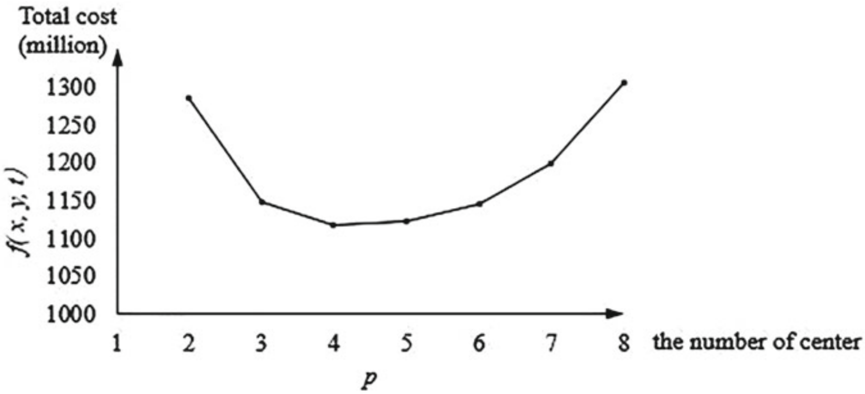

Fig. 4 The sensitivity of the cost to the number of centers (p)

5 Conclusion

This paper studies the location-allocation problem of pallet pooling centers. A location-allocation optimization model is established, considering multiple allocation strategies, with the objective of minimizing the total cost, including transportation and construction costs. Then, empirical experiments using freight data in China validate the effectiveness of the model. The location-allocation model for pallet centers can provide theoretical support for decision-makers. In the future, efforts will be made to design effective algorithm for large-scale real problem. Furthermore, inventory management and route planning will be considered in improving the model and studying integrated optimization problems in pallet pooling systems.

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Research on Development Forecast of New Energy Vehicles in Yangtze River Delta Based on GM(1,1) Model

Chang Senwei, Shao Liangshan, and Wei Yisong

1 Introduction

With the global climate change and the increasingly prominent environmental problems, new energy vehicles, as an important means to replace traditional fuel vehicles, have been widely concerned. The Yangtze River Delta in China is a densely populated area with economic development. The development of new energy vehicles is of great significance for achieving the goal of double carbon. The Yangtze River Delta region has a strong development momentum in the field of new energy vehicles and has become one of the important gathering places of domestic new energy vehicle industry. According to the goals of Technology Roadmap for Energy Saving and New Energy Vehicles 2.0 and New Energy Vehicle Industry Development Plan (2021–2035), by 2035, the market share of new energy vehicles will exceed 50%, and the number of fuel cell vehicles will reach 1 million [1]. It is estimated that by 2035, the number of new energy vehicles in China will reach 80 million to 100 million, and fuel cell vehicles will reach 1 million. The Yangtze River Delta region began to lay out new energy vehicles as early as the early stage of development, and achieved remarkable results [2]. At present, one out of every three new energy vehicles in China is produced in the Yangtze River Delta region. The agglomeration effect of new energy industry in the Yangtze River Delta region is obvious. According to the data of the list of cities with agglomeration degree of new energy industry, half of the cities in this region have entered the top ten, among which 26 cities in East China have entered the top fifty [3]. The rise of new energy and new energy vehicles provides

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an important prerequisite for realizing the country's transformation goal from fossil energy to renewable energy, as well as carbon emission reduction. In the Yangtze River Delta region, the abundant supply of renewable energy and the existence of a large number of new energy vehicles absorbed by renewable energy provide strong support for realizing this transformation goal. Therefore, the Yangtze River Delta region will continue to play an important role in the field of new energy vehicles, help China's automobile industry to realize the electrification transformation, and make further breakthroughs in the development of new energy vehicles.

In recent years, many scholars have used various methods to forecast the development of new energy vehicles. Liu Yaodi [4] and others used the grey prediction model to collect the sales data of new energy vehicles in the Yangtze River Delta region in recent ten years, and made a prediction on the future development of new energy vehicles in the Yangtze River Delta region. Yu Mingyang [5] and others put forward a compound forecasting model based on sudden factors to predict the sales of new energy vehicles in the future. Liu Kaidi [6] modeled and predicted the quarterly sales data of domestic new energy vehicles from 2014 to 2021, and proposed an ensemble learning algorithm to analyze and predict the future development of the new energy vehicle market. Yang Donghong [7] put forward a prediction model based on improved BP neural network to predict the future sales of new energy vehicles. The accuracy of the BP neural network prediction model is as high as 90%, which provides a new direction for the prediction research of new energy vehicles. Zhu Manyu [8] and others established GM(1,1) grey forecasting model, and based on the sales data of new energy vehicles from 2012 to 2021, predicted and analyzed the sales of new energy vehicles in the next five years.

GM (1,1) model is suitable for short-term forecasting and can provide more accurate forecasting results in a short period of time. For the new energy vehicle market in the Yangtze River Delta, GM (1,1) model can analyze the historical sales data, output data and the changing trend of related factors, so as to predict the future sales and output. The market of new energy vehicles is influenced by many factors, such as policy changes, technological progress and market demand. There is a nonlinear and non-stationary relationship between these factors. GM (1,1) model can better deal with these complex relationships, establish the development trend of data through grey differential equation, and accurately capture the nonlinear characteristics of data. Therefore, this paper uses GM (1,1) model to predict the future development of new energy vehicles in the Yangtze River Delta, and obtains the evolution law of new energy vehicles and traditional fuel vehicles in China.

2 The Position and Role of New Energy Vehicles in the Yangtze River Delta Region

The production and sales of new energy vehicles in the Yangtze River Delta region rank among the top in China. In terms of market scale, the Yangtze River Delta region has a huge automobile consumption market and a relatively mature industrial base, which provides a broad market space for the development of new energy vehicles. The Yangtze River Delta region has a high population density and a large number of cars. Coupled with the government's policy support and encouragement, the market scale of new energy vehicles in this region has expanded year by year [9]. In terms of industrial agglomeration, the Yangtze River Delta region has a number of excellent new energy automobile manufacturing enterprises and supply chain enterprises, forming a complete industrial chain. In particular, Shanghai, Suzhou, Ningbo and other places have gathered a large number of new energy vehicle manufacturers and parts suppliers, which has promoted the rapid development of the new energy vehicle industry. In terms of technological innovation, the Yangtze River Delta region has strong strength in technological research and innovation of new energy vehicles. Universities and scientific research institutions in Shanghai and Nanjing have carried out many research projects in the field of new energy vehicles and cooperated with enterprises to promote technological innovation. This technological innovation not only enhances the competitiveness of new energy automobile products in the Yangtze River Delta region, but also promotes the development of the whole industry. In terms of policy support, governments at all levels in the Yangtze River Delta have issued a series of policies to support the development of new energy vehicles. For example, providing incentives such as car purchase subsidies, free parking and construction of charging facilities has attracted more consumers to buy and use new energy vehicles. The government also encourages enterprises to increase investment and promote the coordinated development of the upstream and downstream of the new energy automobile industry chain.

New energy automobile manufacturers in Shanghai, Jiangsu and Zhejiang not only meet the market demand in this region, but also supply new energy automobile products to all parts of the country. One out of every three new energy vehicles in China is produced in the Yangtze River Delta region. In 2022, the national output of new energy vehicles was 7.058 million, and the total output of the Yangtze River Delta reached 2.7855 million, contributing 39.47% to the national production of new energy vehicles. In addition, the total sales volume of new energy vehicles in China is 6.887 million, while the total output of the Yangtze River Delta has reached 2.158 million. At present, the total sales volume of new energy vehicles in the Yangtze River Delta has accounted for 31.33% of the national total, accounting for one third of the national total (Table 1).

The production scale of new energy vehicles in the Yangtze River Delta region is huge. Shanghai has some well-known new energy automobile manufacturers, such as BYD, SAIC and Weilai. There are also many new energy automobile manufacturers in Nanjing, Suzhou, Wuxi and other places in Jiangsu Province, such as Jianghuai

Table 1 Production and sales data of new energy vehicles in Yangtze River Delta

	Output (10,000 vehicles)	Sales (10,000 vehicles)
Zhejiang province	58.15	65.00
Jiangsu province	68.70	66.80
Anhui province	52.70	51.00
Shanghai	99.00	33.00
Yangtze river delta total	278.55	215.80
National total	705.8	688.70
Proportion	0.3947	0.3133

Automobile and Aichi Automobile. There are also some new energy automobile manufacturers in Hangzhou, Ningbo and other places in Zhejiang Province, such as Zhejiang Geely Holding Group. These enterprises have established large-scale production bases in the Yangtze River Delta region with large production capacity, which has made important contributions to the supply of new energy vehicles in the country. In 2023, China Private Economy Development Forum released the report "Research on High-quality Development of Private Economy Driven Industrial Clusters and Top 100 Industrial Clusters in China in 2023", and the Yangtze River Delta region performed well. In the announcement of China Top 100 Industrial Clusters, there are 47 regional industrial clusters in the Yangtze River Delta, and the number of new energy automobile industrial clusters in Jiangsu and Zhejiang provinces ranks first and second in China respectively, which provides favorable conditions for the production of new energy vehicles [10] (Table 2).

In addition, the Yangtze River Delta region has a perfect supply chain system, including manufacturers of core components such as batteries, motors and electronic control systems. These enterprises provide high-quality parts and components, provide important supporting services for new energy automobile manufacturers nationwide, and promote the development of the whole industry. The Yangtze River Delta region has become an important base for the new energy automobile industry, and one out of every three new energy vehicles is produced in the Yangtze River Delta region. This has also promoted the improvement of the industrial chain of new energy vehicles in Jiangsu, Zhejiang and Anhui provinces, and promoted the rapid development of local first-class new energy agents such as Contemporary Amperex Technology Co., Limited, Xusheng and Top Group. The whole ecological chain of new energy automobile parts in the Yangtze River Delta has grown rapidly, and at the same time, it has spawned a number of new forces to build cars in the Yangtze River Delta. These forces are moving at full speed towards the goal of a more advanced "electric + intelligent + ecological" smart car.

Many provinces and cities in the Yangtze River Delta have successively introduced multiple policies to promote the development of new energy vehicles. On January 29, 2023, Shanghai proposed policies to promote mass consumption of automobiles, including a subsidy of 10,000 yuan for replacing pure electric vehicles in the first half of the year. Also on January 29th, Zhejiang Province issued the Action Plan

Table 2 China Top 100 Industrial Clusters in 2023

City	Quantity	City	Quantity	City	Quantity
Shanghai	5	Shaoxing city	2	Xiamen city	1
Suzhou city	5	Wuhu city	2	Shantou city	1
Changzhou city	3	Changsha city	2	Shangrao city	1
Foshan city	3	Zibo city	2	Shijiazhuang city	1
Guangzhou city	3	Bengbu city	1	Weihai city	1
Hangzhou city	3	Baotou city	1	Weifang city	1
Hefei city	3	Baoding city	1	Wenzhou city	1
Ningbo	3	Binzhou city	1	Urumqi municipality	1
Shenzhen	3	City of Dalian	1	Wuhan (city)	1
Taizhou	3	Dongqiao city	1	Xining city	1
Wuxi city	3	Fuzhou city	1	Xinyu city	1
Zhengzhou city	3	Ganzhou city	1	Xuzhou city	1
Chongqing	3	Jinhua city	1	Yantai city	1
Beijing	3	Leshan city	1	Yangzhou city	1
Huzhou city	2	Liaocheng city	1	Yibin city	1
Huizhou city	2	Liuzhou city	1	Yichun city	1
Jiaxing city	2	Maanshan city	1	Yingtan city	1
Lianyungang city	2	Nantong City	1	Zhuhai municipality	1
Nanjing	2	Ningde city	1	Zhuzhou city	1
Quanzhou	2	Qingdao municipality	1		

for Accelerating the Development of New Energy Automobile Industry in Zhejiang Province [11]. The plan sets specific targets. By 2025, the annual output of new energy vehicles in Zhejiang Province will exceed 1.2 million, accounting for more than 60% of the total automobile production in the province. It is estimated that the output of new energy vehicles will account for about 10% of the national total. On January 28th, Changzhou issued "Policies and Measures for Promoting the Construction of New Energy Capital in Changzhou". The policy aims to accelerate the development of new energy automobile industry, and the specific details need to be further understood. Anhui province put forward the development goal of new energy automobile industry in the "High-quality Development Plan of Automobile Industry in Anhui Province during the 14th Five-Year Plan". By 2025, the overall development of new energy vehicle industry in Anhui Province will reach the international advanced level, and the output of new energy vehicles will account for more than 40%. Moreover, Anhui Province plans to basically form a development pattern with pure electric vehicles as the mainstay, plug-in hybrid vehicles as the supplement and hydrogen fuel vehicles as the demonstration [12].

These goals are aimed at promoting the development of new energy automobile industry, increasing output and market share, and strengthening technological innovation and industrial upgrading. By setting specific targets and implementing relevant policies and measures, the provinces and cities in the Yangtze River Delta region will further strengthen cooperation, promote the rapid development of the new energy automobile industry, and make contributions to the realization of sustainable development and green travel.

3 Yangtze River Delta New Energy Vehicle Ownership Forecast

3.1 Establish GM(1,1) Grey Prediction Model

First, the original series is established by using the number of new energy vehicles in the Yangtze River Delta from 2017 to 2022 [13].

$$X^{(0)} = (\mathrm{x}^{(0)}(1), \mathrm{x}^{(0)}(2), \mathrm{x}^{(0)}(3), \mathrm{x}^{(0)}(4), \mathrm{x}^{(0)}(5), \mathrm{x}^{(0)}(6)) \tag{1}$$

Among them, $X^{(0)}(i) \geq 0, i = 1, 2, 3, \cdots, 6$.

Accumulate the established original sequence once to generate an accumulated sequence.

$$X^{(1)} = (\mathrm{x}^{(1)}(1), \mathrm{x}^{(1)}(2), \mathrm{x}^{(1)}(3), \mathrm{x}^{(1)}(4), \mathrm{x}^{(1)}(5), \mathrm{x}^{(1)}(6)) \tag{2}$$

where $X^{(0)}(i) \geq 0, i = 1, 2, 3, \cdots, 6$

Then, the cumulative generation sequence is generated by adjacent mean, and the result is obtained.

$$Z^{(1)} = (Z^{(1)}(2), Z^{(1)}(3), Z^{(1)}(4), Z^{(1)}(5), Z^{(1)}(6)) \tag{3}$$

where, $Z^{(1)}(k) = \frac{1}{2}X^{(1)}(k) + \frac{1}{2}X^{(1)}(k-1), k = 2, 3, \cdots, 6$

The grey differential equation is defined as

$$x^{(0)}(k) + az^{(1)}(k) = b \tag{4}$$

where is the development coefficient; It is the gray action ab.

Constructing albino equation

$$\frac{dx^{(t)}}{dt} + ax^{(1)} = b \tag{5}$$

The estimated values of parameter sum are ab

$$\hat{a} = [a, b]^T = (B^T B)^{(-1)} B^T Y_n \tag{6}$$

The solution equation of the time corresponding function is

$$\hat{x}^{(1)}(k+1) = (x^{(1)}(0) - \frac{b}{a})e^{(-ak)} + \frac{b}{a} \tag{7}$$

where, $x^{(1)}(0) = x^{(0)}(1), k = 1, 2, 3, \cdots 6$

Reduction value

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(0)}(k+1) - \hat{x}^{(1)}(k) \tag{8}$$

Model test includes residual test and posterior difference test.

1. Residual test

   Absolute error

$$\varepsilon^{(0)}(i) = x^{(0)}(i) - \hat{x}^{(0)}(i) \tag{9}$$

   Relative error

$$\omega^{(0)}(i) = |\frac{x^{(0)}(i) - \hat{x}^{(0)}(i)}{x^{(0)}(i)}| \tag{10}$$

2. Posterior difference test

Mean square deviation of original sequence

$$\overline{x}^{(0)} = \frac{1}{n} \sum_{i=0}^{n} X^{(0)}(i) \tag{11}$$

$$S_0^2 = \sum_{i=1}^{n} (X^{(0)}(i) - \overline{X}^{(0)})^2 \tag{12}$$

$$S_0 = \sqrt{\frac{S_0^2}{n-1}} \tag{13}$$

Mean square error of residual sequence

$$\varepsilon^{(0)} = \frac{1}{n} \sum_{i=0}^{n} \varepsilon^{(0)}(i) \tag{14}$$

$$S_1^2 = \sum_{i=1}^{n} \varepsilon^{(0)}(i) - \overline{\varepsilon}^{(0)})^2 \tag{15}$$

$$S_1 = \sqrt{\frac{S_1^2}{n-1}} \tag{16}$$

Variance ratio

$$C = \frac{S_1}{S_0} \tag{17}$$

Minimum error rat

$$P = p\{|\varepsilon^{(0)}(i) - \overline{\varepsilon}^{(0)}| < 0.6745 S_0\} \tag{18}$$

3.2 Model Solving

First of all, the data of the new energy market in the Yangtze River Delta from 2018 to 2022 are collected. Since 2023 is not over half, the data collected in this paper is as of 2022. The data comes from the statistics bureau of various provinces and cities in the Yangtze River Delta, and is summarized as shown in the following Table 3 (Fig. 1):

The prediction model is established and solved by least square method.

GM(1, 1)

$$\hat{a} = [a, u]^T = \left(B^T B\right)^{-1} B^T Y_n = 0.6276$$

The prediction model of the original data sequence is obtained as follows X.

$$\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1) = 70.5624 * e^{0.6276(k-1)}, k = 2, \cdots, n$$

Table 3 Data of new energy market in Yangtze River Delta

Year	2017	2018	2019	2020	2021	2022
Market quantity of new energy vehicles in Yangtze River Delta (10,000 vehicles)	64	97	117	162.91	259.98	366.5

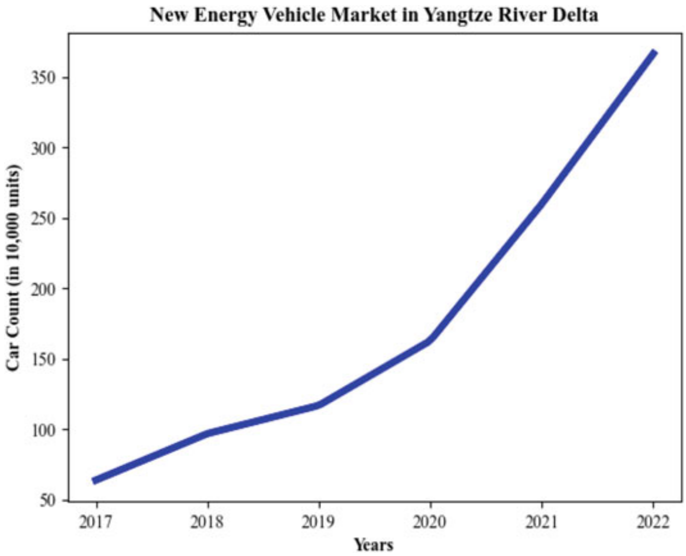

Fig. 1 Fitting curve of new energy vehicle market in Yangtze River Delta from 2017 to 2022

Finally, the forecast data of the new energy vehicle market in the Yangtze River Delta in the next three years are obtained, and the original data are tested for accuracy, and the absolute error, relative error, variance ratio and minimum error rate are solved. The specific results are shown in Table 4.

According to the market quantity data of new energy vehicles in the Yangtze River Delta from 2027 to 2022, the minimum error rate P is 0.023. The smaller the minimum error rate, the more accurate the prediction data of the established grey model, which fully shows that the grey prediction model GM(1,1) has good prediction accuracy and can be used to predict the market quantity of new energy vehicles in the Yangtze River Delta in the next three years.

According to the formula, k = 7, 8 and 9 are brought in respectively, and finally the predicted car ownership of new energy vehicles in the Yangtze River Delta in the next three years is obtained, as shown in the Table 5. Finally, draw a fitting curve

Table 4 Data of new energy market in Yangtze River Delta

Year	Data	Absolute error	Relative error	Variance ratio
2017	64	−0.1257	0.0020	0.3510
2018	97	7.1732	0.0737	
2019	117	−6.2210	0.0531	
2020	162.91	−4.3844	0.0269	
2021	259.98	−7.3968	0.0290	
2022	366.5	4.5027	0.0123	

Table 5 Market quantity of new energy vehicles in Yangtze River Delta

Year	2022	2023	2024	2025
Market quantity of new energy vehicles in Yangtze River Delta (10,000 vehicles)	366.5	521.06	733.33	1033.68

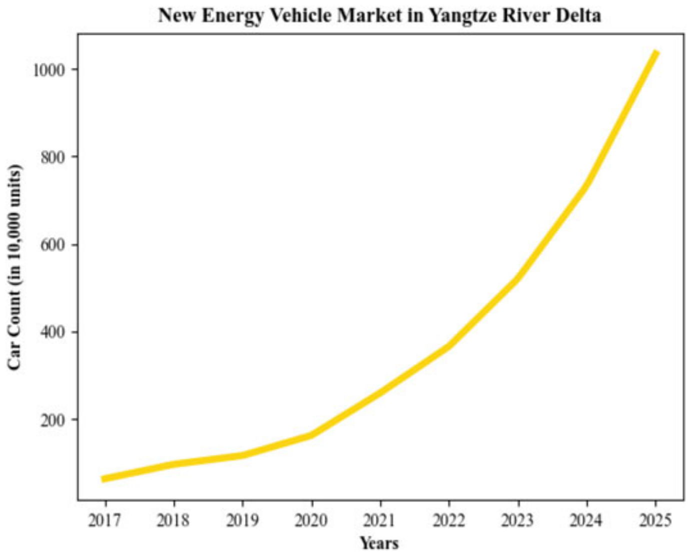

Fig. 2 Fitting curve of new energy vehicle market in Yangtze River Delta from 2022 to 2025

of the new energy vehicle market in the Yangtze River Delta from 2017 to 2025, as shown in Fig. 2.

$$\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1) = 70.5624 * e^{0.6276(k-1)}$$

4 China New Energy and Traditional Fuel Market Quantity Evolution Law

Collect the data of China's new energy vehicle market and traditional fuel vehicle market from 2017 to 2022, as shown in the following table:

According to the data in Table 6, from 2017 to 2022, the market share of new energy vehicles showed a significant growth trend. In the past six years, the number of new energy vehicles in the market has increased by 7.3 million, with a very rapid growth rate. In contrast, the market share of traditional fuel vehicles increased by 90.6 million, with a relatively small increase.