Identifying Significant Parameters of the US Bridges

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***Abstract*— Various bridge parameters, either alone or in combination with other parameters, significantly affect the performance of the bridge decks in various regions. Identifying such parameters and/or their interaction effects allows the bridge authorities to understand and assess the bridge decks' performance in different regions. This paper analyzes 1,732 same-age US bridges from the national bridge inventory dataset with respect to various independent parameters along with bridge deck condition rating as the dependent parameter. The Kruskal-Wallis test was performed on these bridge decks for various independent parameters. Multiple pairwise comparisons between groups were also performed using the Wilcoxon test. Results show that material, design, and region affect the deck condition ratings of the bridges both individually and while interacting with each other. Further, it is observed that bridges made of concrete material with stringer multi-beam girder design, and which reside in the Highplains region perform the worst, whereas the prestressed concrete bridges with the same design and which reside in the same region perform the best.**

Keywords*— *National Bridge Inventory (NBI) Dataset; Kruskal-Wallis Test; Bridge Condition Ratings.

I. INTRODUCTION

The national bridge inventory database is being maintained by the U.S. Federal HighWay Administration (FHWA) since 1992. This database has the information of more than 600,000 bridges which includes both culverts and highway bridges. Information of each bridge is recorded with more than 100 parameters. Each bridge in the U.S. is inspected once every two years [7][8]. In 2017, U.S. bridges received a C+ grade for their overall performance [1]. Bridge decks', superstructures', and substructures' condition is verified by the bridge engineer based on the inspection frequency of the bridge [2]. Bridge decks are assigned a rating value between '0' and '9', as shown in Table 1. Rating condition '9' is assigned to an excellent condition rating bridge and '0' is assigned to a failed bridge. Bridges deteriorate for various reasons which include age of the bridge, material used to construct it, design used, average daily traffic on the bridge, geographical region of the bridge, etc. Population analysis models in association with correlation networks were applied on the civil infrastructures and in financial markets to show that various significantly enriched parameters effect the dependent parameters [2]-[6][11]. Deterioration models were applied to estimate the bridge condition ratings [9] and stochastic systems have been analyzed using stochastic/probabilistic model checking [12][13]. Some research in the recent past showed that climatic region also plays an important role in the deterioration of bridges [10]. However, the research presented in [10] was limited to one parameter, such as concrete material. The U.S. is geographically a huge country and divided into six climatic regions based on the varying environmental conditions, as shown in Fig. 1. All climatic regions have their own environmental conditions. For example, the Southeast region has dry or hot temperatures, and the Northeast region has very cold temperatures.

The National Bridge Inspection (NBI) database [7] consists of the information of each bridge along with more than 100 parameters. These parameters could be divided into both input and outcome parameters [2]-[5]. This paper attempts to study the effect of the independent parameters on a dependent parameter, including the interaction effects of the independent parameters on the dependent parameter. The three independent parameters considered for this study are: material, design, and region. The only dependent parameter considered was the deck condition rating. The aim of this study is to see how same-age bridges perform when the independent parameters are stand alone and when they interact with each other. Further, this study estimates the mean deck condition ratings while comparing the groups of independent parameters when they are alone or in interaction with each other. A one-way analysis of variance (one-way) ANOVA was required to see if the independent parameter groups' means are the same or not. For this, the Kruskal-Wallis test (since the data is not normal) was used for identifying the effects of the independent parameters on the dependent parameter. If the groups' means are the same, then

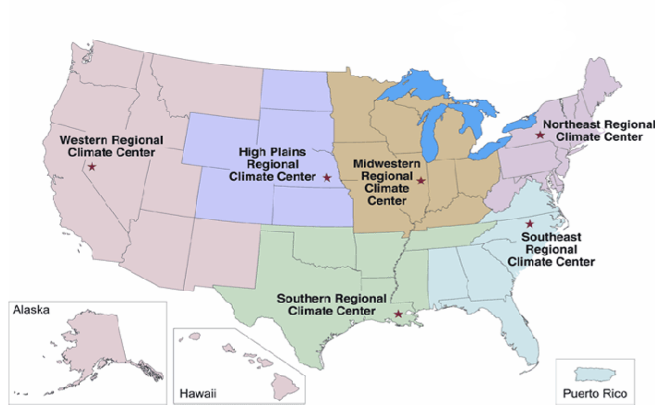

Figure 1. Six climatic regions encompassing the United States.

TABLE 1. DESCRIPTION OF CONDITION RATINGS OF BRIDGES

Condition Rating	Description
9	Excellent condition
8	Very good condition
7	Good condition
6	Satisfactory condition
5	Fair condition
4	Poor condition
3	Serious condition
2	Critical condition
1	Imminent failure condition
0	Failed condition

there is no effect of the independent parameter on the dependent parameters. Otherwise, there is an effect. If the groups' means are not the same, then we need another test to see which group performs better or worse. For this, the Wilcoxon signed-rank test was used for comparing the means of the groups.

II. METHODOLOGY

The dataset used for this study is from the NBI database [7]. The bridges across the USA that were built between the years 1991 and 1993 with an age of 27 years and were not rebuilt (bridges that did not go through any kind of maintenance so far) are selected for this study. The resulting dataset has a total of 1,732 bridges. Three independent parameters and one dependent parameter are considered for this study. The three independent parameters are: material, design, and region, and the dependent parameter is the deck condition rating. The objective is to find whether the independent parameter influences the dependent parameter. This process is done in two steps. First, the Kruskal-Wallis (KW) test is applied individually on each of these independent parameters to see if they influence the dependent parameter. Second, if there is an influence of the independent parameter on the dependent parameter, then the Wilcoxon pairwise comparison test is applied on the independent parameter groups to see the differences within them. The second step is applied only if the independent parameter effects the dependent parameter in the first step. This two-step process is repeated with the interactions of the independent parameters to see their influence on the dependent parameter. The purpose of applying the KW test and the Wilcoxon test on the interactions is to see if the interactions of independent parameters' groups lead to better mean values of the deck condition ratings than the independent parameters' groups mean values alone.

The following hypotheses are tested on all independent parameters and interactions with the deck condition ratings as the independent parameter.

1. The null and alternate hypotheses on materials is given below.

   H_0: The means of deck condition ratings of all material types are equal

   H_a: The means are not equal

2. The null and alternate hypotheses on designs is given below.

   H_0: The means of deck condition ratings of all design types are equal

   H_a: The means are not equal

3. The null and alternate hypotheses on regions is given below.

   H_0: The means of deck condition ratings of all regions are equal

   H_a: The means are not equal

4. The null and alternate hypotheses on material * design * region is given below.

   H_0: The means of deck condition ratings of all material*design*region are equal

   H_a: The means are not equal

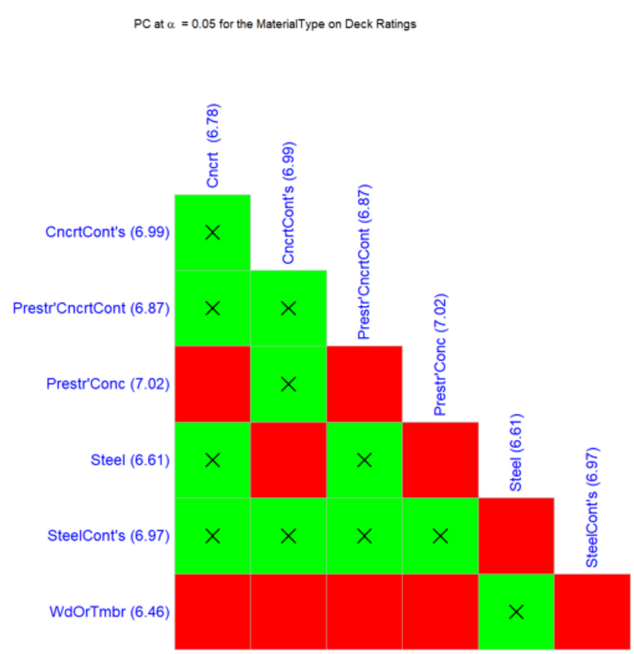

Figure 2. Pairwise comparison among the groups of materials

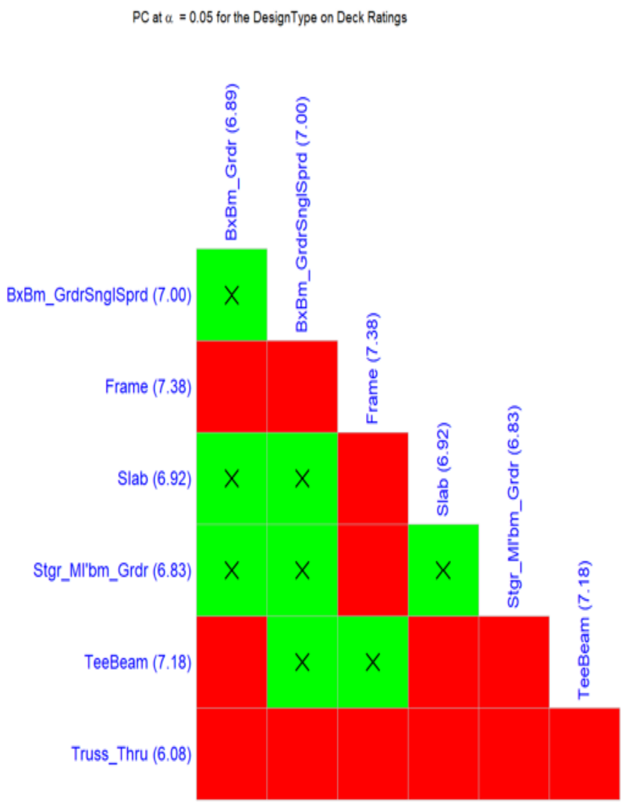

Figure 3. Pairwise comparison among the groups of the designs

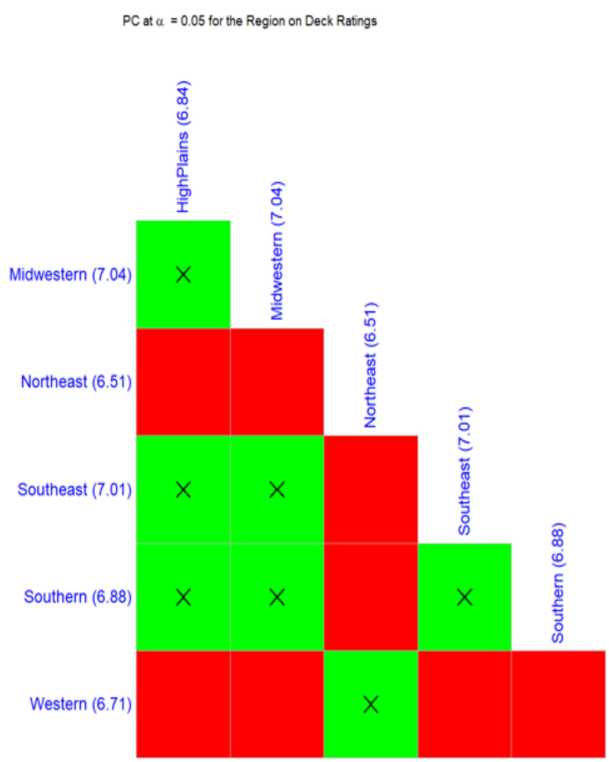

Figure 4. Pairwise comparison among the groups of the region

At the significance level α = 0.05, p-values are < 0.001 for all the above hypotheses. Therefore, the null hypotheses are rejected in all the cases. This clearly indicates that the independent parameters influence the dependent parameter.

III. EXPERIMENTAL RESULTS

This section demonstrates different experimental results for all the given hypotheses.

Initially, the KW test was applied on the material types. The mean values of all the material types are not equal. Hence, the null hypotheses were rejected, and it was concluded that the material types influence the deck condition rating. The Wilcoxon test was applied on the groups of material types to see which material is performing better. Fig. 2 shows various material types and their corresponding mean deck condition rating values (shown inside parentheses) after 27 years. From Fig. 2, we see that the prestressed concrete (given as Prestr'Conc) material type is performing the best compared to all other material types with the average deck condition rating value of 7.02. The lowest performing material type is Wood or Timber (given as WdOrTmbr). Fig 2 also shows two types of boxes while comparing the material type groups. Boxes shown with red color (or boxes without 'x' mark in them) are the material groups whose mean deck condition rating values are significantly different. For example, prestressed concrete material's mean deck condition rating value is 7.02, which is significantly different from the concrete material's (given as Cncrt) average deck condition rating value, which is 6.78. Similarly, the green boxes with 'x' symbol in them indicate that there is no significant difference between the mean values of the two material types. For example, concrete continuous (given as CnctrCont's) and concrete materials do not have a significant difference in their mean deck condition ratings. Seven material types were compared in this test. Out of seven material types, Wood or Timber material is significantly different from five other material types, as shown in Fig. 2. This indicates that Wood or Timber material is behaving differently from almost all other materials in terms of performing lower. Further, there is no performance difference among steel continuous material and concrete, concrete continuous, prestressed concrete, and prestressed concrete continuous materials.

The second independent parameter tested is the design type. Seven different designs were tested, as shown in Fig. 3. From Fig. 3, we see that the Frame type is performing the best with the mean deck condition ratings value 7.38, and Truss-Thru design is performing the worst with the value 6.08. Further, Truss-Thru design's performance is significantly different from all other designs.

The third independent parameter is the region. The US is geographically divided into six different regions, as shown in Fig 4. The KW-test was applied first, and the results show

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that the region effects the deck condition ratings. The Wilcoxon test results are shown in Fig 4. The Midwestern

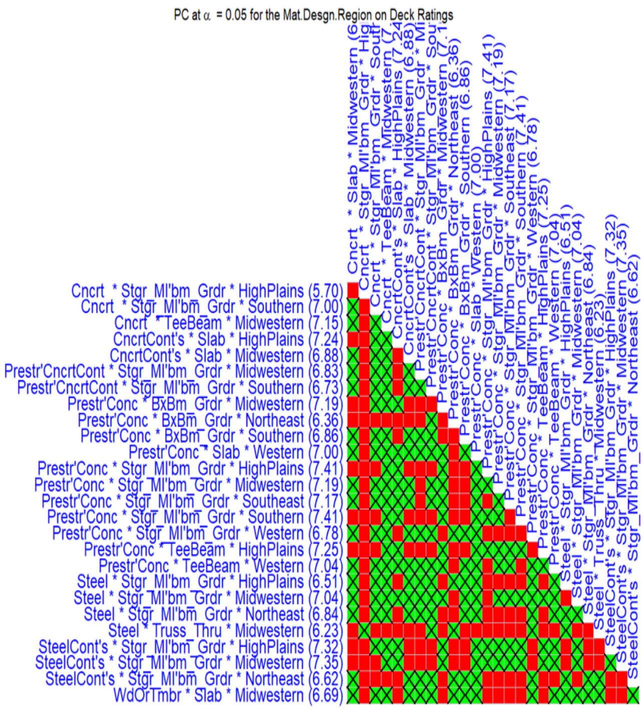

Figure 5. Pairwise comparison among the groups of the interactions of materials, designs, and regions

region is performing the best with the average deck condition rating value of 7.04, and the Northeast region is performing the worst with the value of 6.51. Further, the Northeast region's performance is significantly different from all other regions, except the Western region. The Wilcoxon test result of interactions of all the three independent parameters is shown in Fig 5. The results show that the bridges made of concrete material with stringer multi-beam girder design and that reside in the Highplains region perform the worst with an average deck condition rating value of 5.70, whereas the prestressed concrete bridges with the same design that reside in the same region perform the best with the value of 7.41. Similarly, prestressed concrete bridges with stringer multibeam-girder design that reside in the Southern region are also performing the best after 27 years.

IV. CONCLUSION

This paper analyzed the deterioration of 1,732 US bridges with 27 years of age for each bridge. Three independent parameters, namely, material, design, and region along with their interactions have been considered to see their effect on the dependent outcome condition rating parameter, namely, the deck rating. However, the region parameter was not part of the original NBI database. It was added in this study as the climatic regions play an important role in the deterioration of bridges. As the deck ratings data is not normal, the Kruskal-Wallis test was applied to see if the independent parameters influence the dependent parameter. The Wilcoxon test was applied for the multiple pairwise comparisons between the groups of the independent parameters to see how the groups are performing significantly different. Corrplot package in R language was used to visualize the significant differences among the groups of the independent parameters.

The results show that material, design, and region influence the deck condition ratings of the bridges both individually and in interaction with each other. Further, it is observed that the bridges made of concrete material with stringer multi-beam girder design that reside in the Highplains region perform the worst, whereas the prestressed concrete bridges with the same design that reside in the same region perform the best. Similarly, prestressed concrete bridges with stringer multibeam-girder design that reside in the Southern region are also performing the best after 27 years. Hence, by using the Kruskal-Wallis test followed by the Wilcoxon test, it is concluded that the bridges with concrete material and having stringer multibeam-girder design are not suitable for the Highplains region. The prestressed concrete material is more suitable, as it performs the best.

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