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Original Research

Research on the Demand Forecast for Aviation Transportation Flight Technicians under the Background of Carbon Emission Reduction

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Abstract

Carbon emissions from the aviation industry pose a considerable challenge to climate change. Direct emissions from aviation into the atmosphere notably impact climate change. To control pollution, the Chinese government has set the goal of "carbon peaking by 2030 and carbon neutrality by 2060". This article explores the demand forecasting issue for aviation transportation flight technicians based on aviation carbon emission reduction background, which is conducive to the industry's high-quality development. The article constructs a demand forecasting model for aviation flight technicians based on the gray GM(1,1) model and accurately predicts the number of aviation transportation flight technicians based on historical data from 2014 to 2023. The results show that: 1. The gray GM(1,1) model is reliable for predicting the demand for flight technicians in aviation transportation. Overall, the maximum relative error between the predicted and actual values is 5.09%, the minimum relative error is 0.15%, and the average relative error is 2.015%. 2. The demand for aviation transportation flight technicians shows a positive growth trend. According to the prediction results, the predicted number of civil aviation pilots in China will be 94,744 in 2024 and will reach 187,636 in 2033. 3. The demand forecasting trends for airline transport pilots and commercial pilot licenses are consistent.

Keywords: carbon emission reduction, air transportation, flight personnel, gray prediction model

Introduction

Air pollution and environmental degradation are increasingly threatening human health, and there is a growing consensus among nations to vigorously implement carbon emission reduction plans. The United Nations Framework Convention on Climate Change, the Kyoto Protocol, and other agreements provide crucial foundations for global environmental governance [1, 2]. To effectively address the issue of carbon emissions, the Chinese government has set the strategic goal of "achieving carbon peak by 2030 and achieving carbon neutrality by 2060" [3, 4].

From the perspective of carbon emission sources, carbon emissions are primarily associated with human

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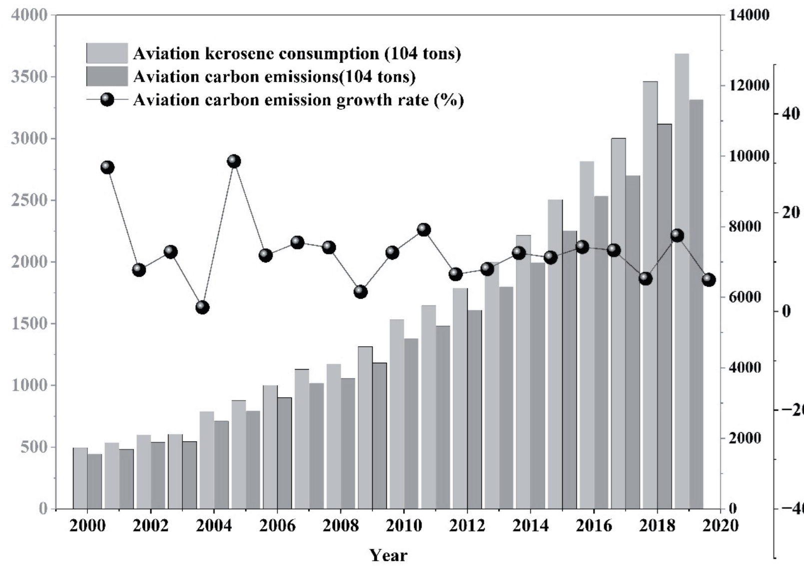

Fig. 1. Carbon emissions data of China's Civil Aviation.
Data source: China Air Transport Carbon Emission Estimation Dataset (2000-2019), global change science research data publishing system.

economic and social activities, with the aviation industry being a significant contributor. Aircraft fuel consumption directly leads to the emission of greenhouse gases such as CO_2. Statistical data indicates a rapid growth trend in aviation carbon emissions. As shown in Fig. 1, China's consumption of aviation kerosene increased from 4.9413 million tons in 2000 to 36.8919 million tons in 2019, with corresponding carbon emissions rising from 15.5652 million tons in 2000 to 116.046 million tons in 2019. Additionally, the carbon emission growth rates from 2016 to 2019 were 12.38%, 6.63%, 15.37%, and 6.38%, respectively. According to relevant statistics, the current CO_2 emissions from the global aviation industry account for approximately 2.4% of the total. If not properly controlled, carbon emissions in 2050 could be 11 times those in 2010 [5].

Compared with other carbon emission methods, aviation carbon emissions have a more significant impact on the ozone layer. In order to limit carbon emissions, the International Civil Aviation Organization issued a special resolution on emission reduction (No. A39-3) in 2016 [6]. In April 2023, the European Union adopted a special legal plan for carbon emission reduction [7]. As a substantial source of CO_2 emissions, vigorously implementing carbon emission reduction in aviation is also one of the important goals of green development for China's civil aviation industry.

Cultivating a sufficient pool of civil aviation flight technicians is a brand-new topic under the practical constraints of aviation carbon emission reduction. Civil aviation pilots are key talent resources for air transportation and play an important role in ensuring the normal operation of civil aviation transportation. Under the dual carbon goals, cultivating an appropriate number of pilots is a crucial task for the industry's high-quality development. Therefore, this article will explore the issue of the demand for aviation transportation flight technicians in a new context.

Focusing on the research theme of this article, scholars both domestically and internationally have primarily conducted extensive research on issues such as "dual carbon goals", "aviation carbon emissions", and "talent forecasting". Through analysis of existing literature, the current research encompasses the following three aspects:

(1) Research related to the "dual carbon" goals. In September 2020, the Chinese government first proposed the goal of "carbon peaking by 2030 and carbon neutrality by 2060" [8]. After that, many scholars put forward specific paths and countermeasures. For example, some scholars pay attention to the problem of "energy-water-carbon" coupling coordination [9], how energy transformation enables new quality productivity [10], and the mechanism of industrial agglomeration to reduce energy consumption [11]. In addition, some scholars have studied the legal system of carbon-inclusive credits [12]. From the technical dimension, some scholars have studied the emission reduction technology of CH4 and SF6WASTE gas [13] and the role of carbon capture and storage (CCS-EOR) technology [14]. In addition, the spatial distribution of carbon emissions has also attracted attention [15]. These studies have explored specific strategies to achieve the goal of "dual carbon" from industry, law, technology, and space perspectives.

(2) Research related to aviation carbon emissions. Aviation carbon emissions are a serious environmental pollution hazard. Many scholars have studied carbon emission control from the perspective of airports and aircraft [16-18]. For example, some studies focus on comparing carbon emission factors between high-speed rail and civil aviation passenger transport [19]

Table 1. Number of pilots in China's civil aviation industry.

Number of pilots	Total number of valid licenses	Sports Pilot License (SPL)	Private Pilot License (PPL)	Commercial Pilot License (CPL)	Multi-Crew Pilot License (MPL)	Airline Transport Pilot License (ATPL)
2014	39881	427	2085	20158	38	15654
2015	45523	733	2450	22870	35	17602
2016	50504	708	2460	25244	104	19693
2017	55765	805	2642	27349	147	22195
2018	61492	894	3735	32084	185	24594
2019	67953	1173	4352	35329	193	26906
2020	69442	1113	4015	37881	192	26241
2021	76236	1515	4822	42445	187	27267
2022	81430	1934	5211	45895	176	28214
2023	86091	2514	5317	48580	158	29522

Data source: Statistical bulletin on the development of the civil aviation industry from 2014 to 2023.

and calculating greenhouse gas characteristics of civil aviation based on the IPCC inventory algorithm [20]. In addition, some studies have used system dynamics methods to simulate the cost and path of aviation carbon emission reduction [21]. Xing Jian and Li Cheng used the PSO-ELM-Markov model to calculate the carbon emissions of civil aviation [22]. Li et al. studied the spatial pattern of urban aviation carbon emissions in China [23]. The above research constructs a variety of quantitative models to conduct multidimensional research on aviation carbon emission measurement and puts forward targeted countermeasures and suggestions.

(3) Research related to talent demand forecasting. Most scholars have conducted forecasts for the automotive and medical industries, as well as technological talents, often using methods such as multiple linear regression, ARIMA, and neural networks. Jin et al. predicted the demand for new energy vehicle talents [24]. Xu et al. used a combined model to forecast the demand for medical and nursing talents in Gansu Province [25]. Wang et al. utilized a gray combined forecasting model to predict the demand for technological talents [26]. Liu et al. used qualitative and quantitative methods to forecast the demand for intelligent connected vehicle talents [27]. Chen et al. used the gray GM(1,1) model to predict the demand for cultural talents [28]. Most of the aforementioned studies are based on historical data and make predictions about future talents, forming a rich system of forecasting methods.

Based on the literature review mentioned above, it can be seen that there have been systematic theories and relatively rich practical research on issues such as dual carbon goals, aviation carbon emissions, and talent demand forecasting both domestically and internationally. However, most research lacks focus on predicting aviation flight talent under dual carbon goals. Flight technology talent is the core resource of air transportation. With the advancement of the "dual carbon" policy, the air transportation industry is bound to be affected, making effective predictions of aviation flight technology talent in the new context of great value. The main innovations of this paper are as follows: 1. Exploring the prediction of aviation flight technology talent under dual carbon goals. Existing research has paid less attention to this issue, lacking the effective prediction of aviation transportation flight technology talent and being unable to provide a scientific basis for aviation development. 2. The gray system GM(1,1) model is introduced to accurately predict the demand for aviation flight technology talent. Compared to parameter estimation models such as multiple linear regression, the gray system GM(1,1) model can obtain accurate prediction results using small samples and limited information. The research in this paper will expand and enrich the prediction theory and practice of aviation flight technology talent.

Materials and Methods

Forecast Data on the Demand for Aviation Transportation Flight Technicians

The data in this article primarily originates from the "Statistical Bulletin on the Development of the Civil Aviation Industry", which spans from 2014 to 2023. According to statistics, as of December 31, 2023, the number of pilots in China's transport airlines stood at 61,480, marking an increase of 3,626 compared to the previous year. To precisely forecast the demand for civil aviation flight talent in China, this article has gathered the raw data of Chinese civil aviation pilots from 2014 to 2023, as presented in Table 1.

Construction of a Gray GM(1,1) Model for Predicting Demand for Aviation Flight Technicians

Aviation transportation flight technicians belong to the category of scientific and technological talents. Due to the nonlinear development characteristics of the demand for scientific and technological talents, the commonly used method for prediction is the gray model [29, 30]. Gray system theory, first proposed by Professor Deng Julong, primarily addresses the analysis, prediction, and decision-making problems related to "small samples and uncertainties" [31]. The GM(1,1) model is a commonly used prediction model, and this paper primarily employs this model for predicting flight technicians. The modeling process is as follows [32, 33]:

(1) Original sequence

Using the historical data on the number of flight technicians as the original data series, denoted as:

$$X^{(0)}=(x^{(0)}(1),x^{(0)}(2),...,x^{(0)}(n))$$

Where n represents the time series.

(2) Accumulation of raw data and generation of mean values

Considering the randomness of the original data, we first perform accumulation and mean value processing on it:

After one accumulation, the following sequence is obtained, denoted as:

$$X^{(1)}=(x^{(1)}(1),x^{(1)}(2),...,x^{(1)}(n)),\ k=1,2,...,n$$

n represents the time series

$$x^{(1)}(k)=\sum_{i=1}^{k}x^{(0)}(i)\text{, and } x^{(1)}(1)=x^{(0)} \tag{1}$$

Let $Z^{(1)}$ be the generated sequence of the adjacent mean of $X^{(1)}$,

$$Z^{(1)}=(z^{(1)}(2),z^{(1)}(3),...,z^{(1)}(n)),\ k=1,2,...,n$$

$$z^{(1)}(k)=0.5x^{(1)}(k)+0.5x^{(1)}(k-1) \tag{2}$$

(3) Establish a GM(1,1) model

Based on Equations (1) and (2), a first-order dynamic gray prediction model is constructed:

$$x^{(0)}(k)+az^{(1)}(k)=b \tag{3}$$

In the formula, a is called the development coefficient and b is called the gray action quantity.

(4) Solution of GM(1,1) model

If $\hat{\alpha}$ is set as the vector of parameters to be estimated, i.e., $\hat{\alpha}=(a,b)^T$, then the least squares estimate of the Equation satisfies,

$$\hat{\alpha}=(B^TB)^{-1}B^TY_n$$

Among them,

$$B=\begin{bmatrix}-z^{(1)}(2) & 1\\ -z^{(1)}(3) & 1\\ ... & ...\\ -z^{(1)}(n) & 1\end{bmatrix},\quad Y_n=\begin{bmatrix}x^{(0)}(2)\\ x^{(0)}(3)\\ ...\\ x^{(0)}(n)\end{bmatrix} \tag{4}$$

define: $\frac{dx^{(1)}}{dt}+ax^{(1)}=b$

which is the whitening equation of the gray differential Equation $x^{(0)}(k)+az^{(1)}(k)=b$, also known as the shadow Equation.

As mentioned above, then there is:

1) The solution of the whitening Equation $\frac{dx^{(1)}}{dt}+ax^{(1)}=b$ is also called the time response function,

$$\hat{x}^{(1)}(t)=(x^{(1)}(0)-\frac{b}{a})e^{-at}+\frac{b}{a} \tag{5}$$

2) The time response series of the gray differential Equation $x^{(0)}(k)+az^{(1)}(k)=b$ is

$$\hat{x}^{(1)}(k+1)=[x^{(1)}(0)-\frac{b}{a}]e^{-ak}+\frac{b}{a},\quad k=1,2,...,n \tag{6}$$

3) If $x^{(1)}(0)=x^{(0)}(1)$, then

$$\hat{x}^{(1)}(k+1)=[x^{(0)}(1)-\frac{b}{a}]e^{-ak}+\frac{b}{a},\quad k=1,2,...,n$$

4) Restore value:

$$\hat{x}^{(0)}(k+1)=\hat{x}^{(1)}(k+1)-\hat{x}^{(1)}(k) \tag{7}$$

That is to say

$$\hat{x}^{(0)}(k+1)=(1-e^{a})(x^{(0)}(1)-\frac{b}{a})e^{-ak} \tag{8}$$

The above formula is the prediction equation.

Gray GM(1,1) Model Test

The accuracy of the model is primarily assessed through residual testing. The calculation methods for residuals and relative errors are as follows:

Residual: $\varepsilon(k)=x^{(0)}(k)-\hat{x}^{(0)}(k)$; ($k=1,2,\cdots,n$);

Relative error: $\Delta_k=\frac{|\varepsilon(k)|}{x^{(0)}(k)}$; ($k=1,2,\cdots,n$);

Among them $\hat{x}^{(0)}(i) = -\hat{x}^{(1)}(i-1) - \hat{x}^{(1)}(i-1)$ $\left(i = 1, 2, ..., n\right)$, if the error value is smaller, it indicates that the model's prediction is more accurate.

Results and Discussion

Forecast Results of Civil Aviation Flight Talent Demand Based on the Gray System GM(1,1) Model

The total amount of aviation talent is a crucial indicator of the high-quality development of China's civil aviation industry, serving as a key basis for assessing the level and extent of its progress. Predicting and analyzing the total amount of aviation talent in China's civil aviation industry is beneficial for air transport enterprises to anticipate and address short-term human resource issues and for institutions directly affiliated with the civil aviation industry to plan talent cultivation, thereby ensuring intellectual support for the development of the civil aviation industry. This article employs the gray GM(1,1) model to forecast the demand for aviation talents in China's civil aviation industry. Initially, it predicts the number of civil aviation pilots in China. The relevant calculation process is as follows:

(1) Initialize the original sequence for modeling

The total number of valid licenses for pilots in China's civil aviation industry is selected as the original data, covering the period from 2014 to 2023.

The original sequence is as follows:

$$X^{(0)} = (39881, 45523, 50504, 55765, 61492, 67953, 69442, 76236, 81430, 86091)$$

(2) The 1st accumulated generating sequence (1-AGO) of the original sequence

Using the original sequence $X^{(0)}$ and the accumulation formula, calculate the first accumulated generating sequence:

$$X^{(1)} = (39881.0, 85404.0, 135908.0, 191673.0, 253165.0, 321118.0, 390560.0, 466796.0, 548226.0, 634317.0)$$

(3) The adjacent mean generation of the 1-AGO-generating sequence

Obtain the adjacent mean sequence based on the original sequence and the accumulated generating sequence:

$$Z^{(1)} = (62642.5, 110656.0, 163790.5, 222419.0, 287141.5, 355839.0, 428678.0, 507511.0, 591271.5)$$

(4) Calculate the development coefficient a and the gray action b of the gray model

a = -0.076 b = 43018.194

(5) Simulated values and simulation error

Using the results and parameters calculated from the aforementioned model, we can obtain the predicted values, absolute errors, and relative errors for China's civil aviation flight talents. The relevant results are shown in Table 2 and Fig. 2.

Based on the results, using the gray GM(1,1) model, the effective number of pilot licenses in China's civil aviation in 2015 was 45,523, with a predicted value of 47,839.299. The difference between the two was -2,316.299, representing a relative error of 5.09%. In 2016, the effective number of pilot licenses in China's civil aviation was 50,504, with a predicted value of 51,612.959. The difference between the two was -1,108.959, representing a relative error of 2.20%. In 2017, the effective number of pilot licenses in China's civil aviation was 55,765, with a predicted value of 55,684.293. The difference between the two was 80.707, representing a relative error of 0.15%. In 2018, the effective number of pilot licenses in China's civil aviation was 61,492, with a predicted value of 60,076.781. The difference between the two was 1,415.219, representing a relative error of 2.30%. In 2019, the effective number of pilot licenses in China's civil aviation was 67,953, with a predicted value of 64,815.758. The difference between the two was 3,137.242, representing a relative error of 4.62%. In 2020, the effective number of pilot licenses in China's civil aviation was 69,442, with a predicted value of 69,928.555. The difference between the two was -486.555, representing a relative error of 0.70%. In 2021, the effective number of pilot licenses in China's civil aviation was 76,236, with a predicted value of 75,444.659. The difference between the two was 791.341, representing a relative error of 1.04%. In 2022, the effective number of pilot licenses in China's civil aviation was 81,430, with a predicted value of 81,395.885. The difference between the two was 34.115, representing a relative error of 0.04%. In 2023, the effective number of pilot licenses in China's civil aviation was 86,091, with a predicted value of 87,816.555. The difference between the two was -1,725.555, representing a relative error of 2.00%.

Therefore, from an overall perspective, the maximum relative error between the predicted and actual values is 5.09%, the minimum relative error is 0.15%, and the average relative error is 2.015%. Therefore, it can be concluded that the reliability of the results predicted using the gray GM(1,1) model is very high.

(6) Prediction of the number of pilots in China's civil aviation industry (2024-2033)

Based on the previous analysis results, the predicted values of the number of civil aviation pilots in China from 2024 to 2033 were calculated using the gray GM(1,1) model, as shown in Table 3 and Fig. 3.

Based on the results, the predicted value for civil aviation pilots in China in 2024 is 94,744. From 2024

Table 2. Predicted results of the number of pilots in China's civil aviation industry.

Particular year	Actual value	Predicted value	Absolute error	Relative error
2015	45523	47839	-2316	5.09%
2016	50504	51613	-1109	2.20%
2017	55765	55684	81	0.15%
2018	61492	60077	1415	2.30%
2019	67953	64816	3137	4.62%
2020	69442	69929	-487	0.70%
2021	76236	75445	791	1.04%
2022	81430	81396	34	0.04%
2023	86091	87817	-1726	2.00%

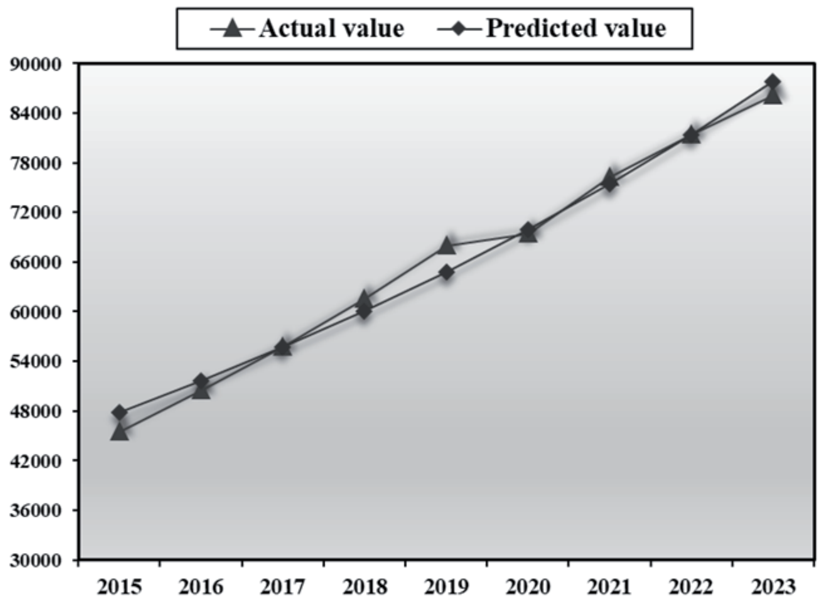

Fig. 2. Number of civil aviation pilots in China.

to 2028, the predicted values for civil aviation pilots in China are 102217, 110280, 118980, and 128365, respectively. From 2029 to 2033, the predicted values for civil aviation pilots in China are 138491, 149415, 161201, 173917, and 187636, respectively. The value in 2024 is the smallest, while the value in 2033 is the largest. Therefore, it can be seen that according to the prediction results, the overall number of civil aviation pilots in China shows a positive growth trend. Fig. 3. provides a more intuitive display of this prediction.

Therefore, it is necessary to increase the cultivation of flight technicians. Civil aviation has a high technological content, intensive capital investment, and strategic importance in the national economy. The cultivation cycle of civil aviation flight talents is long, requiring increased investment, continuous strengthening of flight and specialty construction, and the cultivation of more talents. At the same time, cooperation between civil aviation enterprises and institutions should be strengthened, emphasizing the improvement of practical abilities to further enhance the quality of cultivating civil aviation-specific talents.

Prediction of the Number of Airline Transport Pilot Licenses (ATPL) in China

According to data from the Civil Aviation Administration of China, in 2023, there were 29,281 ATPL (Airline Transport Pilot License) holders among Chinese civil aviation pilots, an increase of 1,283 from 2022, representing a year-on-year growth of 4.58%. Among them, there were 20872 available captains and 31599 first officers in 121 transport airlines, with net increases of 1818 captains and 2935 first officers compared to the same period last year.

Airline transport pilots are an important component of China's civil aviation pilots, and this is the license required to become a captain of a large passenger

Table 3. Predicted number of pilots in China's civil aviation industry (2024-2033).

Serial number	Particular year	Predicted value
1	2024	94744
2	2025	102217
3	2026	110280
4	2027	118980
5	2028	128365
6	2029	138491
7	2030	149415
8	2031	161201
9	2032	173917
10	2033	187636

aircraft. By predicting the number of ATPLs, we can effectively reflect the core quantity level of flight personnel. Therefore, this article further conducts predictive research on it.

(1) Initialize the original sequence for modeling

The original data used in this study are the pilot license data of China's civil aviation routes, covering the period from 2014 to 2023.

The original sequence is as follows:

$$X^{(0)} = (15654, 17602, 19693, 22195, 24594, 26906, 26241, 27267, 28214, 29522)$$

(2) Generation of 1-AGO from the original sequence

Using the original sequence $X^{(0)}$ and the accumulation formula, calculate the first accumulated generating sequence:

$$X^{(1)} = (15654, 33256, 52949, 75144, 99738, 126644, 152885, 180152, 20836600, 237888)$$

(3) The adjacent mean generation of the 1-AGO-generating sequence

Calculate the adjacent mean sequence using the original sequence and the accumulated generating sequence:

$$Z^{(1)} = (24455, 43102.5000, 64046.5000, 87441, 113191, 139764.5000, 166518.5000, 194259, 223127)$$

(4) Calculate the development coefficient a and the gray action b of the gray model

a = -0.055 b = 18196.067

(5) Simulated values and simulation error

Using the results and parameters calculated from the aforementioned model, we can obtain the predicted values, absolute errors, and relative errors for China's civil aviation airline transport pilots. The relevant results are presented in Table 4.

Based on the results, using the gray GM(1,1) model, the actual number of airline transport pilot licenses in China in 2015 was 17,602, with a predicted value of 19,601, resulting in an absolute error of -1,999 and a relative error of 11.35%. In 2016, the actual number of airline transport pilot licenses in China was 19,693, with a predicted value of 20,717, yielding an absolute error of -1,024 and a relative error of 5.20%. In 2017, the actual number of airline transport pilot licenses in China was 22,195, with a predicted value of 21,896, resulting in an absolute error of 299 and a relative error of 1.35%. In 2018, the actual number of airline transport pilot licenses in China was 24,594, with a predicted value of 23,143, yielding an absolute error of 1,451 and a relative error of 5.90%. In 2019, the actual number of airline transport pilot licenses in China was 67,953, with

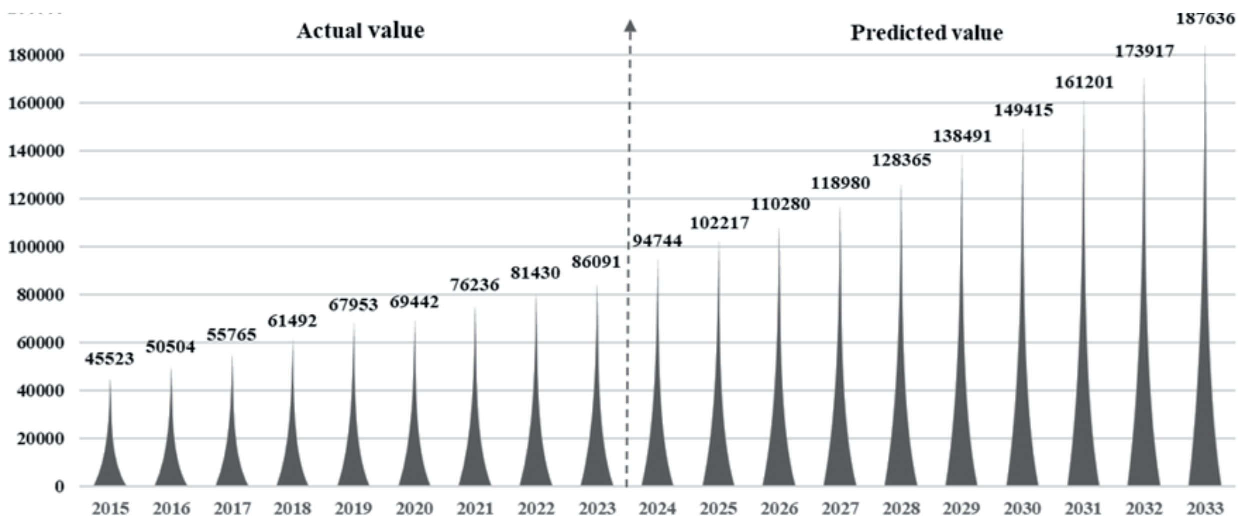

Fig. 3. Forecast number of chinese civil aviation pilots (2024-2033).

Table 4. Predicted results of the number of airline transport pilot licenses in China's civil aviation.

Particular year	Actual value	Predicted value	Absolute error	Relative error
2015	17602	19601	-1999	11.35%
2016	19693	20717	-1024	5.20%
2017	22195	21896	299	1.35%
2018	24594	23143	1451	5.90%
2019	26906	24460	2446	9.09%
2020	26241	25853	388	1.48%
2021	27267	27325	-58	0.21%
2022	28214	28881	-667	2.36%
2023	29522	30525	-1003	3.40%

a predicted value of 64,815.758, resulting in an absolute error of 31,37.242 and a relative error of 4.62%. In 2019, the actual number of airline transport pilot licenses in China was 26,906, with a predicted value of 24,460, yielding an absolute error of 2,446 and a relative error of 9.09%. In 2020, the actual number of airline transport pilot licenses in China was 26,241, with a predicted value of 25,853, resulting in an absolute error of 388 and a relative error of 1.48%. In 2021, the actual number of airline transport pilot licenses in China was 27,267, with a predicted value of 27,325, yielding an absolute error of -58 and a relative error of 0.21%. In 2022, the actual number of airline transport pilot licenses in China was 28,214, with a predicted value of 28,881, resulting in an absolute error of -667 and a relative error of 2.36%. In 2023, the actual number of airline transport pilot licenses in China was 29,522, with a predicted value of 30,525, yielding an absolute error of -1,003 and a relative error of 3.40%.

According to the calculation results, the average relative error between the predicted and actual values is 4.482%. Further explanation shows that the prediction results of the gray GM(1,1) model are highly accurate.

(6) Prediction of the number of airline transport pilot licenses in China (2024-2033)

Based on the previous analysis results, the average relative error of predicting the number of airline transport pilots in China using the gray GM(1,1) model is only 4.482%, indicating the model's high accuracy. Therefore, the results of using this model to predict the number of airline transport pilots from 2024 to 2033 are shown in Fig. 4.

Based on the results, the predicted value of airline transport pilots for China's civil aviation in 2024 is 32,263. From 2024 to 2028, the predicted values are 34,100, 36,041, 38,093, and 40,262, respectively. From 2029 to 2033, the predicted values are 42,555, 44,978, 47,538, 50,245, and 53,106. The value in 2024 is the smallest, while that in 2033 is the largest. Therefore, it can be seen that, according to the prediction results, the overall number of airline transport pilots in China's civil aviation shows a positive growth trend. Fig. 3 provides a more intuitive display of this prediction.

Prediction of China's Commercial Pilot License (CPL)

Commercial pilot license training takes the longest, typically exceeding one year, and includes at least 250 hours of fixed-wing aircraft flight practice and additional high-performance aircraft training. Only pilots with a commercial pilot license are allowed to engage in paid flight activities. Therefore, this article further predicts the number of commercial pilot licenses in China's civil aviation industry.

(1) Initialize the original sequence for modeling

The original data used is the commercial pilot license data from the Civil Aviation Administration of China, covering the period from 2014 to 2023.

The original sequence is as follows:

$$X^{(0)} = (20158, 22870, 25244, 27349, 32084, 35329, 37881, 42445, 45895, 48580)$$

(2) Generation of 1-AGO from the original sequence

Using the original sequence $X^{(0)}$ and the cumulative generation fo rmula, calculate the first accumulated generating sequence:

$$X^{(1)} = (20158, 43028, 68272, 95621, 127705, 163034, 200915, 243360, 289255, 337835)$$

(3) The adjacent mean generation of the 1-AGO-generating sequence

Calculate the adjacent mean sequence based on the original sequence and the accumulated generating sequence:

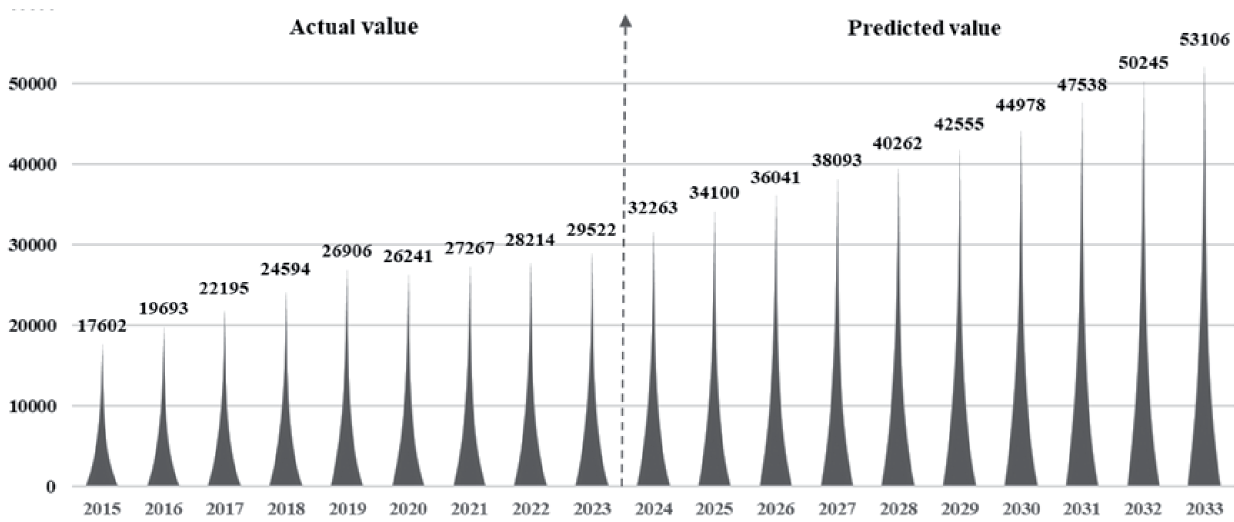

Fig. 4. Forecast number of air route transport pilots in China (2024-2033).

$$Z^{(1)} = (31593, 55650, 81946.5, 111663, 145369.5, 181974.5, 222137.5, 266307.5, 313545)$$

(4) Calculate the development coefficient a and the gray action b of the gray model

a = -0.094 b = 20519.454

(5) Simulated values and simulation error

Using the results and parameters calculated from the aforementioned model, we can obtain the predicted values, absolute errors, and relative errors for China's civil aviation flight talents. The relevant results are presented in Table 5.

Based on the results, using the gray GM(1,1) model, the actual number of commercial pilot licenses issued by China's civil aviation in 2015 was 22,870, with a predicted value of 23,512, resulting in an absolute error of -642 and a relative error of 2.81%. In 2016, the number of commercial pilot licenses issued was 25,244, with a predicted value of 25,837, yielding an absolute error of -593 and a relative error of 2.35%. In 2017, the number of commercial pilot licenses issued was 27,349, with a predicted value of 28,393, resulting in an absolute error of -1,044 and a relative error of 3.82%. In 2018, the number of commercial pilot licenses issued was 32,084, with a predicted value of 31,201, yielding an absolute error of 883 and a relative error of 2.75%. In 2019, the number of commercial pilot licenses issued was 35,329, with a predicted value of 34,287, resulting in an absolute error of 1,042 and a relative error of 2.95%. In 2020, the number of commercial pilot licenses issued was 37,881, with a predicted value of 37,678, yielding an absolute error of 203 and a relative error of 0.54%. In 2021, the number of commercial pilot licenses issued was 42,445, with a predicted value of 41,405, resulting in an absolute error of 1,040 and a relative error of 2.45%. In 2022, the number of commercial pilot licenses issued was 45,895, with a predicted value of 45,500, yielding an absolute error of 395 and a relative error of 0.86%. In 2023, the number of commercial pilot licenses issued was 48,580, with a predicted value of 50,000, resulting in an absolute error of -1,420 and a relative error of 2.92%.

The results show that the average relative error between the predicted and actual values is 2.383%, indicating that the gray GM(1,1) model is highly accurate in prediction and is suitable for this paper's research.

(6) Prediction of the number of commercial pilot licenses in China's civil aviation (2024-2033)

Based on the previous analysis results, the average relative error of predicting the number of commercial pilots in China's civil aviation using the gray GM(1,1) model is only 2.383%, indicating the model's high accuracy. Therefore, using this model to predict the values for the next ten years, we obtain the predicted number of commercial pilots in China's civil aviation from 2024 to 2033, as shown in Fig. 5.

Based on the results, the predicted value of commercial pilots in China's civil aviation in 2024 is 54,946. From 2024 to 2028, the predicted values of commercial pilots in China's civil aviation are 60380, 66352, 72915, and 80127, respectively. From 2029 to 2033, the predicted values of commercial pilots for China's civil aviation are 88052, 96760, 106331, 116847, and 128404, respectively. The value in 2024 is the smallest, while the value in 2033 is the largest. Therefore, it can be seen that, according to the forecast results, the overall number of commercial pilots in China's civil aviation shows a positive growth trend. Fig. 5 provides a more intuitive display of this prediction.

Conclusions

Environmental pollution and climate change are increasingly threatening human health, with aviation carbon emissions being one of the significant sources of carbon emissions. In the air transportation sector,

Table 5. Predicted results of the number of commercial pilot licenses in China's civil aviation.

Particular year	Actual value	Predicted value	Absolute error	Relative error
2015	22870	23512	-642	2.81%
2016	25244	25837	-593	2.35%
2017	27349	28393	-1044	3.82%
2018	32084	31201	883	2.75%
2019	35329	34287	1042	2.95%
2020	37881	37678	203	0.54%
2021	42445	41405	1040	2.45%
2022	45895	45500	395	0.86%
2023	48580	50000	-1420	2.92%

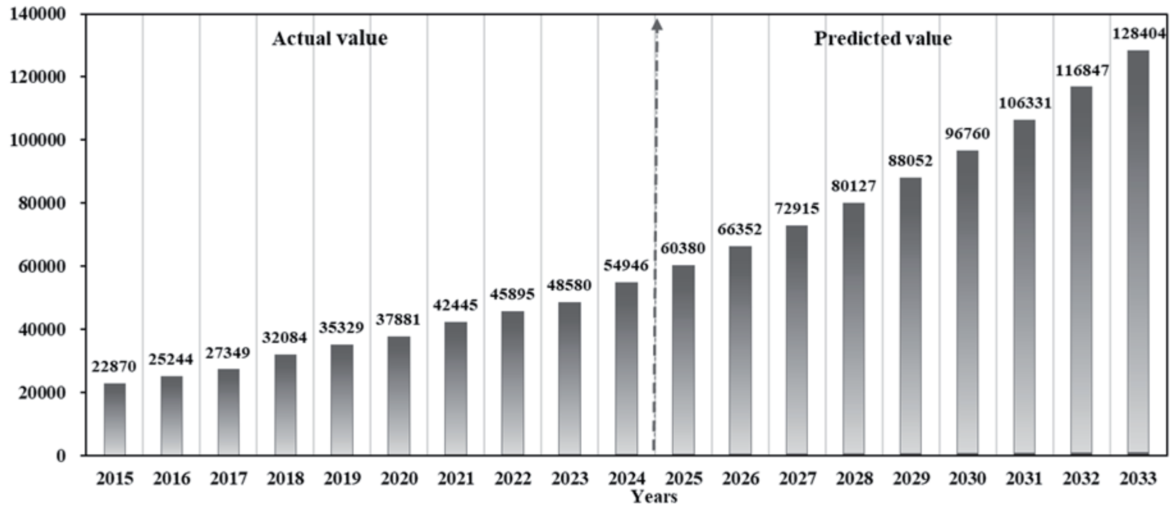

Fig. 5. Forecast number of commercial pilots in civil aviation of China (2024-2033).

aircraft primarily rely on fuel as their power source, and fuel consumption directly leads to the emission of a large amount of greenhouse gases, such as CO_2. The Chinese government has proposed "dual carbon" goals to address this crisis. Based on this background, this article studies the demand forecasting issue for aviation transportation flight technology talents. The article constructs a demand forecasting model for aviation flight technology personnel based on the gray GM(1,1) model and accurately predicts the number of aviation transportation flight technology personnel based on historical data from 2014 to 2023. According to relevant calculations and analysis, the following conclusions are drawn:

Firstly, the gray GM(1,1) model demonstrates reliability in predicting the demand for aviation transportation flight technicians. For the overall prediction of civil aviation flight technicians, the maximum relative error between the predicted and actual values is 5.09%, the minimum relative error is 0.15%, and the average relative error is 2.015%. Furthermore, in predicting the number of airline transport pilot licenses in China's civil aviation, the predicted value is 30,525, with an absolute error of -1,003 and a relative error of 3.40%.

Secondly, the demand for aviation transportation flight technicians shows a positive growth trend. According to the prediction, the number of civil aviation pilots in China is expected to reach 94,744 by 2024. From 2024 to 2028, the projected values of commercial pilots in civil aviation in China are 102,217, 110,280, 118,980, and 128,365, respectively. Similarly, from 2029 to 2033, the predicted values are 138,491, 149,415, 161,201, 173,917, and 187,636, respectively. The value in 2024 is the lowest, while that in 2033 is the highest. Therefore, it can be observed that, based on the forecast results, the overall number of civil aviation pilots in China is showing a positive growth trend.

Thirdly, the forecast trends for airline transport pilot and commercial pilot licenses are consistent. According to the results, from 2024 to 2033, the predicted values for airline transport pilots in China's civil aviation are 32,263, 34,100, 36,041, 38,093, 40,262, 42,555, 44,978, 47,538, 50,245, and 53,106, showing an overall positive growth trend. Similarly, from 2024 to 2033, the predicted values for airline transport pilots in China's civil aviation are 54,946, 60,380, 66,352, 72,915, 80,127, 88,052, 96,760, 106,331, 116,847, and 128,404, also showing a positive growth trend.

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Conflict of Interest

The authors declare no conflict of interest.

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