Research on the characteristics of generations of subway vehicles based on artificial neural networks

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Abstract. Urban rail transit vehicles have become an important part of public transport due to the outstanding advantages: high speed, large traffic volume, low energy consumption and less land occupation. Metro vehicles have been developed for over one hundred years and there are obvious generational characteristics. In this paper, the generational characteristics of metro vehicles are studied from the top index of metro vehicles. First, the paper synthetically analyses 45 specific indicators of four categories: vehicle transport capacity, safety, comfort and environmental friendliness. And then 14 core indicators are extracted via employing the complex network method. Secondly, the first- and second-generation metro vehicles are analysed based on the 14 core indicators. By employing the artificial neural networks, the relationship between the performance and indicators of metro vehicles is obtained. And then the performance of the next generation metro vehicles can be predicted. Finally, the characteristics of the next generation of metro vehicles are predicted based on the performance of the next generation of metro vehicles and the latest technology. The future developing direction of metro vehicles is pointed and the theoretical basis for the next generation of metro vehicle manufacturing is provided in this paper.

1. Introduction

Urban rail transit is an important part of the urban transportation system. With the acceleration of urbanization, the increasing speed of the total urban population is very fast. Urban rail transit has become the main travel mode of daily commute.

With the emergence of new technologies and the raising of people’s requirements, the traditional second-generation metro vehicles can't meet the needs of the society well because of the disadvantages of high operation energy consumption and life cycle cost, insufficient line adaptability, limited passenger carrying capacity, low level of train intelligence, poor comfort, low safety, low level of reliability and availability. Then, the next generate metro vehicles should meet the higher requirements about energy saving, noise reduction, high comfort, high applicability et al.

However, based on the traditional metro vehicle technologies, only the performance improvement and structure improvement of the components cannot systematically solve the shortcomings of the
existing metro vehicles, nor meet the various requirements. Then, it is necessary to carry out the top-
level technical index research on the new framework of metro vehicle.

The work of this paper is as follows. Firstly, by employing the artificial neural networks and
complex network, the index of the traditional first- and second- generation metro vehicles is analyzed
and the core characteristic index is extracted. Secondly, the relationship between the vehicle
performance and the core indices is given and the performance of the next generate vehicle is
predicted via employing artificial neural network. At last, combined with new technologies, the
indices of the next generate metro vehicles are given which can be as the guide for the manufacture of
the next generate vehicles.

2. Methods

2.1. Complex network

Since Erdös and Rényi began to study the stochastic graph model in 1960s, the theory of complex
network\(^{[1]}\) has been rising. A complex network or graph is often represented by a pair of tuples \((V, e)\),
where \(V\) is the node set and \(e\) is an edge set. The elements in \(V\) are called vertices or nodes and the
elements in \(E\) are edges in the network. And each edge is related to two nodes in the node set.

The degree \(k_i\) of the node \(i\) is the number of edges connected to node \(i\). The degree of nodes is
defined by the adjacency matrix.

\[
k_i = \sum_{j=1}^{n} a_{ij}
\]

In the formula, \(n\) is the number of network nodes; \(a_{ij}\) is the value of \(i\)th row and \(j\)th column of the
adjacency matrix; \(k_i\) is the degree of node \(i\) which reflects the complexity of the node \(i\). The larger the
value of \(k_i\), the more nodes connected to node \(i\).

In the complex network \(^{[2]}\), the distribution function \(p(k)\) is often used to describe the degree
distribution of the complex network, where \(p(k)\) represents the probability of randomly selecting the
nodes whose degree value is \(k\).

2.2. Artificial neural networks

Artificial neural network \(^{[3, 4]}\) is an information processing system which aims to imitate the structure
and function of human brain. The theory of neural networks has become an interdisciplinary
comprehensive frontier subject involving many subjects, such as neurophysiology, cognitive science,
mathematical science, psychology, information science, computer science, microelectronics,
bioelectronics and optics. In 1890, James, a famous American psychologist, carried out the research on
the structure and function of human brain, published the first monograph on the structure and function
of human brain, principles of psychology, and made a pioneering research on the basic principles of
learning and associative memory. In 1958, Roseblatt, a computer scientist, proposed a neural network
structure with three-layer network characteristics, which is called "perceptron" \(^{[4]}\). In 1969 Minsky and
Papert published the book perceptron. And in 1982, Hopfield published the famous article "neural
network and physical system". In June 1987, the first international neural network academic
conference was held in California, the United States, and the International Neural Network Society
(INNS) was established, which marks the upsurge of neural network research in the world.

According to the direction of information transmission, neural networks can be divided into two
types: feedforward network and feedback network. There are many kinds of neural network learning
algorithms. According to the widely used classification method, neural networks learning algorithms
can be divided into three categories: supervised learning, unsupervised learning and dead memory
learning \(^{[5]}\).

Artificial neural network has been applied to almost all fields \(^{[6, 7]}\), including pattern recognition,
image processing, nonlinear optimization, speech processing, natural language understanding,
automatic target recognition and expert system, and good results are achieved.
3. The development of metro vehicles in China

Since London subway, the first subway of the world, was in service on January 10, 1863, the urban rail transit vehicle industry has entered a high-speed development stage. In recent years, the number of metro lines in major cities in the world is more than three times the total length of metro lines built from 1863 to 1963. China's urban rail transit vehicle industry has also developed rapidly since the 1990s. The urban rail transit vehicle industry has made remarkable achievements. The development of urban rail transit vehicles in China can be summarized into two generations and three stages of technological evolution. As shown in Figure 1, the metro vehicle industry can be roughly divided into three stages: initial stage (1960s to early 1980s), stable development stage (mid-1980s-2000) and rapid development stage (from the beginning of the 21st century to now).

![Figure 1. Technological evolution of metro vehicles development in China](image)

4. Generation division of metro vehicles in China

In order to scientifically and objectively analyze the characteristics of the next generation (the third generation) of metro vehicles, the typical characteristics of the first generation and the second generation of metro vehicles is firstly analyzed, and the core universal characteristics between the generation of metro vehicles are extracted which are also as the reference standard for the generation feature division between the second generation and the next generation. And then, the typical characteristics of the next generation of metro vehicles are analyzed.

Specifically, all possible metro vehicle indices are firstly selected from transport capacity, safety, comfort and environmental friendliness aspects. Secondly, according to the correlation between these indices, the complex network model of metro vehicle indices is established, and the core indices of metro vehicles are selected. Thirdly, with the help of neural network theory, the neural network model between metro vehicles indices and vehicle performance is established. Combined with the current metro vehicle index performance, the newest technological development and the shortcomings of the
current metro, the next generation metro vehicle indices and characteristics are analyzed and predicted. The specific process is shown in Figure 2.

**Figure 2.** The flow chart of research on characteristics of the next generation metro vehicles

From the four top-level indicators of transport capacity, comfort, safety and environmental friendliness, the indices of metro vehicles are systematic analyzed, and 45 specific indicators of metro vehicles are obtained. The next step work is to extract the core index system of metro vehicles from these 45 indexes.

The 45 indicators are nodes, and according to the correlation between 45 indicators, the edge is generated. Thus, the complex network model is established, which has 45 nodes (indicators) and 466 edges (correlation between indicators). And according to the definition of degree, the degree of 45 indicators are shown in Figure 3.

**Figure 3.** The degree of each index of metro vehicle in complex network model

According to the index degree (index importance) of 45 indices, 14 core indices of metro vehicles are selected which is shown in Table 1.
Table 1. Core indicators of metro vehicles

| name                          | name                          | name                          |
|-------------------------------|-------------------------------|-------------------------------|
| Operating speed               | Critical speed                | Passenger compartment noise   |
| accelerated speed             | service life                  | exterior noise                |
| deceleration                  | failure rate                  | regenerative braking          |
| Load / axle load              | Allowable collision speed     | Operational resistance        |
| Train formation               | Stationarity                  |                               |

By employing the neural networks, a two-layer neural network model including the hidden layer and the output layer is established, in which the number of hidden layer neurons is 5, and the specific neural network structure is shown in Figure 4.

![Figure 4. The structure of the neural networks](image)

70% of the data is used for neural network training, 15% of the data is used for neural networks validity test, 15% of the data is used for neural networks test. By employing the neural networks, the neural network model is as follows.

\[ y = f(x) = LW_{1} \ast (IW_{1,1} \ast x + b1) + b2 \]

\[ IW_{1,1} \] is matrix and it value is shown in Table 2. \( b1 = [1.3, 0.7, -0.2, 1.1, -1.5] \), \( LW_{2,1} = [1.2, 0.3, -0.5, 0.2, -0.2] \), \( b2 = -0.6 \).

| IW1_1 |   |   |   |   |   |
|-------|---|---|---|---|---|
| -0.5  | 0.4| 0.2| -0.2| 0.8| -0.9| 0.1| 0.2| 0.0| -0.5| 0.0| 1.0| 0.4| 0.7 |
| -0.2  | -0.5| -0.2| -0.5| 0.2| 0.3| 0.0| 0.3| 0.6| 0.2| 0.8| 0.7| 0.8| 0.7 |
| -0.8  | -0.4| 0.5| -0.7| -0.3| 0.7| 0.4| 0.1| 1.0| 0.1| 0.5| -0.3| -0.3| 0.2 |
| 0.5   | -0.7| 0.2| 0.5| 0.2| 0.1| -0.8| -1.0| -0.2| 0.3| 0.0| 0.2| -0.1| -0.3 |
| -0.5  | 0.3| -0.5| 0.4| 0.5| 0.6| 0.5| 0.1| -0.3| 0.7| 0.5| -0.5| 0.4| 0.6 |

Based on the latest technological development, the operation speed, acceleration and deceleration, load / axle load, train formation, service life, failure rate, passenger compartment noise, exterior noise, regenerative braking and stability of the next generation of metro will be greatly improved.

By comparing the characteristic indexes of the current and the next generation of metro vehicles, it can be found that the load / axle load, train formation and regenerative braking of metro vehicles are significantly improved. These three indexes are the specific indexes of the third generation. The characteristics of the next generation of metro vehicles can be summarized as intelligence and energy saving.

5. Conclusions

From the system’s view, the top-level indicators of metro vehicles are divided into 45 categories from capacity, safety, comfortable ability and environmental friendliness aspects. With the employment of the complex network model, 14 top-level core indicators are abstracted. Then, with the employment of the neural network model, the neural network model of indices of metro vehicles is established. Combined with the existing rail transit technology, the next generation of metro vehicles is predicted...
to be characterized by intelligence and energy saving, which are embodied in load / axle load, train formation and regenerative braking. The results can be used as a guide for the future metro vehicle manufacturing.

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