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Causes of structural defects to bus rapid transit (BRT) facilities: Example of Xiamen BRT system

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HIGHLIGHTS

- Principal component analysis is used to detect the causes of structural defects of Bus Rapid Transit facilities.
- Reasons for the structural defects of the BRT system are weighted and analyzed.
- More than 25000 structural defect data of BRT facilities were used in the PCA model.

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ABSTRACT

Based on the health diagnosis data of structural defects in reinforced concrete components of Xiamen Bus Rapid Transit (BRT) system, this paper presents a principal component analysis (PCA) – based method to detect the causes of structural crack defects of BRT. The defect data are collected from the health diagnosis work on facilities of Xiamen BRT system, and is divided into six categories: a) aged structure, b) structural weight, c) weather-caused, d) external force, e) BRT operation and f) facility-use. The six dimensions of causes are mapped into the PCA model to calculate the contribution degrees – according to which, the causes of structural defects of BRT facilities are categorized and evaluated. Finally, the main reasons for the structural defects of the BRT system are weighted and discussed.

1. Introduction

The urban public passenger transportation system mainly includes three forms: normal bus transit (NBT), Bus Rapid Transit (BRT) and rapid rail transit (RRT). Nowadays, the NBT has been well developed in each city all over the world. However, with the improvement of the level of motorization of the city, as well as the overwhelm road congestion, the NBT began to restrict the further development of urban space. On the other side, BRT and RRT have been proven to being capable of effectively and reasonably utilizing the road resources and urban space. For this sake, they are gradually winning the favor of many cities all over the world.

As a new type of urban public transportation system, BRT is one of the effective ways to solve the urban traffic problem. It has the characteristics of less investment, short period of construction time, minor traffic interference and speedy running ways. In addition, BRT mainly uses independent lanes and has complete traffic management facilities. The specifics of laying elevated lanes or fully-closed right-of-way, have the obvious difference with the ordinary urban public transportation means, e.g., the bus or street car. In addition, the structure of the BRT system is influenced by many factors, and is more sensitive to pavement structure, building materials and meteorological factors [1,2].

Since 2000, BRT systems have been largely introduced into more than 20 cities of China, to solve the very serious problem of urban traffic congestion [3]. After 15 years of operation, the maintenance of facilities has become an important problem for these cities with BRT. Compared to the planning and design, land use, operational business model design, facility maintenance-related research about BRT system is still relatively few [4,5]. However, many cities are facing the aging of BRT facilities and structural diseases [6–9]. Hence, facility defects due to aging and excessive operation of the BRT systems are imposing significant pressure, and threats to the safety of urban passenger transport system [10]. For this sake, it is necessary to examine the causes of defects in BRT facilities and propose the corresponding countermeasures.

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Many existing studies have discussed the prevention and control methods of bus transit infrastructure diseases. Agbelie et al. [11] identified the bridge damage due to overweight vehicles using a modified equivalent-vehicle methodology and in-service data. At the same time, the marginal cost of repairing the damages is calculated in this studies. Koch et al. [12] proposed a computer-aided method for defect detection and state evaluation of asphalt civil infrastructure. They focused on bus related infrastructures such as concrete bridges, tunnels, underground pipes, and, automatically detected and classified most relevant types of defects. They clarified that how to use machine learning methods online learning for efficient training and calibrating of model parameters is the imminent mission of future defect detection and assessment. Romero et al. [13] used a computer program to simulate vehicle-infrastructure interaction. The speed, payload, road roughness and wheelbase dimension were deemed as main factors which took large effects on the infrastructure deflection. In Wu et al. [14], a method for identifying damages of concrete bridges based on spatially-distributed long-gauge strain sensing technique is proposed. They augured that the vehicle parameters have little influence on the damage identification results. During the defect detection process, it is traditional to install the predefined sensor on the infrastructure bodies. However, predefined sensors usually do not fully cover all potential damage areas of large bridge structures, which will bring additional difficulties to damage identification. In order to cope with these challenges, a multi-level damage identification method is proposed to reconstruct the response by using the divide and conquer method in [15]. At the same time, this study found that the effect of the actual environment on the defect of long span cable bridge is very complicated. They not only depend on the position and function of the bridge, but also on the day or the night.

With the influence of bridge age and climate, oxidation, corrosion and other environmental factors, and under the action of long-term live loads and special loads (earthquakes, typhoons, automobiles, etc.), large-scale transportation infrastructures often have the comprehensive destructions. However, there is few existing research examine the classification of structural diseases and the determination of the influencing factors for the infrastructure. Taking the BRT system of Xiamen city as an example, it is necessary to carry out a targeted disease test on the structure of the BRT facility. How to choose the moderate evaluation method to determine the contribution of various types of causes of defects on BRT system is also an essential task. Among the existing evaluation methods, principal component analysis (PCA) has its excel advantage as follows [16]:

First, the PCA transforms the original index variables to form each other's independent principal components, and it proves that the higher the correlation between the indexes, the better the effect of the PCA.

Second, for other evaluation methods, because it is difficult to eliminate the correlation between the evaluation indexes, it takes a lot of energy to choose the index, but the PCA is relatively easy to choose the selection of indexes because it can eliminate the related influence between factors.

Third, when the rating index is large, the majority of information can also be retained with a few comprehensive indicators instead of the original index in the PCA.

Fourth, the principal components in the PCA are arranged in order according to the size of the variance. In the analysis of the problem, a part of the principal component can be abandoned and the original variables are represented by a few main components of the larger variance. In the comprehensive evaluation function, the weight of each principal component is its contribution rate. It reflects the belief that the principal component contains the original data in the comprehensive evaluation function.

Finally, the calculation of the PCA is more standardized, easy to implement on the computer, and can also use the specialized software.

Thus, this paper proposes a new method to summarize the causes of defects in BRT facilities. The PCA technique is used to detect sixes types of defect causes for Xiamen BRT, and the main contribution of each cause is calculated and ranked. Based on the contribution degree of each cause, the corresponding countermeasures are proposed for the future maintenance of Xiamen BRT. It hopes that the presented method in this paper could give supportive reference to BRT maintenance and structural defect control for cities which are operating BRT in China and other countries.

2. Background

Xiamen City's BRT system (shortened as Xiamen BRT), is one of a typical rapid transit systems of Chinese cities. It was officially put into operation on September 1, 2008. This system includes the special stations, elevated and dedicated lanes. Date to 2016, Xiamen BRT consists of 7 backbone lines, 11 BRT feeder lines, and one ring community line. The map of Xiamen BRT has been shown in Fig. 1 [17].

After eight years of operation, Xiamen BRT also confronts a series of maintenance difficulties resulting from the aging of facilities. To keep the safe operation and sustainable use of the related facilities of BRT, the transit operator of Xiamen City composed a dedicated company (i.e., Xiamen BRT Cooperation) to mitigate the system, further, to collect the defects data of pavements, structures, components along the BRT lines.

With the growth of bridge age, due to the influence of climate, oxidation, corrosion and other environmental factors, as well as the long time under the action of constant, live load and special load (earthquake, typhoon, car collision and so on), and the deficiency in the design and construction, the bridge structures or components have different degrees of natural, artificial and operation-caused damages. Thus, Xiamen BRT Corporation has employed the professional maintenance companies to carry out the related record and analysis of structural damage data for years.

The sample data of defects used in this paper were collected from three lines of Xiamen BRT during January 2013 to January 2016. The sample dataset consists of more than 25,000 defect records of different locations and components of BRT facilities. Where, those fields in Table 1 respectively denote the following meanings:

- Cause-1: aged structures.
- Cause-2: structural weight.
- Cause-3: weather-caused.
- Cause-4: external force.
- Cause-5: BRT operation.
- Cause-6: facility-use.
- Time detected: the duration of time since this defect was detected, in months.
- Defect type: 1 denotes holes; 2 denotes cracks; 3 denotes the large area damage; 4 denotes settlement.
- Defect location: 1 denotes pavement of the lane; 2 denotes the railing of the lane; 3 denotes the support of the bridge; 4 denotes the bean of the bridge; 5 denotes the body of the bridge; 6 denotes the facility of the station; 7 denotes the elevator; 8 denotes other facilities.
- Maintenance cost: the cost to repair the defect.

According to the detected data, it reveals that the various defects exist in all the components of all BRT routes and embodied in various types (See Fig. 2). However, we still could not determine