An overview of strategic bridge life cycle modelling on the British Railway

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ABSTRACT: Bridges are critical assets for the safe, reliable, and functional operation of transportation networks. Infrastructure asset managers are responsible for ensuring that these bridges adhere to rigorous safety standards using the finite resources available to transportation agencies. Predicting future condition, forecasting required interventions, and developing equitable resource allocations from limited budgets is a challenging task for bridge managers. Network Rail is the infrastructure manager for the railway in Great Britain and is responsible for the management of over 26,000 bridges. Network Rail currently use a strategic 'Tier 1' model to forecast work volumes, condition outputs and expenditures for its portfolio of bridge assets. In this paper an overview of the existing strategic model will be provided alongside an account of recent work to transition the model onto a commercial asset investment planning solution, as well as a commentary of model limitations and future model requirements.

1 INTRODUCTION

Operational railways are complex systems that are reliant on the dependable performance of a large quantity of different assets across several asset disciplines including track, signalling, telecoms and civil infrastructure, amongst others. For the civil infrastructure, bridge management and maintenance command a sizeable demand on resources to ensure the continued provision of safe service. The failure of bridges can have devastating human consequences as well as causing social and economic harm (Xie & Levinson, 2011).

The structural assessment and reliability analysis of bridges is well documented in the literature (Frangopol, Dong, & Sabatino, 2017). As part of the asset management strategy for bridges, decision support tools known as Bridge Management Systems (BMS) have been developed to support infrastructure managers in their decision making (Mirzaei, Adey, Klatter, & Thompson, 2014).

The purpose of this paper is to outline the current bridge lifecycle modelling capabilities at Network Rail (NR). Section 2 provides contextual information about NR as an infrastructure asset manager, its bridge inventory and management strategies. Section 3 outlines the current modelling methodologies employed and the platform used. A discussion of the limitations and potential improvements within NR's bridge modelling capability is presented in Section 4.

2 BACKGROUND INFORMATION

2.1 *Network Rail*

NR owns and operates the railway infrastructure in England, Wales and Scotland on behalf of the nation. That's over 30,000 km of track, over 26,000 bridges, 16,000 km of earthworks and thousands of signals, level crossings and points. It is also responsible for maintenance at 2,500 train stations, fully managing 18 of the largest. The network provides a vital service for passengers and freight users. It was crucial during the pandemic, and it is also crucial for economic recovery post-pandemic. The government considers it to be of great strategic importance, both in terms of economic stimulation, particularly in the north of the UK, but also within the low carbon agenda and its ability to reduce road transport. Hence, the necessity for the railway service to be safe, reliable, and good value for money.

NR is financed by the UK government and paying customers (passengers and freight both through operators). Every five years, it must apply for funds to maintain the asset portfolio. As part of that submission, NR must forecast the likely impact on asset condition for 35 years into the future.

The infrastructure is managed in a devolved structure with decisions on which assets to renew/maintain made at region and route level. There are five regions (bold) and fourteen routes (**Eastern**: Anglia, East Midlands, North East, and East Coast. **North West & Central**: North West, Central and West Coast. **Scotland**. **Southern**: Kent, NR High Speed, Sussex and Wessex. **Wales & Western:** Wales and Western), see Figure 1. As the regions make their own decision regarding asset spend, the modelling work only provides 'guidance' on where that spend might be best placed. It also forecasts the outcomes for the railway associated with spending decisions and enables independent assurance of the outcomes associated with regional plans, especially if they differ from the model guidance.

Figure 1. Network Rail's routes and regions.

2.2 *Bridges Portfolio*

The structures portfolio at NR is responsible for underline bridges (rail-over-road), overline bridges (road-over-rail), footbridges, tunnels, retaining walls, culverts, and coastal, estuarine and river defences. There are over 26,000 underline and overline bridges and they dominate the repair investment, so the modelling focuses on those assets. The UK has some of the oldest rail bridges in the world, the majority of the portfolio was built in the 19th century. There are a wide variety of materials employed, typically classified into concrete, masonry, metallic, and timber, with many bridges composed of mixed materials. However, there are large differences within each of those broad material types, for instance metallic ranges from cast iron to modern steel. Some bridges are in benign rural environments, others are close to the coast (high salinity) or within highly corrosive urban environments. Whilst underline bridges receive greater loading than overline bridges, there are great differences between train traffic on different lines. Also, it would be impossible to understand the loading history of a bridge over 100 years old. In summary, it is a huge challenge to model the future behaviour of these assets.

2.3 *Condition Measurements*

Bridges are subject to three types of examination. There are yearly visual examinations that are brief and are principally to check if there have been any significant changes from the previous year. Detailed examinations take more time, and a full report is produced summarising the condition of the bridge. These exams are risk-based and range from an interval of one year for bridges in very poor condition to every eighteen years for good bridges, on average, bridges are examined every seven years. Finally, capability examinations assess the strength of the bridge against its loading requirements, these are rarer and typically each bridge has only had one performed. They are undertaken to quantify the relevance in changes in condition, understand capability for the existing or future loading requirements.

During a detailed examination the worse two defects on each minor element receives a score based on the severity and extent, see Table 1. The scores are alphanumeric with severity (alpha component) defined by the seriousness of the defect and extent (numeric component) determined by how wide-spread the defect is on the element. In the example, a metallic 'B4' defect is less than 1mm of corrosion which occupies between 5% and 10% of the surface of the element. There are similar scoring systems for concrete, masonry, and timber.

Table 1. Detailed examination condition scoring for metallic elements on a severity-extent basis.

Score	**Severity and Extent Definition**
A	No visible defects to metal.
B	Corrosion/loss of Section <1mm deep.
C	Corrosion/loss of section 1mm up to 5mm deep.
D	Corrosion/loss of section >5mm up to 10 mm deep.
E	Corrosion/loss of section >10mm but not through section.
F	Corrosion/loss of section to full thickness of section.
G	Choose most extensive from: Tearing/Fracture/Cracked welds/Buckling/Permanent distortion/Displacement
1	No visible defects
2	Localised defect due to local circumstances (such as isolated damage caused by a single bridge strike or isolated water leakage).
3	Defect occupies < 5% of surface of element.
4	Defect occupies > 5% up to 10% of the surface of the element.
5	Defect occupies > 10% up to 50% of the element.
6	Defect occupies > 50% of the surface of the element.

For the bridges model, the scoring system is simplified onto a one-dimensional scale, see Table 2 for the metallic conversion. Perfect condition 'A1' is given a one-dimensional score of 100 and worst condition 'G6' is given the highest score of 0. The quasi-linear conversion between the alpha-numeric scale and the one-dimensional scale is derived from engineering judgement.

This conversion also loses information because it is irreversible, i.e., it is impossible to know the defect from the one-dimensional score alone, for example a 15 could be either ‘D6’, ‘E5’ or ‘G3’.

Table 2. Conversion from alpha-numeric to one-dimensional scoring for metallic minor elements.

	1	**2**	**3**	**4**	**5**	**6**
A	100					
B		90	80	75	70	65
C		80	65	60	50	40
D		70	60	50	35	15
E		60	50	30	15	10
F		50	30	10	5	0
G		50	15	10	5	0

Using the detailed examination’s minor element scores, a weighted average calculation can be performed to find the BCMI (Bridge Condition Marking Index) of an individual deck or an entire bridge. This is scored on the same 0-100 scale with 100 being perfect condition.

Finally, the definition of poor condition is important because that is typically the trigger to intervene with repair work, for masonry and concrete minor elements that is defined as BCMI=50, whereas for metallic and timber elements the poor threshold is BCMI=40.

2.4 *Interventions*

There are numerous ways that bridges are worked on, with vast differences in their scale, cost and impact. At NR, there is a Cost and Volume handbook, which defines how to categorise and report works. There is a large variance in the size of bridges, Work Volumes are reported in terms of the area (m^2) worked on. Broadly, bridge interventions are reported as:

- Replacement
- Strengthening
- Repair
- Preventative
- Waterproofing
- Minor Works

There is still a large degree of variance within those categories, and it is not uncommon for multiple work-types to be performed on the same deck. Replacement and Strengthening interventions are typically to combat insufficient capability. Replacement is typically installing a new bridge deck but not all of the original bridge will necessarily be replaced, the supports for example could remain. Strengthening activities insert additional support to the structures (e.g. metallic beams) or modify the existing elements. Repair work is usually fixing defects relating to the condition of the elements. Preventative work refers to improving the surface protection, for example, the paintwork for metallic elements. Waterproofing is activity related to protecting the bridge from water ingress and would not be expected to improve condition. Finally, Minor Works are not reported as Work Volumes and are typically cheap activities to a small area or single element on a bridge and are expected to only contribute minimally to condition improvement.

3 CURRENT MODEL METHODOLOGY

Forecasting the impact of projected spend on asset condition is a regulatory necessity. There are three broad questions that a forecasting model needs to address:

- How much work volume/spend is required to maintain a long-term steady state condition distribution for an asset portfolio?
- What is the long-term impact on condition for different scenarios of work volumes/funding?
- What is the impact at a regional and route level?

To attempt to answer those questions, mathematical models have been employed. For bridges, the methodology is ‘bottom-up’ and models every one of its 26,000 bridges individually using a probabilistic simulation with all events (asset degradation, intervention selection and effectiveness, prioritisation) are simulated stochastically.

3.1 *Tiers of Lifecycle Modelling*

This paper is largely concentrated on modelling large asset portfolios, or at ‘Tier 1’ level. NR has historically used modelling for different purposes. Previously, the focus of modelling activity was more on ‘Tier 2’ modelling which is at asset level. This modelling was applied to define asset maintenance policies by finding answers to the following questions for a typical asset, for example, a generic metallic bridge are: How often to inspect? What condition thresholds should be applied to trigger interventions? What type of interventions should be performed in different circumstances?

The development of a Bridges Tier 2 model was the main basis for the current Tier 1 model and is the reason it has a ‘bottom-up’ methodology. In the future, with greater knowledge of the lifecycle of bridges, then the asset maintenance policy will require updating, which will be achieved through the modelling.

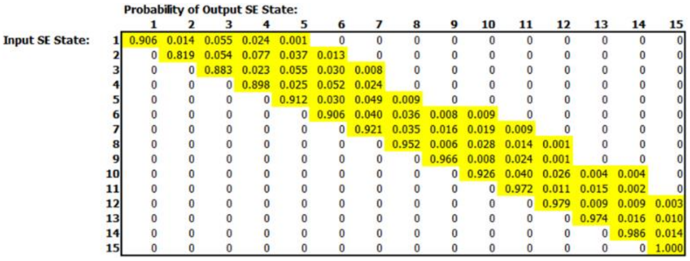
3.2 *Copperleaf Platform*

NR owns forecasting models for asset types associated with large spend. Historically these models were located separately, in programs such as Excel, Access, or bespoke solutions (Visual Basic or C#). This siloed set-up made it difficult to maintain the individual code of each model, both in terms of making changes to methodologies and handing over to new personnel. Hence, recently NR decided to transition the models onto a single platform. The services of Copperleaf Technologies were chosen, who provide a powerful cloud-based solution to asset investment planning. The Copperleaf platform is suitably flexible to enable complex asset modelling and thus far NR's Track, Signalling, Level Crossings, Earthworks and Bridges models have been successfully migrated. It has a browser-based user interface to facilitate wider stakeholders (such as regional personnel) performing model runs and NR modellers have complete control of the model parameters as well as the code itself.

3.3 *Asset Degradation*

In order to understand how bridge condition degrades with time in the future, it is crucial to look at the records of the past. NR has examination records starting in 2000, which is about 20 years of data, however that is still only a small fraction of most bridge's lifetime. On average, each bridge has received two or three detailed examinations on record.

The model degrades condition at minor element level because that is the level of the examinations. To model one minor element's future condition, rather than using just information from its past, it is more useful to amalgamate the records of all similar elements together to produce greater intelligence. The model uses condition states, defined by the one-dimensional scores described in Section 2.3. It operates in yearly timesteps and hence each minor element requires a probability of moving from each condition state to all possible output condition states, see Figure 2 for a degradation probability matrix for metallic girders on underline bridges. This is performed by sampling a random number from a distribution for each element and timestep, its next condition state is dependent on how that random number compares to the transition probabilities.



Probability of Output SE State:

Input SE State:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.906	0.014	0.055	0.024	0.001	0	0	0	0	0	0	0	0	0	0
2	0	0.819	0.054	0.077	0.037	0.013	0	0	0	0	0	0	0	0	0
3	0	0	0.883	0.023	0.055	0.030	0.008	0	0	0	0	0	0	0	0
4	0	0	0	0.898	0.025	0.052	0.024	0	0	0	0	0	0	0	0
5	0	0	0	0	0.912	0.030	0.049	0.009	0	0	0	0	0	0	0
6	0	0	0	0	0	0.906	0.040	0.036	0.008	0.009	0	0	0	0	0
7	0	0	0	0	0	0	0.921	0.035	0.016	0.019	0.009	0	0	0	0
8	0	0	0	0	0	0	0	0.952	0.006	0.028	0.014	0.001	0	0	0
9	0	0	0	0	0	0	0	0	0.966	0.008	0.024	0.001	0	0	0
10	0	0	0	0	0	0	0	0	0	0.926	0.040	0.026	0.004	0.004	0
11	0	0	0	0	0	0	0	0	0	0	0.972	0.011	0.015	0.002	0
12	0	0	0	0	0	0	0	0	0	0	0	0.979	0.009	0.009	0.003
13	0	0	0	0	0	0	0	0	0	0	0	0	0.974	0.016	0.010
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0.986	0.014
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.000

Figure 2. 1-year degradation probability matrix for a metallic main girder on underline bridges.

The calculation of these probability matrices used a frequency approach and required several assumptions. The frequency approach requires that the interval between examinations is fixed and at NR the interval between examinations is variable, thus a normalisation procedure was performed to calculate probabilities for a five-year interval.

Additional assumptions were required on which records to exclude. Records were excluded from analysis because an element's condition improved, i.e. suspected maintenance work performed. Alternatively, records could be excluded because of extreme deterioration, which potentially could be due to an external factor, such as vehicle incursion.

Environmental factors such as being close to the coast (high salinity) or in an area of high corrosivity can significantly affect the degradation of bridge elements (Yianni, Neves, Rama, Andrews, & Dean, 2016), particularly metallic elements. The model adjusts the probabilities in the degradation matrix to either accelerate or decelerate the expected degradation profile.

Correlated degradation of bridge elements is little understood and requires significant research, to be discussed later in Section 4.2. However, the model does implement a crude form of correlated degradation if two minor elements of the same type and material are in similar condition then there is a probability that they degrade in a correlated manner.

Finally, capability information is held at deck level and is a large driver of work. The current model has a crude methodology to degrade capability with time dependent on the condition of the deck's minor elements. An improvement to this relationship is planned, see Section 4.2 for details.

3.4 *Intervention Selection*

First, the model performs its own examinations because detailed examinations are infrequent. There are two condition values stored: 'Actual' and 'Last known', the former updates every year, while the latter only updates after a modelled examination. Then intervention decisions can only be made using the 'Last known' condition information. This is to ensure the model does not have perfect information and replicates reality as much as possible.

The Bridges model suggests candidate interventions using a set of logical decisions, see Figure 3. The first decision is whether the deck requires a capability intervention, this is determined by the latest capability examination and potential degradation. If so, either a Replacement or a Strengthening activity will be suggested (the candidate intervention will only be performed if it meets the constraints and prioritisation criteria, see Section 3.6, and that is the case for all interventions). If no capability intervention is required, then the model looks at the condition of the minor elements. If any minor element has a condition worse than the threshold defined by asset policy, then the model must determine if it is worth suggesting a major work to a group of minor elements on a deck. If it is not worth doing the Multiple Element Works

(MEW), then it suggests the Single Element Intervention. If it is worth doing the MEW, then Secondary Works to a set of minor elements of a different material type on the same deck is a possibility or even Tertiary Work to an adjacent support is an option too.

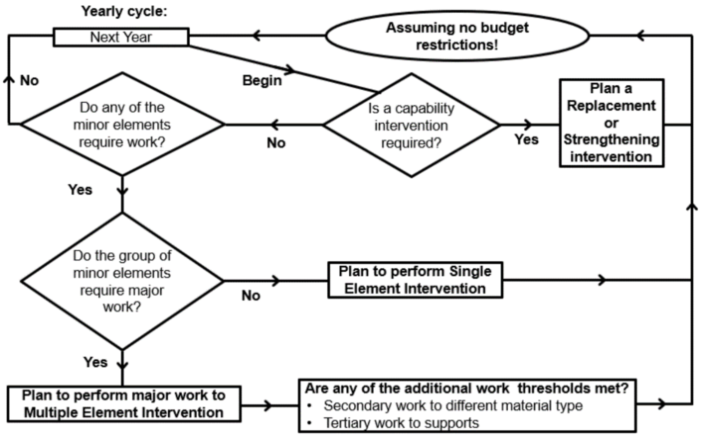


Figure 3. Schematic to explain the intervention selection logic within the Bridges forecasting model.

Even after the model has decided which intervention to perform, it must wait a reasonable time to account for planning the works, typically 3 or 4 years. There are also constraints to delay works (Section 3.6), so it is possible for works to be waiting a long time from entering poor condition to actually being performed. In fact, if the condition or capability of the bridge changes dramatically in the meantime then a different type of works could be selected.

3.5 *Intervention Effectiveness*

Bridges interventions vary significantly, even within the broad categories of Replacement, Strengthening, Repair, Preventative, Waterproofing, and Minor Works. Hence, the resultant condition post-interventions varies too. The works might only be able to fix certain types of defects or cover a small area of the deck and miss other less severe defects. Therefore, it is crucial the model has the functionality to vary the effectiveness, i.e. amount of benefit to asset condition, of interventions. Replacement works are expected to deliver a new bridge and hence perfect condition. Strengthening works and Repair interventions provide some condition benefit but are difficult to quantify. Minor works might only benefit one element and so have minimal effect on the whole deck. Preventative and Waterproofing are expected to have minimal direct condition benefit, but they could slow future degradation.

These post-intervention condition distributions can be defined by intervention type and the material targeted. However, defining intervention effectiveness is challenging, a mixture of data analysis and engineering judgement is required, see Section 4.3 for a full breakdown of the problem.

3.6 *Constraints and Prioritisation*

A critical function of the Bridges model is its ability to constrain and prioritise the suggested candidate interventions, this is how different funding scenarios can be assessed. The model has the functionality to constrain on cost, work volume, and effective work volume with each model year potentially having a different constraint. These constraints are typically applied to portfolios at either national, regional, or route level.

To fit within constraints, the model must prioritise its assets to decide which receives work first. The model prioritises at deck level with a flexible formulation that includes asset condition, capability, and criticality (some bridges are on busier lines and are therefore more critical than others). However, if the model was to apply this prioritisation rigorously, then only the very worst decks would receive work and huge benefits to asset condition would be witnessed. This is unrealistic, see Section 4.3 for full details. Hence the model has the ability to apply random ‘noise’ to the priority score, essentially to make it less efficient, but calibrating that functionality is challenging.

3.7 *Results of Different Funding Scenarios*

The crucial outputs of the Bridges model are estimations of long-term condition for different funding scenarios. The wider stakeholders within NR and outside regulators are typically interested in two condition measures BCMI (Figure 4) and average fraction PLBEs (Principal Load Bearing Elements) in poor condition (Figure 5). Averaging BCMI (see Section 2.3) represents the health of the whole portfolio. The fraction of PLBEs in poor condition describes the size of the condition distribution’s tail and can be thought of as a proxy for risk. We look at these as indicators for the condition of the portfolio to understand implications for the long-term sustainability of an investment approach.

Figures 4 and 5 display two scenarios: ‘Baseline’ which is designed to hold the condition of portfolio as steady as possible and ‘Constrained’ which is an arbitrary lower cost scenario and consequentially shows condition declining. It is a regulatory requirement to forecast for 35 years (7 five-year Control Periods), which for bridges is a useful time horizon because their condition changes so slowly with time. Notice for the first modelled Control Period (2019-2023), the outputs are the same for both scenarios, that is because this funding is locked in. Only from 2024 onwards do the scenarios diverge.

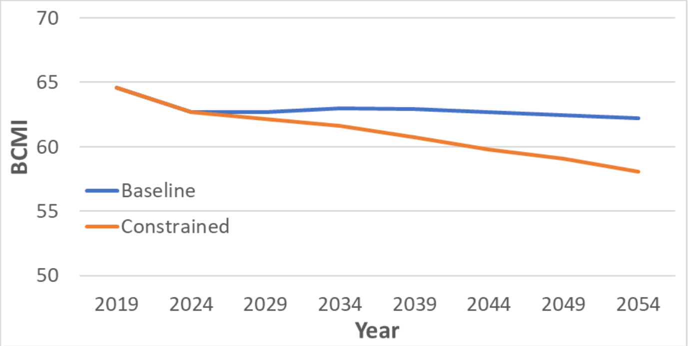


Figure 4. Model outputs: BCMI averaged by deck for the underline bridge portfolio for two funding scenarios.

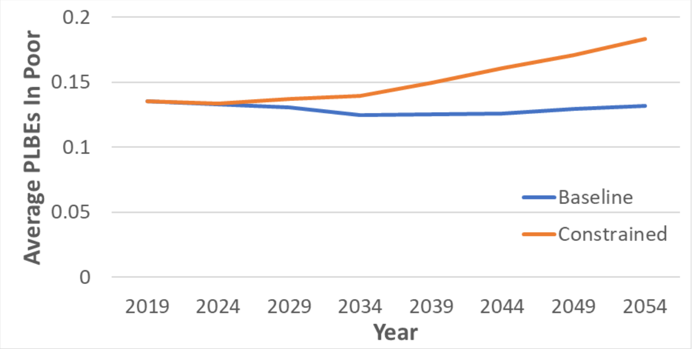


Figure 5. Model outputs: fraction of PLBEs in poor condition averaged by deck for the underline bridge portfolio for two funding scenarios.

The bridges model outputs at regional and route level, by providing 'guidance' on expenditure and work volume splits. Note, as stated in Section 2.1, the regions and routes make their own decisions, and many other factors are included when finalising the final funding submission package. However, the model can estimate the impact on bridge condition of any defined funding scenario.

4 MODEL WEAKNESSES AND FUTURE IMPROVEMENTS

There is no such entity as a perfect model, however it is worth endeavouring to make it as close to the real world as much as reasonably practicable. By using as much science, data analysis and solid engineering assumptions, it enables key stakeholders of the model to have confidence in its outputs and take its guidance with more weight. In the following sections, the weaknesses of and potential future improvements to NR's bridges model are discussed.

4.1 *BCMI Measurement System*

NR's condition measure system for bridges has many limitations. First, there is typically a long time in between examinations (seven years on average), it is risk-based so poorer condition bridges are examined more often, however information is potentially hidden for long periods. BCMI examinations are performed by a large number of personnel with potentially different skill sets, especially as different regions and routes have chosen different inspection contractors. Although there are consistent competence requirements for examiners nationally. This has the potential to introduce a lot of human error and bias even with the same Standard. Additionally, it is probable once a defect has been revealed by one examination then it will likely be seen by subsequent ones.
The current BCMI examination records the worst two defects on each minor element, hence the third worst defect is completely ignored. There is no defect tracking from one examination to the next, i.e. the worst defect from two consecutive examinations may not have the same physical defect. The biggest issue though, is the location of the defect on the element is not recorded, hence there is incomplete engineering context. For example, section loss is far more serious and likely to affect safety if it is the middle of a main girder as opposed to close to the end support.
NR is well aware of the above issues and is due to modify its examination recording capability to include multiple defects and defect locations to enable tracking. However, it will take many years to be useful for the modelling work, although emerging trends will be scrutinised.

4.2 *Asset Degradation*

As alluded to earlier in sections (2.3 and 3.3), there are limitations with NR's current methodology that determines bridge element degradation. The model's mapping from alpha-numeric Severity-Extent scores to one-dimensional loses defect information. Also, is the examination history biased towards bridges that are examined more often? If so, how to fairly adjust the degradation behaviour to reflect that? Finally, given the age of the portfolio, is the last 20 years of examination records representative in order to predict future degradation behaviour?
Outside of the general mathematical approach, exploration is still required into what bridge characteristics are significantly important in relation to degradation behaviour. Environmental effects have been studied and are included in the model; however, they could do with further refinement. The amount of fatigue (weight and frequency of loading events due to train passes) a bridge suffers is likely to affect degradation. The model currently simplifies the material to either concrete, masonry, metallic, or timber, clearly the degradation behaviour of cast iron and modern steel would be expected to be different. Finally, correlated degradation is included crudely in the model, and it makes sense that neighbouring minor elements suffering the same loading forces and environment would likely degrade in a similar manner. However, further work is required to fully quantify this hypothesis with NR's bridge asset portfolio, it is a deep

scientific problem and only basic relationships have been developed thus far.

Section 3.3 outlined the current degradation methodology and stated that it is limited by a frequentist approach that required assumptions in normalising examination record pairs into five-year intervals. However, in the future, a maximum likelihood approach will be utilised in the calculation of degradation matrices (Calvert, Neves, Andrews, & Hamer, 2020). This methodology can account for the variability in the size of interval between examinations.

Additionally, there are ongoing efforts to model bridge condition as a function of multiple degradation mechanisms (Calvert, Neves, Andrews, & Hamer, 2021). This modelling approach holds onto the defect information within the alpha-numeric condition score, which enables the incorporation of defect dependency behaviour. For example, in a metallic element, corrosion is more likely to occur if there is a loss of paintwork, see Figure 6. Further work is required to apply this methodology to NR’s complete set of minor elements and implement the modification within the Copperleaf platform. Once fully embedded though, it will enhance the model’s ability to accurately predict asset degradation.

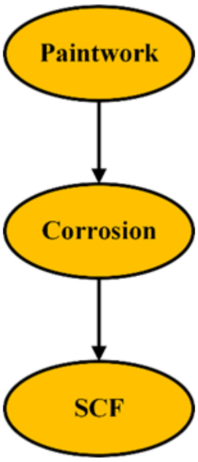


Figure 6. Defect dependency relationships within future modelling framework for metallic bridge elements. SCF is Structural Component Failure (Calvert, Neves, Andrews, & Hamer, 2021).

Regarding the modelling of bridge capability deterioration, the difficulty is there are very few bridges with more than one capability examination. Hence, NR commissioned a study, which has been completed by Mott MacDonald on how the condition of minor elements are likely to affect a deck’s capability. This study largely focused on metallic underline bridges because this is greatest area of concern. It used a parametric analysis, varying many of the element (size, thickness and loading requirement) and defect (depth and location) characteristics and calculated its remaining strength with an approach based on physical forces. The result of the study was a set of probabilities describing the likelihood of an impact to a deck’s capability caused by a minor element with a particular condition. Further work is required to apply these findings within a suitable methodology and implement within the Copperleaf platform.

4.3 *Interventions: Over-efficient Selection and Effectiveness*

Section 3.6 introduced the idea that if the bridges model simply decided to work on the worse condition decks, then that would be wholly unrealistic and over-efficient. In reality, regions and routes make decisions about which bridges to work on based on greater local knowledge than the summarised condition assessments. They know which bridges are particularly vulnerable from their history or location, maybe they are close to water, or the ground has poor drainage. The examination scores may simply not reflect the urgency of need. They may also decide to work on bridges because it is convenient, the work might fit neatly into a scheme or blockage, a local council might be doing works to adjacent utilities or even be willing to contribute to the costs. However, calibrating this ‘inefficiency’ factor is difficult.

The effectiveness of interventions (Section 3.5) is also difficult to calibrate and will require an advanced data analysis exercise. The challenge is the records of interventions performed are held by individuals within the routes and regions not on some central system. Therefore, it is problematic to go back too far into the past, within easy reach is 2014 onwards for some routes. Typically, examinations are not performed soon after intervention work, so there is the unknown effect of degradation both between the pre-intervention examination and the works, and up to the post-works intervention. Only one route (Western), perform an examination as standard procedure soon after interventions. Even if the bridge is known to have had works performed, then it will not be known even which decks are worked on, let alone which minor elements. Only by studying changes in the examined condition of minor elements can the scope of intervention works be inferred. The uncertainties within the available data will require engineering judgement to be applied in conjunction with the results of data analysis.

5 CONCLUSIONS

This paper has presented an overview of the Bridges modelling capability at NR. In summary, a ‘bottom-up’ probabilistic model is employed. Asset condition is degraded at minor element level and capability is degraded at deck level. There is a logical framework on how candidate interventions are suggested. Interventions are prioritised and only the ones that fit into the scenario’s pre-defined constraints will actually be performed. The key outputs are how the portfolio’s condition is impacted, particularly in the long-term, by different funding scenarios. The forecasting model enables an evidence-based discussion on how much expenditure NR should be investing in its bridge portfolio and the potential impact of a shortfall in budget.

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