Engineering Structures 128 (2016) 362–373

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Incorporating local environmental factors into railway bridge asset management

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ARTICLE INFO

Article history:
Received 9 March 2016
Revised 15 September 2016
Accepted 19 September 2016

Keywords:
Rail
Bridges
Asset management
Maintainability
Environmental factors
Petri-Net

ABSTRACT

A novel approach to comparing bridge deterioration rates under different environmental conditions is employed using a network analysis approach. This approach uses a matrix condition scoring system utilised by Network Rail (NR). It does not require any conversion factors which can introduce subjectivity. A number of different factors were analysed to ascertain if they have an effect on bridge deterioration. The key factors were identified and their deterioration profiles incorporated into a probabilistic Petri-Net (PN) model, calibrated with historical data. From these, comparative model outputs pinpointing which factors affect bridge deterioration the most can be computed. Finally, simulations were carried out on the PN model to evaluate which of the factors would have the most financial effect for a transport agency. This allows a bridge manager to categorise bridges in different deterioration sets allowing the definition of different optimal inspection and maintenance strategies for each set.

1. Introduction

The railway is intrinsic to the UK transport sector, however much of the infrastructure is aged and requires regular maintenance. This maintenance, in turn, means that railway managers incur huge costs to maintain their portfolios of infrastructure. Railway structures are critical to the smooth operation of the system. Over time more and more demand has been placed on these structures; with the advancement of more sophisticated signalling systems, trains can run closer together and so the demand increases ever more. This means an effective understanding of the assets is critical to be able to manage them successfully. There has been many studies involving bridge deterioration modelling using a number of different techniques [16,8,3,23]. Many of these authors argue that there are a number of external factors that also affect bridge deterioration, but there are few studies which try to ascertain what the factors are, how they affect the deterioration profile and how much their influence would cost to a railway structure portfolio manager.

Network Rail (NR) data has been used to conduct this research. NR is the largest railway infrastructure manager in the UK. However, the results presented in this study have a wide interest to any organisation responsible for these type of structures.

2. Literature review

Many studies involving bridge deterioration models hint towards the fact that there may be a multitude of different external factors affecting bridge deterioration. The problem with identifying these factors is that a significant pool of data is required to be able to conclude that there is a difference in deterioration profiles. The factors commonly considered include: asset age, traffic volume, span length, number of tracks, structure type, coastal proximity and temperature variation [17,25,26].

Jiang and Sinha [13] and Jiang [12] conducted a study in which 5700 highway bridges in Indiana, USA, were analysed. They created a Markov based model and analysed a number of different categories to understand the effect of different bridge attributes. For instance, the bridges were split into which highway system they were part of: "interstate highways bridges" or "other state highway bridges"; by traffic volume, interstate highways bridges was split between those which experienced less than 10,000 Average Daily Traffic (ADT) and more than 10,000 ADT; other state highways the data was split by those which experience less than 5000 ADT, 5000–10,000 ADT and those which experience more than 10,000 ADT; the climatic regions were analysed, split up into the bridges which were Northern or Southern. For each of the factors a sample set of 50 bridges was selected and used to see if the particular bridge category experienced different deterioration to the rest of the population. The results indicated that for most of

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http://dx.doi.org/10.1016/j.engstruct.2016.09.038
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the bridge subgroups, the factors being analysed were not significant enough to deviate from the standard deterioration experienced by the rest of the population. However, the results did find a statistical difference between the deterioration of interstate highways bridges and other state highway bridges. The authors concluded the analysis of the factors by stating that they will provide different performance curves for interstate highways bridges and other state highway bridges.

Scherer and Glagola [28] studied the highway bridges in Virginia, USA. The authors explain that there are 13,000 bridges in the district and they attempt to model the deterioration process using a Markov approach. Seven condition states were selected and the authors explain that due to the Markov state-space explosion characteristic, the number of states would have been $7^{13,000}$ which was infeasibly large to be calculated by contemporary computing power. So a process of grouping was performed where similar bridges were pooled together to reduce the number of states in the final model. In total 216 cases were created which reduced the number of states to 7^{216}. The groups were decided upon a number of factors including the structure type, road network, environmental condition, age of the structure and the traffic loading. The bridges were split up into which road network they were part of: interstate, urban extension and secondary. In terms of climate the data was split into: East coast, Piedmont plateau and the Western mountains. Finally, the traffic loading was split into a number of different ADT values depending on the size of the road network, ranging from 500 ADT for bridges on secondary road networks to greater than 5000 for bridges on interstate road networks. The authors then explain the assumption that the bridges are grouped into the appropriate categories and that similar bridges in analogous conditions will have comparable performance and deterioration characteristics.

Agrawal et al. [1] also uses the 7 condition states used by Scherer and Glagola [28]. The authors describe an approach to provide the probabilistic lifetime distributions using the Weibull distribution of 17,000 highway bridges across New York State, USA. They use case study elements to study the effects of external factors on the lifetime of the element. The examples used in the study related to the type of materials used in construction. An analysis was performed to see whether girders manufactured from steel deteriorate faster or slower than those made from weathering steel. The result of the analysis showed that elements made from weathering steel deteriorate at the same rate as standard steel elements for the first 20 years of the elements life. Beyond that point weathering steel seems to degrade slower than standard steel elements. The authors continue to analyse the difference in deterioration rates between structures with epoxy coated reinforcement bars and uncoated reinforcement bars. Analysis of the factors that affect deterioration are key to this study, however the focus remains on construction materials rather than external environmental factors.

Huang et al. [10] provides a useful summary regarding all the studies in literature carried out on this topic. They state that there are a plethora of weathering factors that affect bridge deterioration. The study used inspections from 2128 bridges in Taiwan, including traffic and weather data. The study looks at the most common types of defects for reinforced concrete and then tries to ascertain what the major and minor causes of that defect are. For instance, the author concludes that the traffic volume is a major factor in the corrosion of the reinforcement bars. However, distance from the coast is a factor for both spalling and fragmentation. The author then groups the factors by the defect they are likely to cause; cracking seems to be the most sensitive defect as 8 of the 10 factors affect it, however honeycombing is only affected by two factors: the peak monthly rainfall and the maximum days of rain in the month. The author has calculated that distance from the coast is one of the factors that affects bridge deterioration, but it was not one of the major factors. However, the author also states that their sample of bridges did not contain any that could be considered coastal.

Zhao and Chen [33] performed a study regarding the causes of structural deterioration using a fuzzy logic system. A case study exercise was performed where the most critical bridge defects, cracking and spalling, were selected. The artificial intelligence system was used to find the causes of the defects. The parameters included: the structure type, bridge age and overall span length amongst others. The results suggested that cracking was highly dependant on the loading caused by traffic but the construction technique and structural design had little effect. However for spalling, the "other" factors (e.g. bridge age) had the most effect whereas loading was much less of a factor in deterioration.

In summary, a variety of literature has been evaluated. Each study used its own approach of identifying the external factors and assessing their effects. The over-riding conclusion that can be drawn is that there are a variety of external factors and they can greatly affect bridge deterioration.

3. Condition states, deterioration and maintenance policies

3.1. Condition states

Structures are inspected and its condition is recorded according on the Severity Extent Rating (SevEx). The rating system is alphanumeric containing both the classification and intensity of the defect and its extent. The SevEx conditions vary depending on the superstructure material. For concrete structures, the condition ratings go from A1, a new structure, to G6 a heavily deteriorated structure. For this study, deterioration is classified as moving to the immediate neighbouring conditions; this was decided because of the small time step chosen for the analyses. More details about this can be found in Yianni et al. [32].

According to available inspection data, the most important damage for concrete structures is either spalling or cracking. Nielsen et al. [24] found the percentage of concrete structures suffering from either spalling or cracking can reach 89.9%. The full list of SevEx condition ratings can be found in Table 1.

3.2. Maintenance actions

A system of conversion is used to calculate which maintenance action is most appropriate for the defect being identified [20].

Table 1
SevEx defects for concrete structures [21].

Severity	Defect definition
A	No visible defects
B	Surface damage, minor spalling, wetness, staining, cracking <1 mm wide
C	Spalling without evidence of corrosion, cracking ⩾1 mm wide without evidence of corrosion
D	Spalling with evidence of corrosion, cracking ⩾1 mm wide with evidence of corrosion
E	Secondary reinforcement exposed
F	Primary reinforcement exposed
G	Structural damage to element including permanent distortion
Extent	**Definition**
1	No visible defects
2	Localised defect due to local circumstances
3	Affects <5% of the surface of the element
4	Affects 5–10% of the surface of the element
5	Affects 10–50% of the surface of the element
6	Affects >50% of the surface of the element