Bridge Network Performance Forecast—Survival-Based Models

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Introduction

The survival-based network performance forecast models on LTBP InfoBridge™ (Federal Highway Administration (FHWA), 2020) are based on a probabilistic methodological framework that uses Cox proportional hazards survival analysis and Markov chain theory to develop bridge component condition predictions over the lifecycle, integrated bridge condition forecasts, and bridge performance measure projections at the network level. The aim of this project is to provide InfoBridge users with network performance forecasts for any selected groups of bridges from the entire National Bridge Inventory (NBI) (FHWA, 2020).

Survival analysis has the unique ability to consider the impact of incompletely recorded durations in the analysis of duration-based data, giving it an edge over other statistical approaches. Proportional hazards bridge deterioration models are based on the survival analysis of observed continuous durations in each condition rating according to the NBI inspection records (Goyal, et al., 2020). In the absence of associated maintenance records in the NBI, censoring techniques available within survival analysis were used in a novel way to develop additional component models reflecting various levels of preservation, which would allow the user to visualize the impact of maintenance actions at the network level. Three different censoring protocols were designed to develop proportional hazards network performance forecasting models for three different levels of bridge preservation. Network performance forecasts in terms of bridge count, percentage bridge count, and percentage bridge deck area of bridges in good, fair, and poor condition are available on InfoBridge for each set of user-selected bridges corresponding to each preservation level.

Proportional Hazards Bridge Network Performance Model

Proportional hazards bridge deterioration models for the deck, superstructure, and substructure components of a bridge and culverts form the building blocks of the proportional hazards network performance model. For developing the component deterioration models, the semiparametric Cox proportional hazards model (PHM) is used to develop multivariable survival functions and PHM hazard ratios at each condition rating. The PHM outputs are then used to calculate structure-specific Markov chain transition probability matrices to develop lifecycle bridge component deterioration models (Goyal, 2020).

The individual component condition forecasts developed using the PHM deterioration models at each prediction year are used to classify each bridge into categories of good, fair, and poor based on the FHWA guidelines (FHWA, 2018). Deck, superstructure, and substructure condition forecasts are used to determine the overall bridge condition, and culvert condition forecasts are used to determine the bridge condition of culverts. Forecasts of bridge performance measures for selected bridges are calculated based on these bridge condition predictions for individual bridges and culverts.

To enable selection of bridge networks from the entire NBI, the deterioration modeling effort, which was earlier limited to major concrete-deck bridge types, was expanded to all bridges nationwide, including bridges with timber, steel, and other deck types. In addition to deck deterioration models, superstructure and substructure deterioration models for each of the nine bridge types were developed. Proportional hazards deterioration models for concrete culverts, and other culverts, were also developed. Bridges for which all three components of deck, superstructure, and substructure are assigned a condition rating of zero at the current year are not included in the proportional hazards network performance forecasts because such bridges are presumed to be closed and under consideration for replacement. For the same reason, culverts assigned a culvert condition rating of zero in the current year are also not included in the proportional hazards network performance projections.

Impact of Censoring on Survival Function Development

In developing PHM survival functions at each condition rating, condition rating durations that are truncated at the beginning or end year of the NBI recording period (1983–2019) are considered incomplete and classified as "censored" for the calculation of survival probabilities (Goyal, 2020). In addition, there are many instances in the NBI data in which observed condition rating durations are followed by an improvement in condition rating instead of deterioration. Such instances occur presumably due to the performance of maintenance actions, although there are no associated maintenance records in the NBI. Such instances may be classified as censored or uncensored depending on the assumption of whether the maintenance action prematurely shortened the duration of the condition rating or that it was performed in response to an unrecorded deterioration to a lower rating observed during an inspection. Increase in censored durations has the effect of improving the survival probability and reducing the slope of the survival function. Therefore, depending on the number of such instances, the adoption of one censoring protocol or the other affects the slope of the survival functions differently at each condition rating (Goyal, et al., 2020).

Preservation Levels for Network Performance Forecasting

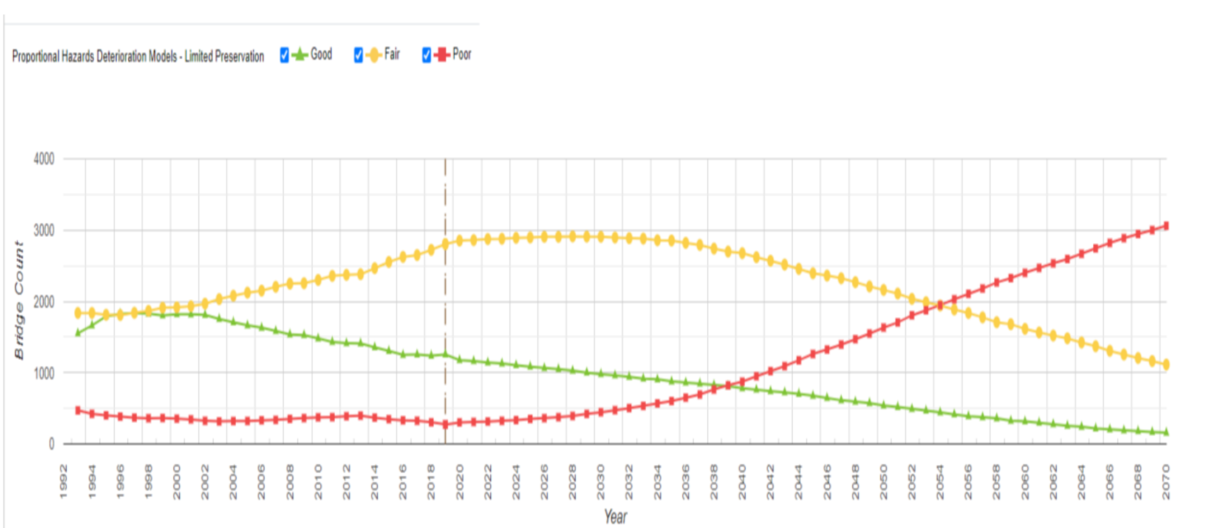
In the current study, three different censoring protocols were designed to consider the effect of maintenance actions on lifecycle deterioration predictions. The proportional hazards network performance forecast models at each preservation level correspond to one of the three censoring protocols as described in what follows:

1. Limited Preservation: The observed continuous durations followed by an improvement in condition rating are considered as uncensored for developing the survival functions of bridge components at individual condition ratings for this preservation level. This preservation level may be considered indicative of maintenance strategies aimed mainly at preventing further deterioration rather than improving the condition of bridge components. The individual bridge component condition forecasts for the proportional hazards deterioration model in InfoBridge correspond to this level.

2. Moderate Preservation: The observed continuous durations followed by an improvement in condition rating by one were considered as censored for developing the survival functions of bridge components at individual condition ratings for this preservation level. In addition to preventative strategies at the limited preservation level, the moderate preservation level may be considered to include maintenance actions targeted toward small improvements in condition rating.

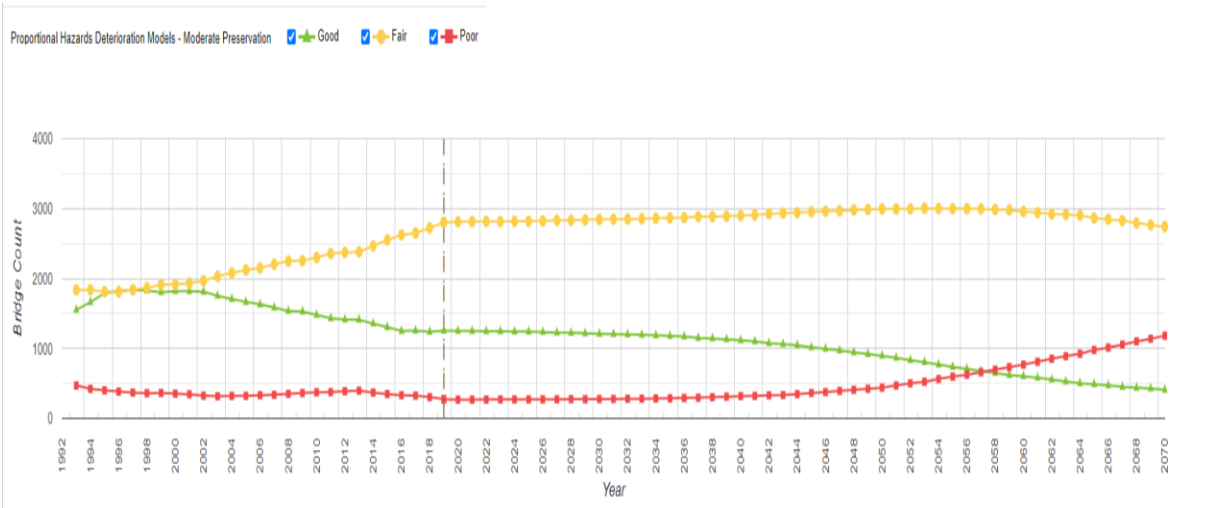
3. Maximum Preservation: All observed continuous durations followed by an improvement in condition rating were considered as censored for developing the survival functions of bridge components at individual condition ratings for this preservation level. In addition to all maintenance actions at the limited and moderate preservation levels, this preservation level may be considered to include major maintenance actions aimed at significant condition rating improvements.

Proportional hazards network performance forecasts for the three preservation levels for a selected group of bridges are shown in Figures 1, 2, and 3.



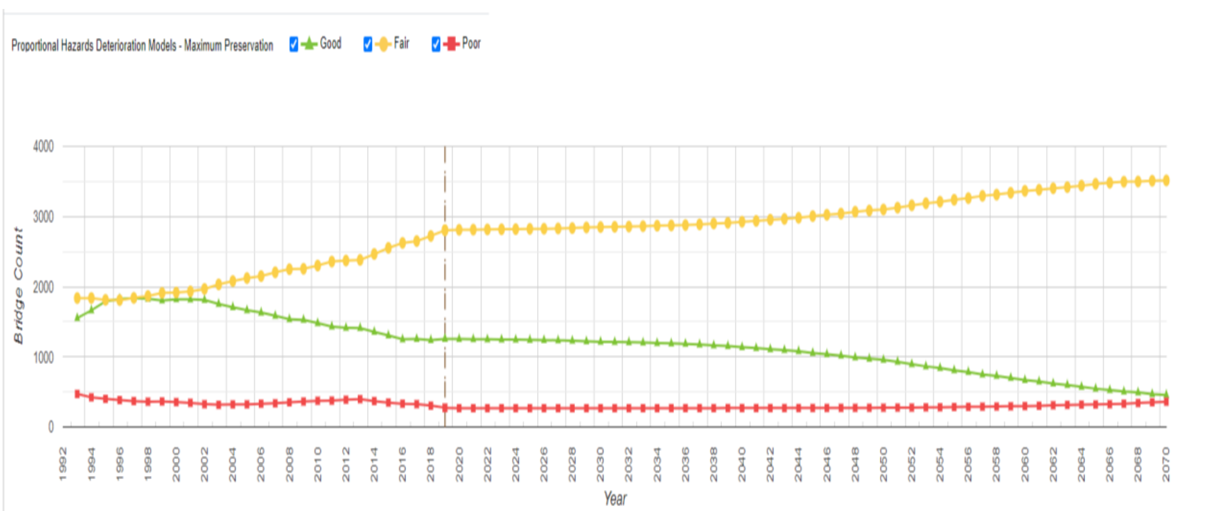
Source: FHWA

Figure 1. Proportional hazards network performance forecast models–Limited Preservation (FHWA, 2020).



Source: FHWA

Figure 2. Proportional hazards network performance forecast models–Moderate Preservation (FHWA, 2020).



Source: FHWA

Figure 3. Proportional hazards network performance forecast models–Maximum Preservation (FHWA, 2020).

On comparing the plots in the three figures, it can be observed that while the numbers of both good and fair bridges increase at the moderate preservation level relative to the limited preservation level, the additional preservation actions at the maximum preservation level seem targeted toward improving the condition of poor bridges only. This is plausible because, even with constrained budgets, most bridge owner agencies are committed to limiting their inventory of poor bridges to very small percentages of their total bridge inventory. The proportional hazards network performance forecasts for different selections of bridges and culverts across the NBI for different preservation levels based on the novel approach of varying survival analysis censoring protocols show similarly consistent and plausible trends. This is noteworthy considering that, for each preservation level, the proportional hazards network performance models draw from 29 distinct component models belonging to 11 different bridge and culvert types. The exact nature of correspondence between the network performance forecasts at various preservation levels with maintenance actions on the ground can be further evaluated in the future when preservation data linked to bridge inspection records become available.

References

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