On Method to Estimate Deterioration of Infrastructure

Naoto Itani, Kazunari Tanaka

1. Introduction

1.1 Background

In Japan, a significant portion of social infrastructure was intensively constructed during the period of rapid economic growth. These structures are now aging, with the number of deteriorating assets expected to increase significantly over the next 20 years. In particular, the aging of bridges presents a major challenge. The percentage of bridges over 50 years old is projected to rise from approximately 37% in March 2023 to 54% in March 2030 and 75% in March 2040.

Additionally, Japan faces the problem of a declining birthrate and an aging population. The population has been decreasing for 13 consecutive years since 2011 and is projected to fall below 90 million by 2070(1).

The number of engineers needed to maintain Japan’s infrastructure is insufficient. In particular, the construction and transportation industries have a higher percentage of workers aged 55 and above and a lower percentage of workers under 29.

In response, the Japanese government is promoting countermeasures such as digital transformation and asset management to help reduce maintenance costs. The Ministry of Land, Infrastructure, Transport and Tourism is promoting ICT and DX by accumulating and releasing BIM/CIM and inspection data.

However, implementing these policies will require approximately 20 years. Therefore, it is necessary to identify the factors that influence bridge deterioration. The goal of this study is to develop a more efficient method for assessing bridge deterioration.

1.2 Method of Maintenance in Japan

In Japan, the condition of bridges must be regularly inspected every 5 years (2). Bridge conditions are evaluated on a four-point scale.

Level Ⅰ is sound stage. It defines that there are no disruptions to the functionality of the bridge.

Level Ⅱ is preventive maintenance stage. it defines that There are no disruptions to the bridge functionality, but it is desirable to take measures from a preventive maintenance perspective.

Level Ⅲ is remedial action stage. It defines that there is a possibility that the bridge functionality is being impaired and measures should be taken early.

Level Ⅳ is emergency action stage. It defines that the bridge functionality is already significantly impaired, or is likely to be substantially impaired, and urgent measures must be taken.

2. Purpose

The purpose of this study is to estimate bridge deterioration by some natural environment. In this study, we analyzed using the Random Forest algorithm. In this analysis, we researched bridges in Fukushima Prefecture. The dataset included 14,498 bridges and was formatted as a CSV file. For creating the dataset, we integrated the information of natural environment and bridges using GIS. From the results of the analysis, we computed the SHAP values for analyzing the most influential factors affecting bridge deterioration.

3. Survey

3.1 Method

We conducted an analysis using the Random Forest algorithm, a machine learning technique available in Python. We chose Random Forest due to its ability to identify key influencing factors and its ease of interpretation.

This analysis targeted bridges in Japan. The objective variable was the degree of deterioration, and the explanatory variables included bridge characteristics and environmental factors. Table 1 lists the explanatory variables we used in this study. "Time" refers to the period of bridge use, defined as the difference between the year of construction and the year of inspection.

The experimental site was Fukushima prefecture. The dataset, formatted as a CSV file, was created by integrating environmental factors and bridge data using GIS.

After the analysis, we extracted SHAP values to understand the influence of each factor in this model and created beeswarm plots based on these values. We considered regional differences in factors and the evaluated the model's validity.

Factor on Bridge	Factor on Environment
Length_Bridge	Avg_Elevation
Width_Bridge	Precipitation
Time	Avg_Temperature
Latitude	Depth_Snow
Longtitude	Avg_Wind
	Distance_Coastline

Table 1. Explanatory variables

3.2 Result

After analyzing, we created confusion matrix for evaluating accuracy of this model. The accuracy of training data is 91%. Overall accuracy of test data is 73%. Especially, level Ⅱ is high accuracy. There are many level Ⅱ bridges, and we considered that their features have been adequately captured. However, level Ⅰ and level Ⅲ are not good accuracy. This is because there are insufficient data to capture features. Additionally, this model cannot level Ⅳ data. This is because there are not sufficient number of level Ⅳ bridges in Japan.

we extracted SHAP values to understand the influence of each factor in this model and created beeswarm plots based on these values.

For the variable "Time," the correlation is negative at level 1, while levels 2 and 3 show positive correlations. This suggests the progressive deterioration of the bridge over time.

Bridge length was found to have a significant impact, likely due to the type of bridge. Longer bridges tend to be made of steel, which is subject to salt damage and other corrosion. This may explain why bridge length is an important factor.

4. Conclusion

In this study, we attempted to estimate bridge deterioration by using the Random Forest algorithm. This study clarifies the importance of variables such as distance from the coastline, precipitation, and wind speed for estimating the degree of deterioration.

Additionally, we extracted SHAP values to understand the influence of each factor in this model and created beeswarm plots based on these values.

The SHAP beeswarm plot showed the influence of variables in the model. In particular, the period of bridge use was consistent with domain knowledge.

Future research will focus on improving the accuracy of this model by using aerial photography, population data and other environmental factors. In addition, this study has the potential to predict the environmental impacts in the early design stages of infrastructure projects.

5. References

1)Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism(MLIT), Summary of the White Paper on Land, Infrastructure, Transport and Tourism in Japan, 2024

2)National Institute for Land and Infrastructure Management, Bridge Preservation and Management,