OFFICE OF RAIL AND ROAD

#23564 – A REVIEW OF NETWORK RAIL'S WHOLE LIFECYCLE COSTING FRAMEWORK

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Key Contacts

Australasia +61 (0) 2 9252 7623

Americas +1 212 370 7319

Europe +44 (0) 207 688 2828

Asia +852 2834 6122

Original held by AMCL at:

221 St. John Street, Clerkenwell, London, EC1V 4LY
Tel: +44 (0) 20 7688 2828
Email: mailto:enquiries@amcl.com
www.amcl.com

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Executive Summary

The Office of Rail and Road (ORR) and Network Rail (NR) are seeking assurance that the Whole Lifecycle Cost (WLCC) models that have been developed by NR are fit for purpose and being used appropriately to analyse investment scenarios and drive investment decisions across the business.

Accurate WLCC models are a key factor in good practice investment decision making, providing insight into the impact of constraints such funding on overall cost, risk, and performance. Given the changes happening across the industry and within NR, driven by factors such as the Covid-19 pandemic, Williams/Shapps Rail Review and the move to Great British Railways, it is critical that there are tools, such as WLCC models, in place to manage risks and react with agility to the changing environment. It is a priority that the modelling framework and the individual models for track, signalling and structures assets are robust and applied consistently, as they influence the three largest areas of renewal expenditure. However sophisticated the models may be, they must support practical decision-making by engineers and planners in the Regions. The Asset Policies and Ready Reckoners support this, providing rules and guidance on asset decisions to the Regions, to enable them to determine the optimal investment options.

This report documents the findings of an independent assessment of NR's WLCC Modelling Framework undertaken by AMCL in partnership with FCP, one of the Independent Reporters (IRs) to Network Rail and the ORR. It presents the findings from a review of the overall WLCC model framework and its use in the development of Regional Control Period Plans and of the models themselves. The overall conclusions of this review are:

1) The IR believes that NR can move forward with CP7 planning with confidence. The IR's view is that the most critical function of the WLCC framework is the ability to forecast the long-term impacts of the work volumes and costs planned in the five-year control period to ensure it is sustainable and is not driving a future bow wave of investment that will not be affordable.
2) There are numerous examples of leading practice within the NR WLCC modelling framework, particularly in the track and signalling models. The Ready Reckoners and mini-ICM are considered by the IR to be some of the most practical tools in the industry to enable end users interact with the WLCC models. Providing the limitations of the underpinning models continue to be communicated alongside these outputs, then NR have an opportunity to maintain stakeholder buy-in whilst improving the models themselves.
3) The outputs of the models and the provision of these through the 'Ready Reckoners' enable a degree of control in the application of policies and the development of the Regional plans, however the model capabilities vary in their accuracy. Many of the limitations with the current models are already understood by NR and there are plans in place to address these, such that a leading industry framework can be maintained.
4) There are many other factors that are driving the decisions being made in the development of the Regional plans such as local stakeholder/customer needs, delivery technology and access constraints and as such any further refinement of the models should take cognisance of this to ensure they continue to provide value to the Regional teams.
5) Whilst evidence of self-assurance processes was seen by the IR during the course of the review, the general approach to model governance is below the standard expected for models such as those in scope of this review. Each model had elements of good practice assurance within them, but the lack of a consistent approach to approval and sign-off of model outputs means that the fundamental principles have been missed (e.g., documented procedures).

6) Devolution of the organisation is driving the outcomes and content of the investment plans to be focused more on the local requirements of the Regions and Routes rather than national policies. To accommodate this NR are restructuring their Asset Policies and developing Regional Asset Strategies. A clear direction is required for the ongoing development of the WLCC Framework, capturing the desired architecture of models, their ownership and their purpose to support this more localised approach.
7) A summary of the findings of the asset discipline models in delivering a suite of requirements is set out below:

Requirement	Trk.	Sig.	Str.	Comment
Calculate and forecast the whole lifecycle costs for the Asset Disciplines at a portfolio level to enable a variety of funding scenarios to be tested and ultimately secure funding	🟩	🟩	🟩	All models calculate and forecast the capital costs and volumes at a national level (assuming a constant maintenance regime), but to various degrees of granularity. The IR believes that the models are fit for purpose to satisfy this requirement, however there is room for improvement in the structures model.
Provide volumes and budgets to the Regions based on applying the Asset Policies and funding scenarios to enable them to develop their plans	🟩	🟩	🟨	The track and signalling models provide Regions with reasonable estimates of the local costs and volumes required over future control periods to maintain certain performance characteristics. Due to the structures modelling working on a national averages basis, an accurate reflection of the work required at a Regional level is not a strength of the current model. For the structures model to satisfy these requirements fully, the modelling approach needs to include a greater number of Regional factors and an improved approach to modelling bridge capability.
Provide a baseline against which the Regional Plans can be tested (counterfactual)	🟩	🟩	🟨	
Model the impact of changes away from Asset Policy or funding scenarios over future Control Periods to understand their sustainability	🟩	🟨	🟨	The track model fully satisfies this requirement. The signalling degradation model is currently too simplistic to reflect changes in policy, however changes in finding scenarios can be modelled through updating the input work bank. Like signalling, the structures degradation model does not allow thorough testing of policy changes, however different budget scenarios can be tested at a national level.
Test and justify Asset Policy decisions	🟩	🟨	🟥	The track model is capable of accurately testing Asset Policy decisions and the impact on future control periods. The current issues with the degradation models in both the signalling and structures model makes modelling asset policy decisions more challenging. Signalling can support options analysis on specific schemes as well as coding policy changes into the work bank, which may inform policy. Difficulties

Requirement	Trk.	Sig.	Str.	Comment
	🟩	🟨	🟥	modelling the structures asset class due to the High Impact, Low Probability (HILP) nature of how bridges degrade, mean it is not currently possible to model accurately at an individual asset decision level. However, the IR feels this could be better satisfied with the current model (moving this to an amber), if degradation modelling and unit costing was significantly improved to better reflect engineering knowledge.
Provide tools to support the development of local sort to medium term intervention plans based on the outputs of the model	🟩	🟩	🟥	In partnership with other DSTs in existence at NR for track and signalling, the current models can support the development of Regional Plans. Due to the way the current structures model has been developed (condition-based) and the lack of an intervention library that reflects actual work being delivered (does not have a Strengthening and Repair option), the structures model does not support development of Regional Plans.
Input Data and Data Quality	🟩	🟩	🟩	Data quality is generally of good standard and does not undermine confidence in the model outputs. Whilst there are improvements still to be made to a small number of inputs, NR should monitor changes to the input data set and feed requirements back to data owners.

Section 4.3 summarises this table again with additional RAG statuses for unit costing and work done since the last review in 2013.

8) Work has been undertaken to improve the models since the last review in 2013, this varies between the three asset disciplines with refinements to the track model, updates to the signalling model and for the structures model, the development of an entirely new model in 2016. The work done for the signalling and structures models has focused on more accurate forecasting of portfolio costs & volumes models. Developing these models to better support asset policy decisions and inform specific asset decisions has not been undertaken, and this has led to the modelling stagnating for these disciplines. This has been recognised by NR and plans are in place to address this.
9) Much of the WLCC development work has led to and continues to lead to positive improvements in the models, such as the move to the Copperleaf C55 platform, however the IR believe much of this was undertaken without an overarching development strategy or plan and a key recommendation from this review is to develop an appropriate improvement strategy linked to the purpose of the models and the value they will provide.
10) Whilst asset information has improved there is still a lot of work that is undertaken by the modelling team to cleanse the data so that it can be used in the models. This data cleansing activity should be pushed back down the data provision supply chain so that it encourages

greater data capture discipline by the data owners. There are specific areas that need addressing such as the supply of actual traffic data, with Actraff, the system that was used to supply this data, having been decommissioned without a replacement.

11) Cost data and the provision of realistic unit rates into the WLCC models remains a challenging area for NR. This is not a unique position as control and provision of accurate unit rates into the investment planning process is a challenge across industries. The IR believe that the devolution to the regions has left the responsibilities for the development of unit rates being uncertain and whilst it is recognised that the intention is for the Regions to pick up this responsibility the degree to which this was taking place was variable. It is recommended that further study should be undertaken into the management of unit rates in the devolved organisation.

The two overarching recommendations the IR would like to highlight to NR and the ORR on completing this review are as follows:

1) Given the current operating context and recent structural changes within NR, there is a clear need to have a framework that the WLCC models are defined within. The IR has recommended several actions to adjust and align the models to a set of outcomes. It is acknowledged that the old structure may not be appropriate given the different levels of model maturity, however the IR feels there are a set of key, fundamental outcomes expected of the models (especially from the perspective of the Regulator). Providing the models continue to meet the key outcomes, the ORR can have confidence that these models provide a baseline against which the Regional plans can be challenged.
2) A significant amount of work has been done (or is ongoing) to ensure quality of input asset data and appropriateness of degradation principles. The IR has recommended that focus be shifted towards improving the cost data, which is an area of large uncertainty for some asset classes. The recommendations provided in this report highlight the need for a common framework, engagement with the Regional finance teams and an overall roadmap to accurate unit costing.

There are a total of thirty-nine specific recommendations given in this report (see Section 4.3). These cover the models themselves, as well as input data, governance, application, and other areas of importance to the output.

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Glossary

ADS	Asset Data Store
DfT	Department for Transport
DSDS	Decision Support Data Store
DST	Decision Support Tool
ETCS	European Train Control System
GEORINM	Geospatial Route Infrastructure Network Model
ICM	Infrastructure Cost Model (Signalling)
INM	Infrastructure Network Model
IR	Independent Reporter
NR	Network Rail
ORR	Office of Rail and Road
SCU	Signalling Control Units
SEU	Signalling Equivalent Units
SICA	Signalling Infrastructure Condition Assessment
SMO	Senior Model Owner
SSADS	Signalling System Asset Data Store
TA	Technical Authority
VTISM	Vehicle Track Interaction Strategic Model
WLCC	Whole Lifecycle Costing
WLC	Whole Life Cost

1. Introduction

1.1 Context

The ORR and NR are seeking assurance that the Whole Lifecycle Cost (WLCC) models that have been developed by NR are fit for purpose and being used appropriately to analyse investment scenarios and drive investment decisions across the business.

Accurate WLCC models are a key factor in good practice investment decision making, providing insight into the impact of constraints such funding on overall cost, risk, and performance. Given the changes happening across the industry and within NR, driven by factors such as the Covid-19 pandemic, Williams/Shapps Rail Review and the move to Great British Railways, it is critical that there are tools, such as WLCC models, in place to manage risks and react with agility to the changing environment. It is a priority that the model framework and the individual models for track, signalling and structures assets are robust and applied consistently, as they influence the three largest areas of renewal expenditure. However sophisticated the models may be, they have to support practical decision-making by engineers and planners in the Regions. The Asset Policies and Ready Reckoners support this, providing rules and guidance on asset decisions to the Regions, to enable them to determine the optimal investment options.

Effective WLCC models, together with a framework for using them in the Regions, will enable NR to:

- Establish long term Asset Management Plans.
- Minimise asset risks and costs.
- Underpin the Strategic Business Plan and Periodic Review (work volumes and costs).
- Identify optimal/minimum whole life strategies.
- Capture and apply learning of the behaviours and degradation of the assets and other factors.
- Test a range of intervention options against differing funding scenario.
- React to changes in demand and funding and adjust their plans accordingly.
- Update the costs based on changes to the marketplace.
- Take advantage of other relevant initiatives (e.g., intelligent infrastructure for input data).
- Test the impact of new technologies (innovation).
- Develop obsolescence strategies.
- Optimise their investment plans.

1.2 Objectives

The Independent Reporter (IR) Framework Statement of Work No. 0011 Review of Whole Lifecycle Cost Modelling Framework stated the requirements for the Independent Reporter to evaluate the sufficiency of the following:

- Modelling framework/principles: robustness of the WLCC Framework.
- Do the models accurately simulate Asset Policy/strategies and asset management regimes?
- Work done progress that NR has made in development of its whole lifecycle cost analysis tools, since the previous review published in June 2013.
- Input data: Are the WLCC analyses based on an appropriate level of asset information (inventory, condition, performance) and influencing factors for deterioration (environment, material, loading). Are asset input data (including number, criticality, condition, age, used life etc.) consistent with NR's asset registers? Are these correctly disaggregated by operating Regions?
- Cost data: basis of unit costs within the models.
- Degradation: Are the degradation assumptions used consistent with current asset knowledge?

1.3 Approach

As per the proposal submitted for this engagement, the review methodology was split into two parts:

Part A – Review of the WLCC Framework and intended application: The objective of Part A is to review the overall WLCC Framework against the Independent Reporter's knowledge of industry good practice.

The approach for Part A was as follows:

1) Establish an understanding of the WLCC Framework, its purpose and intended application. The Independent Reporter conducted a series of interviews with the WLCC Framework owners and stakeholders such as the Professional Heads in NR's central team and the ORR to build a clear picture of how the WLCC, Asset Policies and associated Ready Reckoners are used in NR's end-to-end process.
2) Review the use of the models in the development of Asset Policies and Strategies. The Independent Reporter conducted a series of interviews with the Professional Head's teams for track, signalling and structures to establish how the WLCC models have been used to develop and validate the Asset Policies. The discussions centred around how the WLCC models drive policy decisions, how the models have been used to develop specific asset and product strategies, including the virtual testing of new technologies and obsolescence scenarios. Following this, the Independent Reporter undertook a desktop review of the Asset Policies and the application of the WLCC models in their development to provide the ORR and NR with a level of confidence in the Asset Policies and their alignment with the WLCC models.
3) Review the current application of the framework and models within the Centre and the Regions including the use of the Decision Support tools ('Ready Reckoners'). In parallel, the Independent Reporter undertook a wider review of any relevant artefacts which show how the policies and WLCC outputs have been applied since 2013.
4) Collate the WLCC Framework observations and compared against global industry good practice.

Part B – Evaluation of the WLCC Models (Tier 1 & Tier 2): The objectives of Part B are to review the models themselves, how they have been developed and improved over time, how they are calibrated and validated, the quality of the input data and the overall approach to managing the models.

The process for Part B is as follow:

1) Review of model specifications. To initiate Part B of the review, the Independent Reporter has undertaken a desktop review of the suitability and completeness of model specifications documents for the Tier 1 and the three Tier 2 models for track, signalling and structures (bridges).
2) Interviews with model developers. Following the document review, the Independent Reporter has conducted a series of interviews with the WLCC model owners, model developers and Professional heads to establish how the Tier 1 and Tier 2 models have been developed and maintained in practice. The focus of the interviews has been centred around the information sources that are used to keep the models up to date (e.g., asset degradation information, cost data), how sensitivity analysis has been used to prioritise data and information, how the model owners are interfacing with other asset information projects, as well as the model testing protocols.
3) Information reviews. The Independent Reporter has conducted an evaluation of the information (asset and cost information) and the information sources identified in Step 2. Information on the behaviours of the assets that is embedded in the models, such as degradation curves has been reviewed by the subject matter experts in the Independent Reporter team for track, signalling and structures (bridges).
4) Independent Model Testing. The Independent Reporter reviewed suitability of gaining access to the WLCC models such that the functionality, sensitivity and data quality can be tested. Due to time constraints for this review and the model complexity, it was agreed with NR that it would not be possible to conduct an independent test of the track model. The primary calculation engine within the track model, known as T-SPA, is developed in line with TickIT Quality Assurance guidelines by Serco. A test report was supplied which evidenced the testing and verification carried out in developing T-SPA. It was agreed with NR that wording from the Serco report in combination with NR's own validation and calibration checks can be used to meet the computational accuracy requirements for track. Where possible, the Independent Reporter has carried out testing on the signalling and structures models to verify model outputs but has not assessed model coding or formulae due to the level of complexity involved as this would require proprietary audit software.

For the IR to carry out Part B successfully, it was important to establish a baseline and a reference point against which to compare the models (so as to compare all models to a set of requirements rather than each other). The old 'Tier' structure provided clear requirements the WLCC models needed to satisfy. Whilst the models may have deviated from this Tiered structure in recent years, in the absence of any newer framework this was the most appropriate baseline for the IR to assess the models against. The IR is not suggesting that this framework is taken forward by NR in subsequent phases of development. The Tiers were broadly be defined as follows:

Tier 1 – Portfolio-level analysis to forecast costs & volumes needed to achieve certain outcomes.

Tier 2 – Analysis of changes to Asset Policy on the degradation characteristics of the asset class.

Tier 3 – Analysis to support Regions make local asset decisions on where and how to invest.

1.4 Stakeholders

The list of stakeholders that were engaged through this review are shown in Table 1.

Table 1: Stakeholders engaged by the IR

Stage	Role	Stakeholder & Discipline
Part A – Review of the WLCC Framework and intended application	National Framework Owner	Tim Kersley
	National WLCC Team	Piers Treacher
		Julian Williams - Track
	Professional Heads (representatives)	Mark Bradbury - Track
		Julian Staden - Structures
		Alex Hill - Signalling
	Heads of Engineering and Asset Management and RAMs, ASMS or equivalent	Andy Heather & Andy Bartlett - Track (Wales & Western)
		Sin Sin Hsu Track - Track (Eastern)
		Kafui Agbodo - Structures (Eastern)
		Stewart Lothian - Structures (Scotland)
		Paul Percival - Signalling (Southern)
		Andy Kirwan - all models (Northwest & Central)
Part B – Evaluation of the WLCC Models (Tier 1 & Tier 2)	National WLCC model owners Tier 1 and Tier2 and associated Discipline Experts	Julian Williams - Track
		Matt Hamer - Structures
		Sam Chew and Chris McIndo - Signalling
	Data providers / Intelligent Infrastructure team	Julian Williams - Track
		Matt Hamer - Structures
		Dan Paxton - Signalling Work bank

2. Whole Lifecycle Costing – Framework

2.1 Introduction

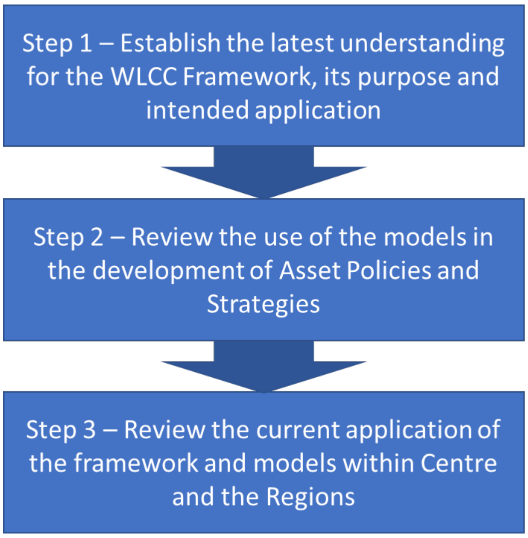
The WLCC Framework and supporting models play a key role in establishing and controlling the development of the Control Period plans across the NR Regions. NR are in the process of developing their plans for Control Period 7. The ORR is seeking assurance that the WLCC models and their use enable a robust, sustainable plan to be developed and options to be tested based on different funding scenarios.

The purpose of this section of the report is to present the findings from the IR's review of the overall WLCC Framework (note, Section 3 of this report provides analysis of the models themselves, application within the Regions, and alignment with policy with more detail in the Appendix). The findings and recommendations detailed in this section, identify challenges across the entirety of the framework that the IR feels should be addressed in order to maintain confidence in the models. The structure of this section is to first present a summary of all findings and recommendations, with appropriate referencing, followed by a sub-section for each finding to present the evidence gathered.

In the Conclusions of the overall report (Sections 2 and 3), all findings and recommendations are collated and summarised in a final table. In the Conclusions, the IR has identified where; NR are aware of the issue, where NR are aware of the issue and have a solution in place and where we believe it to be a new issue. This should enable a productive discussion between the ORR and NR on expediting further solutions to the findings.

2.2 Methodology

The review of the overall WLCC Framework and its application throughout the organisation was achieved through a 3-step approach shown in Figure 1.



Step 1 – Establish the latest understanding for the WLCC Framework, its purpose and intended application

The objectives for Step 1 were to provide an understanding of the overall framework, the architecture of the models and the supporting decisions support tools (e.g., Ready Reckoners), the governance of the framework and the stakeholders involved.

Step 2 – Review the use of the models in the development of Asset Policies and Strategies

The objectives for Step 2 were to understand the relationship between the Asset Policies and the models and to provide confidence to the ORR that the models and policies remain aligned.

Step 3 – Review the current application of the framework and models within Centre and the Regions

The objectives for Step 3 were to capture how the WLCC Framework is supporting decision making across the organisation (Centre, Regions and Routes), the level of confidence that the Regions have in the models, and what involvement the Regions and Routes have in the ongoing development and validation of the models' outputs.

Figure 1: Methodology followed for reviewing the WLCC framework

The IR team has extensive experience in reviewing, establishing, and implementing WLCC frameworks across most infrastructure sectors. Therefore, the recommendations made are based on achievable outcomes observed in other organisations with comparable frameworks.

2.3 Findings & Recommendations

Table 2 summarises the IR's key findings and recommendations from the review. A finding may have one, or many recommendations. This is based on what the IR feels is necessary to satisfactorily address the finding. It was noted that some of these recommendations are already being addressed by NR.

Table 2: Overall WLCC Framework findings and recommendations

Reference	Finding	Recommendation
FWORK1-1	**There is no overall framework that the models align with. The previous tiered approach (Tiers 1, 2 and 3) has been abandoned.** For models such as track, the original Tier 1 & 2 elements have been combined. For others, such as structures and signalling Tier 1 has been kept, whilst Tier 2 has effectively been mothballed. Since the last review, several other Decision Support Tools (DSTs) have been developed in other parts of the NR business, which adds additional complexity to the modelling landscape at NR. None of these changes have been captured in an updated WLCC Framework.	Capture the existing 'As-Is' suite of WLCC models in a single architecture diagram against a common framework (possibly an updated version of the old Tiers). The common framework needs to establish the baseline use-cases expected from each of the models and how they integrate or are used with other DSTs in the business.
FWORK1-2		Publish the 'As-Is' framework to all relevant stakeholders (ORR, Regions, finance, Professional Heads, asset strategy owners), or a group with broad representation of all stakeholders, to gain agreement on expected outcomes. Utilise this as an opportunity to seek feedback from key users on desired WLCC Framework outputs and future direction.
FWORK1-3		Develop a 'To-Be' architecture diagram showing where opportunities for improvement exist (including current in-flight initiatives). Gain approval of this architecture from the stakeholders and adopt this as NR's new WLCC Framework.
FWORK1-4		Establish a governance forum for controlling ongoing usage and development of the WLCC Framework, ensuring the overall purpose is satisfied and remains aligned with stakeholder expectations.

Reference	Finding	Recommendation
FWORK2-1	**There is no formalised and documented approach for the assurance and governance of model outputs.** The Tier 1 aspects of each model (track, signalling and structures) are regarded as being of high importance to NR's core business planning processes. Hence, by 2017 all three models had been added to the Department for Transport's (DfT's) critical model register (the Tier 1 elements). Whilst some self-assurance processes are undertaken, these are not as sufficient or as rigorous as assurance processes seen in other sectors for these types of models.	Establish a robust internal assurance process complying with expected assurance procedures, which recognises the significance of these models in the planning process. Observed good practice in other organisations with models of this sophistication would typically have the following as a minimum: • Documented, step by step procedures for the full process (data pre-processing, model run, post-processing). • A replicated model run carried out by a person entirely independent of the model at critical points in the planning cycle (annual plans, regulatory submissions, business plans). Full validation checks on the outputs versus previous model iterations, commenting on changes and the root causes of significant variations.
FWORK3-1	**There is no independent validation of model outputs from data source to completion.** The complexity, and development of the models over the past decade has meant that picking up the models and quickly understanding how they work is extremely challenging. The current NR modelling team is under resourced when compared to peer organisations. For models of this complexity, it is expected that there would be a minimum of two people fully trained in each model. This would ensure there was redundancy within the team to pick up model ownership if there was any absenteeism.	Review the NR modelling team structure against recognised good practice for National Critical Models and redesign the team to better support the need for robust assurance processes.
FWORK3-2		Introduce internal, independent validation of all models within a process, with defined validation triggers (e.g., annually or at least every CP submission as a back-stop).

Reference	Finding	Recommendation
FWORK4-1	**There was no evidence of an overall approach for unit costing used across all Regions.** It was reported that regional teams record work inconsistently under different cost and volume lines, with limited control by NR Centre. The current work breakdown structure in the finance systems does not always align with standard structures in other systems (for example, it was reported that there is only one cost code and volume line for the structures asset class). Significantly improving the accuracy of unit costs used in all three models is challenging, particularly for the structures asset class, which are highly bespoke assets with limited replication of work activities across them.	Consult with Finance, both centrally and in the Regions, to understand the current challenges faced by the SMO and how these can be improved for future model forecasts.
FWORK4-2		Implement individual findings and recommendations on unit costs related to each of the models reviewed. Further detail on the specific challenges related to generating unit costs for each of the models reviewed, can be found in Section 3.
FWORK5-1	**The perceived accuracy of the modelled outputs and confidence in the results varies across the asset disciplines and Regions.** For track and signalling the concerns are not related to the accuracy of the model itself, but on the input data that is used and the factors that are considered (e.g., deferrals from previous Control Periods). For the structures model confidence in the outputs are deemed not to represent local needs within some Regions, and in general Regions have much less confidence in this model.	Establish a forum, including the Technical Authority, to capture, review and share the Regional decision support tool development activities. Following this, a plan can be developed to consolidate these tools where possible, or take learnings to improve the WLCC models themselves.
FWORK5-2		Review the suitability of the current structures model given the findings presented by the Regions and the later model observations made in this review document. Develop a plan to improve the current model to provide more useable outputs.
FWORK5-3		Further refine the track and signalling models as required following an assessment of other factors that influence the planning process within the Regions and the development of other optimisation tools such as Plan-IT.

2.3.1 FWORK-1: Framework Structure

The original framework of models was structured around three tiers, each of which had a specific purpose:

- Tier 1 – Strategic models used to forecast work volumes, costs, and outputs at a portfolio level.
- Tier 2 – Strategic whole life cycle cost models for specific asset types that model the asset behaviours and a range of intervention scenarios, which are used to support the development of Asset Policies.
- Tier 3 – Tactical models that support local decision making on maintenance and renewals work.

These three tiers of model worked together. The Tier 2 models were the core of the framework modelling the asset behaviours and enabling differing intervention scenarios to be run to enable optimum policies for specific asset types to be developed, documented in the specific Asset Policies. Through applying these policies to the national portfolio of assets in the Tier 1 models, NR was able to forecast work with the aim of producing a sustainable level of activity in terms of costs and volumes linked to output measures. The Tier 3 models enabled the development of work banks at a local level, which could then be played back through the model to determine the long-term impact on volumes and costs.

The purpose of the WLCC Framework has remained broadly consistent, which by the previously seen definitions is to:

- Calculate and forecast the whole lifecycle costs for the asset disciplines at a portfolio level to enable a variety of funding scenarios to be tested and ultimately secure funding (Tier 1).
- Provide volumes and budgets to the Regions based on applying the Asset Policies and funding scenarios to enable them to develop their plans (Tier 1).
- Provide a baseline against which the Regional plans can be tested (counterfactual) (Tier 1).
- Model the impact of changes away from Asset Policy or funding scenarios over following Control Periods to understand their sustainability (Tier 1).
- Test and justify Asset Policy decisions (Tier 2).
- Provide tools to support the development of Regional Plans based on the outputs of the model (Tier 3).

The overall structure that the models currently sit within does not reflect the clarity of the original three tiers. In general, the Tier 2 models have been mothballed, or in some cases (track and signalling) being combined within the Tier 1 model in a single platform. Specific findings for each of the models are summarised in Table 3.

Table 3: Current state of the models against the old Tier structure

Track	The track model combines both the Tier 1 and Tier 2 models and can be used to provide forecasts of work volumes, costs and outputs at a portfolio level as well as enabling Asset Policy development through the modelling of specific assets, asset behaviours and associated intervention scenarios. Whilst this makes the track model extremely complex, it has the advantage of running off a single data source and there is no need for data transfers and calibration requirements between Tier 1 and Tier 2 models. It also enables the impact of policy decisions to be seen at the portfolio level. A Ready Reckoner tool has been developed that takes the outputs from the track model and provides them in a useable Microsoft Excel (MS Excel) format for the Regions and Routes to develop their work banks. Regions often have a more detailed, shorter-term view of the workbanks (containing detail on locations and schedules), and so the Ready Reckoner is primarily used to test their CP7 plans at a total volume level.
Signalling	The Tier 1 model for signalling is the Infrastructure Cost Model ICM and whilst there have been developments to the model it remains as a Tier 1 model providing forecasts of volumes, costs and outputs based on the work banks that are put into it. Whilst the ICM does not model specific asset behaviours it does contain sufficient data to model generic degradation and enable the analysis of transitions between technology types (e.g. conventional signalling to ETCS). The ICM contains the Signalling Equivalent Units (SEUs) for the whole network and as such the run time on the model is extensive and does not support rapid analysis of specific changes. A 'mini ICM' has been created to provide the Regions and Routes with a Ready Reckoner tool that can be used to quickly analyse and update the work bank for their specific areas. Changes made in the 'mini ICM' can then be uploaded back into the main ICM. A Tier 2 model for signalling (and level crossings) exists with supporting Asset Lifecycle Profiles (ALP) and whilst it was originally used to support Asset Policy development in CP4 it has not been updated since this time and has been effectively mothballed. NR have recognised the need to update the Tier 2 models and ALPs and work is planned or underway.
Structures (Bridges)	The structures Model is a Tier 1 model for bridges (underline and overline). This model is relatively new compared to the track and signalling models and was developed in 2016. It provides forecasts of volumes, costs, and asset condition for the bridge assets. A Tier 2 model was developed previously (CP4/2012) but this has not been progressed or used since the development of the CP5 plans. A Ready Reckoner tool has been developed that takes the work volume outputs from the structures model and provides them in a useable (MS Excel) format for the Regions and Routes.

The Technical Authority recognises that the structure and integrations between the models (the model architecture) is not clear and is inconsistent across the asset disciplines. It was also noted by one of the Regional teams that the structure and integration of the components of the framework was not clear. There are benefits to producing and maintaining a model architecture diagram, firstly in terms of providing understanding on the WLCC Framework and secondly it can be used to re-iterate the common data sources providing greater confidence to the Regions on the validity of the model outputs.

The CP7 Planning Framework

Figure 2 shows how the models play a critical role in scenario planning as part of the Control Period submission. The models are used to initiate the process, producing top-down forecasts of volumes and costs required for a range of scenarios based on the predicted out-turn of the previous Control Period and assumptions as to available funding. The models are then updated and re-run based on input from the Regions providing the long term forecast for their maturing bottom-up plans against available funding. In this way the models enable NR to demonstrate the long-term impact (sustainability) of the funding allocation and associated plans. The process is effectively driven by Tier 1 models, or combined Tier 1 / 2 models.

Although the CP7 Planning Framework provides clarity on the CP7 planning process and how the models contribute, it does not replace the clarity of the three Tiers and their specific objectives.

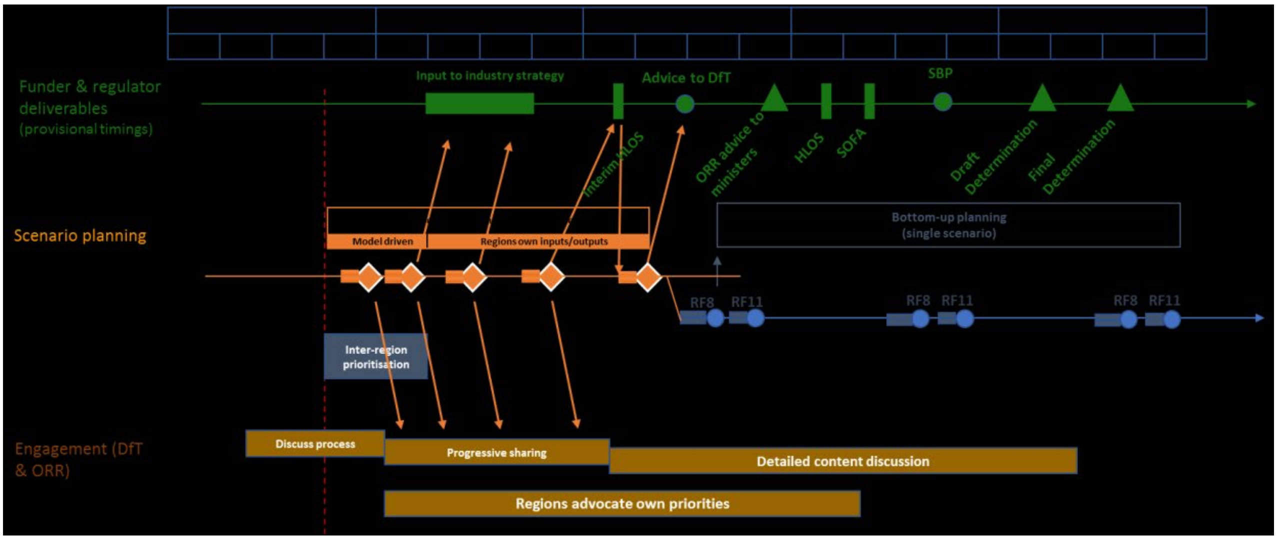


Figure 2: CP7 Planning Framework

2.3.2 FWORK-2: Model Governance and Assurance

All three Tier 1 models are registered on the Department for Transport's (DfT) critical model register with the Senior Model Owners (SMO) named, and the date the model was registered. As such each of the models are subjected to the DfT's analytical assurance framework.

Table 4: Model Assurance Structure

Reference	Model	SMO	Functional	Date Added
NR/01/022	Infrastructure Cost Model (Signalling)	Sam Chew	Technical Authority	11/09/2015
NR/01/021	VITSM (Track Tier 1 Model)	Julian Williams	Technical Authority	11/09/2015
NR/01/034	Bridges Tier 1 Model	Matthew Hamer	Technical Authority	08/12/2017

To ensure NR remains compliant with the DfT's analytical assurance framework they have established the Network Rail Analytical Assurance Policy (21/11/2016) and the SMOs carry out annual self-assurance assessments. Evidence was seen of the self-assessments that had been carried out for both the track and signalling models, but none had been completed for the structures model. It was reported that NR is aware of this, and it was on an internal action tracker to complete. It is of concern to the IR that this process has not been undertaken since the structures model was originally registered in 2017.

The development of the models themselves is undertaken between the SMOs and the relevant Professional Heads team. The Professional Heads of each discipline take ownership of the outputs the models produce and present these to the Regional teams of asset discipline engineers. The track SMO provides overall governance of the Tier 1 models and regularly reviews their coverage, undertaking technical reviews of the outputs. The governance processes followed for this are not documented and there is no structured development process or documented authorisations for changes to the models. Some change logs were seen for the signalling model and reports on changes to the track model were also produced. However, the change control processes observed did not follow a single, consistent format and approach. It was noted that changes to the models are presented at regular meetings with the asset discipline engineers. They provide feedback and challenges to the model, agreeing further updates where necessary.

To ensure a "best practice" approach to assuring the models, current processes were assessed against the DfT's analytical assurance guidelines. Table 5 is a modified version of the guidelines to ensure they are appropriate for the NR WLCC Framework. On assessment of the table, the IR believes the modelling framework is 40% compliant with the guidelines, with a further 40% of the criteria partially met and 20% not met. We believe this is an important area for NR to focus on, so that confidence can be had in the outputs of the models (as well as the limitations understood).

Table 5: Assessment of Processes for Model Control, Validation and Sharing against the DfT's Analytical Assurance Guidelines ***(N – does not meet the criteria, P – partially meets the criteria, Y – fully meets the criteria)***

Process	Sub-process	Track	Signalling	Structures
Access Control	Access restricted on a need-to-know basis	P	P	P
	Population with access to models broadly represents users	Y	Y	Y
Change Control	Changes are subject to a proportionate approvals process before they are made	P	P	P
	Controls in place to prevent unauthorised or accidental changes	P	P	P
Version Control	Keeping a control log of versions and changes made	Y	Y	P
	Naming conventions and version numbers	Y	N	Y
Back-Up and Recovery	Models are located on IT approved infrastructure with back-up and recovery processes	Y	Y	N
Single Person Dependency	There is more than one person with the competences required to build and run the model	N	Y	P
User Guide and Succession Planning	Existence of a user guide for the model	Y	P	P
	Consider succession planning	P	N	N
Documentation Standards	Data, methods, assumptions, and parameters in the model are documented	P	P	P
Skills and Experience	Understanding of how modelling suite fits together	Y	P	Y
	Previous operational versions of the model are kept in restricted areas to prevent changes to historic records	P	Y	P

Process	Sub-process	Track	Signalling	Structures
Developed in line with model life- cycle	All stages of the model life cycle are considered, and appropriate time is given to each stage	Y	P	Y
	Consideration of alternative approaches	Y	P	Y
Input Validation	Measures to check accuracy and reliability of input data	Y	P	Y
	Log of all inputs and sources	Y	P	Y
	Inputs and assumptions are independently signed off	N	P	P
	A walkthrough of the model – checking and testing of code and formulae	P	N	P
	Cross-check of model outputs against an alternative set of data	P	N	P
	Parallel Model Build (full replication of model run, including pre-processing)	N	N	N
	Parameters in the model are fitted to real-world data	Y	P	Y
	Model forecasts are checked against observed information	P	P	P
Communication of Model Limitations and Uncertainty	Sensitivity testing of key model assumptions	P	P	P
	Scenario testing of model assumptions	Y	P	Y
	Communication of limitations	Y	Y	Y
	Communication of model uncertainty	Y	Y	Y
Independent Review	Review of model development or results by someone independent	P	Y	Y
	High level sense-check	Y	Y	Y

Process	Sub-process	Track	Signalling	Structures
Governance	Shared understanding of modelling requirements between analyst and policy partner	Y	Y	Y
Governance	Procedures in place for the flow of information	N	N	N
	Clear process for the internal challenge of results	P	P	P
	Clearance of results from the SMO	Y	Y	Y
	Uncertainty in the modelling output is conveyed to decision-makers	Y	Y	Y
	Fitness for purpose of model under periodic review	Y	Y	Y

2.3.3 FWORK-3: Model Ownership

The complexity of WLCC modelling often requires a specialist skillset, which can be challenging to recruit for. Currently there is a single competent person in the track model, a single person for the structures model and two people for the signalling model. This situation was raised by the IR in the previous review in 2013 and it was reported NR management that attempts have been made to recruit additional people into roles that support the SMO. This is critical for the future sustainability of the modelling framework and progress must be made in filling these open positions as there is currently a high degree of dependability on a select few people.

2.3.4 FWORK-4: Unit Costing Methodologies

Unit costs are a critical input into the WLCC models and a variance in unit costs can have a significant impact on the volumes of work that can be delivered within the budgets that are available. It is essential that unit costs are as accurate as possible to determine the budgets required to deliver a sustainable volume of work. It was reported by the modelling team that accurate unit costs are difficult to generate from source finance systems. The specific reasons for this are given in the sections below, and in the model specific sections later in this report. Pre-processing steps are necessary to correct errors in the source data and to better reflect the actual costs reported by the Regions. Like with asset data, and as far as practically possible, the models should be drawing unit cost data from a framework managed by the appropriate part of the business. It is expected that unit cost data would be maintained by a central finance team and provided to the modelling team on an annual basis. It was found that understanding of the driving factors behind Regional variances in the unit rates was generally limited. Factors reported by the Regions that influence these unit rates could include:

- Access restrictions.
- Customer needs.
- Weather.

- Emerging investment requirements.
- Contractual restrictions/commitments.
- Provision of alternative passenger services (e.g. buses etc.).

On review of the Ready Reckoners and the versions updated by the Regions, it was observed at a high-level that the unit rates almost always varied upwards (i.e. the rates were increased by the Regions to reflect forecast spend).

This may be a process or behavioural challenge in that the Regions are seeking to justify as much spend as possible and are unlikely to decrease the unit rate. Alternatively, the Regions may feel the models are under-forecasting the asset risk and other delivery factors and are compensating by increasing the unit rates rather than adjusting the volumes. It is unclear at this stage and requires further validation to take place between the SMOs, Professional Heads and Regional engineers. Model specific findings and recommendations can be found later in the report.

2.3.5 FWORK-5: Regional Use of Modelling Framework Outputs

To support this study the central Technical Authority and a sample of Regional teams were interviewed to ascertain how the models and model outputs were distributed and developed by the Regional teams in the planning processes.

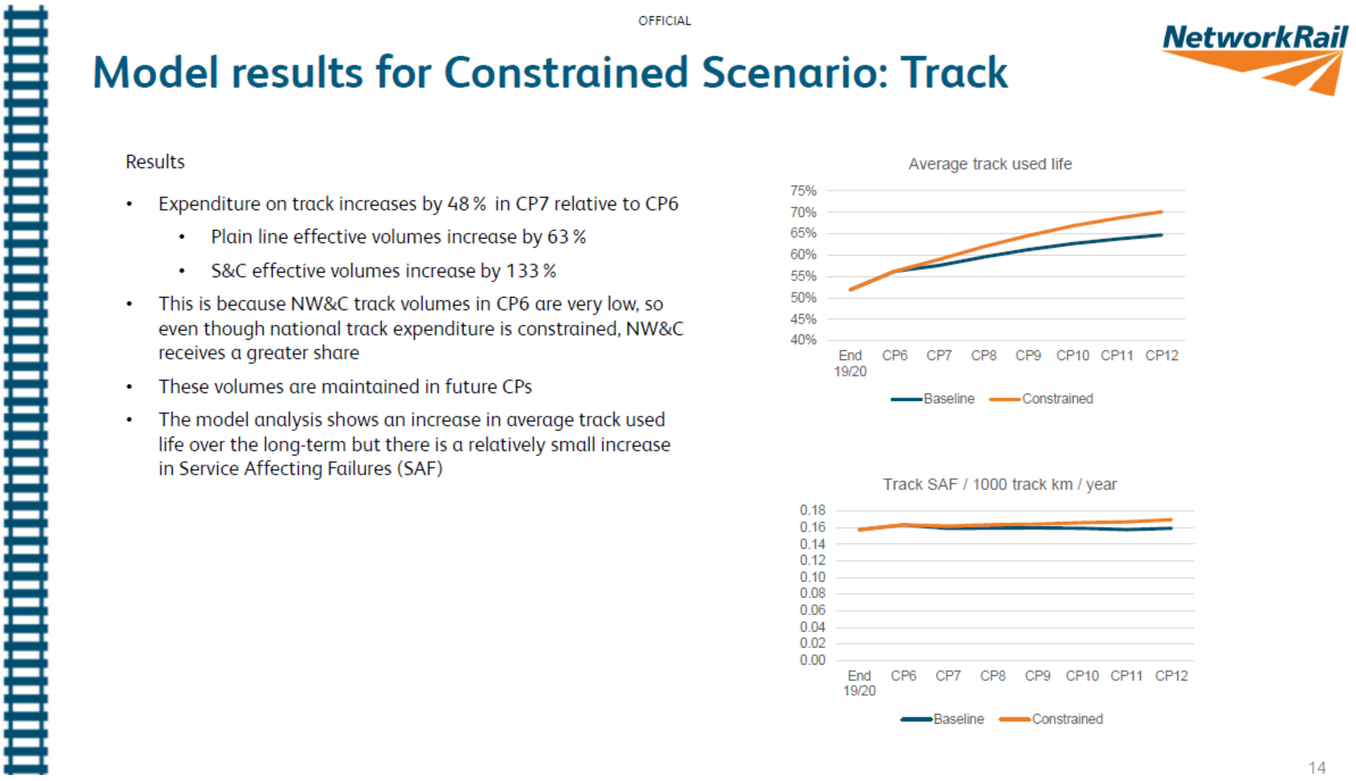
As described in Figure 2 the Control Period planning process is initiated by the Technical Authority issuing an initial version of the model outputs based on the previous Control Period’s outturn and assumptions about the availability of funding. The outputs of the Tier 1 models are provided to the Regions in a comprehensive document that outlines:

- The Control Period planning process.
- The principles of the modelling process.
- The scenarios considered.
- The assumptions such as the unit costs.
- The outputs in terms of:
    - Cost drivers.
    - Costs.
    - Outputs.
    - Forecast assumptions and uncertainties.
    - Future programme (the actions that will be taken to improve future model runs).

In addition to the Tier 1 model forecast documents, the Ready Reckoners (decision support/analysis tools) are provided with the model outputs embedded. On receipt of these documents and Ready Reckoners the Regional teams start developing their Control Period plans, using the model outputs as a guide and developing details based on their local knowledge and updating the Ready Reckoners accordingly.

The Tier 1 Model Forecast documents are comprehensive and well written, enabling the Regional planning teams to easily understand the basis of the outputs even if they have not been involved in a Control Period planning activity and or have limited knowledge of the WLCC models. The future updates and publication of the Tier 1 Model forecasts clearly demonstrate that the Regional inputs have been taken into consideration where applicable. They also demonstrate the updates to the model and the impact on the outputs.

The outputs from the models are a core input into the Control Period planning process, providing an initial view as to the forecast volumes and costs, as well as an insight into the long-term impact of adjustments to the work banks. They play a key role in defining the constraints, initiating the discussions in the Regions and Routes, and testing any changes that are made. Some examples of slides developed by the Regions for internal discussions are shown in Figure 3.



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Model results for Constrained Scenario: Track

Results

- Expenditure on track increases by 48 % in CP7 relative to CP6
  - Plain line effective volumes increase by 63 %
  - S&C effective volumes increase by 133 %
- This is because NW&C track volumes in CP6 are very low, so even though national track expenditure is constrained, NW&C receives a greater share
- These volumes are maintained in future CPs
- The model analysis shows an increase in average track used life over the long-term but there is a relatively small increase in Service Affecting Failures (SAF)

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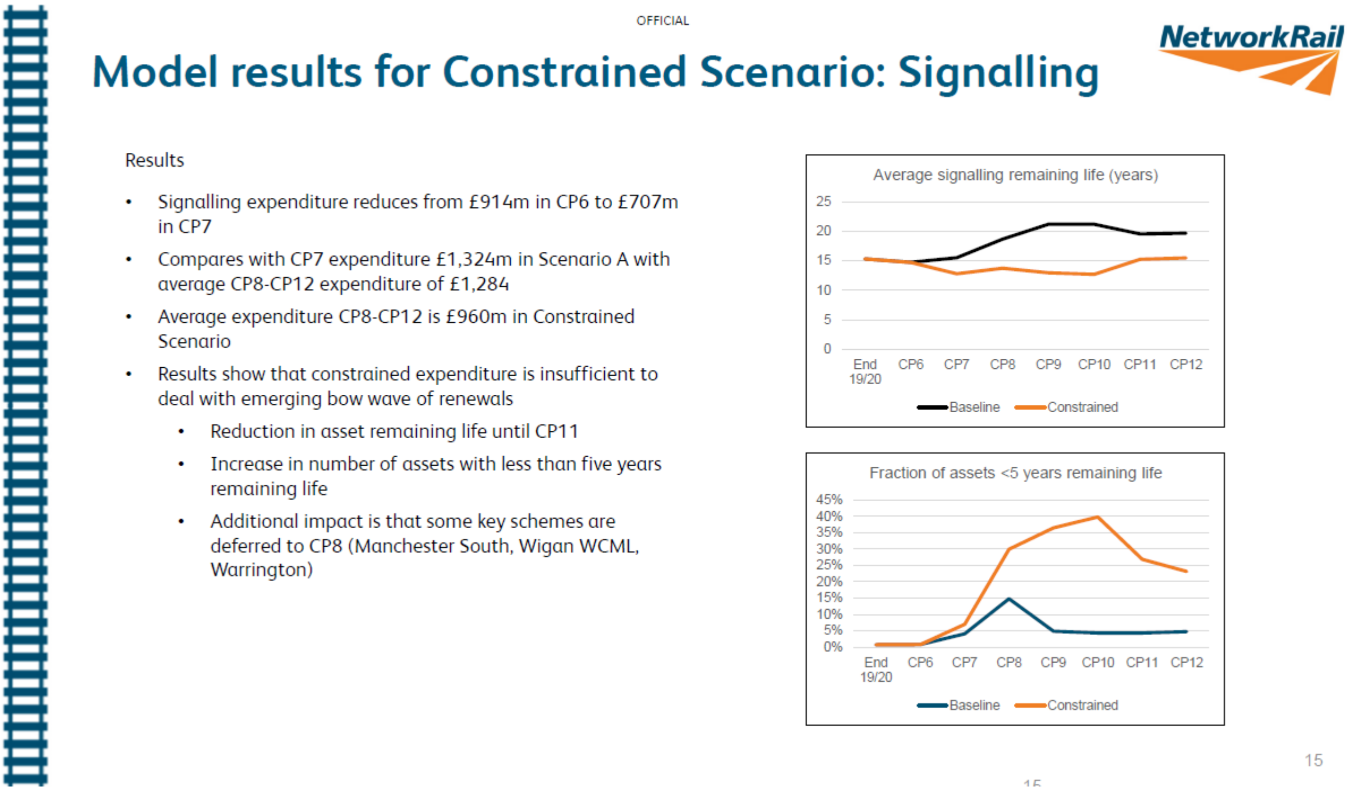

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Model results for Constrained Scenario: Signalling

Results

- Signalling expenditure reduces from £914m in CP6 to £707m in CP7
- Compares with CP7 expenditure £1,324m in Scenario A with average CP8-CP12 expenditure of £1,284
- Average expenditure CP8-CP12 is £960m in Constrained Scenario
- Results show that constrained expenditure is insufficient to deal with emerging bow wave of renewals
  - Reduction in asset remaining life until CP11
  - Increase in number of assets with less than five years remaining life
  - Additional impact is that some key schemes are deferred to CP8 (Manchester South, Wigan WCML, Warrington)

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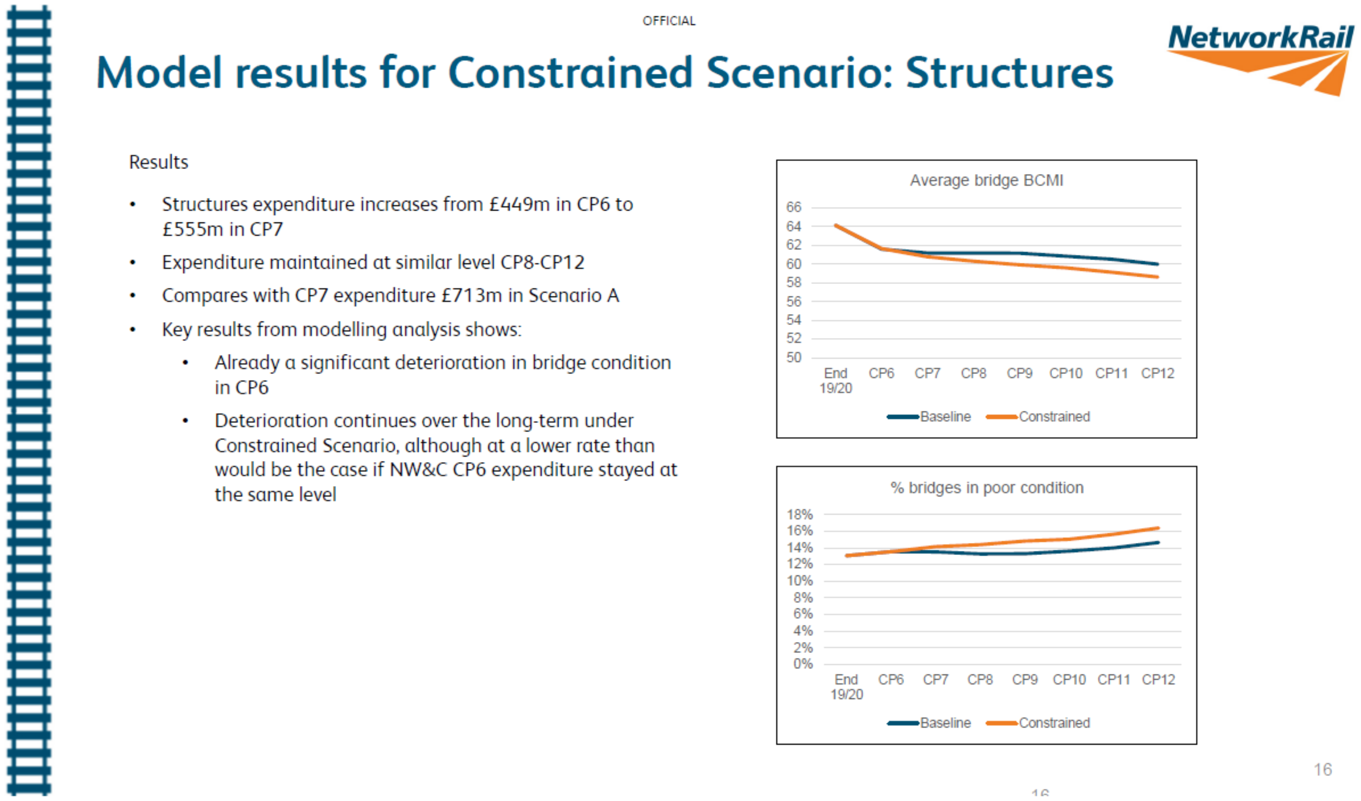


Model results for Constrained Scenario: Structures

Results

- Structures expenditure increases from £449m in CP6 to £555m in CP7
- Expenditure maintained at similar level CP8-CP12
- Compares with CP7 expenditure £713m in Scenario A
- Key results from modelling analysis shows:
  - Already a significant deterioration in bridge condition in CP6
  - Deterioration continues over the long-term under Constrained Scenario, although at a lower rate than would be the case if NW&C CP6 expenditure stayed at the same level

Figure 3: Example outputs from Regions on WLCC model results

The perceived accuracy of the modelled outputs and confidence in the results varies across the asset disciplines and Regions. For track and signalling the concerns are not to related to the accuracy of the model itself but on the input data that is used and other factors that are considered (e.g., deferrals from previous Control Periods).

There is less confidence in the structures model as some Regions do not believe the outputs represent local needs. It has been difficult to validate previous Control Period forecasts generated by the model due to a variety of factors changing the plan during the five years, including actual work volumes delivered. A key factor that influences the model outputs is the unit costs and work has been done to improve this to bring in appropriate local factors.

Throughout the rounds of modelling runs that take place as the Control Period submission is developed, the Regional teams are able to feedback suggestions so changes can be made to the model. These changes are captured in the subsequent Tier 1 Model Forecast documents. National meetings or forums of the respective Regional and central discipline engineers, Professional Heads and modelling teams provide a means for discussion, review, and ratification of updates to the Asset Policies and models.

A variety of DSTs are in use across the Regions to aid in the planning and prioritisation activities. These include the tools provided by the Technical Authority and those that have been developed specifically in the Regions. Whilst the Tier 1 models provide a long-term view of the impact of budget constraints the Regions are subject to more short-term pressures based on their stakeholder and customer needs. To enable the Regions to better articulate the more immediate impact of the budget constraints, NW&C are developing a performance analysis tool which they intend to share with the other Regions. This tool will model the impact of budget constraints on train performance, safety risk, economic and environmental sustainability, and recognise facts such as only 30% of train delays are caused by asset issues. A diagram of the model architecture is shown in Figure 4.

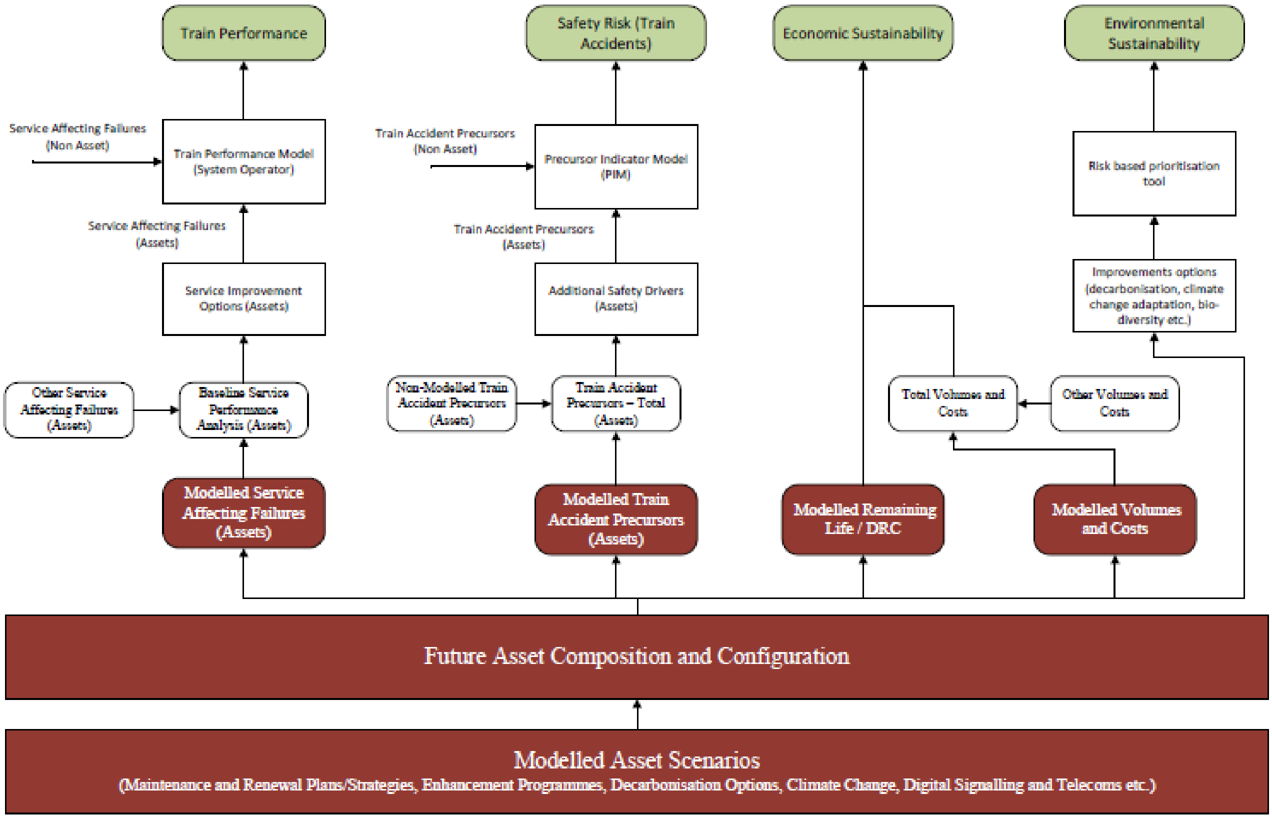


Figure 4: Regional view of model architecture to build plans and asset scenarios

The WLCC models influence the development of the Regional plans by providing a constrained forecast of work based on asset information and a variety of funding scenarios. Fundamentally they provide a realistic baseline of volumes and costs from which the Regions can start to build their plans, thereby saving a lot of plan iterations that would be needed if the Regions were asked to start from scratch.

When developing and prioritising the work banks within the Regions a variety of local factors are considered that are not included in the central WLCC model. This is to be expected as part of an overarching investment planning process as whole life intervention options are one of a series of factors that would be used to prioritise the work banks. Good practice in investment decision making incorporates the measures from an overarching value framework in determining the optimum portfolio of work across asset disciplines, capital, and maintenance activities, see Figure 5. The Network Rail Intelligent Infrastructure Programme is developing an investment planning tool based on a central value framework (Plan-It).

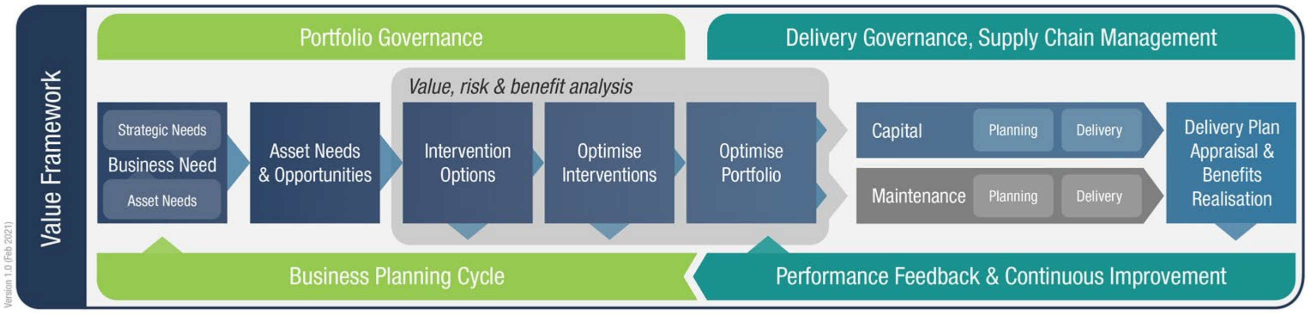


Figure 5: Good practice portfolio optimisation model

In discussion with the Regional teams many of the other factors came to light that impacted the planning process and the unit rates. These factors included but were not limited to:

- Access.
- Delivery technology (e.g. High output).
- Customer needs.
- Regional priorities (funding was moved between asset disciplines).
- Maintenance history and plans.
- Obsolescence.
- Weather resilience.
- Assets outside the scope of the models.
- Enhancements and campaigns.

To take one example, access was a common issue constraining what can be delivered in each time period especially with the move to “putting the passenger first” driving the needs for greater availability of the network. Access also has a significant impact on unit costs, with longer periods of track access typically delivering lower unit rates and vice-versa. Reasons for this include provision of alternative transport arrangements and the deployment of more expensive modular designs to deliver more in shorter time frames. Fixed costs associated with isolations of the line and plant hire are also a larger proportion of smaller jobs which tends to drive up unit costs, and vice-versa.

Within the devolving organisation and with the move to a vertically integrated railway (GBR) there is already increasing local stakeholder pressure to demonstrate how the capital plans will deliver short and medium-term outcomes for the Regional and Route stakeholders. The ability for the models to demonstrate the long-term sustainability of the Regional decisions is going to be increasing important.

3. Whole Lifecycle Costing – Application

3.1 Introduction

The purpose of this section of the report is to present the detailed set of findings and recommendations relating to the each of the models, their alignment to policy and specific use within the Regions. Like the structure of Section 2, a summary of findings covering policy, model and regional application is presented for each model. Detailed observations for each are then contained in the Appendix, for further insight into the review by the IR. This section of the report addresses the following ORR commission requirements:

- To review whether the models accurately reflect the relevant Asset Policy.
- To review the progress that NR has made since June 2013.
- To understand if the WLC analyses are based on appropriate levels of asset information.
- To understand the basis of unit costs within the models.
- To confirm if degradation assumptions used are consistent with current asset knowledge.
- To highlight any gaps or issues that threaten confidence in model results.
- To put forward relevant recommendations as to how the models might be further improved.
- To confirm how the model supports obsolescence management.
- To confirm if the WLC model helps to unlock opportunities for innovation.

In addition to the commission requirements from the ORR, the IR regularly sees several issues with WLC models in asset-intensive organisations. These issues were tested with the NR SMOs, Professional Head teams and Regional teams. Examples of the challenges faced by other organisations in carrying out successfully WLC modelling include:

- Variance in model outputs between the asset classes.
- Generating accurate engineering assumptions driving model degradation principles.
- Understanding sensitive data points and having associated data quality reports/improvement plans.
- Maintaining curves that reflect the asset lifecycle and asset performance.
- Not having data of sufficient enough quality to have confidence in model outputs.
- Data infilling often not done by following a clearly set out procedure.
- Single points of failure in understanding the models.
- Manual nature of the process and existence of possibilities for human error.
- Poor unit costing approaches and data.

This review was undertaken during the planning process for CP7, and as such both the Asset Policies and the WLCC models were undergoing changes. This review focused on the existing CP6 Asset Policies and the current configuration of the models.

3.2 Methodology

To review the application of the WLCC framework, the IR covered three critical areas:

Alignment between WLCC models and Asset Policy.

To understand how well the WLCC framework and models apply the NR Asset Policies, the IR held at least two interviews with each of the Professional Heads for track, signalling and structures. Areas of interest for the IR when conducting these interviews were to understand; what role the WLCC models play in development of Asset Policy, the capability of the models to apply intervention strategies as set out in the Asset Policy, how new innovations set out in Asset Policies have driven model improvements, and what part the Professional Heads play in signing off model inputs and assumptions.

The current WLCC models themselves for track, signalling and structures.

A half day, on-site review session as well as several virtual interviews was held with NR to review the current WLCC models for track and signalling. Due to the solution architecture challenges with the structures model, all sessions held were remotely covering the same topics. To quickly gain a full, end-to-end overview of the WLCC models, the IR covered the following areas:

- Modelling Principles – coverage of WLCC framework requirements (Tier 1, 2 and 3).
- Model Architecture – file type, system requirements and capability required to run model.
- Key Asset Data – critical data points, source and impact on the model outputs.
- Asset Data Quality – current quality of Key Asset Data and measures to monitor/improve.
- Degradation Methodology – approach to modelling asset deterioration (curve types etc.).
- Modelled Interventions – available intervention library and work types that can be used.
- Unit Costs – basis for unit costs in the models and any pre/post-processing required.
- Computational Accuracy – model output accuracy and sensitivity.
- Model Outputs – range of outputs that can be produced by the model and their use.
- Output Validation – assurance of model outputs within modelling team and elsewhere.
- Change Control – scoping, implementation, testing and approval of model changes.

Regional application of the model outputs in development of investment plans.

Several representatives from across the Regions were interviewed across all asset classes to understand the Regional views and application of the model outputs in determining their investment plans. The interviews held initially focused on the Ready Reckoners supplied by the modelling team to the Regions and the review cycles that happen. Next, local DSTs and factors influencing the development of the investment plans were also discussed so the IR could build a picture of other factors influencing the development of investment plans.

3.3 Findings & Recommendations

The next three tables (Table 6, Table 7 and Table 8) provide a summary of the key findings and recommendations made during our review of the individual models themselves and their application to support policy and regional decision-making. Supporting observations and further detail can be found in the Appendices to this document (including a detailed overview of each model in its current state).

3.3.1 Track

Table 6: Track findings relating to the model, policy and regional application

Reference	Finding(s)	Recommendation
TRACK1-1	**The lack of a documented, step-by-step procedure for data preparation, model run, and output development is of high risk to the future sustainability of the track model.** With no documented procedure (and only a single competent person), validation through independent running of the same process is not possible. This standard governance process is not possible in the case of the track model and therefore smaller errors in the preparation of the data, model running or output preparation may be missed. Given the heavy reliance on MS Excel and MS Access, this type of validation is arguably even more important. There is only one person in the organisation who can complete all activities necessary to produce the expected outputs from the track model. From a redundancy perspective this is problematic, as there would be significant challenges if the current model owner was absent for any reason. The migration of parts of VTISM to C55 will reduce the likelihood of some error types, however it will not reduce the requirement for proper governance. The data preparation steps that take place in MS Access and MS Excel will still be required, as well as running VTISM. The addition of C55 adds another system and means another set of competences are required.	Author a documented procedure that covers the end-to-end process for building the data, running the model and preparing the outputs. The procedure should be a step-by-step guide that allows and competent person to achieve the same model results with no prior knowledge of the model itself. It should also cover the various parts of the model architecture, including; MS Access and Excel used for data pre-processing, MS Access for the model itself, C55 when appropriate for running Tier 1 forecasts and MS Excel to prepare the Ready Reckoner.
TRACK1-2		Train a second competent person in the use of the track model suite. This will provide some sustainability to the modelling framework as well as allow the current model owner to focus on improvement actions across the other asset classes.

Reference	Finding(s)	Recommendation
TRACK3-1	**It was observed that a large amount of time is required to request, collate, and prepare the data required for VTISM**. Currently, the model owner receives data in a raw format each year and carries out the documented pre-processing steps (note this is not a procedural document) over the course of 2-3 weeks. Only the model owner can carry out the pre-processing, therefore taking time away from validation and review of outputs from the model. Peer organisations to NR are making good progress in pushing this pre-processing back to the data owner.	Improve the interface between the NR modelling team and the data owners to transfer an agreed amount of pre-processing activity back to the provider. Actively seek to limit the amount of pre-processing that the SMOs currently carry out.
TRACK3-2		Develop a data improvement plan to reduce pre-processing activity with the objective to improve efficiency and save time for all parties involved (note that for track, most of the data was >95% complete. Efforts to improve data and ownership of pre-processing should be focused on S&C assets, where it was observed that the data was of much poorer quality.).
TRACK4-1	**The current process for extrapolating 19/20 Actraff traffic data is not sustainable as the Covid-19 recovery for the rail industry remains unclear**, and the proportions of each vehicle type are also likely to change.	Seek guidance on when the Actraff replacement is due. Ensure that there is representation from the SMO in requirement and specification workshops. If a replacement is not due for several years, the ORR and NR must decide if the current methodology is suitable for that time period.
TRACK5-1	**In some Regions variation was noted between the unit rates used for each Route.** For instance, within the North-eastern Region, the unit rates for track work in Anglia were higher than the rest of the Region based on the proximity to London (restricting access) and the fact that renewals in this Route were delivered by a different delivery organisation.	Conduct deeper analysis of the factors that drive unit rates within the Regions and associated Routes. Ensure that this analysis picks up on the sensitivity of changing the unit rates and present a clear picture of the driving factors to all stakeholders such that changes can be better understood. Fully transfer ownership and responsibility of owning unit costs to central and regional finance teams such that accurate data can be provided on an annual basis to the modelling team.

Reference	Finding(s)	Recommendation
TRACK6-1	**The Regions were unclear in describing how the track model outputs would be used to develop Regional asset strategies.**	Establish guidance for the Regions on how the track model can be used to inform the emerging Regional asset strategies. This should include detailed guidance how Tier 1 forecasts can be used and what Tier 2 questions can be asked of the model.
TRACK7-1	**A key outcome from the inquiry into the Stonehaven accident, that NR must improve its policy towards drainage across its infrastructure. Drainage is not currently factored into the track model.**	Monitor the development of the track drainage policy and DSTs being developed in other parts of NR and look for opportunities to integrate outputs into the track model. (High risk locations should be subject to closer monitoring and always have visual inspections after severe weather events rather than relying solely on modelled forecasts.)

3.3.2 Signalling

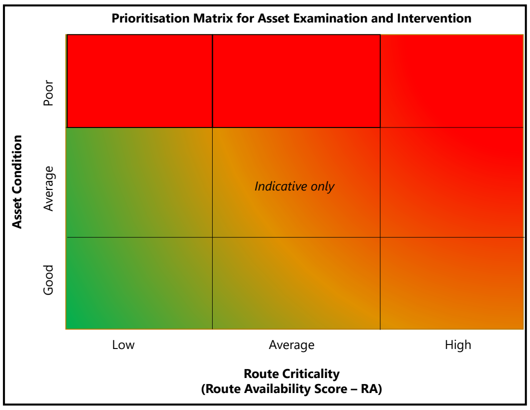
Table 7: Signalling findings relating to the model, policy and regional application

Reference	Finding(s)	Recommendation
SIGNA1-1	The focus has moved away from the original Tier 2 models on to the 'Digital Railway', This has meant that the degradation characteristics of the legacy assets as well as the Asset Lifecycle Profiles have not been updated and means that **representation of the modelled behaviours is out of date.** This has been recognised by NR and work is underway to update these	Review the Tier 2 aspects to the model and update these to reflect latest asset knowledge.
SIGNA2-1	**The degradation methodology for condition score (SICA) is overly simplistic as it is based on asset remaining life, stepped down each year, and does not reflect the differences between the asset types.** This has been recognised by NR and work arounds are in place ahead of an update to the model.	Update degradation methodology within the model so that it better reflects the asset characteristics based on the new data available. Any newly available information needs to be reflected in the policy and asset strategies as part of the ongoing CP7 Policy development activity.
SIGNA3-1	An up-to-date change log exists for the ICM, however, **there is no formal procedure for managing and testing changes before implementation.** At present, changes are made to the model on an ad-hoc basis and are self-assessed by the modeller before the updated model is released to the Regions.	Develop an auditable process for change control of the model. The process should contain a set of criteria that must be met before the updated model can be released.

Reference	Finding(s)	Recommendation
SIGNA4-1	**There is no formal documented procedure for validating the model outputs.** An internal review and validation of the outputs from the models is usually undertaken by the SMO only, before model results are released to the Regions. The final validation process could be considered limited as outputs are only validated by comparison to the previous years.	Establish a formal validation procedure that can be audited against annually and replicated by a competent person to minimise the number of errors in the model.
SIGNA5-1	**The ICM model does not provide the functionality to manage or model obsolete assets.** Obsolescence is managed outside of the model by the asset and Regional teams. Any specific obsolescence activities and campaigns are played back through the ICM as part of the overall work bank. NR recognise this as an area for future development in the ICM.	Explore the opportunity to embed obsolescence management into the model. Obsolescence of specific interlocking equipment is detailed in NR's own independent review report, and it is recommended that the same approach which was applied to the review of SSI interlockings, is also applied to areas such as mechanical interlockings and relays which are currently considered a known obsolescence risk.

3.3.3 Structures

Table 8: Structures findings relating to the model, policy and regional application

Reference	Finding(s)	Recommendation
STRUC1-1	**The structure of the model guidance document currently does not follow that of the Asset Policy**.	Directly align the structure of the model guide to the Asset Policy, so that specific sections map across between the two documents and they can be read in parallel. This will make model and document control more straightforward in addition to interpretation and training / user guidance.
STRUC2-1	**The assets on high Route criticality should be highlighted for more frequent inspection, but this is not a feature of the policy or model.** Instead, the Policy states that these assets will be maintained to a higher standard than mandated in the NR plan on a page.	More focus and frequency should be given to the inspection and intervention planning for the most critical assets, using a simpler matrix of asset condition and Route importance (defined using the Route Availability score, RA). This is illustrated in the diagram below. 
STRUC3-1	**Currently, the model first computes work volumes at a national level, after which Route-level simulations are run** to determine how total work volumes are assigned per Route.	Engage with local asset managers for the structures asset class to apply a greater level of local engineering knowledge, judgement and efficiency proposals to the model runs (for example considering adjoining assets and delivery plans). • This would allow more accurate reflection of asset types and characteristics along a particular Route, especially upgraded Routes where the structures assets would have been assessed and modernised / strengthened for the upgrade, providing a more up to date asset condition baseline.

Reference	Finding(s)	Recommendation
STRUC3-2		Consider applying the model on a Route by Route or Regional basis, then calculating the arithmetic sum of the outputs (expenditure forecasts) to provide forecasts at a national level. • The disaggregated models would be less cumbersome to operate and assure, through having far fewer data points. They would also support a more robust Monte Carlo model that can undertake a far higher number of simulations. The outputs of a true Monte Carlo model such as this would also indicate the sensitivity of the model results. The current model cannot do this because it can only do one simulation at a time. • Route or Regional based models would also allow improved comparability between of costs and volumes for assessment purposes. • The arithmetic total of Route based forecasts would dilute the inherent over-estimating that is locked-in to a single national model.
STRUC4-1	**The current Structures model has a limited scope** and only applies to underline and overline bridges.	A mitigation plan for this is in place. It is intended that Retaining Walls, Culverts, CERDS and Major structures will be added as part of the structures model in the short term.
STRUC5-1	Due to the complexity of the coding language configured by a third party, **navigation around the back-end model proves to be challenging for the NR modelling team.** This presents a challenge when challenging and validating the model outputs. Furthermore, if the model was to be handed over to a new SMO, navigation around the code would be challenging.NR procured the C55 asset management software by Copperleaf in 2020. With the new modelling platform, the risk of not	Develop and retain the coding capabilities underpinning the models, when migrating to the C55 software package, through training provided by Copperleaf to the NR modelling team.

Reference	Finding(s)	Recommendation
	being able to navigate around third-party configured code remains.	
STRUC6-1	**It is not evident that an up-to-date back-up of the model has been stored elsewhere within NR's system.** The model requires a high specification for computing power due to its large memory and processing requirements. It is understood that the model was originally cloud-based, however, it is now run locally on a desktop computer off-site. Migration of the structures model to C55 may address this finding, providing full coverage in the new system.	Store a back-up of the model elsewhere within NR's systems such that it can be relied on if the current model PC should become obsolete. The back-up model should be retained in parallel with the model in use such that any information contained is up to date (i.e. any new model versions should immediately be saved to a more secure location).
STRUC7-1	**It is not viable to perform more than one simulation of the national portfolio run of the model due to its run time** (up to 24 hours). It is also necessary to perform Route-level runs separately to generate Route outputs after the model computes portfolio work volumes.	Utilise the C55 platform to run more robust Monte Carlo simulations varying multiple input factors at a Route, Region and National level.
STRUC8-1	The Markov matrices used in condition degradation of minor elements have not been reviewed or updated since its rollout in 2016. In some cases, the apparent trends in the **Markov matrices do not reflect logical expectations as would be expected from a degradation model, this requires further validation.**	Update the bridge condition degradation mechanism with outputs from the various research projects underway and NR's own validation exercise to compare historical condition data to observed current.

Reference	Finding(s)	Recommendation
STRUC9-1	**There is a limited understanding of the relationship between condition and capability** and the deck capability degradation model based on the condition of its elements is basic.	Improve the current understanding in the model of the relationship between condition and capability. The updated degradation model should take into consideration individual asset characteristics such as location, usage, and material.
STRUC10-1	**There is limited confidence on the quality of the deck area data.** Deck height and width were obtained from the ALARMS system in 2016 and has not undergone a refresh since the date of input. A generic infilling rule has been configured to apply in cases of no recorded deck area. Some data sources feeding into the structures model have not been updated since the initial model release and require a refresh (e.g. deck area data from the ALARMS system by Amey has not been refreshed since 2016).	Document and be consistent in the rules for updating data inputs to the model in order to maintain confidence in the model results. Changes to the models rulesets may mean that previously low sensitivity fields are now an important driver in the model. Maintaining good quality data and frequent sensitivity analyses is critical.
STRUC11-1	**There is no formal audited procedure for managing and testing changes before implementation.** At present, changes are made to the model on an ad-hoc basis and are self-assessed by the SMO (with input by the Professional Head, but not full testing).	Develop and implement an auditable process for change control of the model. The process should contain a set of criteria that should be met before the updated model can be released.
STRUC12-1	**There is no formal documented validation process for assessing the model outputs.** An internal review and validation of the outputs from the models is usually undertaken by the modelling team only before model run outputs are released to the wider business.	Establish an auditable model quality assurance and validation procedures that are undertaken by a third party outside the immediate modelling team or a modeller independent of the structures model.
STRUC13-1	**There is currently no formal documented validation process for assessing the pre-processing**	Document all pre-processing procedures to ensure they are repeatable, and any human errors are identified before results are

Reference	Finding(s)	Recommendation
	routines on model inputs. Model inputs are pre-processed via a mixture of automated and manual methods. Not all automated pre-processing procedures have been documented.	shared with the stakeholders. Any automated processes should be documented with commentary against the code.

4. Conclusion

4.1 WLCC Framework Conclusions

There are numerous examples of leading practice within the NR WLCC modelling framework, particularly in the track and signalling models. The Ready Reckoners and mini-ICM are considered by the IR to be some of the most practical tools in the industry to enable end users interact with the WLC models. Providing the limitations of the underpinning models continue to be communicated alongside these outputs, then NR have an opportunity to maintain stakeholder buy-in whilst improving the models themselves.

It is the opinion of the IR that there is no overall industry standard practice for WLC modelling against which the NR framework can be compared to. There are observed good practices across various asset-intensive sectors, which NR may be able to take learnings from as well as feed into through knowledge sharing events. One strength of the NR framework when compared to other sectors, is that the models (even at the Tier 1 level) are developed bottom-up, from asset data and engineering knowledge. Where there are significant gaps in data or understanding, model outputs aren’t forced, but are instead tailored to what is available. For example, the structures model represents the broad asset base well, but the data isn’t there to accurately forecast individual elements (deck, bridge deterioration, etc.) so this is not currently carried out. This maintains a level of confidence in outputs, without them being completely written off and disregarded, which does happen in other sectors.

There are many other factors that are driving the choices that are being made in the development of the Regional plans such as, local stakeholder/customer needs, work delivery technology (e.g. High Output) and access constraints. The overarching effect of these other factors is that the eventual planned work volumes and costs diverge from the baseline produced by the WLCC models. Again, this is to be expected as part of a planning process. However the size of the divergence between actual plans and modelled outputs should be considered when investing to improve the accuracy of the models, as the current levels of accuracy may be good enough with the benefit coming from providing a controlled baseline against which the impact of changes can be measured.

One critical observation made, is that the models do not truly optimise for WLC. They simply aggregate work volumes and costs based on a set of rules defined in the respective Asset Policy. There is no capability to trade-off the capital, maintenance, and operational interventions (and their effects on asset condition, performance, and reliability) across an asset’s life. It was the intention of the original Tier 2 models to do this. WLCC models that combine deep understanding of maintenance regimes and capital investment options exist independently but have not been brought together into a true WLC model in any sector. Therefore, use of the term ‘WLCC Models’ is somewhat of a misnomer.

4.2 WLCC Application Conclusions

Table 9: WLCC application RAG conclusions and comments

Requirement	Track	Signalling	Structures	Comment
Calculate and forecast the whole lifecycle costs for the Asset Disciplines at a portfolio level to enable a variety of funding scenarios to be tested and ultimately secure funding (Tier 1)	🟩	🟩	🟩	All models can calculate and forecast the capital costs and volumes at a national level (assuming a constant maintenance regime), but to various degrees of granularity. The IR believes that the models are fit for purpose to satisfy this requirement, however there is room for improvement in the structures model.
Provide volumes and budgets to the Regions based on applying the Asset Policies and funding scenarios to enable them to develop their plans (Tier 1)	🟩	🟩	🟨	The track and signalling models provide Regions with reasonable estimates of the local costs and volumes required over future control periods to maintain certain performance characteristics. Due to the structures modelling working on a national averages basis, an accurate reflection of the work required at a Regional level is not a strength of the current model. For the structures model to satisfy these Tier 1 requirements fully, the modelling approach needs to include a greater number of Regional factors and an improved approach to modelling bridge capability.
Provide a baseline against which the Regional Plans can be tested (counterfactual) (Tier 1)	🟩	🟩	🟨	
Model the impact of changes away from Asset Policy or funding scenarios over future Control Periods to understand their sustainability (Tier 1)	🟩	🟨	🟨	The track model fully satisfies this requirement. The signalling degradation model is currently too simplistic to reflect changes in policy, however changes in finding scenarios can be modelled through updating the input work bank. Like signalling, the structures degradation model does not allow thorough testing of policy changes, however different budget scenarios can be tested at a national level.

Requirement	Track	Signalling	Structures	Comment
Test and justify Asset Policy decisions (Tier 2)	🟩	🟨	🟥	The track model is capable of accurately testing Asset Policy decisions and the impact on future control periods. The current issues with the degradation models in both the signalling and structures model makes modelling Tier 2 asset policy decisions more challenging. Signalling can support options analysis on specific schemes as well as coding policy changes into the work bank, which may inform policy. Difficulties modelling the structures asset class due to the High Impact, Low Probability (HILP) nature of how bridges degrade, mean it is not currently possible to model accurately at the Tier 2 level. However, the IR feels this could be better satisfied with the current model (moving this to an amber).
Provide tools to support the development of Regional Plans based on the outputs of the model (Tier 3)	🟩	🟩	🟥	In partnership with other DSTs in existence at NR for track and signalling, the current models can support the development of Regional Plans. Due to the way the current structures model has been developed (condition-based) and the lack of an intervention library that reflects actual work being delivered (does not have a Strengthening and Repair option), the structures model does not support development of Regional Plans.
Input Data and Data Quality	🟩	🟩	🟩	Data quality is generally of good standard and does not undermine confidence in the model outputs. Whilst there are improvements still to be made to a small number of inputs and future model improvements may reduce input data quality, this IR does not feel this is an area of concern.

Requirement	Track	Signalling	Structures	Comment
Work done on developing the model	🟩	🟩	🟨	There have been changes to all the models since the last detailed review in 2013. The very recent introduction of C55 will provide an enduring platform to accommodate most of the WLCC models in the NR framework. Additionally, more tactical improvements have been made, with an entirely new model for structures. Although work has been done to improve the structures model, we believe this work did not move the model on significantly from the previous version. For the signalling model, amendments have been made to the CAPEX cost modelling methodology to include add-on costs in response to inaccuracies within CP5 estimates. Add on costs enable the capture of 'abnormal' works which accounted for much of the disparity seen in estimates from the previous Control Period.
Cost Data and Unit Rates	🟨	🟨	🟥	Unit cost data is a challenge for all models. Regions record Key Cost Lines (KCLs) and Key Volume Lines (KVLs) inconsistently, which means that pre-processing is required to remove mixed work volumes, realign KVLs to KCLs, consolidate all regional data and calculate a national average. Furthermore, the business does not yet understand the key drivers of regional cost variances and so the Regions reported that they generally have to manually alter the unit rates within the Ready Reckoners. It was noted that the latest Round 4 model forecasts for track did use route-specific costs, however there is still uncertainty around these figures.

4.3 Overall Conclusions

This review was undertaken during the planning process for CP7, and as such both the Asset Policies and the WLCC models were undergoing changes. This review focused on the existing CP6 Asset Policies and the current configuration of the models.

1) The IR believes that NR can move forward with the CP7 with confidence, the IR view is that the most critical function of the WLCC framework is its ability to forecast the long-term impacts of the work volumes and costs planned in the five-year control period to ensure it is sustainable and is not driving a future bow wave of investment that will not be affordable.
2) The outputs of the models and the provision of these through the 'ready reckoners' enable a degree of control in the application of policies and the development of the Regional plans however the model capabilities vary in their accuracy. Many of the weaknesses and limitations of the models are already understood by the Technical Authority and are communicated with the outputs. Plans are in place or underway to address many of these limitations.
3) There are many other factors that are driving the decisions that are being made in the development of the Regional plans such as, local stakeholder/customer needs, delivery technology and access constraints and as such any further refinement of the models should take cognisance of this to ensure they continue to provide value to the Regional teams.
4) There are numerous examples of leading practice within the NR WLCC modelling framework, particularly in the track and signalling models. The Ready Reckoners and mini-ICM are considered by the IR to be some of the most practical tools in the industry to enable end users interact with the WLC models. Providing the limitations of the underpinning models continue to be communicated alongside these outputs, then NR have an opportunity to maintain stakeholder buy-in whilst improving the models themselves.
5) Devolution of the organisation is driving the outcomes and content of the investment plans to be focused more on the local requirements of the Regions and Routes rather than national policies. To accommodate this NR are restructuring their Asset Policies and developing Regional Asset Strategies. A clear direction is required for the ongoing development of the WLCC Framework, capturing the desired architecture of models, their ownership and their purpose to support this more localised approach.
6) Work has been undertaken to improve the models since the last review in 2013, this varies between the three asset disciplines with refinements to the track model, updates to the signalling Tier 1 model and for the structures model the development of a new Tier 1 model in 2016. The work for the signalling and structures models has focused on the Tier 1 Portfolio models, the Tier 2 models have not been developed and this has led to the modelling and understanding of asset degradation stagnating for these disciplines. This has been recognised by NR and plans are in place to address this.
7) Much of the WLCC development work has led to and continues to lead to positive improvements in the models, such as the move to the C55 platform, however the IR believe much of this was undertaken without an overarching development strategy or plan and a key recommendation from this review is to develop an appropriate improvement strategy linked to the purpose of the models and the value they will provide.
8) Whilst asset information has improved there is still a lot of work that is undertaken by the modelling team to cleanse the data so that it can be used in the models. This data cleansing activity should be pushed back down the data provision supply chain so that it encourages greater discipline in the capture of by the data owners. There are specific areas that need

addressing such as the supply of actual traffic data, with ACTRAFF, the system that was used to supply this data, having been decommissioned without a replacement.

9) Cost data and the provision of realistic unit rates into the WLCC models still remains a challenging area for NR. This is not a unique position as control and provision of accurate unit rates into the investment planning process is a challenge across industries. The IR believe that the devolution to the regions has left the responsibilities for the development of unit rates being uncertain and whilst it is recognised that the intention is for the Regions to pick up this responsibility the degree to which this was taking place was varied. It is recommended that further study should be undertaken into the management of unit rates in the devolved organisation

A full list of recommendations from this review is presented below, identifying where the IR believes NR has in-flight mitigations and where groups of recommendations may be addressed with a single action.

Table 10: Summary of WLCC framework recommendations and comments on NR mitigations the IR is aware of

Reference	Summary of Recommendation	Comment
FWORK1-1	Capture the existing 'As-Is' suite of WLCC models in a single architecture diagram against a common framework.	NR aware and working to address this recommendation. It is acknowledged that there needs to be some flexibility around the framework, but the IR feels this still needs to be addressed.
FWORK1-2	Publish the 'As-Is' framework to all relevant stakeholders (ORR, Regions, finance, Professional Heads, asset strategy owners), or a group with broad representation of all stakeholders, to gain agreement on expected outcomes.	IR not aware of any current plans to address.
FWORK1-3	Develop a 'To-Be' architecture diagram showing where opportunities for improvement exist (including current in-flight initiatives).	IR not aware of any current plans to address.
FWORK1-4	Establish a governance forum for controlling ongoing usage and development of the WLCC Framework, ensuring the overall purpose is satisfied and remains aligned with stakeholder expectations.	IR not aware of any current plans to address.
FWORK2-1	Establish a robust internal assurance process complying with expected assurance procedures, which recognises the significance of these models in the planning process.	NR aware, but a plan to address this set of recommendations needs to be developed. Whilst there are specific asset class challenges with governance, there is overlap with recommendations FWORK3-2, TRACK1-1, TRACK1-2, SIGNA3-1, SIGNA 4-1, STRUCT5-1, STRUCT6-1,

Reference	Summary of Recommendation	Comment
		STRUCT11-1, STRUCT12-1 and STRUCT13-1.
FWORK3-1	Review the NR modelling team structure against recognised good practice for National Critical Models and redesign the team to better support the need for robust assurance processes.	IR unaware of any current plans to address, however it is acknowledged that there is an approved increase in headcount for the NR modelling team which the IR would support.
FWORK3-2	Introduce independent validation of all models within a process, with defined validation triggers (e.g. annually or at least every CP submission as a back-stop).	See FWORK2-1.
FWORK4-1	Consult with Finance, both centrally and in the Regions, to understand the current unit cost challenges faced by the SMO.	IR not aware of any current plans to address.
FWORK4-2	Implement individual findings and recommendations on unit costs related to each of the models reviewed.	IR not aware of any current plans to address.
FWORK5-1	Establish a forum, including the Technical Authority, to capture, review and share the Regional decision support tool development activities.	IR not aware of any current plans to address.
FWORK5-2	Review the suitability of the current structures model given the findings presented by the Regions and the later model observations made in this review document.	There is work underway to review how capability can be better represented in the model. This needs to feed into a wider review of the model given the findings and recommendations in this report.
FWORK5-3	Further refine the track and signalling models as required following an assessment of other factors that influence the planning process within the Regions and the development of other optimisation tools such as Plan-IT.	IR not aware of any current plans to address.

Table 11: Summary of track model recommendations and comments on NR mitigations the IR is aware of

Reference	Summary of Recommendation	Comment
TRACK1-1	Author a documented procedure that covers the end-to-end process for building the data, running the model and preparing the outputs.	See FWORK2-1.
TRACK1-2	Train a second competent person in the use of the track model suite.	See FWORK2-1.
TRACK3-1	Improve the interface between the NR modelling team and the data owners to transfer an agreed amount of pre-processing activity back to the provider.	IR not aware of any current plans to address.
TRACK3-2	Develop a data improvement plan to reduce pre-processing activity with the objective to improve efficiency and save time for all parties involved.	IR not aware of any current plans to address.
TRACK4-1	Seek guidance on when the Actraff replacement is due. Ensure that there is representation from the SMO in requirement and specification workshops.	IR not aware of any current plans to address.
TRACK5-1	Conduct deeper analysis of the factors that drive unit rates within the Regions and associated Routes.	IR not aware of any current plans to address.
TRACK6-1	Establish guidance for the Regions on how the track model can be used to inform the emerging Regional asset strategies.	IR not aware of any current plans to address.
TRACK7-1	Monitor the development of the track drainage policy and DSTs being developed in other parts of NR and look for opportunities to integrate outputs into the track model.	IR not aware of any current plans to address.

Table 12: Summary of signalling recommendations and mitigations the IR is aware of

Reference	Summary of Recommendation	Comment
SIGNA1-1	Review the Tier 2 aspects to the model and update these to reflect latest asset knowledge.	NR recognises the need to update the Tier 2 models and ALPs and work is planned or underway.
SIGNA2-1	Update degradation methodology within the model so that it better reflects the asset characteristics based on the new data available.	NR are aware and underway with reviewing the signalling degradation assumptions. The IR feels this is important to monitor as the current approach does reduce confidence in the model outputs.
SIGNA3-1	Develop an auditable process for change control of the model.	See FWORK2-1.
SIGNA4-1	Establish a formal validation procedure that can be audited against annually and replicated by a competent person to minimise the number of errors in the model.	See FWORK2-1.
SIGNA5-1	Explore the opportunity to embed obsolescence management into the model.	NR considers its obsolescence modelling knowledge to be underdeveloped and plans to go out to tender for further support in this area.

Table 13: Summary of structures recommendations and mitigations the IR is aware of

Reference	Summary of Recommendation	Comment
STRUC1-1	Directly align the structure of the model guide to the Asset Policy, so that specific sections map across between the two documents and they can be read in parallel.	IR not aware of any current plans to address.
STRUC2-1	Improve the inspection and intervention planning for the most critical assets, using a simpler matrix of asset condition and Route importance.	IR not aware of any current plans to address.
STRUC3-1	Engage with local asset managers for the structures asset class to apply a greater level of local engineering knowledge, judgement and efficiency proposals to the model runs.	IR not aware of any current plans to address.
STRUC3-2	Consider applying the model on a Route by Route or Regional basis, then calculating the arithmetic sum of the outputs (expenditure forecasts) to provide forecasts at a national level.	IR not aware of any current plans to address.
STRUC4-1	It is intended that Retaining Walls, Culverts, CERDS and Major structures will be added as part of the structures model in the short term.	NR underway in planning to add further sub-asset classes to the structures model.
STRUC5-1	Develop and retain the coding capabilities underpinning the models, when migrating to the C55 software package, through training provided by Copperleaf to the NR modelling team.	See FWORK2-1.
STRUC6-1	Store a back-up of the model elsewhere within NR's systems such that it can be relied on if the current model PC should become obsolete.	See FWORK2-1.
STRUC7-1	Utilise the C55 platform to run more robust Monte Carlo simulations varying multiple input factors at a Route, Region and National level.	Migration to C55 underway for the structures model. Approach to monte Carlo then needs to be improved.

Reference	Summary of Recommendation	Comment
STRUC8-1	Update the bridge condition degradation mechanism with outputs from the various research projects underway and NR's own validation exercise to compare historical condition data to observed current.	Research projects currently underway. Model improvement plan then needs to be developed. See FWORK5-2.
STRUC9-1	Improve the current understanding in the model of the relationship between condition and capability.	See STRUC8-1 and FWORK5-2.
STRUC10-1	Document and be consistent in the rules for updating data inputs to the model in order to maintain confidence in the model results.	IR not aware of any current plans to address.
STRUC11-1	Develop and implement an auditable process for change control of the model.	See FWORK2-1.
STRUC12-1	Establish an auditable model quality assurance and validation procedures that are undertaken by a third party outside the immediate modelling team or a modeller independent of the structures model.	See FWORK2-1.
STRUC13-1	Document all pre-processing procedures to ensure they are repeatable, and any human errors are identified before results are shared with the stakeholders.	See FWORK2-1.

Appendix A – Document List

Document Name
CP6 Track Asset Policy
CP6 Signalling Asset Policy
CP6 Structures Asset Policy
AMF Handbook
AM Process SIPOCs
Whole life cycle cost model support to life extension and efficiency
CP7 Model Forecasts
Bridges Model Configuration
Signalling Model Configuration
Track Model Configuration
CP7 Round 2 Model Forecasts
Round 2 Summary Baseline Results
CP7 Round 4 Track Forecast Ready Reckoner
UB_OB Ready Reckoner
P13 Data Quality Measurement Report
SBP Review
Signalling Mini ICM
Independent Review of Signalling Planning for CP7
CP7 Round 4 Model Forecasts (Round 4 Report)
Failure Regression Report for Track
Validation Report for Track
Tier 1, 2, 3 Model Framework Slides
Model Fit diagram & Description
DFT Register of Critical Models
Model Guidance Documentation
Model Change Logs
AA Self Assurance - (Asset Tier 1 Whole Life Cost Model - Signalling) RF11The
AA Self Assurance - (Asset Tier 1 Whole Life Cost Model - Track VTISM)
AQA Audit Report - Signalling ICM - FINAL v1.0 - 30Sep2020

Document Name
Network Rail Business Critical Model Register - Spring 2021
NR Analytical Assurance policy Nov 2016 (1)
Strategic Planning Models Overview Sep 21 - AMCL
Sig ICM Change Control Log
Mini ICM Guide 2020
Signalling Data Dictionary
Signalling Asset Model Test Plan v2
Modelling Analysis for NWG v0.1
Modelling Analysis for Round 3.5 Draft v0.1
Combined Service Safety Sustainability Models Draft v4
AVA Intro
RAMP Information Sources
Data Preparation 2020 Issue 1
Track Processing Data Record
Track Unit Costs V2
RF11 F21 Budgets CP6
All Routes Results Summary Round 4 High
Track Vols and Costs
Model Runs Post Processing Costs (Bridges)
Model Runs Post Processing Condition (Bridges)
Module 01 Workbank Planning (Signalling)
Module 02 Technology (Signalling)
Module 03 Maintenance (Signalling)
Module 04 Environmental and Social Performance (Signalling)
Signalling Renewals Analysis – ORR Version
Signalling – SICA Deterioration Regression Analysis

Appendix B – Detailed Observations on the Track Model

ALIGNMENT OF POLICY AND THE TRACK MODEL

Subject	Observations
Alignment of the model to the Asset Policy	The CP6 policy was developed in principle to: • Maintain the target for overall track condition achieved during CP5 and improve on the high criticality/high traffic Routes. • Maintain the CP5 end target for number of service affecting failures, averaged over CP6. • Maintain the CP5 end target for train delays and costs. • Improve the condition of S&C geometry and switch gauge. For CP7, there is an intention to continue with the same policy which is to maintain a steady state scenario that retains the track outputs from the end of CP6 and subsequent Control Periods at the lowest whole life cost. The structure of the Policy is being changed for CP7. The Technical Authority will be responsible for a high-level Policy document setting out key principles for managing the track assets. This document will be supported by technical standards. The Regions will then be responsible for developing Asset Strategies for their particular Regions. This change has been included within NR's standards brief for September 2021, becoming a requirement in December 2021. The model has calculated the optimal distribution of renewal and heavy maintenance works for each operating Route based on policy guidelines. The guidelines are built around asset and Route criticality, though for some areas, the track priorities have not been updated due to boundary changes or changes in traffic forecasts. An outcome of the inquiry for the Stonehaven accident is that NR improves its policy towards drainage on its infrastructure. This may have a significant impact on the track assets and drainage is currently not explicitly included in the track model. Renewals – the policy for renewals is targeted at where the existing track system performance is critical and would be more cost effective to replace the entire track system rather than the components. The policy rightly assumes that the following scenarios are the most likely to be required:

Subject	Observations
	• High criticality Routes. • High criticality S&C. • Where the track system has life expired components. • The track is located on poor formation. The model does reflect the policy for renewals and is regularly reviewed. The most recent review has identified a reduction in the work bank for the remainder of CP6 with the Anglia Route having the biggest reduction in its work bank. The track model is built on the basis of 220 yard track sections and the outputs from the model to date have been specific intervention activities related to these individual sections. From a planning perspective, outputs at this level of granularity are not practical. This has been recognised by the modellers and work is underway to develop the rules and functionality to group adjacent sections. The model has recently considered adoption of new technologies for use in renewals. An example is the introduction of sleeper pads. This was not reflected in the CP6 policy, however the model has been used to understand the impact on asset life. Refurbishment – The policy towards refurbishment is to maximise the service life of the track system and its constituent components. The policy mentions that the proportion of refurbishment to full renewal is higher on low criticality Routes, which is appropriate. Refurbishment can also be used on high criticality Routes if the cost benefit is demonstrated via the model. The model reflects the policy for refurbishment categorising it as follows: • Medium refurbishment does not include full ballast replacement and is expected to extend the service life of the track system by 20%. • Heavy refurbishment, which also includes ballast replacement, it is expected to deliver a 50% extension in service life. • Several scenarios are considered as part of refurbishment. These include the following: ○ Single or both rail replacement ○ Single or both switch replacement ○ S&C regauging

Subject	Observations
	• OTM work • Ballast cleaning Some of the items above are undertaken by the maintainer and the model assumes that, for example, S&C components (i.e. half set or full set of switches or cast crossing) will be replaced at one-half or one-third of their lives, as necessary, to achieve the overall system life.
Do the Asset Policy and modelled behaviours reflect the latest knowledge of the asset class?	The track model is designed to enable continual feedback and updates to the asset behaviours based on actual behaviours monitored through the various inspection and condition monitoring activities and tools. The model is updated based on trends in actual behaviours (over at least three years) to avoid anomalies influencing the model. There is continual dialogue between the central Technical Authority team and the Regional Track Engineers to review and decide on updates to the asset behaviours and factors that influence them. Based on the IR's understanding, the track model reflects the latest intelligence across the industry. This is enabled through several inputs and controls, including external forums which help model development such as R&D organisations and universities.
How is maintenance reflected in the model?	The track Asset Policy includes a mixture of manual and automated methods to complete maintenance and inspection activity. The CP6 policy does mention that where it is economically possible, this is to be undertaken by automated means. The track model includes the heavy maintenance activities that are undertaken on the infrastructure (tamping, ballast cleaning, grinding etc.). For the remaining maintenance activities, the model assumes maintenance practice will remain the same in irrespective of any changes in track specification and condition. Since the steady-state scenario keeps track approximately the same, this results in approximately constant maintenance resource requirements. It takes no account of any changes to maintenance practices outside of heavy maintenance and how these may influence the asset behaviours. It does not include day to day maintenance activities or account for the costs associated with this maintenance to drive intervention decisions.

SUMMARY OF THE TRACK MODEL – VTISM

Asset Discipline:	Track	
Asset Classes:	Plain Line	Switches & Crossings
Modelling Principles	VTISM is the most complex model of the three reviewed in this report. It models the asset class at least to the level of a typical NR Tier 2 model. It can be used to both develop high level business plans (Tier 1), and answer Tier 2 type questions such as the impact of different vehicle characteristics and traffic volumes on lifecycle costs. Its development is jointly managed by the Rail Safety and Standards Board (RSSB) and NR. With the transfer to C55 underway, VTISM will in the future, be used to answer Tier 2 questions, whilst the C55 platform will manage the Tier 1 aspects.	
Model Architecture	Data pre-processing is carried out in multiple MS Access databases and MS Excel files, with multiple linking tables and automated processing algorithms. Results from pre-processing steps are summarised in a single MS Excel file, detailing % metrics on missing data and assumptions made. A short summary of each pre-processing step is documented in a single MS Word file.	
Key Asset Data	To prepare data for VTISM, raw data exports from several systems are requested from the data owners. The information is provided as a raw export from the system, with no pre-processing done by the owners. All pre-processing is done by the model owner. For Plain Line, the most important data sources are the Integrated Network Model (INM) and the Asset Data Store (ADS). INM contains key Plain Line inventory information such as track layout and is updated weekly. ADS is an interim data store holding copies of information from a range of other NR systems. It primarily holds S&C data from Ellipse and is updated at least once per week. It was identified that there was limited discussion with the data owners on the quality of the information being supplied. A consolidated plan of data improvements to enhance model outputs and reduce model uncertainty was not seen, which may become problematic in the future as Regions begin gathering more information themselves. Traffic data is a critical input to VTISM as the volume and type of traffic (usage) has a significant bearing on the degradation of the track assets. Actraff is the primary source of this data containing actual volumes and train types that have been moving around the network. However, there are a couple of key challenges with the data:	

Asset Discipline:	Track	
	• Issue: Actraff was decommissioned in 2019/20 but has not yet been replaced and other data sources do not provide the level of granularity required for the model. Actraff was an important system for VTISM (and other use cases), and it is not yet known when the replacement will be delivered. Impact: As it currently stands, most data for VTISM is updated annually. At the point of annual update, Actraff data from 19/20 has to be extrapolated in the absence of any new actuals data. Another data source, TABS, can be used to adjust Actraff traffic data at a total volume level, but this does not distinguish between traffic type. • Issue: Track layout in the Actraff system is outdated, in some cases by more than a decade. VTISM is an asset-level model that assesses the degradation of individual track sections based on a current track layout. In some instances, Actraff models certain parts of the network as 2-track when it is now 4-track. As track volumes have increased, Actraff with its old layout has assumed that all traffic goes down the original 2-track lines. Impact: Significant pre-processing and extrapolation of the Actraff data is required before the data can be used within VTISM. Traffic volumes are divided by two, where the track layout as since changed to 4-track.	
Asset Data Quality	Asset data used to model Plain Line is generally of good quality. However, significant pre-processing is required on an annual basis in preparation for the VTISM model to be run. Much of the pre-processing is required because: • There are numerous source systems holding data required for VTISM requiring consolidation. • The various methods for sectioning the track across the source systems, require alignment. • Many of the interim data points required by VTISM need calculating from the raw asset data before importing. The pre-processing observed was largely automated (through established rulesets and algorithms), with some manual	S&C assets inherit many of the attributes from the track section to which it is assigned. It is therefore important to have accurate locational information. Much of this data is held within Ellipse and there are issues with the location details. The VTISM model uses length as a key attribute in numerous calculations, hence it is critical to have an accurate location of each asset. Some pre-processing is required to correct these locations, which is done manually through tools such as GEORINM. The plan to migrate S&C asset data over to INM is anticipated to solve some of these issues, however it was reported that this is 2-3 years away at the time of this review. For both Plain Line and S&C, data collation and pre-processing steps are documented within an MS Word file. However, this was observed to not be a full procedural document and a new

Asset Discipline:	Track	
	intervention required where anomalous data points could not be corrected by the algorithms.	user would still require substantial training in the methods before this could be replicated.
Degradation Methodology	Track condition is measured at the asset level in terms of: • Ballast fouling index. • Rail/sleeper/S&C used life. • Track geometry. • Rail defects. • Rail wear. Each aspect of track condition is recalculated at the end of every period (a calendar year is divided into 13 periods), prior to any interventions that either monitor or affect the track condition within the model. In addition, the user has the ability to change the modelled characteristics of the track related to tonnage and line speed via database queries to analyse the impact of different utilisation scenarios on track deterioration. Current and future modelled track condition for each track section are assigned a track quality band, a measure of good track geometry (GTG) and a measure of poor track geometry (PTG) are calculated based on the track quality at a route level for each route criticality band.	
Modelled Interventions	After calculation of initial track condition, the track condition at the end of the current Control Period is calculated. CP6 budgets are then gathered from Regions based on latest forecasts for the remainder of the Control Period. This data is gathered from Hyperion and adjustment to volumes is made by analysis of the Oracle Projects (that are the input to Hyperion). TRS is used to distribute the works on a route by route criticality. This 'direct work' is applied first before indirect work is generated for the remainder of the Control Periods forecast in the model. The broad intervention types contained within the track model are: • Enhancement (changing the capability of the asset). • Renewal (wholesale replacement of the asset). • Refurbishment (restoring the performance of the asset).	

Asset Discipline:	Track
	• Maintenance (maintaining the current performance of the asset). These categories are disaggregated further within the model into more specific interventions, broadly covering all types of investment that can be made into the track asset class. The process for building the work banks is comprehensive, with VTISM iterating through several loops to identify, prioritise and schedule work.
Unit Costs	Accurate unit costs are difficult to produce for all model interventions. Generally, the unit costs for the track asset class are the most accurate (due to the lower complexity, but mostly due to highly repeatable work types), however there are still challenges with the data in its current format. The two key data points required to calculate unit costs are: • KCLs – Key Cost Lines • KVLs – Key Volume Lines These are recorded in Oracle Projects at a Regional level (i.e. by cost code). For track, there is good alignment between the KVLs and intervention types within VTISM (almost a 1:1 matching). However, there are inaccuracies at the Regional level where data is missing or costs/volumes are recorded incorrectly. Once KCLs and KVLs are matched, the track model owner adjusts for mixed volume work (work that spans multiple KCLs/KVLs but is not split out when recorded) and sums to a national level. Finally, the national rate is then adjusted for Regional variances based on historic data. It was reported that there is currently a limited understanding of why Regional variances occur and what the drivers are behind them. Further investigation is required to better understand and predict these variances.
Computational Accuracy	Serco Rail Technical Services have undertaken a review of the T-SPA model and associated VTISM databases on behalf of NR in 2018 following a recent re-calibration. Model outputs were first validated by comparing a test case output in the latest version of the model to the previous version which identified no deviations. The model configuration was tested by tracking of the changes to service life groups, ballast behaviour parameters and resultant deterioration rates and renewals on the T-SPA trace files and asset dump as the result of each test case. The report concluded that the model performs as designed and was able to run without errors. The model was found to respond correctly to changes in input parameters in line with specifications in the model configuration documentation and was approved for release.

Asset Discipline:	Track
Model Outputs	On completion of the data pre-processing, the VTISM model (also contained in an MS Access file) can be run individually for each Region or all Regions at the same time. The current process is to take each Region individually, define work volumes for CP7-12, run the model and analyse track performance outputs. The process is repeated several times, adjusting the work volumes, until the desired set of track performance levels are met. This trial-and-error process requires an understanding of how each intervention work type affects track performance outcomes. Interim results are viewable in the VTISM model. When a final set of work volumes and associated track performance profiles have been reached for CP7-12, the model run is finalised, and an MS Excel file is produced. The process is repeated for each Region. The output file provides the information necessary to then build the Regional Ready Reckoners.
Output Validation	Once the Ready Reckoners are complete, they are sent to the Regional representatives for review. The SMO seeks feedback from the Regions on the forecast work volumes, and receives edited versions of the Ready Reckoners back, with adjusted work volumes, unit costs and associated key outputs metrics (total cost etc.). Variances are tracked and identified within the Ready Reckoner allowing for discussion, but this is not pursued fully.
Change Control	Changes to the track model are reasonably well controlled as VTISM is jointly owned by NR and the RSSB. Furthermore, changes made to T-SPA are thoroughly tested and calibrated by Serco with detailed reports provided.

REGIONAL APPLICATION OF THE TRACK MODEL

Subject	Observations
Use of the WLCC model outputs in the Regions	The process to develop the Control Period plans in the Regions and Routes is well understood from the receipt of the model outputs from the Technical Authority through to the eventual feedback into the model of the planned bottom-up work plans. On receipt of the initial outputs the Region co-ordinates a response from the Routes and feeds-back using the Ready Reckoner to the Technical Authority for Round 2 and so on. The Regional teams generally work closely with the Technical Authority (in some cases weekly discussions) to review and validate the work volumes from the track model and provide feedback. The Regional teams have the ability to feedback and include factors specific to their areas such as local deterioration factors and 'One off' assets such as the slab track outside St Pancras (this was added through an adjustment to cost).
Accuracy of the models & confidence in outputs	With accurate inputs to the model there is generally a high level of confidence in the outputs from the track model in terms of the volumes of work that it predicts and the impacts the volumes of work planned will have on long term remaining life and service lives of the assets. The confidence that the inputs are correct varies between the Regions. For example, in the Western Region the initial runs of the models were deemed to underestimate the work required by 50% based on factors such as deferred renewals from previous Control Periods not being factored in. The limitations of the model are understood, such as it only models the running lines. There are many factors outside of the model that have to be considered in the development of the Control Period work banks, such as funding availability, allocation of funding across the disciplines, access and the use and efficiency of High Output plant. Access constraints in some locations are driving inefficiencies or increased costs. The trade-off between productivity, cost and access is not considered in the model nor is trade-off between disciplines. In producing the early model runs one of the discrepancies was the actual work done in the previous Control Period (CP6) verses what was planned.

Subject	Observations
Regional contribution to model development	The Regional track team work closely with the Technical Authority through the development of the Control Period plans. They have the opportunity to feedback any concerns in the model outputs, make changes and suggestions for improvement. If appropriate, the changes and updates are addressed in future runs of the models and associated Tier 1 modelling forecast documents.
DSTs	The Regions have found the Ready Reckoner for track very useful and it has enabled them to quickly and easily look at the impacts of changes to the work bank key measures such as SAFs, efficiencies and unit rates. New track DSTs (e.g. Insight) are coming on line more and more data is being provided to the local teams on asset condition. The same level of data is not included in the central track WLCC and the Regional teams are finding the situation that they can clearly justify a decision at a local level that has not been reflected in the outputs of the WLCC tool. This could lead to an erosion of confidence in the central model.
Data and information currency and quality	Regions have confidence with the data and information quality in the model. The model uses INM data and is updated twice a year. One area of weakness has always been a challenge and that is rail age. Through the various interactions between the Regional teams and the Technical Authority, driving factors and underpinning assumptions (e.g., asset degradation) are challenged and areas that could be improved are identified. An example from the Eastern Region was that they were seeing a potentially longer service life for sleepers, and were liaising with the Technical Authority to see how this can be better represented within the model.
Unit rates	The unit rates used in the model look at the previous years and then through liaison with the Programme Director for track renewals, factors are identified that drive the rates (e.g. access) and an average unit rate is agreed relevant to the Region. This unit rate is fed back into the model. It was noted that there are variations in some Regions between the unit rates for each Route. For example, for the North-eastern Region the unit rates for track work in Anglia were higher than the rest of the Region based on the proximity to London (restricting access) and the fact that renewals in this Route were delivered by a different delivery organisation.

Appendix C – Detailed Observations on the Signalling Model

ALIGNMENT OF POLICY AND THE SIGNALLING MODEL

Subject	Observations
Alignment of the model to the Asset Policy	The NR Signalling Asset Policy [NR/L1/SIG/50021] and supporting modules (Work Bank Planning, Technology Strategy, etc.) specify the approach for Control, Command and Signalling (CCS) systems for CP6 and beyond. The CCS level 1 policy sets out requirements for the following areas: • Strategy and planning. • Safety and improvement principles. • System interfaces. • Work bank planning. • Enabling the digital railway. • Minor works. • Technology. • Maintenance. • Asset information and decision tools. • Environmental and social performance. The CCS Asset Management Policy seeks to optimise the performance, risk and cost of ownership of the signalling estate across all of its life cycle stages from concept to disposal to deliver minimum whole life cost. The requirements to ensure alignment of signalling Asset Policy with the ICM and C55 tool are defined in the Asset Investment Planning Specification for Platform Configuration for Signalling document, last revised in May 2020.

Subject	Observations
	Through a structured document review and interviews with key stakeholders, it is evident that significant thought has gone into the alignment of the signalling model and its configuration with the Asset Policy, although improvements in areas such as obsolescence planning and Route Criticality (RC) assignments were identified. The accuracy of input data is varied, and a number of recommendations have been made which will further ensure the modelling reflects actual needs. These recommendations should be read in conjunction with the independent review of planning for CP7 signalling, commissioned by NR, which aligns with the key findings in this report. Obsolescence of signalling assets has been considered within the Asset Policy. Obsolescence of specific interlocking equipment is detailed in NR's own independent review report, and it is recommended that the same approach which was applied to the review of SSI interlockings is also applied to areas such as mechanical interlockings and relays which are currently considered a known obsolescence risk. We were informed that obsolescence modelling knowledge is considered underdeveloped and NR plan to go out to tender for further support in this area.
Do the Asset Policy and modelled behaviours reflect the latest knowledge of the asset class?	It is acknowledged that the shift to "digital rail" and the introduction of NR's Intelligent Infrastructure (II) programme will improve existing issues with degradation monitoring and obsolescence management, however potential savings which may arise from the Intelligent Infrastructure rollout have not been considered in the model because there has been no communication with the central team on programme rollout, the impact on improvements to asset lifecycle and what assumptions (if any) will need to be updated to accurately model its end state. This was considered by those we spoke with to be a key missing input which will need to be revisited. Further development of the Tier 2 models has been on hold and the models have effectively been 'mothballed' as the focus has moved to the 'digital rail'. This has meant the degradation modelling of the legacy assets as well as the Asset Lifecycle Profiles have not been kept up to date and means that any representation of the modelled behaviours in the ICM is out of date. The technology module (Module 2) of the Asset Policy has been updated to provide more information on the degradation of the Signalling assets. Whilst this section provides a good overview of the degradation, its importance, the degradation types and characteristics (Random, Predictable etc.), there is no quantified insight into how the assets degrade. Much of this information is stored in the Asset Lifecycle Profiles and NR recognises that this data requires updating. The degradation equation (equation 6 in the configuration document) for condition (SICA) is simplistic and based on asset remaining life stepped down each year by a year. The degradation equation does not reflect the differences between the asset types. NR has recognised that there is now

Subject	Observations
	more information available and this can be updated. This new information needs to be reflected back into the policy and asset strategies as part of the ongoing CP7 Policy development activity. It is reasonable to assume that degradation of signalling assets will differ by geography (e.g. coastal vs mainland), usage and age. Remote Condition Monitoring (RCM), Ellipse, FMS2000, SICA and Route risk register data could be utilised to further improve the accuracy of degradation assumptions.
How is maintenance reflected in the model?	There is a maintenance module within the ICM that provides forecasts for maintenance standard jobs and presents output in terms of forecast volumes of work, costs and headcounts based on condition scores and changes to condition scores. Small capital projects, known as minor works, are also accounted for within the model. Minor works programmes are built by the Regional teams and inputted into the ICM so that the entirety of the capital budgeted activities are included in the model. There is no functionality to forecast forward the minor works programme other than to take the Regional inputs and roll them forward.

SUMMARY OF THE SIGNALLING MODEL – ICM

Asset Discipline:	Signalling
Asset Classes:	Signalling
Modelling Principles	The signalling Infrastructure Cost Model (ICM) was developed as an MS Excel based Tier 1 model that forecasts work volumes and costs at the portfolio level and calculates the associated impact on the condition/remaining asset live based on SICA scores. As a Tier 1 model, it does not generate a work bank, the work bank is the input into the model, the model is then used to forecast future volumes and costs and provides a means to generate a smooth delivery profile for the work bank interventions and provide a visualisation of the planned activity volumes. The outputs are driven by the intervention work banks that are inputted into the model and the application of embedded calculations and through-life performance characteristics within the model that were originally generated by the Tier 2 model. Other outputs are also able to be produced by the model such as operations costs and signallers' headcounts. Asset lifecycle profiles are then combined with the results of the condition outputs and used to calculate safety and service risk. The Technical Authority has recently migrated the ICM model into a proprietary decision-support modelling platform; C55. The teams are running in parallel the C55 and the ICM MS Excel model. It was unclear when the original model was due to be decommissioned. The requirements to ensure alignment of signalling Asset Policy with the ICM and C55 tool are defined in the Asset Investment Planning Specification for Platform Configuration for Signalling document, last revised in May 2020.
Model Architecture	Signalling is currently modelled using an Infrastructure Cost Model (ICM) tool, alongside a *Mini* ICM tool. The ICM uses plans of major signalling renewals to forecast outputs for Cost & volume, condition, operations, safety, reliability, and maintenance for a period of up to 50 years. The mini ICM is simplified to enable it to run reports with reduced (excluded) inputs to improve data processing speeds while subsequential changes are being made. It outputs renewal cost & volumes and remaining asset life via condition.

Asset Discipline:	Signalling
Key Asset Data	The model utilises various inputs the input data sources are updated at different frequencies leading to some uncertainty in the model's outputs. The full list of input data sources, their sources, and their update frequencies are provided below: • **Signalling System & Active Level Crossing Data** *SSADS* – Updated with each submission. • **Signalling System Remaining Asset Life Data** *SSADS* - Updated with each submission. • **Signalling Asset Data & Connection to System Data** *ELLIPSE* – Updated with each submission. • **Signalling Unit Rates** *Infrastructure Projects* – Updated as required and/or during heavy planning cycles. • **Asset Lifecycle Profiles** *Tier 2 Model* – Last updated 9-10 years before this report. • **Failures, frequencies, and consequences** *FMS & Trust Data* – Updated as required. • **Signalling Work bank** *Route Teams* – Updated with each submission. Data pre-processing is undertaken by the modelling team before being uploaded into the original ICM. This has been superseded within the C55 ICM. This data is now combined within a Decision Support Data Store (DSDS) removing the pre-processing requirement. The DSDS provides an accessible list of the relevant assets and their characteristics that can be viewed and potentially updated by the wider Signalling teams in the Regions. The SMO recognises SEU counts as being the area of model input that is most poorly populated. It was pointed out that the SEU count are not always readily updated after renewal activities, which would have an impact on the model output

Asset Discipline:	Signalling
Asset Data Quality	The SSADS data is reported to be generally of a good standard and sufficient for the purposes of the ICM model. There are still a number of areas where asset counts are ‘approximate’ as opposed to ‘absolute’ and that some data processes were not being applied robustly, signalling cables was identified as one of the areas for improvement. However, it should be noted that there are not currently companywide IDs in use for signalling assets, these are created directly when fed into the model. The SICA scores are generally perceived to be optimistically applied and it is reported that a study has been initiated to address the factors influencing the validity of this data. The model owner recognises SCU (Signalling Compatibility Unit) counts as being the area of model input data that is most poorly populated. It was pointed out that the SEU count are not always readily updated after renewal activities have concluded, which would have an impact on the accuracy of the model output. To reduce the risk of human error and drive consistency in the data pre-processing, a macro has been developed that automates the pre-processing procedures, however the structure and processes within this macro have not been documented. As model users are required to take their copy of the ICM from a centrally shared location before running the model. Users feedback their copies to the model owner at the end of each submission round so that the model is aligned at the start of the next submission round (every 4 weeks). This implies that in the period between each submission round, users may have slightly different versions of the model work bank if they have made modifications it, which potentially creates conflicting modifications which could drive rework and realignment activity. It is understood that this issue will be mitigated by C55, which will be deployed as a single platform accessible to multiple users with the ability to configure user permissions. There are built in validation checks within the ICM to ensure that input data is in the correct format. A true/false column exists for each validation check, if an input tab contains one or multiple items that have failed validation, the tab will be flagged on the Control page prompting the user to rectify the error before running the model. It is explicitly stated in the model guidance documentation that the model should only be run when all the validation rules are satisfied. However, it is understood that there is no built-in model mechanism to prevent the user from undertaking a model run without satisfying all the validation rules. It is possible for the ‘Run’ command to be activated even when errors are detected. This issue is understood to be mitigated in the C55 model, where all inputs must satisfy a set of pre-determined validation rules before being accepted by the model.

Asset Discipline:	Signalling
Degradation Methodology	The model measures condition in terms of the average remaining life (RAL) of the assets. This is recorded in years from SICA inspections. The current condition of assets within each interlocking area is taken from the most recent inspection and is now stored in the Decision Support Data Store (DSDS). It should be noted that SICA assessments can vary in complexity and sophistication. For instance, it has been reported that early life assessments can be conservative. The model contains a simple condition degradation calculation based on the SICA life. This is calculated as a minus 1 year per year rate and is applied equally across all asset classes. An optimal approach would take into consideration aspects of asset specific degradation and failure modes. However, it has been recognised that more knowledge on Signalling system degradation is now available and work is underway to analyse and incorporate this into the model where appropriate. It is also recognised that some of the Asset Lifecycle Profiles that forecast the deterioration in performance, as developed in the original Tier 2 models, need to be updated and plans are being developed to address this. It is reasonable to assume that the degradation of some signalling assets will differ by geography (coastal vs mainland or rural vs urban), usage, and age and these factors should be considered when updating the underpinning data in the model. Remote Condition Monitoring (RCM), Ellipse, FMS2000, SICA, and Route risk register data could be utilised to further improve the accuracy of degradation assumptions. **Obsolescence** Obsolescence of specific interlocking equipment is detailed in NR's own independent review report, and it is recommended that the same approach which was applied to the review of SSI interlockings is also applied to areas such as mechanical interlockings and relays which are currently considered a known obsolescence risk The ICM model does not provide the functionality to manage or model obsolete assets. Obsolescence is managed outside of the model by the asset and Regional teams and any specific obsolescence activities and campaigns are played back through the ICM as part of the overall work bank. NR recognise this an area for future development in the ICM. It is acknowledged that the shift to "digital rail" and the introduction of NR's Intelligent Infrastructure (II) programme will improve existing issues with degradation monitoring and obsolescence management, however potential savings which may arise from the II rollout have not been considered in the model because there has been no communication with the central team on programme rollout, the impact on improvements to asset lifecycle and what assumptions (if any) will need to be updated to accurately model its end state. This was considered by those we spoke with to be a key missing input which will need to be revisited.

Asset Discipline:	Signalling
Modelled Interventions	The model accounts for four modelled intervention types depicted below: **Major Capital Works -** these are the key focus of the signalling model efforts and are specified in the form of a work bank. The model accounts for major capital works via the work banks for each Region. For major capital works, add-on project costs can also be included for differing project types. Major capital works will incur a work volume, from which the total work costs are calculated by multiplying the work volume by respective unit rates. The resulting impact from major capital works is an uplift in asset and overall system condition reflected by an increase in remaining asset life within the model. The system size and the asset types installed may also change as an outcome of implementing major capital works. As well as generating forecasts, when processing the work bank, the work item updates the anticipated asset counts and composition in the asset data and remaining asset life output elements. **National Schemes –** these activities incur central costs, each Region contributes funding towards the schemes. For each year the model is run, it establishes the national sum of Signalling Controlled Units (SCU) in each Region. The costs of each scheme are stored in the model against each Region and modelled year. **Minor Capital Works –** these activities are calculated by year for asset areas by Region. A table of intervention costs is provided by the model users. This is provided by Regions typically at each year of the current and next Control Period. Minor works costs are not calculated in the model, rather they are output as they are input. **Maintenance Works -** activities that are estimated from asset counts, condition, failure rates and Route initiatives.
Unit Costs	Unit costs are captured within the ICM and are aligned with the Unit Cost Framework for signalling, they are provided by the Estimating Managers. The national average unit rates are applied for the initial model run in the Control Period planning cycle. The Regions can then apply appropriate add-on rates, which can be applied selectively to an intervention, thus representing the costs of additional work. Costs within the model are split into CAPEX, maintenance and reliability. The model considers operational costs via direct staffing costs of the signallers via headcounts at year-end and signalling staff salaries. SEU rates in the ICM have historically come from Estimating Managers within NR. Separate to unit rates produced by the Estimating Managers, the finance function calculates national average unit rates through a review of the previous Control Periods estimates and actual costs against each work type. A national average unit rate is then calculated after outliers have been removed. This is

Asset Discipline:	Signalling
	provided to the Regions as a baseline with which to compare their own unit rate calculations. Deviations from the finance function baseline require a formal explanation from the Regions. The weakness in this method is the number of projects of a type that were undertaken in the previous Control Period. Typically only about 50% of the work types are delivered and If only one project was undertaken nationally then the average was only based on a small sample. For example there was only one ETCS project in CP6. This weakness would be addressed by the Regions adjusting the unit rates however this is rarely undertaken. CP5 estimates were observed to be significantly different from the actual costs. Subsequent amendment to the CAPEX cost modelling methodology were made to include add-on costs, and thus capture the "abnormal" works which accounted for much of the disparity in the previous Control Period. Routes and Regions are permitted to give their own fixed costs if they disagree with the national average figure provided. It is recommended that the Routes use actual costs vs national average wherever more accurate information with supporting evidence exists. It was also noted that the ICM model contains the capability for Regions to upload their own costs, however as mentioned previously this is rarely undertaken. As such, only national average unit rates are being used in the model. No discounting has been applied to financial values within the model. The model owner indicated that discounting was not felt to positively contribute to the primary use of the model output as it is used to forecast 'real' spend over time, rather than being used to justify potential business cases constraints.
Computational Accuracy	It was not possible to access the new C55 version of the ICM to a carry out an assessment. It was agreed that the mini-ICM was sufficiently representative to be assessed for computational accuracy. See the model testing section following this table for further detail on the model accuracy.
Model Outputs	Outputs are produced in the format of a master report containing a breakdown of renewals costs determined for each Control Period. This is then aggregated by asset class and renewals type, maintenance, and headcount costs. The model also estimates the remaining asset life calculated from the relationship between interventions in the work bank and modelled conditions / degradation data. The model outputs are as follows: • Renewal Costs & Volumes. • Ops Headcounts & Costs.

Asset Discipline:	Signalling
	• Safety Risks. • SAF Counts, Minutes & Costs. • Non-SAF Counts. • Maintenance Hours & Costs. • MDU (Maintenance Delivery Unit) Headcounts.
Output Validation	An internal review and validation of the outputs from the models is undertaken by the modelling team in the Technical Authority before the models runs are published to the wider business. There is no formal, documented validation process. Once the model has produced its outputs in a standardised template they are provided to the Regions. The Regions then compare this to their expected forecasts. A close dialogue is maintained between the centre and the Regions and the Regions will update their work banks via the Mini ICM (Ready Reckoner) tool as needed and provide this back to the central team. The final validation process could be considered limited as outputs are only validated by comparison to the previous years.
Change Control	An up-to-date changelog exists for the Signalling ICM. There is also a guidance document however this is updated less regularly. The model owners are responsible for implementing changes. No audited formal process currently exists for managing and testing changes, they are typically made as required. The model would benefit from a systematic approach. A review of the change log evidences a history of ongoing development with various changes to existing functionality and new functionality added since 2013.

Model Test:

An initial comparison was made between the mini-ICM and the signalling configuration document. This confirmed that 100% of the relevant forecast had been accounted for in the configuration document. To test the accuracy of major capital scheme forecasts, a sample of three work bank items was selected on the basis of containing a mixture of work types and cycles.

Work Bank Item	Operating Route	Maintenance Delivery Unit (MDU)	Interlocking Tech Type	Signalling Controlled Units (SCU)
ALNM1 SSI	East Coast	Newcastle	Electronic IXL	19
ALNM2 SSI	East Coast	Newcastle	Electronic IXL	14
ALNM3 SSI	East Coast	Newcastle	Electronic IXL	26

All non-relevant work bank items were removed from the model, and it was configured to only forecast for the signalling asset class. The model was then run, and the sum of costs (£M) and volumes recorded for each work type across all Control Periods. To verify the basic computational accuracy of the forecast, manual calculations were computed in parallel using equations provided in the Signalling Configuration Documentation.

- Volume:

Volume output is measured in equivalent volume units ($SEVU$), the overall work volume for interventions in the work item are calculated by

$$Vol_w = \%_{Act,w} \times SCU_w$$

Vol_w	The work volume for interventions described in the workbank (measured in $SEVU$).
$\%_{Act,w}$	The percentage activity volume for the intervention.
SCU_w	The SCU count of the IXL.

- Cost:

Each work type within the work bank has a specific unit rate. Cost is generated by multiplying these by the post-intervention SCU count. The unit rate is made up of two components: a base unit rate and there may also be an add-on unit rate applied reflecting site-specific activities.

This gives the intervention *w* specific unit rate as

$$R_w = \begin{cases} R_{w_{base}} + R_{w_{Add-on(p)}}, & \text{option 1} \\ R_{w_{base}} + R_{w_{Add-on(w)}}, & \text{option 2} \\ R_{w_{base}} + R_{p_{Add-on}}, & \text{option 3} \\ R_{w_{base}}, & \text{option 4} \end{cases}$$

R_w	The intervention *w* specific unit rate in £ by SCU.
$R_{w_{base}}$	The intervention *w* specific base unit rate in £ per SCU.
$R_{w_{Add-on(p)}}$	The intervention *w* add-on unit rate, based on the project AFC, in £ per SCU.
$R_{w_{Add-on(w)}}$	The intervention *w* specific add-on unit rate, defined per intervention in £ per SCU.
$R_{p_{Add-on}}$	The project-wide add-on unit rate in £ per SCU.

Using the equations above, test outputs were calculated using data inputs for cost (work type, unit rate, add-on rate, SCU count) and volume (work type, activity volume (%), SCU count). The volume and cost for each work type were summed across all modelled control periods (up to CP17) to compute work type totals. The outcome of the computational accuracy assessment showed a 100% match between the test output and the model output, indicating that no model computational errors were identified for the chosen sample. No VBA run-time errors were detected during the test model run.

	Signalling Renewal Costs (£M)			Signalling Work Volumes		
Work Type	**Model Output (£M)**	**Test Output (£M)**	**+/- (%)**	**Model Output (SEVU)**	**Test Output (SEVU)**	**+/- (%)**
WT 54 – External 10% new	0.63	0.63	0 (0.00%)	1.30	1.30	0 (0.00%)
WT 56 – External 30% new	2.38	2.38	0 (0.00%)	4.95	4.95	0 (0.00%)
WT 65 – Interlocking hardware renewal	4.00	4.00	0 (0.00%)	18.12	18.12	0 (0.00%)
WT 68 – Ctrl system hardware renewal	0.77	0.77	0 (0.00%)	4.72	4.72	0 (0.00%)
WT 12 – Re-control (control system renewal, inc. transfer of control)	3.64	3.64	0 (0.00%)	7.08	7.08	0 (0.00%)
WT20 – Resignalling (ETCS Level 2 without signals)	14.62	14.62	0 (0.00%)	57.82	57.82	0 (0.00%)
Total	26.03	26.03	0 (0.00%)	93.99	93.99	0 (0.00%)

REGIONAL APPLICATION OF THE SIGNALLING MODEL

Subject	Observations
Use of the WLCC model outputs in the Regions	The process for developing Control Period plans is understood within the Signalling teams in the Regions. Following the provision of the initial forecast from the Technical Authority based on the predicted out turns of the previous Control Period, the Regional teams start to develop their local work banks using the tools that are provided (Rail BI and Ready Reckoners) and local knowledge. The majority of the work to develop the work banks is done outside of the ICM, including for example, addressing obsolescence issues. However, the Mini ICM/Ready Reckoner is used to test the work banks against the long-term impacts on cost, volume and condition. The Regional work banks are fed back into the ICM through Ready Reckoners. The ICM is run to develop the national programme of work (what, when and how much) based on budgets available. The Regions then receive an overall visualisation of the work banks including any adjustments to timings based on the national picture, budget available and the impact on the average remaining asset life. The Regions can force or overwrite the base unit rates for each work type. To do so, Regions are required to provide justification for the divergence. For individual work bank items, Regions can provide add-on rates that do not require justification.
Accuracy of the models & confidence in outputs	The signalling teams in the Regions acknowledged that there have been significant improvements in the model output over the CP5 and CP6 predominantly driven by improvements in input factors such as unit rates. It is recognised that the model is limited in its capability to forecast activities such as minor works. The model does include this data as a direct input from the Regional teams to enable a visualisation of the complete work banks, costs and outputs. There are still challenges overlaying long term strategies technology strategies such as the move to ETCS.
Regional contribution to model development	The majority of recent updates to the ICM are driven by the Regions, and the Regions also validate the changes once they are complete. An example of this was the need for a 6 year output profile rather than a 5 year profile.

Subject	Observations
DSTs	The Regional Signalling teams have been involved with the development of the Signalling decision support tools, for example the Rail BI tool and the development of the ready reckoners (Mini ICM) to enable them build work banks and run local scenarios and test them before they are uploaded into the main ICM. The Regional Signalling team were not aware of the bigger centrally led projects that are underway such as the move of the ICM model to the Copperleaf Technologies C55 platform or the ALP tool that is being developed by the Intelligent Infrastructure programme. Rail BI tool is a system built to produce business cases for rail projects, this is prominently used to develop DR schemes across each Route, however this is not considered a replacement for the previous Tier 2 model. When each Route produces its forecast work-bank there are tools available to model different scenarios where they exceed budgetary limits, such as extending renewal dates to profile renewals for a consistent yearly budget as an example. It was noted that whilst this makes logical sense and will ensure plans are deliverable with the resources available, there is no check to agree that changing a sites renewal date is safe and that in doing so the Route is able to maintain KPIs without additional funding to bridge the gap between the proposed renewal date and its re-planned date.
Data and information currency and quality	The information in SSADS, the Rail BI Tool and the ICM are generally thought to be of satisfactory quality. The Signalling Infrastructure Condition Assessment (SICA) lives in the model are believed to be optimistic however it is recognised that there is an ongoing study to address this. National Signalling system asset counts are fundamental to the accuracy of any forecast. NR predominantly uses the management system Ellipse for managing and recording asset maintenance activities. In March 2019 at the end of CP5, NR concluded its Offering Rail Better Information Services (ORBIS) programme which sort to improve its knowledge of asset data, removing many localised record keeping systems into a national model aimed to put data at the heart of the railway through the introduction of mobile apps and tools specifically designed to capture high-quality asset data which offered new ways of viewing the railway. Through CP6 there was a reasonable expectation that asset data quality would be maintained and possibly improved further, following several significant re-signalling schemes throughout the country, and that this data would be utilised to further improve the accuracy of future modelling. Unfortunately, this is not reflected in the configuration inputs, and is a shared frustration with specific individuals we spoke with during this review. A number of asset counts are “approximate” vs “absolute”, and we were

Subject	Observations
	informed that there is not a robust process in place to ensure data is kept in a good state, one example of this would be signalling cables.
Unit rates	There is a national approach for developing unit rates for SEU's and work types that includes standard costs but also provides the ability to add costs locally that may apply to specific projects, for example, building in additional redundancy for critical assets. These costs are developed through the Rail BI tool and then included into the ICM. It was noted that the Regions can also force in a unit cost for a project, however justifications must be provided and this is rarely undertaken so the majority of the modelling is based around national unit rates.

Appendix D – Detailed Observations on the Structures Model

ALIGNMENT OF POLICY AND THE STRUCTURES MODEL

Subject	Observations
Alignment of the model to the Asset Policy	The focus of this review was the alignment of the current Bridges Model (Developed in 2016 by Amey) with the CP6 policy. It was recognised that both the model and the Asset Policy were in the process of being updated for CP7. The Bridges model is a Tier 1 model and its purpose is to forecast forward the costs and volumes at the portfolio level. There are aspects of a Tier 2 model within it as it does model bridges specifically, however it does not recognise the many different types of bridge that there are on the network. There is broad alignment of the Asset Policy to the models insofar as the models seek to address the principal components of the Asset Policy, namely asset and sub-asset register, condition, capability, lifespan, work bank, interventions, and costs. The policy and model have been continually evolved in parallel, increasing in complexity as asset knowledge increased over successive Control Periods. The ORR has raised challenges to previous iterations of the model over the balance between modelled values and actual asset knowledge / engineering input, this has led to improvements in the model. A key priority within the Asset Policy is bridge capability for both under and over bridges. Currently there is a basic relationship established within the model between condition and bridge capability. NR recognises that the current understanding of the relationship between condition and capability is limited and plans are in place to address this. From a rail customer perspective, the Route Availability (RA) is a key measure and if traffic is going to be constrained down certain lines based on bridge capability this will be a key factor in the interventions that may be planned. The Tier 1 Bridges model is highly complex, with multiple levels of inputs provided in the form of matrices, arranged to represent asset condition, deterioration, capability, asset life and interventions and processed in a chain. The underlying code is very complex and hard to navigate and the resultant model requires very large computer memory and processing capability, to the extent that it can take 24 hours to perform one complete national model run.

Subject	Observations
Do the Asset Policy and modelled behaviours reflect the latest knowledge of the asset class?	The first point to make here is that there is a discrepancy in asset numbers between the model and policy, namely the numbers of overbridges and underbridges, this may be due to the difference between the publication date of the policy and changes that have now been made to the asset base. The degradation model that is included in the bridges model was established in 2016 based on historic data. It has not been updated since this version so does not reflect latest knowledge. Asset knowledge is gained through a schedule of visual inspections, which are infrequent and measured in years, typically occurring every 7 years. As bridge assets have very long design life, with slow rates of degradation, this is not necessarily an issue, but it should be noted that "latest" asset knowledge may not be "recent" in this asset group. The Asset Policy says little on bridge examinations, other than to say in section 2.2.2 Asset Condition, that bridges are subject to regular condition recording to NR standards. Also, in CP5 NR is updating its standards to better integrate the process of examination and assessment through a single evaluation following each examination to consider changes that could affect a bridge's capability (s.2.2.1). Assets on high Route criticality should be highlighted for more frequent inspection, but this is not a feature of the policy or model. Instead, the Policy states that these assets will be maintained to a higher standard than mandated in PoaP. More specifically, the Policy states that bridges use specific marking indices to score condition whereas other assets use qualitative measures. The Policy does not comment on whether they are aligned to the alphanumeric scoring matrices that underpin the model but refers to "supporting documents" that we have not seen. It is also noted that the Policy refers to average "whole structure" condition scores in table 2.3, with Principle Load Bearing Elements dealt with in the "supporting documents", whereas the model deals with "minor elements" rather than whole structure scores. Asset Policy section 2.3 Asset Data provides scores for bridge attributes, but the source and date are not provided and these scores are not reflected in the model. The models do not attempt to compute actual structural integrity or performance at any level. The model uses "generalised indices" to calculate "capability scores" and "intervention triggers" that are high-level and which can only ever be as accurate as the last set of inputs (condition indices) provided and even then can only calculate a "most likely" result. By definition this

Subject	Observations
	cannot be definitive in terms of structural engineering capability at an individual asset level, and it does not attempt to calculate structural behaviour at all. To the extent that the model can provide any output at all at the level of a single major asset (bridge) or minor asset (Principal Load Bearing Element, PLBE), this can only ever be the result of assumed indices which may not reflect actual data or performance. It is important to understand that the calculation of "structural behaviour" would require more a far more detailed analysis than this model has been designed to perform. It would require specific inputs on material, components, condition and loading information (both dead loads and imposed loads) and factors of safety, which are set out in the relevant design codes, whether British Standards or Eurocodes, and so forth. To include the capability to calculate and represent detailed structural behaviours in the Bridges Tier 1 model would not be practicable, it would require a significant increase in functionality of the model and put a significant burden on the information required to keep the model up to date. Based on the current purpose of the Tier 1 model the benefits of providing this level of functionality would not outweigh the effort required to build it and maintain it. It would be more beneficial to investigate the development of Tier 3 decision support tools that enable the Regions to look at a specific bridge or a series of bridges on a critical Route. Discussions with the Regions identified that the Scottish structures team had developed a local model although no further detail was provided on this.
How is maintenance reflected in the model?	Interventions are dealt with in section 6 of the Policy and section 8 of the Model, with the latter setting out a range of light and heavy maintenance and replacement activities for different materials at a minor element level, which can be grouped and collectively sum to a whole bridge replacement. Examinations are triggered through modelling depending on the asset material and its condition band (worst minor element in the integer state). It is noted that the model does not address the "Basic Safety Limit (BSL)" as a stand-alone measure, rather this is factored into the BCMI scores. There are a number of other indices, including a range of defects with likelihood scores but no source or engineering input is referenced. The grouping of separate interventions is not modelled aside from batch interventions to the same sub-asset. Interventions to different decks (sub-assets) on the same bridge (asset), or adjacent bridges on the same line need to be treated as separate interventions.

SUMMARY OF THE STRUCTURES MODEL

Asset Discipline:	Structures
Asset Classes:	Bridges (underline and overline)
Modelling Principles	The structures model operates at Tier 1 level and covers underline and overline bridges assets. Latest condition data for each bridge asset is obtained from its last examination. Degradation of the bridge elements is simulated using a Monte Carlo model using Markov matrices. The portfolio condition is projected forward from the date of each bridge’s last examination to the ned of CP5, applying degradation model with the CP5 work bank. Intervention candidates from CP6 onwards are chosen based on asset condition triggers aligned with the structures Policy. Projected intervention volumes are constrained against a yearly budget on national work volumes and prioritised based on bridge condition, capability and criticality. The resulting work volumes are disaggregated art Route level and smoothed between Control Periods. The model is rerun for each Route to obtain Route outputs. Unit costs are applied to the output work volumes, total costs are normalised against the latest Route forecasts for CP6 and the cost of minor works are added. The costs on other structure types and other minor works from CP6 are also added in all subsequent Control Periods.
Model Architecture	The current Tier 1 structures model was configured by Amey Plc to supersede the MS Excel model reviewed in 2013. The model is coded in vb.net with an input form front-end and links to a background SQL database. There is a migration underway to move the current model to the C55 platform, which should enable faster running and more in-depth analysis of the outputs.
Key Asset Data	Key inputs into the model are:

Input	Data Source

<table>
<tr><th>Asset Discipline:</th><th>Structures</th></tr>
<tr><td></td><td>
<table>
<tr><td rowspan="2">Asset register</td><td>CARRS (Civils Assets Register and Reporting System)</td></tr>
<tr><td>ALARM for deck areas</td></tr>
<tr><td>Asset condition</td><td>BCMI (Bridge Condition Marking Index) database</td></tr>
<tr><td>Capability information</td><td>VERA and other Route based sources</td></tr>
</table>
The model does not link to live data sources. The model owner is required to obtain an extract of the relevant data sources and follow a set of pre-processing steps. Asset data from multiple sources are cleansed, matched and arranged in a form that can be input to the model. Asset condition data obtained from the BCMI database is analysed and transformed to the appropriate numerical scale that is required by the model.
</td></tr>
<tr><td>Asset Data Quality</td><td>
It is recognised that there is significant uncertainty in the engineering judgement to convert capability assessments to an estimated time before an intervention is required, the model is configured to stochastically apply an uncertainty factor between 50% and 150% based on a uniform distribution. It is not apparent that the 50% to 150% interval was constructed based on quantitative evidence. The model assumes that the required strength will remain constant for each deck. It is understood that Regions are aware that data within the model on required strength is out of date and that several Regions use their own system to compute this.
There is limited confidence on the quality of the deck area data. Deck length and width have been obtained from the ALARMS system in 2016 and has not undergone a refresh since the date of input. The model has been configured to infill any bridge that does not have a recorded deck area to 90m^2. It was understood that the infilled quantity for undefined deck area of 90m^2 was used as it was close to the average value and has passed through the TA Engineering sign off.
The model is primarily driven by the BCMI data and the condition scores at the time of last inspection, which provides the starting point for each condition simulation. However, it is understood that some assets have a ‘Not Examined’ code assigned to their condition score for reasons such as accessibility. As such, only 90% of over and underbridges assets remain in the model.
</td></tr>
</table>

Asset Discipline:	Structures
Degradation Methodology	Bridges are modelled for individually within the structures WLCC model using a 'Markov Chain' process to represent the deterioration of the assets between condition and capability states. The model begins from the current asset condition and uses Monte Carlo simulations to simulate random events based on a probability matrix. Output probabilities for each input state are mapped by Amey in 2016 using historical examination results between 2 points in time. For the purposes of inputting into the model, the time period between 2 inspections has been normalised to 5 years regardless of the actual number of years elapsed. At the time of the 2013 report, capability degradation was not a part of the structures model due to model complexity. The current model applies degradation on each deck's capability measure based on the condition of its minor elements. If one of its Principal Load Bearing Elements (PLBE) is assessed to be in a 'poor' condition, the deck capability deteriorates by 1 year. On the other hand, if a deck has no PLBE in the 'poor' condition category its capability remains the same. At present, no distinction is made between a single or multiple PLBEs being assessed to be 'poor or specific bridge characteristics (e.g. material, level of traffic). NR recognises that the current understanding of the relationship between condition and capability is limited and that further study is required to accurately model for the deterioration of capability and condition. In some cases, the apparent trends in the Markov matrices do not reflect logical expectations as would be expected from a degradation model. The table below presents the probability of achieving the same output SE (severity-extent) state or a worse output SE state given an input SE state ranging from 1-15 (15 being the worst condition band). The analysis shows that according to the degradation matrices used in the Structures model, as the input SE state worsens the likelihood of the output SE state worsening grows smaller. A standard degradation curve would be expected to show a higher rate of deterioration as the initial condition worsens, this is not being reflected in the model degradation matrices and should be validated further.

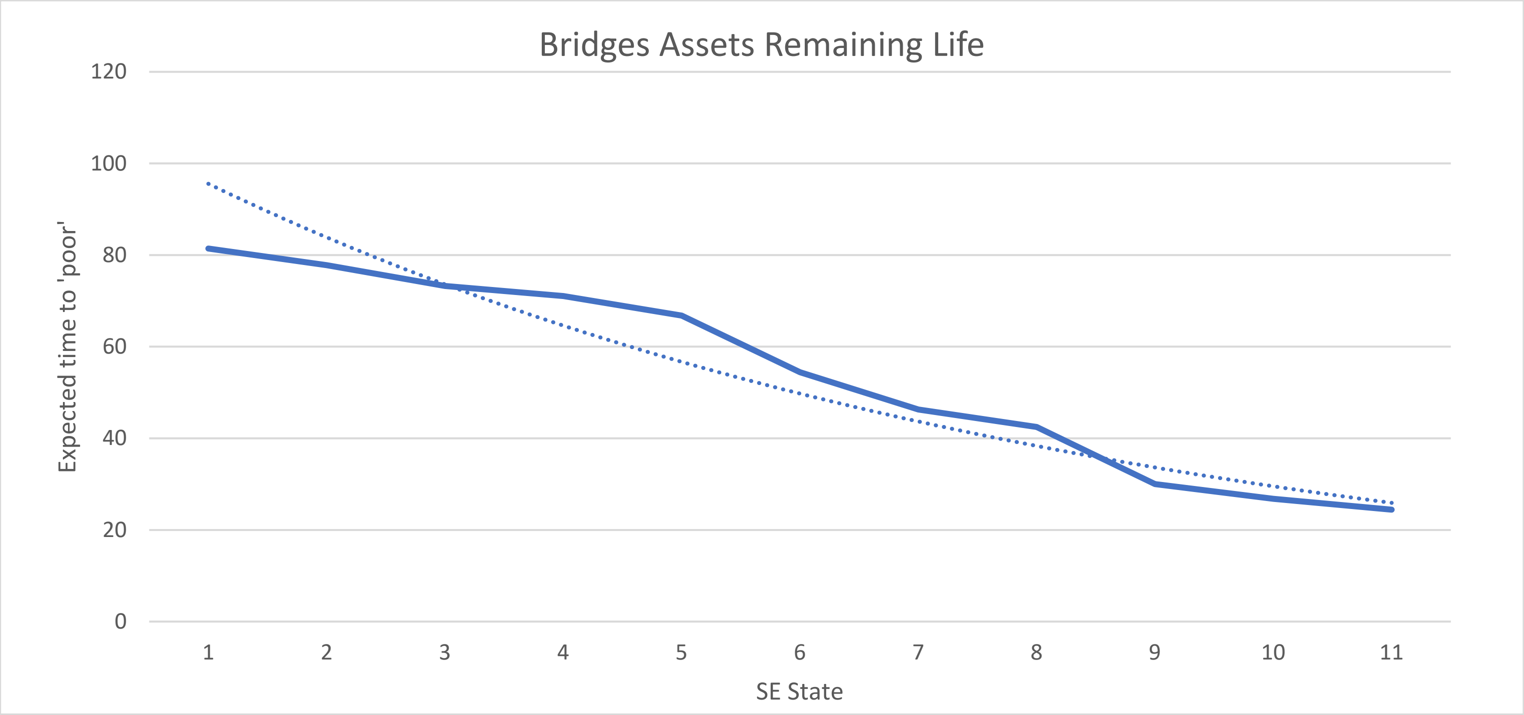
Input SE State	p(Output SE State = Input SE State)	p(Output SE State > Input SE State)
1	0.906	0.094
2	0.819	0.181
3	0.883	0.117

Asset Discipline:	Structures

4	0.898	0.102
5	0.912	0.088
6	0.906	0.094
7	0.921	0.079
8	0.952	0.048
9	0.966	0.034
10	0.926	0.074
11	0.972	0.028
12	0.979	0.021
13	0.974	0.026
14	0.986	0.014
15	1	0

It was understood from the modeller that statistical anomalies may be attributed to the fact that each SE state is individually derived, and that the relationship between states are not linear. An alternative way of viewing the relationship between the rate of degradation and the initial SE state is to observe the 'expected time to poor', which can be constructed using a conversion from the model degradation matrices. An example of this has been provided by the modeller:

<table>
<tr><th>Asset Discipline:</th><th>Structures</th></tr>
<tr><td></td><td>
<table>
<tr><th>SE State</th><th>Expected Time to Reach Poor Condition (Years)</th></tr>
<tr><td>1</td><td>81.42</td></tr>
<tr><td>2</td><td>77.81</td></tr>
<tr><td>3</td><td>73.26</td></tr>
<tr><td>4</td><td>71.06</td></tr>
<tr><td>5</td><td>66.81</td></tr>
<tr><td>6</td><td>54.42</td></tr>
<tr><td>7</td><td>46.30</td></tr>
<tr><td>8</td><td>42.47</td></tr>
<tr><td>9</td><td>30.02</td></tr>
<tr><td>10</td><td>26.81</td></tr>
<tr><td>11</td><td>24.43</td></tr>
</table>
When viewed on a line chart, it was observed that the change in the expected time to poor condition grows smaller as the SE state worsens in line with the observations on degradation curve anomalies above. There is a degree of variation around the trend line, which should be investigated further as part of the quality assurance process for model inputs. It is recommended that further
</td></tr>
</table>

<table>
<tr><th>Asset Discipline:</th><th>Structures</th></tr>
<tr><td></td><td>analysis should be applied to the degradation matrices outputs to investigate the cause of statistical anomalies to ensure that relationships used within the model are not skewed by outliers.
 </td></tr>
</table>

<table>
<tr><th>Asset Discipline:</th><th>Structures</th></tr>
<tr><td>Modelled Interventions</td><td>
<p>Interventions are triggered on a cyclical basis and are risk-based with the interval dependent on the structural form of the asset and its condition. The intervention types modelled for are:</p>
<table>
<tr><th>Intervention Type</th><th>Intervention</th></tr>
<tr><td rowspan="3">Condition intervention (element level)</td><td>Examination</td></tr>
<tr><td>Single element works</td></tr>
<tr><td>Multiple element works</td></tr>
<tr><td rowspan="2">Capability intervention (deck level)</td><td>Replacement</td></tr>
<tr><td>Strengthening</td></tr>
</table>
<p>Modelled examinations take place at the bridge level and record the observed condition of every minor element, the output of which triggers other interventions. The condition band of each bridge is obtained by comparing its minor element with the lowest condition score against pre-established low, medium and high thresholds, which in turn determines the interval between examinations.</p>
<p>Single element works are triggered when an element’s condition score falls below a pre-established single element works trigger threshold. Multiple element works are triggered when the average condition across a group of elements of the same material type have a mean condition worse than the single element works trigger threshold multiplied by the multiple element works multiplier factor.</p>
<p>Strengthening or replacement works are triggered when the deck capability falls below a pre-determined threshold. The incorrect calculation of the split between replacement and strengthening interventions was an area highlighted in the 2013 report. It is not apparent that this has been addressed in the current model. The model does not have the capability of calculating the impact of combined works. The 2013 report found that the structures model only allows for like-for-like replacements and did not offer the</p>
</td></tr>
</table>

Asset Discipline:	Structures
	opportunity to replace a structure with a lower whole life cost option. It is understood that the current model now replaces the original elements with a set concrete elements.
Unit Costs	For overbridges, the total cost of applied interventions is obtained by first applying the unadjusted IP unit rates for different work types. The calculated total cost is normalised against the total underbridge and overbridge costs in the latest Route forecasts for CP6 through an uplift factor to match the calculated cost against actual cost. For underbridges, unit rates were found through a bottom-up costing exercise in 2020, estimating bridge intervention costs using a 'Set Up' cost plus a 'Modified Unit Rate' work volume. As this adds extra variability, this is normalised nationally per CP using effective volume of each work. The structures model contains national average unit rates per work type. On the other hand, the structures ready reckoner defaults to national unit rates but has the ability to use varying Regional rates if required. There is potential misalignment between the model and Ready Reckoner outputs if Regional unit rates are used in the Ready Reckoner. To account for the possible combination of both strengthening and repair works, a 50% cost uplift is applied to all strengthening work. It is understood that the standard uplift applied has no quantitative basis and is an approximate estimation based on the expert judgement of the SMO who recognises the need for a more in-depth analysis to accurately determine the level of combined work and their impact.
Computational Accuracy	See model testing section after this table.
Model Outputs	Outputs from the structures model are: • Work volumes. • Condition. • Costs.

Asset Discipline:	Structures
	Outputs from the model are fed into the structures Ready Reckoner (UB_OB Ready Reckoner v2). The structures Ready Reckoner exists as an external MS Excel file to the model. It is designed as a simplified version of the model for Regions to view model outputs and analyse the potential sustainability implications of different work activity scenarios. Model outputs are presented graphically for reporting purposes as part of the CP7 model forecasts. Work volumes, condition and costs are reported on by Control Periods as well as Regions.
Output Validation	Outputs are verified by the model owner without a formal procedure that must be followed. At present there is no self-assurance report (which exists for track and signalling assets) for the structures model. It is understood that this is to be completed within the coming months. There is no documented process in place for the validation of outputs. Outputs from the model are usually self-assessed by the model owner.
Change Control	There is no evidence for a formal change control process. It is understood that changes are initiated via a two-way discussion with TA Engineering and the Regions. The model owner conveys changes made to the model or Ready Reckoner via email to the Professional Head.

Model Test:

The model is executed using a Monte Carlo simulation framework to model each of the 25,000 bridges assets individually as well as at the portfolio level. It is understood that model run time is a challenge with the current model, where a full portfolio simulation takes 24 hours to compute. As such, the model owner will set the model parameters to run only one portfolio-level simulation.

By definition, the Monte Carlo methodology requires repeated simulations that generate random outcomes given a probability distribution of the possible outcomes. The practice of only running the portfolio-level simulation once exposes the model to risk of statistical bias as the single outcome may be produce a result on the extreme ends of the probability distribution that does not represent the true underlying quantitative parameter being estimated. As such, a model testing approach has been developed to test the hypothesis that outputs from the structures model provides biased outputs given its limited number of repeated simulations.

Due to model system constraints, it had not been possible for the Independent Reporter to obtain a copy of the model for independent testing. For this reason, a mitigation measure was undertaken to perform the computational accuracy analysis on an extract of historical outputs (dated December 2020) provided by the model owner. The data extract contains model outputs over 4 to 5 iterations for each Route over the CP6 – CP12 period.

The testing approach can be summarised as follow:

1. Configure the model to run one simulation for a given scenario.
2. Repeat the simulation using identical model parameters x times.
3. Compute and assess the spread of standard deviation on the Route-level as well as portfolio-level outputs.

Standard deviation is to be calculated using the equation below:

$$\sqrt{\frac{\sum(X-M)^2}{N-1}}$$

Where:

X = the individual score

M = the mean of the sample

N = the sample size

The model outputs to be tested are defined as:

Output	Definition
Avg_PoorPLBEs	The fraction of PLBEs in poor condition.
Avg_BCMI	The average BCMI score.
Avg_RemLife	The average remaining life in years.

The model testing outputs are defined as:

Output	Definition
Average SD_PoorPLBEs	The average standard deviation of the Avg_PoorPLBEs outputs.

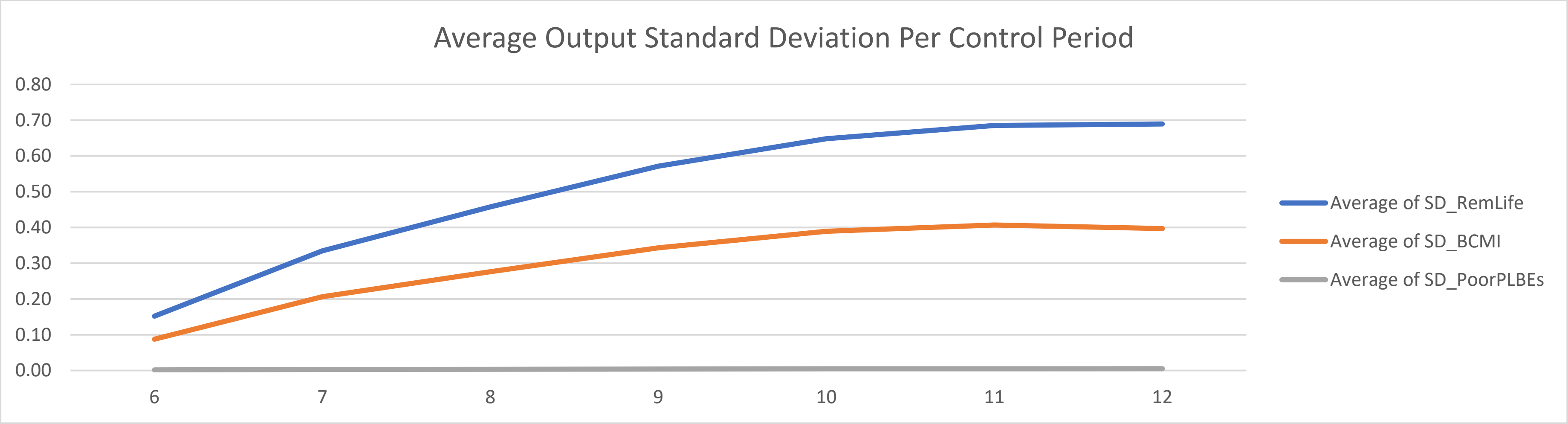
Average SD_BCMI	The average standard deviation of the Avg_BCMI outputs.
Average SD_RemLife	The average standard deviation of the Avg_RemLife.

The average standard deviation of lower and upper estimates of each model output is summarised below:

	Average SD_PoorPLBEs		**Average SD_BCMI**		**Average SD_RemLife**	
Route	Lower	Upper	Lower	Upper	Lower	Upper
Anglia	0.00	0.00	0.26	0.43	0.35	0.94
Central	0.00	0.00	0.29	0.33	0.53	0.59
East Coast	0.00	0.00	0.23	0.36	0.54	0.75
East Midlands	0.01	0.00	0.30	0.37	0.42	0.59
Kent	0.00	0.01	0.25	0.36	0.34	0.62
North East	0.01	0.00	0.65	0.41	0.94	0.69
North West	0.00	0.00	0.17	0.16	0.29	0.24
Scotland	0.00	0.00	0.13	0.19	0.32	0.30
Sussex	0.00	0.01	0.34	0.56	0.52	0.84
Wales	0.01	0.00	0.34	0.26	0.59	0.31
WCML South	0.01	0.00	0.37	0.39	0.93	0.64

	Average SD_PoorPLBEs		Average SD_BCMI		Average SD_RemLife	
Wessex	0.00	0.01	0.34	0.36	0.48	0.59
Western	0.00	0.00	0.28	0.30	0.40	0.41
Grand Total	0.00	0.00	0.30	0.34	0.51	0.58

The test outputs show that the degree of variation between each model run is minimal both when aggregating the outcome over all modelled Control Periods and separating the outcome over each Control Period. When comparing the average standard deviation across Control Periods, it was apparent that the level of output deviation increases with the time horizon. This may be attributed to the increasing degree of variability in forecasting into the future. However, the yearly standard deviation still remains minimal. The outcome of the model testing refutes the basis for the hypothesis that outputs from the structures model provides biased outputs given its limited number of repeated simulations. This outcome may be attributed to the nature of structures asset data, where the number of variables that can change is low, therefore, the Monte Carlo simulation of outputs has only limited impact on the model outcome.



REGIONAL APPLICATION OF THE STRUCTURES MODEL

Subject	Observations
Use of the WLCC model outputs in the Regions	The Regions use the central modelling outputs as a benchmark in terms of volumes and cost rather than providing specific insight into the needs of the bridges in the area. The scope of the model was limited to Under and Over Bridge, these make up 70% of the cost of the structures work bank. (A simple retaining wall model has been developed to support improved planning). The process through which the modelled outputs are developed into work banks is clear. The bridges work banks are developed bottom up based on tacit knowledge and proposals and in some of the Regional team's local 'unofficial' models that take into account the wider structures asset base. Following Round 3 of the CP7 development process the CEO presented a challenge to the Technical Authority and the Regions to develop a further two further scenarios – 'steady state' and 'realistic minimum'. This was only mentioned in detail by the team in Eastern Region, however it was subsequently understood that this was across all Regions and asset Disciplines. Much of the work bank adjustments for round 3.5 were based on the judgement of the Regional teams rather than modelled outputs. In comparison to previous Control Period development activities there is a lot more discussion between the Regional and central teams in the development of the model and work banks
Accuracy of the models & confidence in outputs	The structures model is perceived as being less mature than the models for other asset disciplines. It provides the Regions with a "rough estimate" of the work required, as too many averages and assumptions are included in the model. It was noted that the model remains under continual development and greater granularity was being added to work types and costs to improve the model outputs. Local knowledge and information on underline and overline bridges s is considerably richer and there is frustration in some Regions (Scotland) because of the gap between local knowledge and the model outputs. An example of this was from the Scotland Region where they did not think the model accurately reflected the history, conditions and challenges (metallic assets, Route criticality) that Region experiences. A particular area of concern for the Scottish team was the impact of weather on their structures and that this was deemed to be a significant factor in the discrepancy between local knowledge and the model outputs. Where there are gaps in the model information such as the impacts of Scour, work items are able to be forced into the model. A positive update has been the ability to provide more granularity on the unit rates in the model and the Regional teams have been working with the Technical Authority to develop this.

AMCL+

Subject	Observations
Regional contribution to model development	There has been increased engagement between the Regional teams and the Technical Authority during the CP7 development process. There are a variety of forums that the Regional teams attend to provide feedback including the Asset Technical review meetings, structures Business Planning and assurance working groups. The update to the structures Policy is being consulted with the Regional team.
DSTs	In the Scotland Region local models were developed to support the development of the Bridges work bank. There was awareness of the Plan-IT tool that is under development as part of the *Intelligent Infrastructure* Project but there is some concern with its implementation due to the significant number of factors it would need to consider in order to optimise the Regional plans. The National Prioritisation Tool is used by the Regional teams to assist in prioritising work activities based on Route criticalities.
Data and information currency and quality	The work banks are developed and managed within CARRS, this system holds the asset register, examination data. It is recognised that there could be improvements in the underpinning data. It was evident that the Eastern Region had put data quality improvement plans in place covering technology, and competence of staff.
Unit rates	There has been an improvement in the unit rate approach for CP7 with the ability to include local unit rates in the model and subsequent forecasts. Much of the development of unit rates is being undertaken in the Regional teams. The Eastern team found the main discrepancies unit rates were associated with bridges, both under and over bridges. Examples of key factors that are impacting structures unit rates were: Service diversion costs, reductions in track access, third party land access costs, environment agency requirements, COVID, extreme weather. There is the intention that the Eastern team will transition complete to the use of its own unit rates in the future.