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Development of an Evidence-based Geotechnical Asset Management Policy for Network Rail, Great Britain

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Abstract

Network Rail (NR) is the owner, operator and asset manager of the majority of the rail network of Great Britain, an infrastructure network totalling approximately 32,000 kilometers of track. The challenge faced by Network Rail's earthworks asset managers is the aging infrastructure. Failures within the portfolio of nearly 200,000 earthwork assets that NR manage are relatively common, particularly in periods of adverse or extreme weather.

As a regulated industry, NR are constantly challenged to demonstrate continuous improvement to their management processes through each of their five year Control Periods (CPs). For the current CP5 (2014-2019), NR undertook a series of activities to develop an evidence-based asset management policy, the key steps of which are summarised in this paper, including:

- The development of a risk-based prioritisation matrix for all earthwork assets and determination of quantitative likelihood of earthwork failure
- The determination of quantitative consequences of earthwork failure
- The development of a series of earthwork intervention types, and the determination of the impact of these on the likelihood of earthwork failure
- The development and use of a strategic Whole Life Cost Decision Support Tool (DST) to model and optimise the CP5 earthworks policy and determination of key inputs to the DST, such as the assessed rate of asset portfolio deterioration. DST outputs were used to inform work bank development and Key Performance Indicators (KPIs) to measure the progress of the asset management policy through CP5

The paper briefly describes these activities and their results, and outlines how the policy has been embedded into the NR business. It describes how the policy has been used to secure funding for CP5, and how the work banks prepared against this funding have undergone assurance to determine alignment to the policy. Finally, the paper touches on future developments.

Keywords: Network Rail, earthworks, asset management, risk, prioritisation, policy, whole life cost

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1 Introduction

Network Rail (NR) is the owner, operator and asset manager of the majority of the rail network of Great Britain, an infrastructure network totaling approximately 32,000 kilometers of track. This rail network is of vital economic importance, carrying 4.4 million passengers daily on 22,000 passenger trains, and carrying 11% of Britain's daily freight traffic. NR have responsibility for a considerable range of assets: track, signaling systems, structures, earthworks and drainage, all of which must be managed in an efficient manner to ensure safety and good network performance.

The earthworks that NR manage pose a particular challenge. The majority of the British rail network was constructed before 1900 (with a peak of construction in the 1840s), and the modern network still operates on a foundation of the earthworks constructed at that time. Early locomotives required shallow gradients, necessitating the construction of often very large cuttings and embankments. This construction occurred well before the development of modern geotechnical understanding and practice, and as a result NR have been left with a legacy of earthworks constructed at far steeper angles, and by considerably less robust construction methods than would occur today.

The age of the NR earthwork asset also pre-dates detailed record keeping of interventions undertaken on the earthworks to maintain their stability in a form that is readily accessible today. Hence, a considerable proportion of the earthworks that NR manage have been "patched up" over their history, the impacts of which may well be contributing to the stability of the slopes, but whose presence cannot necessarily be easily determined.

Failures of NR earthworks do occur (see **Figure 1**), with a marked increase notable during prolonged and/or intense periods of rainfall. Occasionally, these failures can be very significant resulting in considerable damage to the railway, and on rare occasions, derailment of a train. Due to the safety and performance risk that such failures pose, NR are extremely proactive in ensuring that their management of this aging asset is as effective, cost-effective and leading edge as possible.

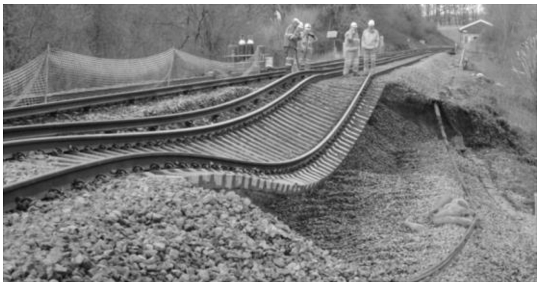

Figure 1 Failure of a Network Rail embankment

2 Network Rail Earthworks Asset Management

Formal management of the NR earthwork asset began in the 1990s, and standardised collection of earthwork inventory and condition information has been undertaken since 2005 with the data held in an online database and an associated field data-collection tool. An earthwork is defined as a cutting, embankment or natural slope segment up to 100m long lying within the NR boundary that is equal to, or greater than, 3 metres high, or if less than 3m high, whose failure could pose an unacceptable risk to the safe operation or performance of the railway infrastructure. The earthworks that NR manage are categorised into the asset types of embankments, soil cuttings or rock cuttings (see **Table 1**).

NR are externally regulated by the Office of Rail and Road (ORR), an independent non-ministerial government department, who oversee safety, reliability and economic performance and are responsible for assessing the funding submissions that NR make to government for each of the five year Control Periods. As part of this funding mechanism, NR must demonstrate to the ORR that they have robust asset management frameworks in place (including asset specific policies) and that regulatory requirement for outcomes within each CP can be met. This paper describes the risk-based asset management framework that has been developed for the earthworks asset.

Asset type	Number of earthworks
Embankments	101,502
Soil cuttings	71,971
Rock cuttings	15,844
Total	**189,317**

Table 1 Number of earthwork assets that NR manage (data from October 2015)

3 Risk-based Prioritisation of Earthworks

Management of nearly 190,000 discrete earthworks (see **Table 1**) would not be possible without the use of a prioritisation methodology. NR have developed a risk-based methodology that allows each of their earthworks to be represented on a risk matrix (see **Figure 2**), with axes determined by:

- A series of Hazard Indices for each of the asset types, determined primarily (though not entirely) through earthwork visual examinations, undertaken at least once every 10 years. These Hazard Indices (described in the next section) allow each earthwork to be placed into an Earthwork Hazard Category (EHC) that can be statistically linked to the likelihood of failure of an earthwork within that category,
- A measure of the safety consequences of failure of an asset based on its location within the rail network, and the particular characteristics of that location. Each location, and hence each earthwork, can be placed into one of five Earthwork Asset Criticality Bands (EACB). The EACB can be related to a statistical measure of safety consequence that is used throughout NR, allowing comparison across asset types to be undertaken.

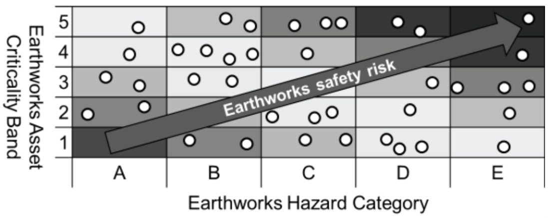

Figure 2 The Network Rail earthworks risk-based prioritisation matrix. Each dot represents a single earthwork.

The safety risk level that each earthwork presents is determined by the combination of its likelihood and consequence of failure, and is therefore represented by the position of the earthwork on the risk matrix. Intervention works can then be prioritised to those earthworks at higher risk levels in the top right of the matrix. By determining the position of all their earthworks on the risk matrix and prioritising their works accordingly, NR can demonstrate that the principles of risk management required by UK legislation and their operating license are being adhered to.

3.1 Determination of Likelihood of Earthwork Failure

NR has had a condition based Hazard Index for earthworks in place since the early 2000s. Whilst performing well as a works prioritisation tool, a review in 2013, and a drive for continuous improvement, determined that an unacceptable number of earthworks were failing that were indicated to be in the best two condition categories. A decision was taken to attempt to improve the ability of the Hazard Index to predict earthworks failure insofar as possible with an asset group that is inherently unpredictable, and where failure is so dominated by climatic and other external factors.

Soil cuttings and embankments were addressed as a priority. The condition of NR earthworks are primarily assessed through visual, site-based examination of a number of parameters (such as tension cracks, presence of retaining walls, presence and performance of drainage), supplemented by desk study for further parameters (such as geological composition). An algorithm is used to combine scores given to each parameter into an overall Hazard Index for the earthwork. The improvement work carried out determined new optimised algorithms based on analysis of over ten years of legacy field examination data and failure records.

Analysis of the available data for both the whole population of earthworks, and just those examination records made prior to a recorded failure, was carried out for each parameter (approximately 200 for each of the soil cuttings and embankments), as shown in **Figure 3**.

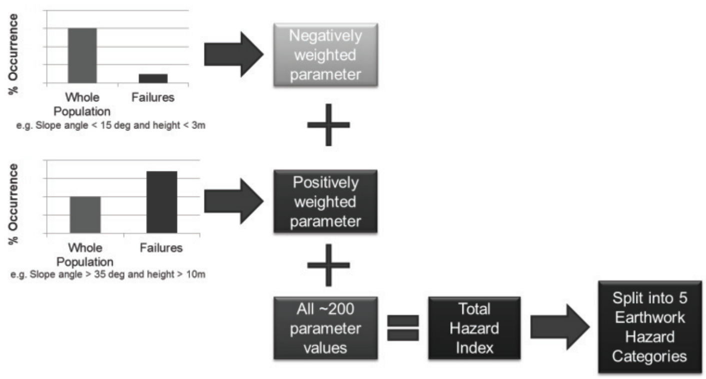

Figure 3 Analysis process to improve Hazard Index algorithm

Parameters more prevalent in the pre-failure examination of failed earthworks than the whole population of earthworks were given a positive weighting in the new algorithm. Those more prevalent in the whole population were negatively weighted. The parameter weightings were then summed and the resultant Soil Embankment Hazard Index (SEHI) and Soil Cutting Hazard Index (SCHI) scores segmented into the five EHCs, ranging from A (lowest Hazard Indices, lowest likelihood of failure) to E (highest Hazard Indices, highest likelihood of failure). Because the number of assets in each EHC is known, and the number of failed earthworks in each category is also known, a comparison of the statistical likelihood of failure of an asset in each category can be carried out (see **Figure 4**).

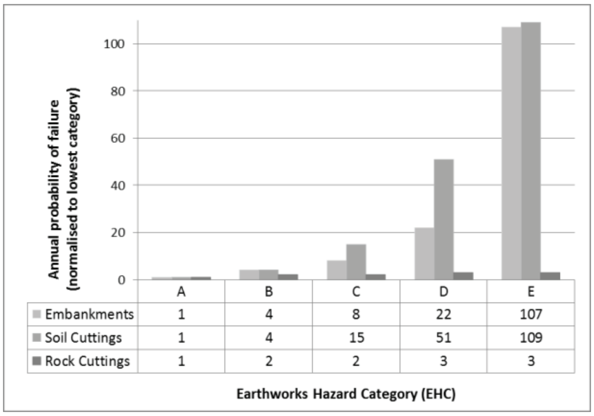

Figure 4 Annual probability of failure (normalised to the lowest EHC category) for each EHC and each earthwork asset type

In **Figure 4**, the annual probability of failure in each EHC has been normalised to the value in EHC A. With the previous Hazard Indices, an embankment or soil cutting in the worst condition category was 10 to 20 times more likely to fail than one in the best condition category. It can be seen in **Figure 4** that this multiplier has been improved by the new algorithms to over 100, an order of magnitude improvement in the ability to predict earthworks failure. The rock cuttings Hazard Index has yet to be analysed, with the old algorithm being a particularly poor predictor of failure.

3.2 Determination of the Consequences of Earthwork Failure

It is a fundamentally important feature of the risk-based prioritisation approach that asset management decisions are made on the basis of the consequence of a potential failure as well as its likelihood. In practice, this means that an earthwork in moderate condition could be prioritised for intervention above one in worse condition, if its failure could lead to a catastrophic safety incident, whereas the failure of the latter, for example being on a section of single track with lower speed trains, would pose an overall lower safety risk.

Network Rail have used a quantitative earthwork criticality as a measure of failure consequence for a number of years. However, as part of the enhancement of the risk management approach, a new criticality measure has been developed known as the Earthworks Asset Criticality Band (EACB). The EACB for an individual earthwork is a combination of two components:

- The probability of an earthwork, having failed, causing a train derailment. This is based on a number of factors including the likely size and hardness of the failed material, but also factors such as the distance of the slope from the rails.
- The potential safety consequences of a train derailment at a given location derived through the Common Consequence Tool (CCT). It takes into account factors such as the maximum speed of trains on the line, whether a derailing train is likely to hit an oncoming train or a hard structure at the side of the track.

The CCT component is interesting, being ‘agnostic’ of the original cause of the derailment, but highly dependent on the location and the physical features present, factors which are in fact ‘common’ to a train derailment resulting from the failure of any asset type. CCT is therefore being applied as part of the risk assessment to other NR asset types, not just earthworks. CCT uses the probability event tree approach illustrated in **Figure 5** to estimate the severity of a potential train derailment, expressed as the predicted number of deaths and injuries through a widely used safety metric, the Fatalities and Weighted Injuries (FWI).

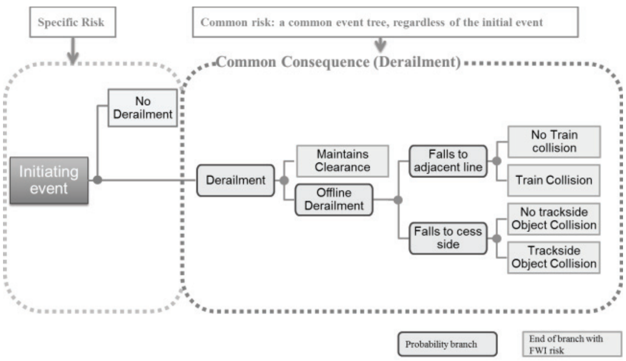

Figure 5 The Network Rail EACB definition including the Common Consequence Tool (CCT)

4 Strategic Decision Support Tool (SCAnNeR)

With the understanding of the safety risk profile of the earthwork asset portfolio that Network Rail now has through the risk matrix, prioritisation of intervention works to maintain, refurbish or renew their earthworks can be undertaken in a systematic way. The budget for interventions is, however, constrained and in order to determine the most efficient and cost-effective means of utilising the available funding, NR have developed a strategic whole life cost Decision Support Tool (DST) known as earthworks SCAnNeR (Strategic Cost Analysis for Network Rail). SCAnNeR is an optioneering DST, that allows a large number of mixes of interventions to be applied to the asset portfolio, and to assess how these interventions impact on the condition of the portfolio, when balanced against modelled earthwork degradation. This modelling is carried out over a series of 20 five-year Control Periods, to allow whole life costs to be determined. The process flow of SCAnNeR is shown in **Figure 6**.

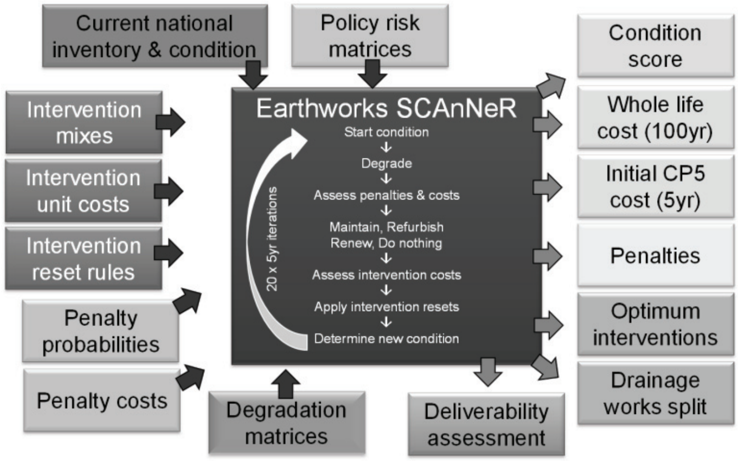

Figure 6 Schematic representation of the Network Rail earthworks SCAnNeR model

4.1 SCAnNeR Inputs

The inputs that the SCAnNeR model requires are as follows:

- The current national inventory of earthworks, in terms of their condition (EHC) and criticality (EACB) as set out on the policy risk matrix
- A pre-defined range of mixes of different interventions types, of which thousands of mixes can be modelled. The interventions are split into three types: maintenance (light, rapid activities such as clearing drainage), refurbishment (heavier maintenance, such as scaling of rock slopes) and renewal (major engineering activities, such as the installation of sheet piling or soil nails)
- An understanding of the unit costs of each intervention type, varying by earthwork type
- Rules for the impact that each of the intervention types has on earthwork condition (in terms of changing the earthwork's EHC)
- The probability and cost of penalties that can be expected for a given portfolio condition, in terms of expected earthwork failures and costs associated with delays to the network
- The rate of degradation of the asset portfolio, in the absence of interventions

Whilst all of the above inputs required significant work to determine robust, evidence-based values, assessment of degradation was particularly challenging. A Markov Chain analysis was carried out (see **Figure 7**), to determine the probability (within the modelled 5 year time steps of SCAnNeR) that an asset would either stay in the same condition band (EHC), or move to another EHC, or undergo failure. Precedent use of this technique can be found for bridges (Casare et al., 1992) and water pipes (Baik et al., 2006).

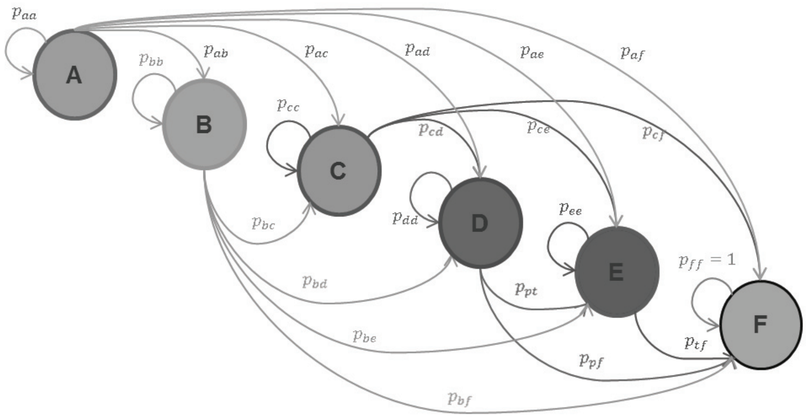

Figure 7 Markov Chain method for determination of earthwork degradation rates (A-E are the EHC values for an earthwork, F is failure)

4.2 SCAnNeR Outputs

For each 5 year modelling step, SCAnNeR determines a series of outputs:

- Changes in the overall condition and risk level of the total earthworks population as measured by Key Performance Indicators (KPIs) such as Condition Score
- Costs of the interventions undertaken, for each time step (allowing analysis of costs for a single Control Period, or of longer, whole life costs over periods of up to 100 years). Penalty costs are also calculated
- An optimum mix of interventions, that achieves the required aims of the modelled scenario (such as a requirement to sustain overall portfolio condition), for the lowest whole life cost. An assessment of the deliverability of the intervention mix is also used to constrain the modelled intervention mixes to a realistic solution.

5 Workbank Development

The SCAnNeR whole life cost model, produces an optimum mix of earthwork interventions (renew, refurbishment and maintenance) and their associated cost that will achieve the required aims of the national earthworks management policy. These intervention volumes and costs are then used to provide targets for the development of bottom up (engineering driven) workbanks.

Models such as SCAnNeR, work at a strategic level, generalising the complex behaviour of a large portfolio of assets, to allow funding decisions to be made. It is essential that engineering judgement and experience is used, at a tactical level, to produce the workbank of exactly which assets are to be subject to an intervention. To aid in this decision making, Network Rail have developed a tactical DST (called the Powerpack) to allow a 10 year workbank to be built at individual earthwork level, guided by the outputs of the SCAnNeR model. The Powerpack provides instant analysis of the degree of alignment of the developed workbank to the earthworks asset policy, and calculates estimated total intervention costs based on the same unit rates used by SCAnNeR. A further tool (the Powerpack ANalysis ToolSet), models the impact of the Powerpack workbank, offset by the assessed degradation of the earthworks assets, to produce an estimate of the condition of the asset portfolio at the end of the period of time being considered.

6 Earthworks Policy and Funding Submissions

Based on the combination of strategic SCAnNeR ('top down') modelling, and tactical, engineering led ('bottom up') workbanks developed in the Powerpack, NR have a powerful, evidence based set of information, that is used as the basis of their funding submissions to the ORR and onward to government. Detailed assurance activities have been carried out, to investigate the degree of alignment between the tactical plans and the strategic policy. Where variance exists (as is inevitable for complex assets such as earthworks), these can be explained within the tactical plans.

7 Future Developments

Network Rail strives for continuous improvement across all of its business, and this applies to the management of the earthworks asset. A suite of improvement tasks are planned for the immediate future, leading into the next Control Period (CP6), including:

- Evaluation and improvement of the Rock Slope Hazard Index (RSHI)
- Consideration of the inherent stability of earthworks based on their material properties and morphology (slope angle and height)
- Updating of the earthworks asset policy and standards to reflect the continuous improvements and ongoing embedment and feedback on the enhanced asset management procedures within the Network Rail business

Acknowledgements

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