Hierarchical coding system of tunnel engineering for highway maintenance informatization

Kunlin Han\textsuperscript{1,2*}, Feng Qin\textsuperscript{2}, Duan Pu\textsuperscript{2}

\textsuperscript{1}The State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing 400030, China
\textsuperscript{2}China Merchants Chongqing Highway Engineering Testing Center Co., Ltd. Chongqing 400067, China

*Corresponding author. Tel: +86-18008376537; E-mail address: 276929168@qq.com.

Abstract: With the constant promotion of the “comprehensive and accurate” highway maintenance policy, the demand for application of tunnel maintenance informatization is expanding, and the standardization of hierarchical coding for the tunnel engineering is critically urgent. In this paper, the hierarchical informatization and coding system of related industries are analysed firstly, and then the hierarchical coding structure and classification code with high accuracy on the level of structural units and affiliated facilities are designed according to the combination of highway tunnel properties and maintenance characteristics. At last, the modular congruence algorithm is adopted for automatic verification, and a set of hierarchical coding system for highway maintenance information is preliminarily established. Furthermore, the research of the hierarchical coding system application has laid a solid foundation for the whole life cycle maintenance management of highway tunnel.

1. Introduction
In the past 30 years, road traffic in China has developed rapidly. By the end of 2018, there have been 17738 highway tunnels in China, with a total length of 17236.1 km [1]. Meanwhile, about 20000 kilometers of various tunnels are under construction, and about 20000 kilometers of tunnels are planned to be built. With the constant improvement of the national highway network, the construction of highway tunnel case to grow rapidly, and gradually achieved the maintenance peak. The maintenance of the highway tunnel has been transfered from the traditional "rush repair era" to the "comprehensive and accurate maintenance era".

However, due to the large number of highway tunnels, wide range of divisions and various management methods, the maintenance and management of highway tunnels is difficult, which often leads to the situation of considering one thing and losing the other. At the same time, the organization forms of maintenance and management of highway tunnels in China are diverse, and the information asymmetry between different organizations, the lack of information sharing platform and channels and other factors results in the industry among various highway tunnel maintenance information systems. "Information island" stems from different digital standards of business objects, which results the data-sharing is difficult and seriously affects the construction of modern highway maintenance system [2].

In order to realize the comprehensive sharing of highway tunnel maintenance data, it is necessary to carry out unified and standardized management of management objects. The current standards and
specifications related to highway coding in China mainly include Mark rules of highway route and number of national trunk highway (GB / T 917-2017) and Cataloging and coding rules for highway database (JT / T 132-2014), where the (GB / T 917-2017) mainly specifies the requirements for highway classification, naming rules, numbering rules, highway technical grade code, highway section code and public information identification and processing [3], and the (JT / T 132-2014) specifies the classification method, compilation principle and classification code of highway (road, bridge, tunnel and traffic engineering) infrastructure and relevant information [4]. However, the minimum unit of tunnel maintenance management in Technical Specifications of Maintenance for Highway Tunnel (JTG H12-2015) has been accurate to the level of civil structure unit and affiliated facilities [5]. Under the new requirement, the minimum unit of the above current coding standards is road, bridge, tunnel and other traffic infrastructure level, which are difficult to meet the needs of "comprehensive and accurate" highway maintenance.

In order to further refine the information management requirements of tunnel maintenance, some scholars have carried out some research work. Xu et al. [6] studied the coding method of mechanical and electrical equipment of expressway and coded it in accordance with equipment classification. Gu et al. [7] established a set of Expressway Asset Management classification coding system, which realized the effective management of highway traffic assets in Zhejiang Province, and the effective docking with OA, finance and other systems. Qiu et al. [8] realized the effective management of intelligent transportation infrastructure by using two-dimensional code and RFID technology based on the facility classification coding method. Lee et al. [9,10] designed and developed an integrated information system for highway safety management to perform highway health management. Although the previous researches have attempted to code the traffic infrastructure, they have not formed a highway tunnel engineering hierarchical coding system oriented to the maintenance management informatization, and has not formed a unified reference standard.

In review of the above shortcomings, the research on the hierarchical coding system of tunnel engineering for highway maintenance informatization has been conducted in this paper, the coding rules of tunnel engineering classified and accurate to the structural unit and auxiliary facility level are established, and then support for the association, exchange, circulation and migration of the whole life cycle information of highway tunnel is provided. At last, the informatization work of highway tunnel maintenance management, which broken the "data island" is promoted, and the cost of maintenance information is diminished. In this way, a modern highway maintenance system was built, which helps to construct the foundation for faster and higher quality industry.

2. A brief introduction of the hierarchical coding system

According to the properties and maintenance characteristics of highway tunnel maintenance, the hierarchical coding system of highway maintenance informatization should adopt specific principles and methods to classify the levels and categories of the tunnel structural units and affiliated facilities to form a multi-level hierarchical coding structure. In addition, in order to prevent duplication, typing and coding errors in coding applications, the verification method is also an essential part of the system.

2.1. Coding principle

The hierarchical coding of tunnel engineering for highway maintenance informatization mainly follows the following principles:

(1) Applicability. The coding should be based on the whole life cycle and meet the requirements of different stages, different management organization forms and different operation levels. That is to say, it should not only meet the requirements of trial and maintenance management stages, but also not violate the engineering classification principle of construction period (design stage and construction stage).

(2) Systematic. The coding should form a multi-level and reasonable classification system according to the specific classification method. The same level cannot contain each other. There is a
subordinate relationship between levels, and the upper level should contain the lower level in structure or attribute.

(3) Expansibility. The coding should ensure that it can be supplemented and improved without affecting the existing classification system to meet the requirements of different management accuracy and stages.

(4) Uniqueness. In the hierarchical coding system, each category has only one code, and vice versa.

2.2. Hierarchical coding method

The main methods for information classification include line classification, surface classification and hybrid classification. The Hybrid classification is the fusion of line classification and surface classification. Firstly, the objects are divided into many surfaces, and then the line classification is used to decompose each category. The Hybrid classification can be better applied to the classification of complex objects, and the most typical one is omniclass classification [11]. In this paper, on the basis of absorbing and summarizing all kinds of classification standard methods, the hybrid classification method is adopted to form a set of highway tunnel engineering classification code for maintenance informatization, which provides a kind of method for highway tunnel maintenance management.

The hierarchical coding of tunnel engineering for maintenance informatization mainly includes seven levels: highway code, administrative region code, tunnel code, direction code, structural unit and affiliated facility code, life cycle code and verification code. The corresponding coding structure is shown in Figure 1.

![Hierarchical coding structure of highway tunnel engineering](image)

Fig.1 Hierarchical coding structure of highway tunnel engineering

(1) Highway code.

Highway code which is the first part of the hierarchical coding structure follows the relevant provisions in the rules for highway route identification and national highway number (GBT 917-2017), to indicate the route of the tunnel. This part starts with the highway administrative grade code, and the field includes 1 English character and X digit (the maximum value of X is 4). The highway grade identifier is described as follows: national road-G, provincial road-S, county road-X, township road-Y, village road-C, special road-Z.

(2) Administrative region code.

The second part of the hierarchical coding structure is the administrative region code, which is composed of six Arabic numerals. The code of this part mainly uses the administrative region code above the county / district specified by the Ministry of Civil Affairs of the people's Republic of China as the administrative region code of highway tunnel. The administrative region code and the first part of the route code together constitute the road section code of the tunnel. For the special case that the tunnel spans multiple (generally two) administrative areas, the administrative area can be divided and coded according to the administrative area where the maintenance unit is located. If a single tunnel involves multiple maintenance units and does not belong to the common administrative area, it can be classified as multiple tunnels according to the maintenance boundary.

(3) Tunnel code.
The third part of the hierarchical coding structure is tunnel code, which is denoted with the letters "U" and four Arabic numerals. The definition and use of the coding letters in this part refer to the (JTT 132-2014). The first of the four Arabic numerals is the tunnel classification level, and the other three digits are the tunnel number. Referring to the (H12-2015), the classification level of tunnels and their corresponding codes are shown in Table 1. And the tunnel coding is sequentially coded according to the direction in which the station number increases, one tunnel corresponding with one code.

| Tunnel classification | Classification standard | Code |
|-----------------------|-------------------------|------|
| Short tunnel          | $L \leq 500$            | 1    |
| Medium tunnel         | $1000 \geq L > 500$     | 2    |
| Long tunnel           | $3000 \geq L > 1000$    | 3    |
| Super long tunnel     | $L > 3000$              | 4    |

Where the $L$ stands for the length of the tunnel.

(4) Direction code

Direction code is mainly used to distinguish the direction of the traffic, which belongs to the fourth part of coding. This part mainly starts with the letter "F" and encodes "F × ", where "F" is the direction defining character, followed by "× " is the direction code, which mainly includes: left direction - L, right direction - R. Specially, if the infrastructure has no direction, the direction code is U.

(5) Code of structural unit and affiliated facility

The code of structural unit and affiliated facility is the fifth part of hierarchical code. The starting position of civil structural unit is denoted as letter "C", followed by one letter plus four digits. The letter is unit type, the number is structural unit serial number, and the specific structural unit code is shown in Table 2. The starting position of auxiliary facilities code is letter "D", followed by two letters plus three digits, where the letter is the classification category of auxiliary facilities, and the number is the serial number of auxiliary facilities. The specific category code of auxiliary facilities is shown in Table 3 and Table 4. The tunnel structure unit should be coded every 10 meters, if it is less than 10 meters, it should be counted as 10 meters. If the structure changes, it should be coded separately. The auxiliary facilities should be coded according to the number of equipment, and the coding sequence should be carried out according to the increasing direction of maintenance pile number.

| Serial number | Maintenance project         | Structural unit type               | Code |
|---------------|-----------------------------|------------------------------------|------|
| 1             | Tunnel portal               | Tunnel portal                      | H    |
| 2             | Tunnel end wall             | Tunnel end wall                    | P    |
| 3             | Lining                      |                                    |      |
| 4             | Road surface                |                                    |      |
| 5             | Side Pavement               |                                    |      |
| 6             | Drainage structures         |                                    |      |
| 7             | Ceiling and various embedded parts | Tunnel cave                      | I    |
| 8             | Interior decoration         |                                    |      |
| 9             | Signs, markings, delineators|                                    |      |
| 10            | transverse traffic tubes    | transverse traffic tubes           | V    |
| 11            | Pedestrian passage          | Pedestrian passage                 | M    |
Table 3. Classification code of subproject of auxiliary facilities

| Serial number | Professional name                  | Sub name                          | Code |
|---------------|------------------------------------|-----------------------------------|------|
| 1             | Mechanical and electrical engineering | Power supply and distribution facilities | G    |
| 2             | Mechanical and electrical engineering | Ventilation facilities            | T    |
| 3             | Mechanical and electrical engineering | Lighting facilities              | L    |
| 4             | Mechanical and electrical engineering | Fire protection facilities       | F    |
| 5             | Mechanical and electrical engineering | Monitoring and communication facilities | M    |
| 6             | Traffic safety facilities           | Sign                             | A    |
| 7             | Traffic safety facilities           | Marking line                      | B    |
| 8             | Traffic safety facilities           | Guardrail                         | D    |

Table 4. Classification code of auxiliary facilities

| Serial number | Divisional facilities                  | Sub facility                     | Code |
|---------------|---------------------------------------|----------------------------------|------|
| 1             | Power supply and distribution facilities | High voltage incoming cabinet   | J    |
| 2             | Power supply and distribution facilities | High voltage metering cabinet   | L    |
| 3             | Power supply and distribution facilities | ...                              | ...  |
| 4             | Power supply and distribution facilities | Lightning protection grounding | Q    |
| 5             | Power supply and distribution facilities | Jet fan                         | J    |
| 6             | Ventilation facilities                | ...                              | ...  |
| 7             | Ventilation facilities                | Power distribution box           | C    |
| 8             | Ventilation facilities                | Lighting section                 | L    |
| 9             | Ventilation facilities                | ...                              | ...  |
| 10            | Lighting facilities                   | Cable                            | P    |
| 11            | Lighting facilities                   | Fire pool                        | P    |
| 12            | Lighting facilities                   | Water pump                       | W    |
| 13            | Lighting facilities                   | ...                              | ...  |
| 14            | Fire protection facilities            | FBG temperature sensing fire detection system | G    |
| 15            | Fire protection facilities            | Brightness detector              | L    |
| 16            | Fire protection facilities            | Visibility detector              | V    |
| 17            | Fire protection facilities            | ...                              | ...  |
| 18            | Fire protection facilities            | Monitoring distribution box      | C    |
| 19            | Fire protection facilities            | Sign                             | A    |
| 20            | Fire protection facilities            | Marking line                     | B    |
| 21            | Fire protection facilities            | Guardrail                        | D    |

(6) Life cycle code

The life cycle code should be able to accurately reflect the times of disease treatment, repair and replacement experienced by the structural units and affiliated facility of the highway tunnel. The life cycle code starts with the letter "Q", and the following three digits represent the times of disease treatment, repair and replacement.

(7) Verification code

The verification code is the third part of the hierarchical coding structure, consisting of only one Arabic digit. The more details of the verification method are described in the next section.

2.3. Calibration method

In order to ensure the accuracy of hierarchical coding transmission in tunnel engineering, a set of check character system is used to correct errors during the process of copying, typing or collecting code data. The code usually consists of ontology code and check code [12].
The commonly used calibration methods include parity calibration, Hamming calibration, cyclic redundancy calibration, longitudinal redundancy calibration, cumulative sum calibration, total exclusive or calibration [13]. By the definition of standard files, the encoding code usually adopts the modular parity methods for calibrating character systems. There are usually two kinds of calibrating character systems: one is a pure system in which all the calculation stages use a single module, and the other is a mixed system in which two modules are used, one module being even, and the other module being 1 larger. In order to simplify the checking calculation, this paper first converts the letters in the unit coding of the highway tunnel structure into corresponding numbers, and then adopts the single module pure system coding method. Finally, the polynomial method is used to calculate the check code adding the parity bit. The number character value at each location should satisfy the following calibration formula:

\[ \sum_{i=1}^{18} (a_i \times W_i) \equiv 0 \pmod{10} \] (1)

Where the \( i \) represents the sequence number of the number character from right to left, including the verification code character, \( a_i \) represents the value of the number character at the \( i \)th position. \( a_i \) is the verification code of tunnel engineering hierarchical coding, and \( W_i \) represents the weighting factor at the \( i \)th position. The weighting factor calculation formula is:

\[ W_i = 2^{i-1} \pmod{10} \] (2)

3. Application of hierarchical coding system

The hierarchical coding of highway tunnel engineering can be applied in daily maintenance with combination of new technologies and management methods, so as to achieve the maintenance management granularity at the level of civil structure unit and auxiliary facilities of the tunnel, meet the requirements of tunnel maintenance management, and improve the informatization and intelligence level of highway maintenance management. The unique identification of highway tunnel structural units and affiliated facility mainly includes the following applications:

(1) Rapid identification of tunnel structural units and affiliated facilities

The application of automatic recognition based on hierarchical coding can adopt the method of two-dimensional code scanning recognition. The two-dimensional code is a square array, which is composed of a series of square modules and consists of three parts: pattern feature area, data symbol area and blank area. Among them, the pattern feature area includes image finding graphic, separator, positioning graphic and correction graphic, while the data symbol area includes data codeword, error correction codeword, version information and format information [14]. According to the hierarchical coding system of tunnel engineering, two-dimensional code is generated for each civil structure unit and affiliated facility for management. The two-dimensional code label is installed on each structural unit and auxiliary facilities, which is automatically identified by scanning the two-dimensional code, used for information viewing, inspection records of structural facilities and etc.

(2) Rules of highway asset management

The digital management of highway tunnel can be realized through the classification coding rules, and the comprehensive control of highway tunnel’s structural units and affiliated facilities can be realized through the reverse solution of classification coding.

(3) Identification of data exchange

The highway maintenance management information system may involve multiple subsystems to carry out data exchange with other systems (such as OA management system). The hierarchical coding can be used as the business identification of data exchange between multiple ends of the same system (APP end, web end and application program end) or between different systems.

(4) Keywords associated with life cycle information

The hierarchical code can be used as the key word for the information association of the whole life cycle of highway tunnels, which includes the basic information such as time, structure type, design
parameters, detection results, construction unit during the construction period, and the maintenance information such as operation environment, disease type, disease parameters, regular inspection, patrol inspection data, maintenance data during the operation period.

4. Conclusions

The establishment of a hierarchical coding system suitable for the whole life cycle of highway tunnels is an important guarantee for the realization of highway maintenance information. Through the research and analysis of information classification and coding system in domestic and foreign highway and municipal areas, combined with the attribute and maintenance characteristics of tunnel engineering, this paper divides the highway tunnel engineering coding into seven levels of structure, each level of business object belonging to the subordinate relationship. The classification code is developed according to different structural units and affiliated facilities. The hierarchical structure can determine the subordinate relationship of coding elements, and users can select the required levels for use according to their needs; the structural unit and auxiliary facilities classification coding can ensure the uniqueness of tunnel maintenance objects; the combination of the two methods provides an important guarantee for the transmission of highway tunnel maintenance information and the orderly management of business management objects, and proposes a set of classification suitable for highway tunnel maintenance information.

The proposed hierarchical coding system in this paper has been applied in different provinces and achieved outstanding performance. In addition, the hierarchical coding object can also be extended to road, bridge, traffic engineering and other disciplines, which can further improve and unify the highway engineering classification coding system for maintenance informatization.

Acknowledgements

This research was supported by the Chongqing Municipal Science and Technology Commission’s key projects for social and people's livelihood. Finally, the author would like to thank the anonymous reviewers for their helpful comments and suggestions.

References

[1] Ministry of transport. Development Statistics Bulletin of transport industry in 2018 [J]. People's transport, 2019, (8): 49-55.

[2] Wang T, Jiang C, Fei Y. Maintenance information management and application based on new digital highway cloud service technology [J]. Highway transportation technology (application technology version), 2018,14 (03): 309-311.

[3] General Administration of quality supervision, inspection and Quarantine of the people's Republic of China and China National Standardization Administration. Mark rules of highway route and number of national trunk highway.: GB / T 917-2017 [S], 2017.

[4] Cataloging and coding rules for highway database.: JT / T 132-2014 [S], 2014.

[5] Technical Specifications of Maintenance for Highway Tunnel.: JTG H12-2015[S],2015.

[6] Xu N. Research on coding method of mechanical and electrical equipment of Expressway [J]. Science and technology and enterprise, 2016 (10): 45-45.

[7] GU H. Probe into Practical Techniques for Classification Codes of Management for Assets of Expressways[J]. Technology of Highway and Transport, 2012, (3):130-132.

[8] Qiu J, Qu X, He L. Research on Intelligent Traffic Infrastructure Management Based on Two -dimensional Code and RFID[J]. Transportation Technology, 2018,7(5):319-325.

[9] Lee S.M, Jang S G, Kim T J, et al. Integrated Information Systems for Highway Safety Management: Conceptual Design for Interoperability[J]. 2007 International Conference on Multimedia and Ubiquitous Engineering (MUE 2007), 26-28 April 2007, Seoul, Korea. IEEE, 2007:1-6.

[10] Kang S.L. A GIS-based Traffic Accident Analysis on Highways using Alignment related Risk Indices [D],Seoul National University, Seoul, KOREA, 2002: 5-12.
[11] Yuan Y, Liu Z, Shi G, et al. Analysis of current situation of classification and coding of highway engineering information model [J]. China highway, 2018, (9): 94-95.

[12] Sun D. Video digital coding design for highway network location and identification[J]. Journal of Chang’an University (Natural Science Edition). 2014, 34(5):123-128.

[13] Zhang G, Huang Y, Gu W. Analysis of Coding and Checking Technology in Standard[J]. QUALITY EXPLORATION. 2017, (6):51-58.

[14] Chen J. Research and Implementation of the Encoding and Decoding Technology of QRcode[D]. Xi’an University of Electronic Science and technology. 2012.