Research on Information Coding and Management for Big Data Mining in Highway Bridge Operation and Maintenance

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Abstract. In order to make full use of the available information in the operation and maintenance (O&M) stage, such as historical inspection results, and enhance the effectiveness of bridge O&M, this paper presents a method for classifying and coding bridge O&M stage information. An analysis of common construction information classification systems, including OmniClass, GB/T 51269–2017, and JTG/T 2420–2021, which are widely adopted domestically and internationally, reveals their inadequacy in addressing the data recording requirements of the bridge O&M process. In response, the proposed method improves upon existing systems and employs a combination of linear classification and side classification methods. The method comprises six recommended tables for information classification, each with corresponding classification rules and coding methods. This approach effectively transforms O&M phase data into structured bridge status information, thereby providing a database for big data mining.

Keywords: Big Data Mining · Bridge · Information Coding Classification · Operation and Maintenance

1 Introduction

Due to the large-scale development of highway construction in China, the number of highway bridges in the country has continued to increase. As of the end of 2021, there were 961,000 highway bridges, including approximately 819,000 small and medium-span bridges, which account for 85.2% of the total. However, years of operating loads and environmental erosion have resulted in structural damage and performance degradation of in-service bridges, which has become increasingly serious over time, thereby affecting public transportation and the safety of people's lives and properties [1]. As crucial nodes in the traffic network, it is equally important to ensure the safety of small and medium bridges. Currently, the performance maintenance of bridges in China primarily involves a small number of important large-scale bridges adopting health monitoring systems, while a large number of small and medium-sized bridges adopt the pattern of regular and special inspections. Despite the fact that medium and small-span bridges constitute the majority of the total number of bridges in the country, they generally lack special bridges and health monitoring systems. Furthermore, many bridges have undergone long periods of construction and service, which exacerbates operation safety concerns.

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Currently, the O&M of small and medium-sized bridges in China primarily rely on manual inspections, which suffer from inadequate inspection efficiency and depth. The increasing number of bridges that require inspection coupled with limited funding and personnel further exacerbate this issue. Additionally, inspectors' technical experience, level, and time constraints make it challenging to provide a comprehensive and efficient scientific and reasonable follow-up inspection and maintenance decision program. The large number of bridges in service and the lack of resources for maintenance significantly compromise the safe operation of small and medium-sized bridges, with bridge accidents frequently reported in the news to highlight the issue's existence.

The health monitoring system employed in large bridges records real-time monitoring data using sensing equipment [2], which exhibits characteristics such as large quantity, specification, and continuity. Conversely [3], inspection data for small and medium-sized bridges are derived from various equipment sources across multiple inspection agencies, with diverse data sources and formats, as well as heterogeneous, multi-source, unstructured, and discontinuous data characteristics [4]. A significant volume of historical inspection data, design information, climate, environment, traffic volume, and other multi-source data are accumulated in the regular maintenance management of bridges, which can be structured and stored to establish a bridge condition information base [5]. The bridge condition information database can subsequently be utilized for bridge condition assessment, data mining, and bridge operation safety warning. The bridge operation safety warning refers to a notification or alert issued to warn bridge users of potential safety hazards or risks during the operation of the bridge, which is critical for maintaining the safety and integrity of bridge infrastructure.

To develop a bridge condition information database that is suitable for China's highway bridge maintenance and management, this paper proposes a bridge component classification system, a common bridge damage classification system, and corresponding information coding methods. These systems are intended to provide a database for the mining and analysis of big data related to bridge O&M.

2 Study on the Classification System of Building Information

This paper presents a framework for the classification of bridge condition information using a hybrid classification method, based on a summary of information classification principles and methods. Domestic and foreign construction information classification systems are compared to inform the proposed framework. The hybrid classification method takes into account the unique characteristics of the bridge O&M phase, with a particular focus on the structured storage and management of status information during this phase.

2.1 Information Classification Methods

Information classification should satisfy the requirements of scientific, compatible, practical, and scalable. Commonly used methods of information classification include line classification, surface classification, and hybrid classification [6]. Line classification, also known as hierarchical classification, sorts classification objects into corresponding categories according to selected attributes or characteristics, forming a classification system that unfolds level by level. The line classification method results in objects being classified into levels such as major, medium, minor, and sub-categories, each of which has a subordinate relationship. For example, bridge construction can be classified by composition. The facet classification method treats several attributes or characteristics of the selected object as several "facets", each of which can be divided into several independent categories. The result of the facet classification method is that the object is organized into a mesh structure, with different "facets" in a parallel relationship representing different attributes and characteristics [7]. For instance, bridges can be classified according to their form, function, materials, and properties. In practice, the hybrid classification method combines the line and facet classification methods. In this paper, a combination of line and facet classification methods is used to build a more complete bridge condition information base.

2.2 Domestic and Foreign Construction Information Classification System

Among foreign building information classification systems, OmniClass in North America and Uniclass 2015 in the UK are widely utilized. For instance, they are both implemented in the most widely-used Building Information Modeling (known as BIM) software, Revit. These classification systems comply with the information classification framework of ISO12006–2 and use a classification method that combines the facet and line classification methods. Specifically, OmniClass utilizes the idea of face classification to sort building information into 15 classification tables that cover the entire life cycle of building design, construction, operation, and demolition [8]. As indicated in Table 1, the classification methods employed by these tables follow the recommended tables of ISO12006–2, and the line classification method is applied within each table to encode information hierarchically. The Uniformat and Masterformat, which were previously more widely utilized classification systems, adopt the idea of line classification, and their outcomes are respectively applied to Tables 21 and 22 of the OmniClass standard.

The prevalent classification system for construction information in China is the Standard for Classification and Coding of Building Information Model (GB/T 51269–2017), which is also based on the ISO12006–2 classification standard system and comprises 15 recommended tables. This system covers four aspects of building information, namely, construction results, construction process, construction resources, and construction attributes. Additionally, in the field of highway engineering, the more widely used information classification system is the Unified Standard for Application of Building Information Modeling in Highway Engineering (JTG/T 2420–2021). This system is also based on ISO12006–2 and classifies information according to five aspects, namely, results, process, resources, attributes, and others. Furthermore, it provides a total of 11 recommended classification tables, and within each classification table, the classification should be divided into four levels according to the hierarchy.

However, the existing information classification systems fail to effectively support the management and maintenance of highway bridges, mainly due to their incomprehensive coverage of bridge damage and related information in the classification tables, incomplete consideration of component classification to record bridge inspection results, and difficulty in correlating bridge damage information with specific components. To

Table 1. The 15 tables of OmniClass.

Table Number	Table title	Suggested tables in of ISO 12006–2
Table 11	Construction entities by function	A2 A3 A6
Table 12	Construction entities by form	A1
Table 13	Spaces by function	A5
Table 14	Spaces by form	A4
Table 21	Elements	A7 A8
Table 22	Work results	A9
Table 23	Products	A13
Table 31	Phases	A11 A12
Table 32	Services	A10
Table 33	Disciplines	A15
Table 34	Organizational roles	A15
Table 35	Tools	A14
Table 36	Information	A16
Table 41	Materials	A17
Table 49	Properties	A17

address these limitations, this paper builds on the classification standard system of ISO12006–2, and draws from the Unified Standard for Application of Building Information Modeling in Highway Engineering to establish a bridge inspection information classification and coding system.

3 Method for Establishing Bridge Maintenance Information Database

3.1 Framework of Bridge Maintenance Information Classification System

In order to effectively utilize the large amount of historical detection data accumulated in bridge maintenance management and realize data mining of bridge maintenance information, it is necessary to establish a bridge maintenance stage status information database as the basis for data [9, 10]. The data in the database should be strictly standardized, versatile, and easy to mine. To achieve this, it is necessary to collect a significant amount of historical inspection data, such as inspection results, damage information, and component ratings, as well as information on the bridge working environment, including climate, environment, and traffic volume. The classification and encoding of relevant information is an effective method for processing these data.

To address the demands of bridge O&M, an information classification system framework has been formulated, as presented in Table 2. This framework consists of 6 hierarchical tables, that encompass the essential information required for the bridge maintenance phase. Additional information that is not considered a key element in the bridge maintenance phase may be referenced to the standards set forth in JTG/T 2420–2021. The classification system framework aims to facilitate the processing of information related to bridge maintenance by classifying and organizing it in a systematic and efficient manner. By doing so, it enables the establishment of a bridge maintenance stage status information database that meets the requirements of strict specifications, versatility, and easy data mining, which is fundamental for effective data processing and analysis.

3.2 Classification Rules and Coding Methods of Bridge O&M Information

According to Table 2, the bridge O&M information can be classified into 6 tables. The Location attributes Table is used mainly to determine the unique identifier of the bridge based on information such as administrative areas, routes, and mileage stakes. The code can also reflect the location relationship between bridges in the same domain. The Feature attributes Table primarily describes the fundamental characteristics of the bridge, such as grade, scale, and type, while the Material Table describes the type of materials used in the bridge. These two classification tables can be cited from JTG/T 2420–2021 and will not be recompiled. The Bridge Components Table is of utmost importance, as it facilitates the systematic decomposition of a bridge facility into its constituent components.

The EBS method is employed to break down the bridge structure into components, with reference to The Bridge Components Table. This classification process is carried out systematically, starting with the structure type, followed by the parts, component, and damage location. By doing so, the bridge components can be effectively organized and recorded, facilitating the collection and mining of O&M information for future use.

Table 3 illustrates the completion of the bridge structure decomposition based on the decomposition rules. The bridge components are specified using codes, facilitating accurate identification of the bridge O&M components, and correlation with corresponding O&M inspection data and bridge damage information.

Table 2. The 6 tables of bridge O&M information classification system.

Table Number	Table title	Classification purpose
Table 01	Location attributes	To determine the unique identifier of the bridge
Table 02	Feature attributes	To describe bridge characteristics
Table 03	Bridge components	To determine number of each component
Table 04	Materials	To determine number of each material
Table 05	Bridge damage conditions	To describe bridge damage conditions
Table 06	Environmental conditions	To describe the environmental conditions that surround bridges

Table 3. Examples of classification and coding of bridge components

Code of components	Types of bridges	Bridge parts	Subparts	Component	Damage location
03–01.00.00.00.00	Beam bridge				
03–01.01.00.00.00		Superstructure			
03–01.01.01.00.00			Bridge girder		
03–01.01.01.01.00				Concrete box girder	
03–01.01.01.01.01					Girder roof
03–01.01.01.01.02					Girder floor
03–01.01.01.01.03					Girder web
03–01.01.01.02.00				Concrete t-beam	
03–01.01.01.03.00				Solid plate girder	
03–01.01.01.04.00				Hollow slab beam	
				……	
03–01.01.02.00.00			Bridge bearing		
03–01.02.00.00.00		Substructure			
03–01.03.00.00.00		Bridge deck system			
		……			
03–02.00.00.00.00	Truss bridge				
03–03.00.00.00.00	Arch bridge				
03–04.00.00.00.00	Cable-stayed bridge				
	……				

4 Conclusions

Bridge operation and maintenance (O&M) encompasses the routine activities and procedures essential to guarantee the safety and functionality of bridge infrastructure while preserving its useful life. Bridges are a critical component of infrastructure, and effective O&M are essential for ensuring their good condition. However, despite the vast amount of historical data generated during the bridge O&M process, the heterogeneous and unstructured nature of the data, combined with multiple sources, makes it challenging to apply data analysis methods such as data mining. Moreover, existing classification systems, both domestic and international, including but not limited to OmniClass, GB/T 51269–2017, and JTG/T 2420–2021, do not adequately meet the requirements for data recording in the bridge O&M process.

To address this issue, this paper proposes an improved system for classifying and organizing bridge O&M information. The system includes 6 classification tables covering key information related to the bridge O&M process. The Environmental Conditions Table enables the recording of environmental category, traffic volume, temperature, and other relevant information in coded form. The classification and coding rules of the Bridge Component Table fully consider the need to record bridge damage information, and an example demonstrates the specific form of component classification and coding.

The system of bridge O&M information classification established in this paper can be used to build a bridge O&M database, thereby providing the necessary data foundation for big data analysis.

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