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# Life Cycle Cost Estimation of Large Freight Cars Based on BP Neural Network Integration

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**Abstract.** With the continuous growth of China's economy, the demand for large freight cars is increasing day by day. Therefore, it is necessary to estimate the total life cycle cost of large freight cars. Design for cost (DFC) is a method to reduce the LCC-Life Cycle Cost from the perspective of Design. From the perspective of DFC, the design features of large freight cars are mainly obtained through analysis, such as wheelbase, rated load, torque and other parameters, and LCC is estimated based on BP neural network integration.

## 1. Introduction

The large freight cars market in the automotive industry has a distinct periodicity. After two rounds of rapid development in 2010 and 2017, various practical problems put forward higher requirements for the large freight cars manufacturing enterprises. It is the general trend of the truck manufacturing industry to transform the product manufacturing mode characterized by product as carrier and life cycle management and service. LCC-Life Cycle Cost refers to the sum of research, design and development costs, production costs, usage and guarantee costs and final abandonment costs spent in the whole life cycle of a product from its inception through demonstration, research, design, development, production, use to final scrap[1]. Life cycle cost management has been widely used in manufacturing industry and even in automobile industry. It is precisely because there are many parts of manufacturing cost in automobile industry, such as design cost, manufacturing cost, sales cost, use cost and recycling scrap cost. Because of the large amount of data involved, using LCC to simulate and analyze it can strengthen cost management and reduce enterprise costs.

## 2. Selection of LCC Estimation Method for Large Freight Cars

DFC (Design For Cost) is a key parameter to reduce the cost as much as possible under the influence of various factors in the whole life cycle, such as product research and manufacturing process, use, maintenance and scrap recycling, to meet the basic requirements of users. It also provides a tool for designers to evaluate costs[2].

According to the actual situation, we chose the method of BP neural network integration to estimate LCC. BP(back propagation) neural network is the most widely used neural network at present. It has arbitrary complex pattern classification ability and excellent multi-dimensional function mapping ability.Essentially, BP algorithm takes the square of network error as the objective function and uses gradient descent method to calculate the minimum value of the objective function. BP neural network integration is based on the prediction of multiple neural networks. Taking the average value as the prediction result, it can effectively reduce the error.

This paper mainly studies the design stage of the concept of large truck, at which time we can determine: Rear axle allowable load, the length, width and height of large truck, wheelbase, torque, rated load, etc. In this paper, based on DFC theory and practice, the design features extracted are: Rear axle allowable load, body length, rated load, displacement, torque, maximum output power, wheelbase.

## 3. Examples of LCC Estimation and Performance Prediction for Large Freight Cars

### *3.1. Data collection*

Most cost estimation methods need to use historical data, so LCC information of products must be accumulated. Reasonable use of network technology, mining network resources, has become a new way to collect LCC data. The data in this paper are mainly collected from the truck home and other websites.

LCC = Car purchase cost + Use cost + Maintenance cost

The data are arranged in the following table Unit: 10thou. Yuan

Table 1. Calculation of LCC

| | Manufacturer's Guidance Price | Car purchase cost | Use cost | Maintenance cost | LCC |
|---|---|---|---|---|---|
| FAW Jiefang J6L Quality Benefit Edition | 17.8 | 18.85 | 210.461 | 3 | 232.311 |
| Dongfeng Commercial Vehicle Tianjin Zhongka | 15.5 | 16.41 | 172.401 | 3 | 191.811 |
| Dongfeng Liuqi Xinchenglong M3 Card | 13.6 | 14.4 | 141.921 | 3 | 159.321 |
| Dongfeng Liuqi Chenglong H5 | 17.7 | 18.74 | 157.16 | 3 | 178.9 |
| Jianghuai Gelfa K5L Middle Card | 18.88 | 19.99 | 88.595 | 3 | 111.585 |
| Qingdao Jiefanglong V Overvalue Edition | 12.2 | 12.92 | 96.062 | 3 | 111.982 |
| Fukuda Omarco 5 Series Kazakhstan | 14.85 | 15.72 | 80.718 | 3 | 99.438 |
| Xugong Hanfeng G7 Composite Edition | 33.7 | 35.68 | 205.99 | 3 | 244.67 |
| Dongfeng Dolica D9 | 16.5 | 17.47 | 119.052 | 3 | 139.522 |
| Fukuda Rivo Q5 170 | 13.9 | 14.72 | 80.75 | 3 | 98.47 |
| Jianghuai Gelfa A5 Middle Card | 15.08 | 15.97 | 80.79 | 3 | 99.76 |
| Liberation Lin VH | 13 | 13.76 | 103.646 | 3 | 120.406 |
| Jianghuai Junling V9L | 16.68 | 17.66 | 119.057 | 3 | 139.717 |
| Shaanxi Auto Heavy Cadelong L3000 | 18.71 | 19.81 | 127.38 | 3 | 150.19 |
| Fukuda Aoling CTX | 13 | 13.76 | 111.364 | 3 | 128.124 |
| China Heavy Truck HOWO | 17 | 18 | 111.439 | 3 | 132.439 |
| Qingling Isuzu 700P Series Central Card | 19.84 | 21 | 133.638 | 3 | 157.638 |
| Jianghuai Shuailing W570 Central Card | 19 | 20.12 | 111.297 | 3 | 134.417 |
| Jianghuai Gelfa K3L Central Card | 13.58 | 14.38 | 96.03 | 3 | 113.41 |
| Dongfeng Dolica D12 Zhongka | 17.6 | 18.64 | 119.151 | 3 | 140.791 |
| Emancipation J6F Reloaded Edition | 13.98 | 14.8 | 95.362 | 3 | 113.162 |
| China Heavy Truck HOWO General | 12.9 | 13.65 | 95.344 | 3 | 111.994 |
| Dongfeng 2018 Dolica D8 | 12.58 | 13.32 | 95.526 | 3 | 111.846 |
| Fukuda Omarco S3 Series | 13.1 | 13.87 | 95.362 | 3 | 112.232 |
| Dongfeng Dolica D6 Heavy Duty Mountain Edition | 11.18 | 11.84 | 87.742 | 3 | 102.582 |
| Dongfeng Commercial Vehicle Tianlong Heavy Truck | 28.79 | 30.48 | 166.07 | 3 | 199.55 |

The original data and LCC (Life Cycle Cost) calculation data of various types of trucks collected in this paper. There are 26 groups of experimental data, which can be divided into two categories: 1) training data of trucks, 2) inspection data of trucks.

Table 2. Training data for trucks

| | Wheelbase（mm） | Body length（m） | Rated load（t） | displacement（L） | Maximum output power（KW） | torque（N·m） | Rear axle allowable load（kg） | LCC |
|---|---|---|---|---|---|---|---|---|
| FAW Jiefang J6L Quality Benefit Edition | 5300 | 8.5 | 9.9 | 5.7 | 165 | 720 | 11150 | 232.311 |
| Dongfeng Commercial Vehicle Tianjin Zhongka | 5000 | 9 | 9.9 | 4.752 | 132 | 700 | 11500 | 191.811 |
| Dongfeng Liuqi Xinchenglong M3 Card | 5100 | 9 | 9.9 | 4.73 | 136 | 700 | 11500 | 159.321 |
| Dongfeng Liuqi Chenglong H5 | 5100 | 9 | 9.9 | 6.87 | 162 | 860 | 11500 | 178.9 |
| Jianghuai Gelfa K5L Middle Card | 5000 | 9 | 9.82 | 6.87 | 162 | 860 | 11500 | 111.585 |
| Qingdao Jiefanglong V Overvalue Edition | 5250 | 8.995 | 9.52 | 3.8 | 121 | 560 | 10400 | 111.982 |
| Fukuda Omarco 5 Series Kazakhstan | 4700 | 8.645 | 7.995 | 3.76 | 125 | 592 | 9390 | 99.438 |
| Xugong Hanfeng G7 Composite Edition | 6500 | 9.84 | 15.37 | 9.726 | 257 | 1600 | 18000 | 244.67 |
| Dongfeng Dolica D9 | 5200 | 8.999 | 9.995 | 5.9 | 132 | 700 | 11000 | 139.522 |
| Fukuda Rivo Q5 170 | 5700 | 8.998 | 9.95 | 3.76 | 125 | 600 | 10185 | 98.47 |
| Jianghuai Gelfa A5 Middle Card | 5000 | 9 | 9.8 | 4.088 | 115 | 520 | 10000 | 99.76 |
| Liberation Lin VH | 4700 | 8.51 | 9.855 | 4.088 | 115 | 520 | 10400 | 120.406 |
| Jianghuai Junling V9L | 5000 | 9 | 9.955 | 4.748 | 140 | 740 | 11500 | 139.717 |
| Shaanxi Auto Heavy Cadelong L3000 | 5000 | 8.995 | 9.99 | 6.75 | 162 | 850 | 11000 | 150.19 |
| Fukuda Aoling CTX | 3360 | 5.995 | 1.495 | 3.76 | 105 | 440 | 2695 | 128.124 |
| China Heavy Truck HOWO | 5600 | 9.995 | 9.99 | 4.58 | 151 | 830 | 11500 | 132.439 |
| Qingling Isuzu 700P Series Central Card | 5200 | 8.955 | 4.69 | 5.193 | 141 | 510 | 6345 | 157.638 |
| Jianghuai Shuailing W570 Central Card | 5700 | 9.995 | 9.1 | 4.5 | 132 | 700 | 9995 | 134.417 |
| Jianghuai Gelfa K3L Central Card | 5000 | 9 | 9.8 | 3.767 | 118 | 550 | 10000 | 113.41 |
| Dongfeng Dolica D12 Zhongka | 7160 | 11.995 | 8.9 | 5.9 | 140 | 720 | 11495 | 140.791 |

Table 3. Inspection data of trucks

| | Wheelbase（mm） | Body length（m） | Rated load（t） | displacement（L） | Maximum output power（KW） | torque（N·m） | Rear axle allowable load（kg） | LCC |
|---|---|---|---|---|---|---|---|---|
| Emancipation J6F Reloaded Edition | 3300 | 5.998 | 1.495 | 3.8 | 121 | 560 | 2645 | 113.162 |
| China Heavy Truck HOWO General | 3280 | 5.995 | 1.56 | 3.92 | 125 | 600 | 2550 | 111.994 |
| Dongfeng 2018 Dolica D8 | 4700 | 8.38 | 9.245 | 3.856 | 125 | 600 | 8435 | 111.846 |
| Fukuda Omarco S3 Series | 3360 | 5.995 | 1.495 | 3.76 | 105 | 450 | 2495 | 112.232 |
| Dongfeng Dolica D6 Heavy Duty Mountain Edition | 3800 | 5.995 | 1.495 | 3.767 | 103 | 450 | 2700 | 102.582 |
| Dongfeng Commercial Vehicle Tianlong Heavy Truck | 7050 | 11.99 | 14.09 | 6.7 | 198 | 970 | 10000 | 199.55 |

The input of BP neural network is 7 features (rear axle allowable load, body length, rated load, displacement, torque, maximum output power, wheelbase), and the output is LCC.

### *3.2. Realization of BP Neural Network Model*

Through the above data, using BP neural network training data, the following results are obtained. From the table, it can be seen that the average error is more than 20%, and the error is large. Therefore, BP neural network integration method is used to train data.

Table 4. BP Neural Network Error Value Unit: 10thou. Yuan

| Prediction object | LCC calculated value | BP Neural Network Estimation Results | |
|---|---|---|---|
| | | predicted value | relative error（%） |
| 22 | 113.162 | 139.9855129 | 23.70407 |
| 23 | 111.994 | 121.2240413 | 8.24155 |
| 24 | 111.846 | 72.86613703 | -34.851492 |

| | | | |
|---|---|---|---|
| 25 | 112.232 | 137.0082311 | 22.075906 |
| 26 | 102.582 | 115.5462433 | 12.637932 |
| 27 | 199.55 | 159.5328913 | -20.053676 |
| Average relative error (%) | | 20.260771 | |

Error = 100%* (LCC Predicted Value - LCC Calculated Value) / LCC Calculated Value

### *3.3. Realization of BP Neural Network Integrated Model*

Traditional BP neural network training algorithm converges slowly, so LM (Levenberg-Marquardt) method[3][4] is used for training. Because of the small amount of data, the LM algorithm converges quickly and can get better prediction value.

The concrete steps to realize the prediction model are as follows:

The input data matrix and output matrix are normalized and the BP neural network is established. The maximum number of training cycles is 500, the learning rate of the network is 0.05, and the target error is 1e-3.

After setting the parameters, start training the network.

### *3.4 Results Based on BP Neural Network Integration*

Each prediction object is forecasted by several neural networks. There are six groups in total. Then the average value is taken as the forecasting value. After calculation, we get six groups of forecasting values:

Table 5. Neural Network Integrated Data Unit: 10thou. Yuan

| Prediction object | predicted value 1 | predicted value 2 | predicted value 3 | Average Prediction Value |
|---|---|---|---|---|
| 22 | 127.2084612 | 120.3933645 | 128.1107769 | 125.2375342 |
| 23 | 117.0885958 | 104.8221655 | 128.1103638 | 116.6737083 |
| 24 | 92.86678102 | 96.91360021 | 109.0782192 | 99.61953348 |
| 25 | 128.0072917 | 125.5464948 | 128.1099158 | 127.2212341 |
| 26 | 123.5907999 | 115.5460032 | 91.70963341 | 110.2821445 |
| 27 | 191.1358088 | 240.9233882 | 232.1212417 | 221.3934796 |

Using predicted values and LCC calculations, the relative errors of six sets of data are calculated. Finally, the average relative errors are calculated, as shown in the table below.

Table 6. LCC error estimates

| Prediction object | LCC calculated value | BP Neural Network Estimation Results | |
|---|---|---|---|
| | | predicted value | relative error（%） |
| 22 | 113.162 | 125.2375342 | 10.671 |
| 23 | 111.994 | 116.6737083 | 4.172 |
| 24 | 111.846 | 99.61953348 | -10.932 |
| 25 | 112.232 | 127.2212341 | 13.355 |
| 26 | 102.582 | 110.2821445 | 7.506 |
| 27 | 199.55 | 221.3934796 | 10.946 |
| Average relative error (%) | | 9.597 | |

In the process of estimating cost data, due to the changing needs of different stages, the information of products is constantly enriched, the information obtained in the conceptual design stage is not complete, and the accuracy of cost estimation is generally between - 30% and 50%. When the design information is further enriched and the historical cost data similar to the current design can be used, the accuracy of estimating can generally reach -15%~30%[5]; The error of this paper is basically controlled in this range, and it is an effective estimation method.

As shown in figure 1,the correlation coefficient R of regression line is 0.98882, approximate to 1. It shows that the deviation between the output value and the target value of BP neural network is very small, and it is an effective prediction method.

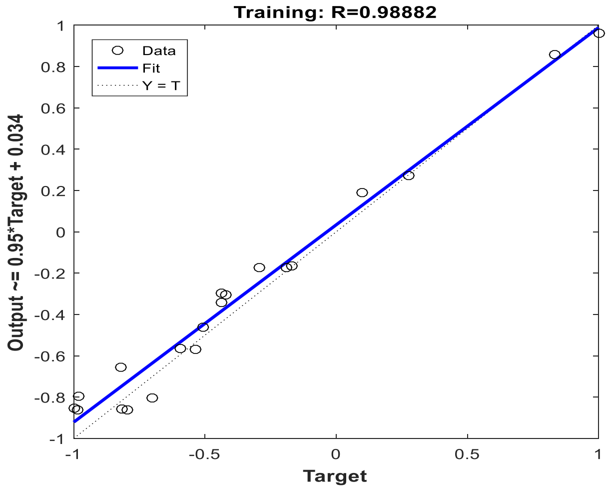


Fig 1. Training sample output regression line

## 4. Conclusions

In this paper, the life cycle cost of large freight cars is estimated by BP neural network. Before estimating, a large amount of data was collected, including different types of trucks and manufacturers. Data were collected not only through the Internet, but also through telephone contact. A large amount of data collection ensured the accuracy and practicability of LCC estimates. After data collection, MATLAB neural network is used for training. Relatively speaking, the more training times, the more accurate the results will be. After the training is completed, the collected data are compared with the training results, and the errors are observed. The use of LCC technology in large freight cars and the comprehensive evaluation of the purchase and use of large freight cars are conducive to improving product performance, RAMS (reliability, availability, maintainability and safety) requirements, while reducing the later use cost.

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