Research on the development trend of new energy vehicles based on GM (1.1)

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Abstract. The new energy vehicles have many advantages that traditional cars can't match, such as energy conservation, environmental protection and recycling. Through the investigation of the development situation of Tianjin's new energy vehicles, GM (1,1) model is used to predict and analyze the sales of BYD, Toyota, Zotye and Tesla, which are more popular brands in Tianjin. The conclusions can provide a basis for the corresponding car manufacturers to develop a strategy, at the same time, it also proposes corresponding countermeasures and suggestions for the development of Tianjin new energy vehicles.

1. Introduction

The development of new energy vehicles has become a common measure that the international community must take. Therefore, the development strategies of new energy vehicles are also focused differently in different countries in the world. The focus of US development is to reduce dependence on petroleum resources and to make full use of renewable resources. In order to accelerate the achievement of this goal, the United States has introduced corresponding bill standards. In 2007, through the Energy Independence and Security Act 2007, the bill sets targets for renewable fuel use – at least 22% of automotive fuels use renewable fuels in 2022, with a total use of 36 billion gallons (about It is 110 million tons).

1.1 Foreign research background

The focus of Japan's development of new energy vehicles is to minimize the dependence on imported energy. The development of Japan's new energy automobile industry has been promoted by corresponding policies. At the same time, Japan has not fallen in the pure electric vehicle industry. It has systematically proposed and implemented the corresponding power battery research and development plan. By 2030, it will increase the performance of the battery by 7 times and reduce to 1/40 of the cost.

European countries put the greenhouse gas emission reduction strategy in the first place. One of the strategies of Europe in the development of new energy vehicles is that the promotion of private consumption to purchase new energy vehicles will focus on the rental market. The most direct and effective way to solve the European CO2 emission limitation standard is actually electric vehicles. However, the current proportion of electric vehicles in Europe is not large. Therefore, the development trend of European new energy vehicles is mainly electric vehicles.

Table 1 Development Strategy for new energy vehicles in several major foreign countries

| country    | Planning period | The production and sales target of the new energy vehicle | Major new energy vehicles |
|------------|-----------------|----------------------------------------------------------|----------------------------|

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1.2 Domestic research background
As an essential product for the sustainable development of human society, new energy vehicles have been promoted by countries all over the world, and it is the same as China. In order to promote industrial development, China has implemented a corresponding subsidy policy. In recent years, with the support of policies, China's new energy vehicles have successfully achieved continuous breakthroughs in production and sales. In 2011, the output of the new energy vehicles was only 0.8 million units, which was far from the total national automobile production. By the end of 2017, the statistics show that China's new energy vehicles have reached a production of 794,000 vehicles. The proportion is 2.7%. According to China's production and sales data trends and China's planning goals, it is estimated that by 2020, China's new energy vehicles will exceed 2 million production and sales; after 10 years, China's new energy passenger cars will reach 13 million.[1-3]

2. Model
2.1 Grey prediction model construction
The construction of GM (1.1) model is mainly based on the evolution characteristics of the system's main variables. The model analyzes the evolution trend of the main variables of the system mainly through two mathematical methods: one is the first-order differential equation and the other is the first-order difference equation. The GM (1.1) model is usually called a first-order university grey prediction model.[4-5] The GM (1.1) model completely embodies the small sample features of the grey system and is the core of the grey prediction model.

The raw data sequence of the main variable about the system is set up
\[
X^{(0)} = \left( x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(m) \right)
\]
Its Accumulating Generate Operator sequence is
\[
X^{(1)} = \left( x^{(1)}(1), x^{(1)}(2), \ldots, x^{(1)}(m) \right)
\]
where
\[
x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), k = 1, 2, \ldots, m
\]
The sequence is
\[
Z^{(1)} = (-, z^{(1)}(2), z^{(1)}(3), \ldots, z^{(1)}(m))
\]
The mean value is called the background value of the sequence or system, where
\[
z^{(1)}(k) = \frac{1}{2} \left( x^{(1)}(k) + x^{(1)}(k - 1) \right), k = 2, 3, \ldots, m
\]
\[
x^{(0)}(k) + az^{(1)}(k) = b
\]
It is one order single variable grey model. GM(1,1), where the parameter $a$ is the main variable parameter (system development coefficient), and $b$ is the grey action coefficient of the GM(1,1) model, or the background value. $\hat{a} = (a, b)^T$ is determined by the least squares method, that is,

$$
Y = \begin{bmatrix}
    x^{(0)}(2) \\
    x^{(0)}(3) \\
    \vdots \\
    x^{(0)}(m)
\end{bmatrix}, \quad
B = \begin{bmatrix}
    -z^{(1)}(2) & 1 \\
    -z^{(1)}(3) & 1 \\
    \vdots & \vdots \\
    -z^{(1)}(m) & 1
\end{bmatrix}
$$

(7)

then

$$
\hat{a} = (B^TB)^{-1}B^TY
$$

(8)

The Equation

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

(9)

It is called the shadow equation of the GM(1,1) model, which is also called the whitening equation. Combining the parameter values $a, b$ solved by equation (9) and substituting into equation (10), the time response sequence of the GM(1,1) model is

$$
\hat{x}^{(1)}(k + 1) = \left( x^{(0)}(1) - \frac{b}{a} \right) e^{-ak} + \frac{b}{a} \cdot k = 1, 2, \ldots, m - 1
$$

(10)

The simulated value $\hat{X}^{(1)}$ of the cumulative generation sequence $X^{(1)}$ by equation (11) was solved

$$
\hat{X}^{(1)} = \left( \hat{x}^{(1)}(1), \hat{x}^{(1)}(2), \ldots, \hat{x}^{(1)}(m) \right)
$$

(11)

Using equations

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

(12)

The simulated and predicted values $\hat{x}^{(0)}(k)$ of the original sequence can be solved separately, and the sequence of analog values of the original sequence is obtained

$$
\hat{X}^{(0)} = \left( \hat{x}^{(0)}(1), \hat{x}^{(0)}(2), \ldots, \hat{x}^{(0)}(m) \right)
$$

(13)

The model is tested by combining Mean Absolute Percent Error (MAPE) with the formula (12) and formula (13) to obtain the model simulation effect. MAPE is defined as

$$
MAPE(\%) = \frac{1}{n} \sum_{k=1}^{n} \frac{|x^{(0)}(k) - \hat{x}^{(0)}(k)|}{x^{(0)}(k)}
$$

(14)

2.2 Grey prediction model testing

After the model is built, the model needs to be tested. There are three test methods:

1. Calculate the relative error: $q(x) = e^{(0)}(k)/x^{(0)}(k)$

   $e^{(0)}(k)$ is the residual between $x^{(0)}(k)$ and $\hat{x}^{(0)}(k)$

   $e^{(0)}(k) = x^{(0)}(k) - \hat{x}^{(0)}(k)$

2. Calculating the variance ratio $C = \frac{s_2}{s_1}$

   $s_1$ is the variance of the original data, $s_2$ is the variance of the residual

3. Error probability $P = P[|e(k)| < 0.6745s_1]$
The accuracy level of the model is evaluated according to the grey model accuracy check table (as shown in Table 2).[6-7]

| level | relative error q | the variance ratio C | small error probability p |
|-------|------------------|----------------------|---------------------------|
| I     | <0.01            | <0.35                | >0.95                     |
| II    | <0.05            | <0.50                | <0.80                     |
| III   | <0.10            | <0.65                | <0.70                     |
| IV    | >0.20            | >0.80                | <0.60                     |

The difference between the GM(1,1) model and other time-varying prediction models is that the former is based on cumulative generation of data, while the latter is based on the original sequence. In the modelling process of GM(1,1) model, the random disturbance of the original data is greatly reduced due to the corresponding data processing of the original sequence, so that the variation law of the system can be predicted more accurately. Even with relatively few data, good simulation and prediction results can be obtained by the GM(1,1) model.

3. Case study
The following is a forecast of the future development of Tianjin New Energy Vehicles, which consist of BYD, Toyota, Zotye and Tesla in 2015-2017. The amount of its holdings is shown in Table 3.

| brand | 2015  | 2016  | 2017  |
|-------|-------|-------|-------|
| BYD   | 2269  | 7049  | 11546 |
| Toyota| 1254  | 9644  | 18408 |
| Zotye | 65    | 4281  | 7318  |
| Tesla | 63    | 113   | 638   |

Source: Automotive Data Analysis Platform - Data

We can take BYD as an example

(1) Constructing the original sequence

\[ X^{(0)} = (x^{(0)}(1), x^{(0)}(2), x^{(0)}(3)) = (2269, 7049, 11546) \]

(2) Calculating the accumulated sequence from the original sequence

\[ X^{(1)} = (x^{(1)}(1), x^{(1)}(2), x^{(1)}(3)) = (2269, 9318, 20864) \]

(3) Building a matrix B, Y

\[
B = \begin{bmatrix}
-5793.5 & 1 \\
-15091 & 1
\end{bmatrix}, \quad Y = \begin{bmatrix}
7049 \\
11546
\end{bmatrix}
\]

(4) From \( \hat{a} = \begin{bmatrix} a \\ b \end{bmatrix} \) = \( (B^T Y)^{-1} B^T Y \), seeking valuation a, b From ,

\[
B^T B = \begin{bmatrix}
2.613029e+8 & -2.088450e+4 \\
-2.088450e+4 & 2
\end{bmatrix}, \quad (B^T B)^{-1} = \begin{bmatrix}
0 & 0.000242 \\
0.000242 & 3.022819
\end{bmatrix}
\]

\[
(B^T B)^{-1} B^T = \begin{bmatrix}
0.000242 & 0.000242 \\
1.620792 & -0.629203
\end{bmatrix}, \quad (B^T B)^{-1} B^T Y = \begin{bmatrix}
-0.449999 \\
4606.4081
\end{bmatrix}
\]
Then we calculated \( a = -0.449999 \), \( b = 4606.4081 \).

(5) Bring \( a \) and \( b \) into the time response equation. Since \( x^{(0)}(1) = 2269 \), so the time response equation is

\[
\hat{x}^{(1)}(k + 1) = 12505.4852e^{0.449999k} - 10236.4852
\]

Similarly, the prediction models for the other three major brands are:

- **Toyota**: \( \hat{x}^{(1)}(k + 1) = 25721.0689e^{0.3730916k} - 24467.0689 \)
- **Zotye**: \( \hat{x}^{(1)}(k + 1) = 9778.23736e^{0.3526096k} - 9713.23736 \)
- **Tesla**: \( \hat{x}^{(1)}(k + 1) = 2579.05293e^{0.1337531k} - 2516.05293 \)

(6) Calculate the analogy value of \( X^{(1)} \)

\[
\hat{X}^{(1)} = \left( \hat{x}^{(1)}(1), \hat{x}^{(1)}(2), \hat{x}^{(1)}(3) \right) = (2269, 9376, 22070)
\]

The simulated values were solved:

\[
\hat{X}^{(0)} = \left( \hat{x}^{(0)}(1), \hat{x}^{(0)}(2), \hat{x}^{(0)}(3) \right) = (2269, 7107, 12694)
\]

(7) Accuracy test and prediction

| Brand | Year | Original Value | Analogue Value | Relative Residual |
|-------|------|----------------|----------------|-------------------|
| BYD   | 2015 | 2269           | 2269           | 0                 |
|       | 2016 | 7049           | 7107           | -0.008228117      |
|       | 2017 | 11546          | 12694          | -0.09942837       |
|       | 2015 | 1254           | 1254           | 0                 |
|       | 2016 | 9644           | 9659           | -0.001555371      |
|       | 2017 | 18408          | 18864          | -0.2477184        |
| Toyota| 2015 | 65             | 65             | 0                 |
|       | 2016 | 4281           | 4199           | 0.0191544         |
|       | 2017 | 7318           | 7208           | 0.01503143        |
|       | 2015 | 63             | 63             | 0                 |
|       | 2016 | 113            | 126            | -0.1150442        |
|       | 2017 | 638            | 665            | -0.04231975       |

After calculation

\[
C_{\text{BYD}} = \frac{S_2}{S_1} = 0.13939964 \quad C_{\text{Toyota}} = \frac{S_2}{S_1} = 0.0523088
\]
\[
C_{\text{Zotye}} = \frac{S_2}{S_1} = 0.01504728 \quad C_{\text{Tesla}} = \frac{S_2}{S_1} = 0.04239252
\]

Error probability \( P = P\{|e(t)| < 0.67455s_1 \} > 0.95 \), so Prediction accuracy level is I
Table 5  Forecast of the number of new energy vehicles in Tianjin from 2018 to 2020 (unit: car)

| brand | 2018   | 2019   | 2020   |
|-------|--------|--------|--------|
| BYD   | 15962  | 19711  | 25084  |
| Toyota| 21323  | 24556  | 28753  |
| Zotye | 10135  | 12445  | 14913  |
| Tesla | 935    | 1463   | 2057   |

4. Conclusion
Through the sales data of the brands of BYD, Toyota, Zotye and Tesla in Tianjin, the paper uses the grey forecasting analysis method to forecast the above brands of new energy vehicles in 2018, 2019 and 2020. It can provide a basis for decision-making by automotive-related companies. In addition, due to the limitations of the conditions in this study, the following problems exist:

1) The development of new energy vehicles in Tianjin involves many problems, such as the market and the consumer psychology, the market is changeable, and the consumer psychology of different people is different. It is necessary to conduct relevant research on these two parts.

2) The data collection is not sufficient based on the limitation of the time and sample number, so the development of Tianjin new energy vehicles needs to continue to follow-up analysis and conduct in-depth research.

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