Evaluation and Analysis of GPS Operators Based on Multi-Layer Hierarchical Analysis

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Abstract. As a complex process, road transportation is restricted by many factors. In order to carry out safety management of road transportation, this paper puts forward an evaluation index system with multiple risk factors for the service providers of satellite positioning system (GPS) for tourist buses, long-distance passenger vehicles and dangerous goods vehicles. Through the construction of multi-level analytic hierarchy process (AHP) for the comprehensive evaluation of safety production and related management of satellite positioning operators, the weight evaluation model is obtained; and the evaluation results are compared with the neural network model by using linear regression model. The experimental results show that: in terms of evaluation, the average absolute error of neural network model is 0.137, and the hierarchical model is 0.232, the former is slightly better than the latter; in terms of stability, the hierarchical model performs best. Comprehensive comparison shows that hierarchical model has better performance in evaluation accuracy and stability. The method proposed in this paper provides technical support for the evaluation of satellite positioning operators.

1. Introduction

In recent years, with the rapid development of road transportation, the number of various transport vehicles is increasing rapidly, but the traffic accidents are also increasing. Especially for tourist buses, long-distance buses and dangerous freight vehicles, namely “two passengers and one dangerous” vehicles, the safety requirements are high. Once these vehicles have an accident, it will bring great negative impact on social security [1]. Therefore, governments have strict regulations on the satellite positioning devices to be monitored by these vehicles. These regulations force the operators who provide positioning services to provide accurate dynamic monitoring and evaluation indicators for key operating vehicles. Therefore, how to evaluate the operators fairly and reasonably is one of the important links to ensure the safety of road transportation.

The main component of road transport consists of drivers, road transport enterprises, and road transport vehicle positioning system service providers. As the data hub of government and enterprise and the supervisor of safety production, the operator is of great significance to the development of road transport industry. Previous studies generally focus on drivers [2, 3] and transportation enterprises [4, 5], but there is a lack of evaluation on operators. This paper is based on the evaluation of operators, establishes evaluation indicators of operators, establishes hierarchical analytic hierarchy process model, and analyzes and compares the models through examples.

Many scholars have applied the theoretical algorithm of this problem in different fields. Factor analysis method, entropy weight method and grey correlation analysis method, coefficient of variation method and simulation method are commonly used models.
In the algorithm research of satellite positioning operator evaluation, the calculation of each index weight needs to rely on a large number of prior data, so it needs to spend a lot of energy in the early data collection. Moreover, it is difficult to analyze some complex and fuzzy problems with complete quantitative thinking [2, 6]. In addition, the evaluation of operators is a complex multi-factor problem. It is the core content of this paper to find a simple and explanatory model to evaluate the operators. This paper takes the operator evaluation algorithm as the research object, and proposes a method to determine the factor weight based on AHP. The structure of this paper is as follows: Section 2 describes the evaluation framework of operator management; section 3 is the framework and calculation method of hierarchical analytic hierarchy process model; section 4 takes XX City as an example for application, and compares with neural network model and multiple linear regression model. Section 5 is the conclusion.

2. Management Evaluation Index Framework of GPS Operators

In this paper, the operator evaluation indicators can be divided into subjective indicators and objective indicators according to the nature. The subjective indicators are the assessment and scoring of operators' units by the relevant departments, and the objective indicators are the relevant data information of operators positioning vehicles. According to the project classification, the evaluation framework mainly includes three items: basic hardware (BH), technical indicators (TI) and management (MS). Among them, BS and MS are subjective indicators and TI are objective indicators.

2.1. Basic Hardware (BH)

The assessment item consists of three items: basic hardware, system construction and personnel security. The corresponding standards are as follows.

1. Infrastructure (in): it is defined as the infrastructure that meets the standard, and is quantified as binary, that is, whether it meets the requirements corresponds to (0, 1).

2. System construction (SC): the content includes three parts: whether there are personnel monitoring content and abnormal vehicle disposal process, whether there are management systems and terms of operation service provider technology, whether the daily duty records of technical maintenance records are consistent, and one hot coding.

3. Personnel support (PS): whether the technical maintenance personnel meet the requirements and whether the monitoring personnel training is carried out regularly, one hot coding is adopted here.

To sum up, the basic hardware (BH) calculation formula is as follows:

$$BH = a_1 \text{IN} + a_2 \text{SC} + a_3 \text{PS}$$

Where, \(a_1 + a_2 + a_3 = 1\). \(a_1\), \(a_2\), and \(a_3\) are the weights for infrastructure, system construction and personnel security respectively.

2.2. Technology Indexes (TI)

The assessment item consists of six items: platform connectivity rate, vehicle online rate, track integrity rate, data pass rate, satellite positioning vehicle rate and platform Post search response rate. The corresponding standards are as follows.

1. Platform connectivity rate (PC): count the connectivity rate of platforms within the jurisdiction, continuous value 0-100, unit is %.

2. Vehicle online rate (VOR): count the online rate within the jurisdiction, continuous value 0-100, unit is %.

3. Track integrity rate (TIA): statistics the track integrity rate within the jurisdiction, continuous value 0-100, unit is %.

4. Data pass rate (DPR): count the qualified rate of data within the jurisdiction, continuous value 0-100, unit is%.

5. Adrift vehicle rate of satellite positioning (SPR): the rate of adrift vehicles within the jurisdiction area is counted. The continuous value is 0-100. The lower the value, the better. The unit is%%.
(6) Platform job search rate (PCR): statistics the platform job search rate within the jurisdiction, continuous value 0-100, unit is %.

To sum up, the calculation formula of technical index (TI) is as follows:

\[ TI = b_1 PC + b_2 VOR + b_3 TIA + b_4 DPR + b_5 SPR + b_6 PCR \]  

Where: \( b_1 + b_2 + b_3 + b_4 + b_5 + b_6 = 1 \).

2.3. Management Situation (MS)

The assessment item consists of six items: emergency treatment, file management, terminal maintenance, vehicle data storage, coordination and management department, and vehicle real-time monitoring. The corresponding standards are as follows.

(1) Emergency response (ER): random sampling of emergency and daily duty classes, one hot coding.

(2) File management (FM): to establish shift record account; to establish daily off-line vehicle investigation report; to make daily off-line vehicle report; to make terminal maintenance report; to make summary table of illegal vehicles and carry out one hot coding.

(3) Terminal maintenance (TM): whether there are corresponding maintenance files, which are consistent with the terminal maintenance report records, binarization.

(4) Vehicle data storage status (VDS): the number of years of filing illegal and processing information, continuous integer.

(5) Coordinate with the situation of the management department (CMD): whether to complete the work assigned by the management departments at all levels according to the requirements, binarization.

(6) Vehicle real-time monitoring (VRM): terminal connectivity, personnel real-time monitoring, violation push, abnormal push, one hot coding.

\[ MS = c_1 ER + c_2 FM + c_3 TM + c_4 VDS + c_5 CMD + c_6 VRM \]  

Where, \( c_1 + c_2 + c_3 + c_4 + c_5 + c_6 \).

To sum up, the evaluation contents of each index are given by the regulations, and the qualitative indicators are quantified. The evaluation model of dynamic supervision and management of operators is as shown in Figure 1.

![Evaluation index system for performance evaluation of GPS operators](image)

**Figure 1.** Evaluation index system for performance evaluation of GPS operators.

3. Analytic Hierarchy Process

Analytic hierarchy process (AHP) is a kind of analytic method of analytic hierarchy process (AHP), which is mainly used in network system theory and multi-objective comprehensive evaluation method. It is a decision analysis method combining qualitative and quantitative methods to solve multi-objective complex problems. The weights of various factors are measured by the experience judgment of decision makers, and the advantages and disadvantages of each scheme are sorted by weight, which can effectively solve the problems that are difficult to quantify. The algorithm principle is as follows:
The general analytic hierarchy process (AHP) model is composed of three layers, namely the bottom layer, the middle layer and the top layer. The layers are all connected in the form of full connection, and the factors influence each other. In this paper, starting from the actual demand, considering the weight calculation method of the inter layer factors under the condition of incomplete connection, a multi-layer analytic hierarchy process model is constructed.

In order to reduce the difficulty of comparing different factors and improve the accuracy, the judgment matrix is constructed and the importance of the two factors is scored by experts.

4. Experiment and Comparative Analysis

4.1. Calculation Results of the GPS Operator Assessment Model

The analytic hierarchy process (AHP) is used to solve the relative weight of each layer. The resultant judge matrixes of each leg of evaluation index have been shown in Tables 1 to 4.

| Table 1. Operator Evaluation Judgment Matrix |
|---------------------------------------------|
| BH  | TIA  | MS  |
| BH  | 1    | 1/6 | 1/5 |
| TIA | 6    | 1   | 2   |
| MS  | 5    | 1/2 | 1   |

| Table 2. Relative basic hardware (BH) judgment matrix |
|------------------------------------------------------|
| IN  | SC  | PS  |
| IN  | 1   | 1/3 |
| SC  | 1   | 1/7 |
| PS  | 3   | 7   |

| Table 3. Relative Technical Index (TI) Judgment Matrix |
|-------------------------------------------------------|
| PC  | VOR | TIA | DPR | SPR | PCR |
| PC  | 1   | 1/5 | 1   | 1/2 | 1   |
| VOR | 1   | 1/5 | 1   | 1/2 | 1   |
| TIA | 5   | 1   | 5   | 3   | 5   |
| DPR | 1   | 1/5 | 1   | 1/2 | 1   |
| SPR | 2   | 1/3 | 2   | 1   | 2   |
| PCR | 1   | 1/5 | 1   | 1/2 | 1   |

| Table 4. Relative Operations Management (MS) Judgment Matrix |
|-------------------------------------------------------------|
| ER  | FM  | TM  | VDS | CMD | VRM |
| ER  | 1   | 1/3 | 1   | 2   | 3   |
| FM  | 3   | 1   | 3   | 5   | 8   |
| TM  | 1   | 1/3 | 1   | 2   | 3   |
| VDS | 1/2 | 1/5 | 1/2 | 1   | 1   |
| CMD | 1/3 | 1/8 | 1/3 | 1   | 1   |
| VRM | 2   | 1   | 2   | 3   | 5   |

According to the expert scoring and weighting, combined with the judgment matrix, the weight of the evaluation index layer factors is obtained. The result has been listed in Table 5.
Table 5. Weights for hierarchical analysis

|       | BH    | TI    | MS    |
|-------|-------|-------|-------|
| w1    | 0.082 | 0.575 | 0.343 |
| IN    | 0.179 | PC    | 0.090 | ER    | 0.133 |
| SC    | 0.136 | VOR   | 0.090 | FM    | 0.354 |
| PS    | 0.685 | TIA   | 0.464 | TM    | 0.133 |
| eigenvalue | 3.0816 | DPR  | 0.090 | VDS   | 0.067 |
| CR    | 0.07  | SPR   | 0.176 | CMD   | 0.050 |
| eigenvalue | 6.0037 | PCR  | 0.090 | VRM   | 0.263 |
| CR    | 0.0006 | 6.05  |

It can be seen from Table 5 that the CR values of the consistency judgment values are all less than 0.1. That is, the weights in the above table are available, and the judgment matrix has consistency within a certain range.

In the operator evaluation layer, the technical index (TI) has the largest weight, and the basic hardware (BH) has the lowest contribution to the score, which is obviously lower than the other two indicators.

Compared with infrastructure hardware, the weight of personnel support (PS) is significantly greater than that of infrastructure (IN) and system construction (SC), and the weights of the other two indicators are basically the same.

Relative to the technical index (TI), the track integrity rate (TLA) is the highest, followed by the satellite positioning adrift vehicle rate (SPR) weight is higher, the two indicators are vehicle location information related, which is closely related to the functions of satellite positioning operators, proving the effectiveness of the weight model.

Compared with operation management (MS), file management (FM) and vehicle real-time monitoring (VRM) have higher weight. The requirement of real-time and accuracy of data is the core work content of satellite positioning company.

Through the weight combination obtained by AHP, we can get the following formula for operator evaluation:

\[
Score = 0.082BH + 0.575TI + 0.343MS
\]

\[
BH = 0.179IN + 0.136SC + 0.685PS
\]

\[
TI = 0.09PC + 0.09VOR + 0.464TIA + 0.09DPR - 0.176SPR + 0.09PCR
\]

\[
MS = 0.133ER + 0.354FM + 0.133TM + 0.067VDS + 0.05CMD + 0.263VRM
\]

Therefore, we can obtain the weight of each part of the measurable index, as shown in the table below. The results have been shown in Table 6.

Table 6. Measurable index weight value

| Measure indexes | TIA | FM | SP | VR | PS | PC | VO | PC | DP | ER | TM | VDS | CMD | IN | SC |
|-----------------|-----|----|----|----|----|----|----|----|----|----|----|-----|-----|----|----|
| Weight          | 0.2 | 0.1| 0.1| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0  | 0.0  | 0.0 | 0.0 |
| 67              | 21  | 01 | 09 | 56 | 52 | 52 | 52 | 51 | 46 | 46 | 23  | 17  | 15  | 11  |

It can be seen from Table 6 that the weight of measurable indicators is obtained through hierarchical analysis. Considering the influence of upper level factors, the top measurable indicators are TIA, FM and SPR.
4.2. Model Comparison and Algorithm Error Analysis

In order to verify the validity of the model, the weight model is compared with neural network [7] and multiple linear regression method [8]. The data are the operation evaluation data from June 1 to June 30 of five major operators in Xiamen City, China, with a total of 150 datasets. As the basic hardware and operation management are artificially checked, too many subjective factors are incorporated, and the values of the inspection contents are found in the data cleaning process. There is no significant difference in the upper distribution. Therefore, the technical index is considered as the comparison index. The measurable variables of the index provide data for the vehicle GPS positioning system, which is objective and true. Ten of them are randomly selected for accuracy test, and the remaining 140 are training sets. The accuracy is based on relative error. Considering the dimension and value difference of data, the data are normalized. The formula is as follows.

\[ x' = \frac{x - \text{minx}}{\text{maxx} - \text{minx}} \]  

(8)

Since the data is normalized to the (0,1) interval, the evaluation standard adopts absolute error. The absolute error of each model is shown in the figure below. It can be seen from the figure that the error of linear regression model is the largest, while that of neural network model is the smallest. Calculate the mean value and variance of absolute error of each model, as shown in Table 7.

|        | AHP   | BP neural network | LP    |
|--------|-------|-------------------|-------|
| Means  | 0.232 | 0.137             | 0.392 |
| error  | 0.064 | 0.188             | 1.534 |

It can be seen from Table 7 that the average absolute error of neural network is the lowest, while that of linear regression is the highest. In terms of variance, the variance of AHP is the lowest and its performance is relatively stable, and the variance of linear regression is the highest. To sum up, the neural network evaluation model has the best accuracy, while the hierarchical analysis has good accuracy and excellent stability, and the AHP does not need a large number of prior data for training to obtain the weight, relying on expert scoring to obtain the relative importance, and the cost is low.

5. Conclusions

In this paper, a comprehensive evaluation index of satellite positioning operators for tourist buses, long-distance buses and dangerous goods transport vehicles is constructed. In addition, according to the evaluation content, the hierarchical analytic hierarchy process (AHP) is proposed to evaluate the operators. The weights of each index are obtained by the expert scoring matrix, and the simple evaluation model is constructed by linear weighting. And compared with the linear regression model and neural network model. Taking Xiamen city of China as an example, AHP is better than linear regression model in accuracy, slightly worse than neural network model, but better than neural network model in stability. Moreover, the analytic hierarchy process (AHP) has no complex structure of neural network and does not need prior data to train the network, so it has low cost and high realizability. The research in this paper provides a method for evaluating the satellite positioning system operators and ensuring the safety of road transportation.

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7. References

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