ORR Composite Sustainability Index 28/10/2020

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MEASUREMENT METHODOLOGIES OF INFRASTRUCTURE ASSET HEALTH

SYSTRA SCOTTLISTER

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1 EXECUTIVE SUMMARY

The Office of Rail and Road (ORR) contracted SYSTRA Scott Lister UK Ltd (SSL) to evaluate the Composite Sustainability Index (CSI) methodology against infrastructure asset condition measurement methods used elsewhere in the rail sector and in other highly regulated industries. The ORR also wished to determine whether infrastructure asset condition measurement methodologies have advanced significantly since the CSI's inception in 2014, and the extent to which other asset managers and regulators make use of composite indices to express investment needs.

1.1 Methodology

A weighted scoring matrix was compiled by SSL in consultation with the ORR asset management team, who provided input to guide the selection of criteria weighting values. The scoring matrix was used to compare 21 alternative infrastructure asset condition measurement methodologies against the CSI using 10 separate scoring criteria. The alternative methodologies were drawn from a public domain literature search, and via consultation with SYSTRA staff with experience in overseas railway asset management practices. The quantified evaluation was supplemented with a review of the highest-scoring methodologies to build a qualitative understanding of asset condition reporting best practice. The purpose of the scored and qualitative evaluations was to guide policy options concerning the retention, replacement, or targeted improvement of the existing CSI method.

1.2 Findings and Conclusions

The weighted scoring matrix results show that some alternative methods scored above the CSI in specific criteria, but none outscored CSI overall when account was taken of the data collection and modelling process change hurdles associated with adopting a new methodology. The literature review revealed that the majority of railway methodologies are based on an accountancy depreciation impairment approach that has not changed markedly over the past decade. More variation in reporting methods and model sophistication was evident among the utilities, but here too the methodologies were found to be evolutionary in nature. The prevalence of composite indices among the 21 methods reviewed was approximately 75%, indicating a generally accepted practice.

SSL further noted during the review that long-term sustainability as measured by CSI is complemented within the overall asset management process by nearer-term tactical performance indicators including the Composite Reliability Index and Service Affecting Failures. CSI is also underpinned on a planning and operational level by annual engineer's reports by route and asset type, and by Network Rail management data on planned and delivered renewals. It is important to consider these other measures of asset stewardship in the context of evaluating policy options for CSI, since taken collectively they provide a similar breadth and depth of asset information as some of the more sophisticated comparator methodologies.

1.3 Recommendations

SSL's recommendations based on the evaluation findings are summarised as follows.

1. The CSI methodology should be retained but would benefit from the targeted improvements listed in section 5.2 of this report.

2. A simple monetised risk metric would be beneficial to complement the CSI's remaining life-based approach. Monetised risk should include the impact of future asset degradation or failure on wider stakeholder groups such as rail users.

3. Consider re-incorporating currently excluded asset groups, particularly tunnels, drainage, light maintenance depots, and retaining walls using the condition assessment methods identified in the literature review and summarised in section 4.2.5 of this report.

4. Maintain the practice of supplementing network CSI with scores at individual route level.

2 INTRODUCTION

2.1 Background

The Office of Rail and Road (ORR) contracted SYSTRA Scott Lister UK Ltd (SSL) to evaluate the Composite Sustainability Index (CSI) metric and its underlying methodology to determine how it compares with current best practice in infrastructure asset condition measurement. In particular, the ORR wished to understand whether significant improvements have been made in asset condition measurement methods since the CSI was established in 2014, and the prevalence in the use of single composite indices to represent infrastructure investment needs for asset maintenance and renewals.

2.2 Purpose

The purpose of this report is to:

- Explain the research methodology applied in evaluating potential alternatives or improvements to the existing CSI metric;
- Present the results of a scored comparison between CSI and infrastructure asset measurement methodologies from rail and other highly regulated sectors;
- Interpret and explain the findings of the scored comparison;
- Provide a qualitative overview of the alternative methods to highlight facets of their approach that have the potential to enhance or supplement the CSI;
- Draw conclusions and make recommendations on the basis of both the scored and qualitative methodology evaluations.

2.3 Scope

The scope of activities described in this report are as follows.

- Identify and summarise the current (2020) state-of-the art in infrastructure asset condition measurement as applied by industry and government organisations including:
  - Railway regulatory authorities and Infrastructure Managers (IMs) from the UK and overseas;
  - Asset custodians operating in highly regulated non-rail sectors.
- Compare the relative merits of identified asset condition measurement techniques by means of a scoring matrix to enable a recommendation to be made in respect of the following policy options:
  - Retain the existing CSI method unchanged;

- Replace CSI with an alternative methodology, if justified by the benefits obtained;
- Improve the existing CSI process or form of output by means of targeted changes.

- Supplement the quantified evaluation with a qualitative interpretation of the findings to answer the following ORR research objectives:
  - Establish whether significant advances have been made in asset condition measurement methods since the CSI was established by NR and the ORR in 2014;
  - Determine whether other infrastructure asset managers make use of composite indices, and if so, in what proportion;
  - Summarise methods used to monitor and report changes in asset condition;
  - Understand the metrics used to quantify asset condition and continued fitness for purpose, such as Remaining Useful Life (RUL) or percentage life used;
  - Understand how investment requirements in fiscal terms are derived from asset condition data in order to inform senior stakeholder decisions;
  - Establish how priorities are established across the asset portfolio so that scarce funds can be most effectively targeted;
  - Summarise best practice in asset condition forecasting methods over the short, medium, and longer term.
- Assess the feasibility of transferring alternate methodologies to either replace or complement the existing CSI method if justified by the potential benefits.

The scope of the report includes a conclusion based on the quantitative and qualitative evaluations outlined above, and recommendations to support the choice of CSI policy option.

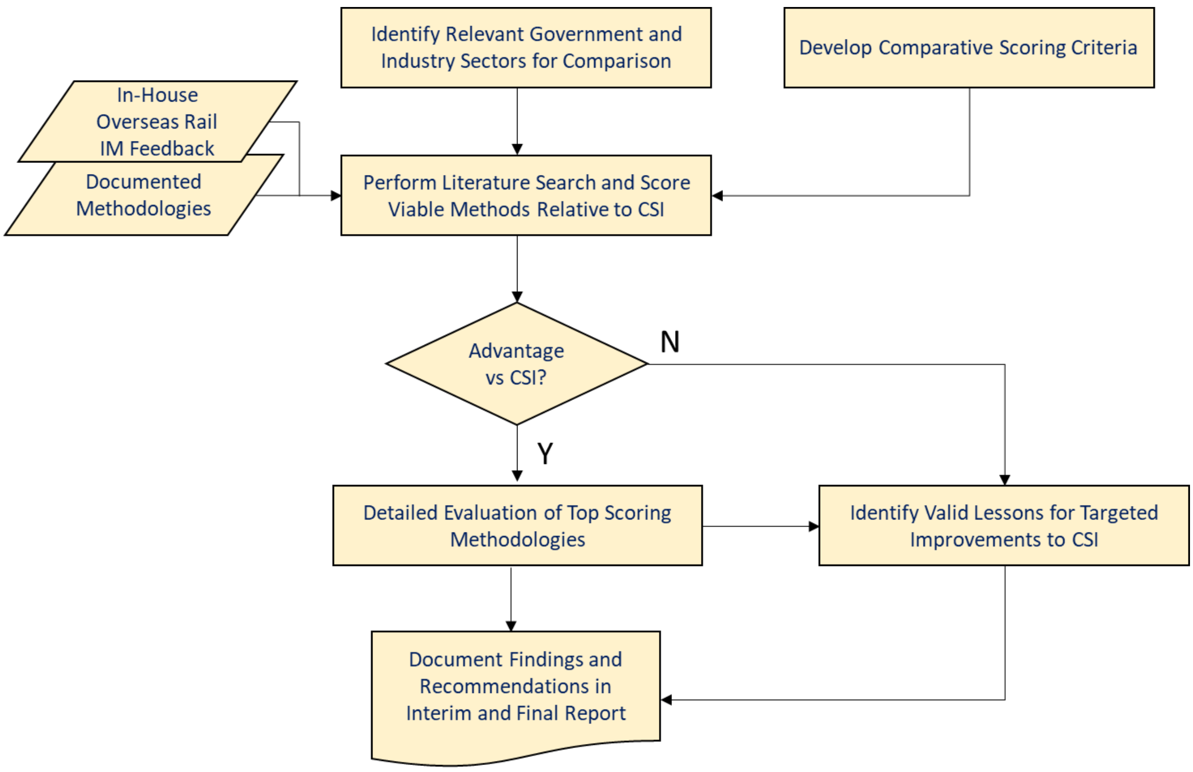
3 CSI EVALUATION METHOD

This section details the methods applied by SSL in identifying relevant infrastructure asset measurement methodologies for comparison with the CSI, and the approach used for scoring and ranking alternatives. The section also describes the criteria used to identify sources of targeted improvement that have potential application if the CSI method is retained.

3.1 Process Overview

The search for and evaluation of comparative asset condition measurement methodologies followed the process illustrated in figure 1.

Figure 1. Infrastructure Asset Condition Measurement Method Evaluation Process



The process began with the selection of sectors for comparison as described in section 3.2. Information on potential CSI alternatives or improvements was derived using a combination of desk-based literature search, and reach-back to SYSTRA staff from overseas offices with experience in the measurement practices employed by US, European, and Australian rail IMs. Measurement methods that were documented in sufficient detail to allow a meaningful comparison to CSI were evaluated by means of a scoring matrix. The assessment criteria used in the comparative scoring exercise are described in section 3.3. and the resulting rankings relative to CSI are given in section 4.1. The scoring matrix itself is presented in Appendix A of this report. The asset condition measurement methodologies with the highest ranked scores were further evaluated to extract facets of the approach that may be developed into targeted improvements for the CSI. The process culminated in the capture of conclusions and recommendations as summarised at the end of this report.

3.2 Sector Selection

The choice of sectors from which to seek infrastructure asset measurement methods for comparison with the CSI was informed by the applicability criteria listed below.

- Measured assets are operated in a highly regulated, safety-critical environment;
- The asset portfolio has a reasonable level of diversity such that condition metrics must accommodate asset classes with different useful lives and different degradation characteristics (for example, telecommunications equipment alongside buildings and civil structures);
- The measurement method must be applicable to "high-stakes" infrastructures in that investment decisions on maintenance and renewal are made at national or regional level, and a significant loss of capability would impact a large number of stakeholders.

The choice of sectors was also informed by the literature search in terms of the volume and quality of asset measurement method information made available in the public domain. The most prolific and informative material for comparison was derived from the sectors listed in Table 1.

Table 1. Sectors and Asset Categories Selected for Comparison

Government or Industrial Sector	Sector Categories
Rail	- Conventional - Sub-surface/metro
Metropolitan/Mass Transit	- Trams and buses - Built infrastructure
Utilities	- Electricity - Water - Gas
Defence Facilities	- Built infrastructure
Airports	- Built infrastructure - Airport operational systems

3.3 Scoring Matrix Approach

The existing CSI methodology and form of output was compared with 21 identified alternatives by means of a weighted scoring matrix. The matrix assessed each approach against 10 criteria as described in Table 2 by assigning each a score between 1 and 5, where 5 is the best and 1 the lowest rating. The weighting values assigned to each criterion were developed by SSL with input from the ORR project team to identify the most critical areas for comparison. The complete weighted scoring matrix table is presented in Appendix A.

Table 2. Measurement Methodology Scoring Matrix Heading Descriptions

Matrix Heading/Scoring Criterion	Description/Definition
REF	A unique identifier assigned to each methodology.
Sector	The government or industry sector from which the methodology is derived.
Originating Organisation	The organisation, typically that of an asset manager or regulator, who designed the methodology and/or applies it in practice.
Model Name	Name (including abbreviation) assigned to the methodology by the originating organisation.
Brief Description	A summary of the scope and application of the methodology.
Portfolio Differences	Scoring criterion (1 to 5) that assesses the level of asset commonality between a potential alternative method and the ORR/NR asset portfolio. A high degree of technical and material similarity with the type of assets measured using CSI attracts a high score, whereas less comparable infrastructures receive a lower score. Weighting selected = 2, reflecting the fact that portfolio differences may introduce some unknowns in terms of the degradation model's validity if applied in the context of railway assets.
Asset Diversity	Scoring criterion (1 to 5) that assesses the material and technological diversity of the asset manager's portfolio. A diverse infrastructure incorporating a blend of civil structures, buildings, Mechanical and Electrical (M&E) services, and telecommunications systems attracts a high score, whereas infrastructures where a few asset types predominate (e.g. pipelines, powerlines, or buildings) receives a lower score. Weighting selected = 2, since a methodology proven in use with a limited variety of assets may lack the flexibility of one designed for more diversity, though the low weighting reflects the fact that this criterion is a function of the infrastructure modelled rather than the quality of the methodology itself.

Matrix Heading/Scoring Criterion	Description/Definition
Model Maturity	Scoring criterion (1 to 5) that considers the amount of experience in practical application for each methodology, based on the available evidence. The highest score is assigned to methodologies proven in use for ten years or more, with lower scores assigned to methods with fewer demonstrable years in use. For cases where the model was felt to be robust enough to merit comparison with CSI in other criteria but had not been used in service (e.g. methods developed in academia) a maturity score of 1 is assigned, or 2 if the academic method is derived from an existing, proven model. Weighting selected = 3, because while proof in use is good validation evidence for any replacement methodology considered, a higher weighting may have unduly penalised new but innovative approaches.
Ease of Data Collection	Scoring criterion (1 to 5) based on a subjective assessment, from reading the methodology, of the level of effort needed to generate input data for the model. High scores were assigned to methodologies that make use of condition data that would be collected as part of the asset manager's normal maintenance and renewal regime, such as condition inspection reports and Work Orders. Lower scores were assigned where more complex attributes are required to populate the asset condition model. Weighting selected = 4: ease of data collection was identified as a priority criterion by the ORR asset management team due to the process and workload implications.
Transparency	Scoring criterion (1 to 5) that rates how simply the asset manager could answer the senior stakeholder question "where does this number come from?" In scoring this criterion, care was taken to avoid penalising sound mathematical or statistical models provided that calculation steps were clearly explained in the published methodology. Lower scores were assigned to analytical approaches that were incomplete or embedded in proprietary software. Weighting selected = 3, since although clarity is important, a high weighting value may have excluded mathematically complex but otherwise innovative potential alternative methodologies.
Asset Inclusivity	Scoring criterion (1 to 5) that evaluates, approximately, the proportion of infrastructure within the asset manager's portfolio that is included and quantified within the scope of the condition measurement index. The approximation considers inclusivity on the basis of asset value rather than quantity, and is made using the information available from the literature search and reach-back exercise. Weighting selected = 3, since although less inclusivity implies a lower degree of in-use validation evidence, the range of assets included is often a function of the originating organisation's policy rather than a limitation of the methodology itself.

Matrix Heading/Scoring Criterion	Description/Definition
Future State Included	Scoring criterion (1, 3, or 5) that assigns one of the three ratings according to whether the measurement methodology gives a projection of future asset condition (scores 5), present condition (scores 3), or is limited to a hind-cast view only (scores 1). Weighting selected = 5: inclusion of future asset condition was identified as a priority criterion by the ORR asset management team, since it is an indicator of sustainability, a key component of CSI and an important requirement for any potential replacement.
Composite Index	Scoring criterion (1, 3, or 5) that assigns one of three ratings depending on the method's ability to present data in an aggregated form. Output as a single index figure scores 5, a condition summary of 2 or 3 figures scores 3, and multiple output variables scores 1. Credit is given for approaches that show multiple output values for presentation purposes (e.g. a figure per major asset group), but have a calculation method that would permit output values to be aggregated into a composite index. Weighting selected = 5: the ability of a methodology to derive a composite index was identified as a priority criterion by the ORR asset management team.
Output Scope	Scoring criterion (1 to 5) that evaluates the amount of information about infrastructure asset condition that the output metric provides to support the strategic decision maker's choice of action. Those methods that give a panoramic understanding of physical condition, risk, and fiscal need score highest, while those whose scope is purely technical and fiscal receive an intermediate score. Low scores are applied to metrics that provide a value but no context, such as a figure of merit with no unit of measure. Weighting selected = 4: the ability to express asset condition and investment need as an index that considers a broad range of factors was identified as a priority criterion by the ORR asset management team.
Adaptation Effort	Scored criterion (1 to 5) that gives a subjective assessment of the degree of difficulty that would be involved in migrating from the current CSI methodology to the approach being scored. The criterion takes account of procedural changes that would be needed to collect the necessary data, and the degree of theoretical difference between the methodology under evaluation and the CSI. Approaches with small differences in required data and simply constructed calculation methods score highest, while methods requiring wholly different data collection and processing methods score the lowest. Weighting selected = 5: ease of adoption of any new methodology was identified as a priority criterion by the ORR asset management team.

It can be seen from the criteria in Table 2 that there are trade-offs to be struck when evaluating alternative methodologies, for instance between 'Ease of Data Collection' and 'Output Scope', and for this reason the relative weightings of these and other criteria were discussed with the ORR asset management team to ensure appropriate prioritisation.

The overall weighted scores for each methodology were calculated as follows:

$WS = W_1C_1 + W_2C_2 + W_nC_n$ ....Equation 1

Where:

WS is the overall weighted score;

W_n is the weighting factor assigned to a criterion;

and C_n is the basic criterion score assigned.

The basic scores, C_n, and weighting values W_n, are shown in the methodology scoring worksheets in Appendix A. A summary of the resultant overall weighted scores as calculated for each methodology using equation 1 is given in Table 3 in section 4.1. "Scored Comparison Results".

In addition to providing an overall ranking of the alternative methods and the existing CSI based on common criteria, the scoring matrix approach was designed as a means of identifying relative strengths and weaknesses in specific areas. This was used to perform a gap analysis to identify aspects of the existing CSI process that offer the greatest potential for targeted improvement.

4 SCORING MATRIX RESULTS AND QUALITATIVE FINDINGS

This section gives the quantitative evaluation results from the scoring matrix and adds qualitative observations of relevance to targeted improvements in CSI methodology and form of output.

4.1 Scored Comparison Results

The results which follow give weighted scores in two categories:

- Overall weighted scores for each of the 21 methodologies evaluated, inclusive of all 10 scoring criteria and presented in ranked order;

- A gap analysis weighted score which identifies those alternate methodologies that scored higher than CSI under specific categories.

The overall weighted score is intended to guide overall policy option selection by identifying if any of the alternate methodologies revealed a higher score than the CSI. The purpose of the gap analysis score is to highlight specific aspects of the alternate methodologies that offer the potential to make targeted improvements in the existing CSI metric such that its overall score could be improved further. It should be noted that the gap analysis covers only those scoring criteria that are a function of the method being evaluated. As an example, the gap analysis scope includes intrinsic qualities such as the range of information conveyed in the output metric ("Output Scope"), but excludes comparison criteria such as "Portfolio Differences" which are a function of the infrastructure being measured rather than of the methodology itself.

Table 3 lists the ranked overall weighted scores for the 21 comparative methodologies evaluated. The complete matrix showing each methodology's scores for all 10 rating criteria may be found in Appendix A. The table lists the methodology's unique reference number, the sector and organisation from which it originates, and the name assigned to the methodology by its originating organisation. The 'Total Score' column shows an overall preference for the current CSI model, though it should be noted that comparison criteria such as 'Adaptation Effort' will favour the incumbent methodology. These comparison criteria are nonetheless a valid part of the overall comparison strategy, since there would be a considerable cost and time impact involved in replacing CSI in its entirety. Thus, an alternate method is unlikely to be worth adopting unless it can be shown that it outperforms CSI to the extent that the penalties associated with a complete change of methodology are justifiable. The alternative methods whose overall weighted score came closest to that of CSI include the accountancy depreciation and impairment method employed by Queensland Rail, Australia, and the non-rail industry Base Asset Health methodology employed by United Utilities Water Ltd.

The overall weighted scores therefore suggest that although there are a number of alternate methodologies whose score approaches that of the existing CSI method, their overall scores do not indicate that their adoption would justify the resources and costs of a complete methodology change. It is clear from examining the weighted scores of individual rating categories in Appendix A, however, that there is good potential for targeted improvements in some aspects of the CSI methodology.

Table 3. Overall Weighted Scores for CSI and Alternative Methodologies

REF	Sector	Originating Organisation	Model Name	Total Weighted Score
C0	Rail: Conventional	ORR/NR	Composite Sustainability Index (CSI)	**157**
C13	Rail: Conventional	Queensland Rail (Australia)	Accountancy depreciation & impairment	**152**
C3	Utilities: Water	United Utilities Water Ltd, 2018	Base Asset Health (BAH) indicator	**146**
C6	Rail: Sub-Surface	London Underground Ltd (LUL), 2013	Benefit to Cost Ratio (BCR) approach	**144**
C15	Rail: Conventional	DB Netz (Germany)	Accountancy depreciation & impairment	**144**
C16	Rail: Conventional	SNCF Réseau (France)	Accountancy depreciation & impairment	**144**
C19	Rail: Conventional	BNSF (USA)	Accountancy depreciation & impairment	**143**
C17	Rail: Conventional	ProRail (Netherlands)	Accountancy depreciation & impairment	**142**
C14	Metropolitan Transport Systems	Public Transport Victoria (Australia)	Accountancy depreciation & impairment	**140**
C18	Rail: Conventional	Amtrak (USA)	Accountancy depreciation & impairment	**140**
C9	Utilities: Gas	Wales & West Utilities, 2011	Health Index (HI)	**138**
C10	Utilities: Water	Segura River Basin Authority & Technical University of Cartagena, Spain, 2019	Asset Sustainability Index (ASI)	**138**
C2	Metropolitan Transport Systems	Regional Transport Authority, NE Illinois, 2014	'COST' model	**134**
C20	Rail: Conventional	Union Pacific (USA)	Accountancy depreciation & impairment	**133**
C5	Airports	Los Angeles World Airports, 2016	Facility Condition Index (FCI)	**130**
C4	Defence: Facilities	US Government Accountability Office (GAO), 2016	Facility Condition Index (FCI)	**126**

REF	Sector	Originating Organisation	Model Name	Total Weighted Score
C7	Rail: Conventional	Amtrak, 2019	Asset Condition Assessment used to determine State Of Good Repair (SOGR)	**126**
C8	Utilities: Electrical	National Grid, 2018	Asset Risk (Licensing condition on UK Transmission Owners (TOs))	**124**
C1	Utilities: Electrical	UK Distribution Network Operators (DNO), 2017	DNO Common Network Asset Indices Methodology	**121**
C12	Rail: Conventional	Sydney Trains (Australia)	Structured risk rating	**110**
C11	Defence: Facilities	RAND Project AIR FORCE (PAF), 2017	Infrastructure Project Prioritization Model modified adjusted for Mission Criticality	**102**
C21	Rail: Metro	MetrôRio	Asset Status Risk Matrix	**93**

Table 4 presents the results of the gap analysis based on a comparative score that considers those rating criteria that can be influenced by the design of the asset measurement methodologies. The scoring criteria listed in Table 2 that are not considered to be intrinsic to the methodologies and therefore not included in the gap analysis in Table 4 include “Portfolio Differences”, “Asset Diversity”, “Model Maturity”, and “Adaptation Effort”. Scores for the remaining 6 criteria are included, and methodologies that score higher than CSI in these specific areas are highlighted together with the applicable scoring criteria that achieved the higher score.

Table 4. Gap Analysis of Specific Scoring Criteria

REF	Originating Organisation	Model Name	Ease of Data Collection	Transparency	Asset Inclusivity	Future State Included	Composite Index	Output Scope
C0	ORR/NR	Composite Sustainability Index	16	12	9	25	20	20
C13	Queensland Rail (Australia)	Accountancy depreciation & impairment	20	15	9	15	20	15
C3	United Utilities Water Ltd, 2018	Base Asset Health (BAH) indicator	16	12	12	25	20	25

REF	Originating Organisation	Model Name	Ease of Data Collection	Transparency	Asset Inclusivity	Future State Included	Composite Index	Output Scope
C6	London Underground Ltd (LUL), 2013	Benefit to Cost Ratio (BCR) approach	16	12	9	25	12	25
C15	DB Netz (Germany)	Accountancy depreciation & impairment	20	12	9	15	20	15
C16	SNCF Réseau (France)	Accountancy depreciation & impairment	20	12	9	15	20	15
C19	BNSF (USA)	Accountancy depreciation & impairment	16	9	9	25	20	15
C17	ProRail (Netherlands)	Accountancy depreciation & impairment	20	12	9	15	20	15
C14	Public Transport Victoria (Australia)	Accountancy depreciation & impairment	20	12	9	15	20	15
C18	Amtrak (USA)	Accountancy depreciation & impairment	20	12	9	15	20	15
C9	Wales & West Utilities, 2011	Health Index (HI)	12	12	12	25	20	20
C10	Segura River Basin Authority & Technical University of Cartagena, Spain, 2019	Asset Sustainability Index (ASI)	16	12	9	25	20	20
C2	Regional Transport Authority, NE Illinois, 2014	COST' model	16	6	12	25	20	25
C20	Union Pacific (USA)	Accountancy depreciation & impairment	16	9	9	15	20	15
C5	Los Angeles World Airports, 2016	Facility Condition Index (FCI)	16	12	9	15	20	15
C4	US Government Accountability Office (GAO), 2016	Facility Condition Index (FCI)	16	12	9	15	20	15
C7	Amtrak, 2019	Asset Condition Assessment used to determine State Of Good Repair (SOGR)	16	9	12	25	4	20

REF	Originating Organisation	Model Name	Ease of Data Collection	Transparency	Asset Inclusivity	Future State Included	Composite Index	Output Scope
C8	National Grid, 2018	Asset Risk (Licensing condition on UK Transmission Owners (TOs))	12	12	15	25	12	20
C1	UK Distribution Network Operators (DNO), 2017	DNO Common Network Asset Indices Methodology	12	12	9	25	12	20
C12	Sydney Trains (Australia)	Structured risk rating	12	9	12	15	4	10
C11	RAND Project AIR FORCE (PAF), 2017	Infrastructure Project Prioritization Model modified adjusted for Mission Criticality	8	6	9	25	12	15
C21	MetrôRio	Asset Status Risk Matrix	8	6	9	15	4	10

Given that the overall weighted scoring comparison in Table 3 indicates that targeted improvement rather than total replacement of CSI is the preferred option, the gap analysis in Table 4 suggests that improving the range of assets covered and amount of information about asset condition, expressed as "Asset Inclusivity" and "Output Scope" respectively, show potential for improvement by drawing lessons from the highest-scoring methods in these categories.

Sources of best practice for the CSI targeted improvements include the United Utilities Base Asset Health (BAH) methodology [Ref. C3], TfL's Benefit to Cost Ratio (BCR) approach [Ref. C6], and the Regional Transport Authority of NE Illinois COST model [Ref. C2] for the "Output Scope" category. Lessons can also be drawn from the National Grid's Asset Risk (AR) methodology [Ref. C8] which scores well for "Asset Inclusivity" and "Output Scope". The improvements exemplified in these methodologies are further discussed in section 4.2, and in the conclusions and recommendations in section 5.

4.2 Qualitative Evaluation of Review Findings

This section supplements the quantitative evaluation presented in section 4.1 with SSL's qualitative observations from the literature search and in-house subject matter reach-back activities.

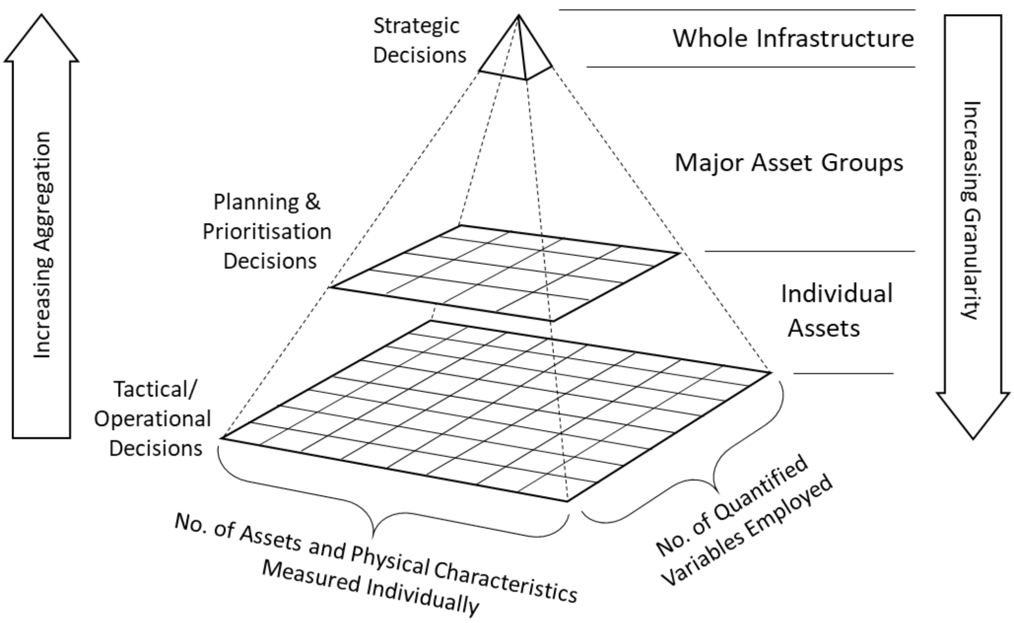
4.2.1 Strengths and Weaknesses of Composite Metrics

The majority of alternative methodologies reviewed provided a means of aggregating data to form a single composite indicator. In many cases, however, this index was supported by a breakdown of condition information to a more detailed level, typically that of major asset groups or classes within the infrastructure. The order and presentation media for composite and disaggregated indices varied between reporting authorities and organisation, but all were tailored to meet the needs of a specific stakeholder audience in terms of the scope and level of detail presented.

Composite indices are appropriate and necessary to inform strategic decisions by senior stakeholders whose role requires them to assimilate large amounts of information under constraints of time and budget. The advantage of using a composite index in this context is its brevity and simplicity, coupled with the ability to aggregate information about multiple asset groups and condition metrics into a single value. A weakness of the approach is the loss of transparency and supporting detail such as the relative contributions of major asset groups, or of cost categories such as deterioration versus consequence and likelihood of failure. In the context of CSI and fully aggregated indices in general, this weakness can be mitigated by providing visibility of asset health and investment need at a lower level of aggregation in order to give confidence in the methodology or reveal what drives the investment need. The level of detail for supporting data will depend on the intended stakeholder group, though the literature review suggests that a breakdown to major asset group level is commonly used for senior decision makers and an informed lay audience among the general public.

Best practice from the literature search suggests that compound indices should form part of a hierarchy of aggregation levels that are tailored to the needs of specific groups of stakeholders as shown in figure 2. In the context of the UK rail network, the CSI used at the strategic decision level is supported by more granular information such as annual engineer's reports by route and asset type, and NR management data on planned and delivered renewals volumes.

Figure 2. Asset Condition Index Aggregation Levels Tailored to Stakeholders



4.2.2 Data Confidence Levels and Quality Metrics

Strategic decision makers may seek reassurance concerning the level of confidence in asset condition metrics, but may lack the time or detailed knowledge to review the underlying details. The literature review revealed that some asset managers employ a simple graphical indicator that shows the degree of confidence or uncertainty inherent in the reported indices. The most concise example of this approach was found in a city infrastructure asset condition report [Ref. I10]. A simple sliding scale comprising a bar spanned by two indicator arrows is shown alongside the condition indices of each major asset group. The sliding scale ranges from 'high' to 'low' and the two indicator arrows show 'reliability' and 'accuracy' based on the veracity and completeness of the asset condition data used to score the health rating. The same asset manager states an order of preference in terms of source data used in asset condition measurements, ranging from physical inspection findings as the most robust, followed by percentage of asset life used, and defaulting to desk-based expert judgement of likely degradation rate if no other source of information is available.

4.2.3 Integration of Risk Indices

In addition to asset condition expressed in terms of percentage of Remaining Useful Life or life used, measurement methodologies that achieved high scores in the "Output Scope" category qualified their condition assessments with additional Key Performance Indicators (KPIs) to give decision makers a deeper understanding of present and future determinants of funding need. The most frequent supplemental metric was a risk-based indicator used to capture the impact of condition degradation or failure for all stakeholders, including asset owners, operators, and end-users. Rail IMs found to be employing risk-based indices included Sydney Trains (Australia) and MetrôRio (Brazil), both of whom use these metrics to prioritise asset investment. Typical non-rail examples of the risk-based approach include the US Air Force [Ref. C11] which links facilities degradation with the risk of reduced mission capability, and [Ref. C8] produced by the UK National Grid, which mandates the reporting of risk by Transmission Owner's (TOs) under the conditions of their operating license. The National Grid risk method applies the classical definition of risk as the product of Probability of Failure (PoF) and Consequences of Failure (CoF). Risk is calculated at asset level and termed Asset Risk (AR), and the CoF is expressed in monetary terms to give a cost-based measure of risk. Deriving the PoF and CoF involves an evaluation of the principle failure modes and their effects for each asset category, though the risk calculation excludes inconsequential failure modes as well as external events such as storm damage or vehicle collisions with transformer installations. The methodology has parallels with the CSI in that the AR results for specific asset groups are further aggregated to give a total for each operator's network, which the methodology terms Network Risk (NR).

Other methodologies reviewed were found to apply variations in terms of presentation method and measurement units used to quantify risk, though the underlying calculations shared the concept of multiplying consequence by probability. SSL's opinion is that metrication using risk is a useful supplement to basic condition assessment since it offers a more inclusive approach toward the different stakeholder groups who may be impacted by asset failure or degradation. It also helps to prioritise spending in the short term.

4.2.4 Presentation Format

Several of the reference documents reviewed made use of graphics to add impact and clarity to the basic numerical KPIs presented. A representative selection includes:

- Metropolitan asset manager's 'state of infrastructure' report [Ref. I10]: a simple 'speedometer' with a needle indicator gauging asset condition from 'very good' (green) to 'very poor' red, applied in conjunction with both composite metrics representing the entire infrastructure, and at the level of major asset categories such as water supply networks and roads.

- Airport infrastructure asset manager [Ref. C5]: a two-dimensional 'heat map' with 'Facility Condition Index' plotted along the horizontal axis and 'Criticality Rating' on the vertical axis, with grid squares ranging from 'low priority' (green) in the lower left corner, to 'high priority' (red) in the top right corner.

- Highways administrator [Ref. I3]: a combined histogram and line graph showing the drop-off in sustainability ratio over coming years as a row of bars reducing in height, superimposed by an ascending red line corresponding to the sustainability gap expressed in dollars.

- Gas utility [Ref. C9]: a summary of risk and health indices presented as a line graph showing in different colours the expected trend in future years of health and risk indices both with and without the requested level of investment. The degree of divergence between the pairs of lines gives a good indication as to the relative impact of funding decisions on different major asset groups.

SSL's opinion based on the literature review is that regardless of the calculation methodology applied, the use of graphical media can be a powerful tool in terms of adding impact to the funding message, and provides a quickly assimilated means of conveying trends and relative impacts to decision makers.

4.2.5 Inclusivity

In addition to the National Grid [Ref. C8] best practice of maximising inclusivity, the following targeted improvement references may serve as the basis for deriving asset condition measurement metrics for some of the assets currently excluded from the CSI:

- Coastal and estuarine defences, culverts, and retaining walls: joint research performed by DEFRA and the Environment Agency in 2009 [Ref. I1] produced guidance material for assessing condition grade deterioration curves based on construction and materials, local environment, and maintenance regime.

- Light maintenance depots, lineside buildings, Maintenance Delivery Unit (MDU)/National Delivery Service (NDS) buildings, and Track Paralleling (TP) huts: a Canadian government Public Infrastructure Management Framework [Ref. I2] details two simple condition rating models comprising a Building Deterioration Index (BDI) and a more detailed Facility Condition Index which is based on evaluation by inspection. An option to extend the scope of CSI may be to apply a BDI-type metric to simple structures such as TP huts and apply FCI to more complex facilities such as substations and light maintenance depots. A technical paper by Virginia Tech [Ref. I5] proposes a variation on this approach, deriving an inspection based rating method termed Building Component Condition Index (BCCI) which can be aggregated to combine multiple facilities in a composite index termed Whole Facility Condition Index (WFCI).

- Tunnels: a simplistic indicator based on tunnel density is described in a railway asset management working group paper published by the UIC [Ref. I4]. Tunnel density is quantified as the number of tunnels per track-km, or alternatively as a percentage of mainline track that runs within tunnels. The metric would require adaptation to incorporate the effects of age-dependent degradation to be relevant to the CSI, though since tunnels have a high failure consequence (albeit with a low probability) SSL considers that the development of a workable condition measure would be worthwhile.

- Electrical power cables: although Overhead Line Equipment (OLE) is covered in the existing scope of the CSI, pages 7 and 8 of a technical paper on health indices applied to high-tension cables in power distribution networks describes a condition-based approach which may offer more predictive accuracy than the existing percentage of OLE life remaining. The Total Health Index (THI) described in the reference considers component type and environment, and includes modifiers driven by age and criticality in deriving the overall rating.

- Drainage: a prerequisite for condition measurement of drainage assets is their capture in the asset register, which is a challenge given the UK rail network's age and organic growth. Literature reviewed as background to the existing CSI revealed that Wales' route makes use of an iPhone application known as 'My Work' to gather data on drainage assets for the purposes of inspection and maintenance (section 7.2 of the 2017 "Network Rail Monitor", [Ref. I7]). Processes used to first identify and then risk assess drainage assets have been developed by Highways England in Design Manual CD 535 [Ref. I11]. Hazards arising from degraded drainage assets in the highways environment differ slightly from those of railways though there is common ground on issues such as flood prevention. [Ref. I11] includes process flow-charts and relatively simple condition attribute ranking tables which may be adaptable to railway drainage asset condition assessment. A very simple risk-based methodology addressing drainage asset condition as commissioned by a US metropolitan authority is provided in [Ref. I12]. Drainage assets are risk-assessed as the product of failure probability and consequence, with failure probability rated high, medium, or low based on the percentage of life used (<50%, >50%<85%, and 85% or above, respectively). Seven consequence factors are used which take account of geospatial factors, asset types, and the impact on city infrastructure in the locality. The consequence factors are each assigned a weighting value. Outputs of the risk assessment are aggregated graphically using tabulated risk matrices with probability and consequence as the axes, and in a city-wide 'risk map' showing drainage assets in red/amber/green according to risk status. The output is monetised as the sum of replacement and maintenance costs of all drainage assets in the high risk category. Given the challenges involved in gaining a complete knowledge of drainage assets as a starting point, section 5 of [Ref. I12] describes a method to grade and rank asset information risk as a means of prioritising inspection resources in the field. The method considers drainage asset register completeness, and the availability and quality of condition assessment data, among others. This methodology could be adapted to provide a means of prioritising drainage asset cataloguing and inspection activities across the UK rail network routes so as to improve the drainage asset data quality used to feed the CSI.

4.2.6 Recent (Post 2014) Developments in Asset Condition Measurement

The literature review and overseas rail IM reach-back investigations suggest that changes in asset measurement methodology since the CSI's inception in 2014 have involved variations on a theme rather than radical overhaul in terms of the metrics used and their derivation. Starting with overseas rail IMs, it was evident that financial models of asset health have tended to stabilise around established methods involving some variation of accountancy depreciation and impairment, and approaches along these lines have been employed by DB Netz, SNCF, and conventional rail IMs in the US and Australia for several years. Among infrastructure managers from the non-rail sectors, developments in modelling over recent years have tended toward improving the alignment of asset condition and performance metrics with the requirements of their regulatory authorities, and with internationally recognised asset management standards such as ISO 55000. Beyond the modest theoretical and procedural developments noted across the sectors in terms of methodology, enabling technologies that underpin the assessment and capture of asset condition continue to evolve. Notable among these are asset management decision making tools and the inclusion of Asset Information Models in the Building Information Modelling (BIM) standard PAS 1192. SSL's recent HS2 technology scouting activity also revealed advances in railway semi-automated condition assessment technologies which may offer scope to improve the frequency and granularity of inspections to assets including track, OLE, and tunnels. These capabilities are linked to the continued evolution of laser scanning and video feature extraction technologies offered by inspection vehicle suppliers.

4.2.7 Prevalence of Composite Indices

The weighted scoring matrix evaluation in Appendix A shows that composite indices as a measure of overall infrastructure asset condition are in common use across both rail and non-rail sectors. Of the 21 measurement methods assessed, approximately 75% included a means of aggregating their output into a single figure. Although fiscal values similar to that used by the CSI are applied in many cases, some asset managers use composite indices that consider other variables such as risk, as for example in United Utilities Water Ltd.'s Base Asset Health (BAH) indicator [Ref. C3].

In addition to providing a single compound metric to summarise the condition and investment needs of complete infrastructures, many of the approaches reviewed also gave an indication of asset health at lower hierarchical levels. The hierarchical breakdown typically presents metrics by major asset group or class. This approach is analogous to the NR/ORR practice of providing CSI indices for individual routes but on a functional rather than a geographical basis. SSL's opinion is that either method is acceptable, since the breakdown method must be matched to the funding arrangements in place for each infrastructure asset manager or regulator. In addition, the literature search revealed other examples where indices are presented along geographical or organisational lines rather than by asset class, such as the breakdown by Transmission Owners in the case of the National Grid [Ref. C8].

4.2.8 Measuring Changes in Condition

Asset managers were found to apply various levels of sophistication in evaluating degradation behaviour across their asset portfolios. The degree of theoretical rigour applied appears to vary according to the metrication approach used (see section 4.2.9). Organisations using risk-based methodologies tended toward the more complex end of the spectrum with reliability theory underpinning the models used to quantify changes in asset condition as a function of time and usage. Condition-based methodologies place more reliance on physical inspection which suggests that a higher level of subjective judgement is being used to quantify rates of degradation. Arguably the simplest but least rigorous way of predicting changes in asset condition are those employed in the straight-line depreciation methodologies, where useful lives are assigned to assets and their levels of degradation implied by the percentage of that life used or remaining. An example drawn from ProRail [Ref. C17], which is also typical of other rail IMs, includes initial useful life assignments of 3 years for telecommunications assets, and 120 years for built assets, with allowance in the process to adjust the slope of the depreciation line based on inspection findings and renewal works carried out.

In SSL's experience of the application of Reliability Centred Maintenance (RCM) practices in the rail, aerospace, and defence sectors, a reasonable starting point for deriving failure models for highly diverse asset portfolios is the 'six patterns of failure' model. This model considers the conditional probabilities of failure with respect to time that are typical of different classes of asset including those which fail randomly, such as signalling or telecommunications equipment, and those more likely to fail as a function of elapsed time or some other usage parameter. The behaviour of assets subject to the six patterns of failure can be expressed mathematically using equations based on the Weibull distribution, though caution is required because all but the simplest assets have several modes of failure, each of which can exhibit a different pattern of failure. An example is a steel structure that is protected by a paint system. Both steelwork and paint system are likely to follow a similar failure pattern with respect to time, but the life of the paint system will be decades lower than that of the steelwork it protects. There is also a dependency between paint system and steelwork in that deterioration of the former will have an adverse effect on the steelwork's rate of degradation and useful life. These effects can be successfully modelled using a risk-based condition assessment methodology such as [Ref. C1], but a level of care is needed with complex models in order to avoid misleading results.

4.2.9 Metrication

The literature review and study of overseas railway IM practices revealed that metrication of asset condition follows one of three broad approaches:

- Risk-based metrics based on the product of probability and severity due to degradation-induced failures or impaired function. The severity component is often monetised as in [Ref. C1] so that risk is expressed in fiscal terms. The severity measure often incorporates societal costs alongside the cost of restoring degraded assets to full functionality once their level of performance has reached an unacceptable level. In similar fashion, risk-based metrics can help identify high-leverage but low value assets whose investment priority may be underrated or missed by methods that consider condition only. An example would be maintenance of drainage channels whose neglect could lead to water accumulation and subsequent landslips with major safety and operational consequences for the railway.

- Condition-based indices, whose derivation is based on a recognised set of evaluation criteria, which are often set or mandated by a regulatory authority. An example of condition-based metrication is the State Of Good Repair family of methodologies typified by the SOGR index employed by Amtrak [Ref. C7]. This index scores asset classes using one or more of the following criteria:

  - Age or cumulative usage: a metric analogous to used or remaining life as applied under the CSI methodology;

  - Visual condition, assessing obvious signs of asset wear or deterioration;

  - Reliability, based on the asset group's actual level of functional performance relative to the required level;

  - Measured condition, based on automated or manual asset inspection findings and comparable to inspection-based metrication methods such as Signalling Infrastructure Condition Assessment (SICA) results incorporated into the CSI method;

  - Maintenance condition, which evaluates the capacity of existing maintenance resources and plans in preserving acceptable asset performance levels, and the extent of any backlog in scheduled maintenance or renewal activities.

  As for the risk-based approach to metrication, the condition-based approach can be used to produce fiscal output metrics by asset group. A typical reporting approach is to present the percentage of each asset group that fails to meet SOGR criteria, alongside the value of assets within the category that are past their useful life.

- Straight line depreciation approach, which is derived from accounting practice but tempered with physical condition assessments and inspection findings so that design-based depreciation rates and estimated useful lives can be continuously updated with real-world feedback on the asset group's true condition. This approach is the most common by far among international railway IMs as indicated in the weighted scoring table in Appendix A. The advantages of this method are that it:

  - Outputs a fiscal measure of required spend directly, without an intermediate translation step from condition or risk, making the derivation process more transparent to senior decision makers;

  - Uses accountancy principles that have an established pedigree and are widely recognised across industry and government;

  - Enables international benchmarking of railway IM performance.

  There are variations in the level of sophistication employed in depreciation models. Some IMs restrict their models to a few high-value asset groups, while others include a more diverse portfolio. Depreciation rates are re-assessed on an annual basis and tailored to the type of line and usage by some asset managers, while more generic rates are adopted by others. The effects of expected changes in the level of use are also considered by some IMs as a means of predicting investment needs in future years.

Since all three approaches can produce fiscal output metrics, all three methodologies are capable of producing a single aggregated metric that reflects the complete infrastructure.

4.2.10 Defining Investment Need

The vast majority of the 21 methodologies evaluated produced a monetised output either directly from the condition index calculation or in conjunction with a parallel or derivative calculation method. In addition, the asset condition metrics and their associated investment needs were quantified at the level of major asset categories or groups, often in association with a single composite index and investment figure summarising the requirement for the entire infrastructure.

Two broad categories of investment need were identified from the literature:

- Investment required to maintain the steady-state value of assets over time. This category of investment is typically derived using condition or depreciation-based methodologies as described in section 4.2.9, and quantifies required investment based on the level or backlog of work required to maintain a State Of Good Repair (SOGR approach), or on the book value of assets which are at or beyond their useful life. Some flexibility in terms of spending commitment is possible in this investment category.

- Investment required to mitigate the risk of catastrophic failure. This investment category is most easily quantifiable using a risk-based methodology as described in section 4.2.9. It targets investment need according to the combined impact of the severity and probability associated with an asset's failure, or performance degradation to the point where functionality is critically impaired. Dependent on the probability and severity of risks identified, risk mitigation investment may offer less flexibility in terms of investment deferral.

An understanding of both risk related and depreciation-driven infrastructure asset liabilities are needed in order to build a truly comprehensive picture of required investment to guide budget holders. Methodologies from the literature review that demonstrate how these two facets are combined include the National Grid Asset Risk approach [Ref. C8] and the Sydney Trains (Australia) risk rating index [Ref. C12]. Both of these methodologies are further described in section 4.2.11.

4.2.11 Identifying Investment Priorities

Making priorities clear to decision makers and funding authorities is as much a function of the presentation of results as the methodologies used to derive them. The literature review made clear that asset managers often present their data in an impactful way using graphics and colour to highlight areas at greatest risk from underfunding. An example of this tendency can be seen in table 44 of the US Federal Highway Administration's Asset Sustainability Index (ASI) guide [Ref. I3]. ASI is a fiscal metric calculated using the amount spent on each asset category as the numerator, and the required level of investment is the denominator. This ratio of planned versus committed funding is presented in a table listing major asset groups as rows and future years as columns. To accentuate the prioritisation levels conveyed by the raw figures, the table entries follow a colour scale spanning red/amber/green. Using this presentation format, the severity of investment deficits and the timescales over which they arise are quickly discerned.

Those methodologies that incorporate a risk-based metric, especially where the 'consequence' component of risk includes the impact of asset degradation on end-users, arguably have an advantage over purely investment-based indices in that they take a more inclusive view of impacted stakeholders when assigning priorities. As an example from the rail IM methodologies reviewed, Sydney Trains (Australia) [Ref. C12] applies a risk rating index to evaluate the consequences of not replacing an asset at or near the end of its useful life. The index scoring is determined taking account of the asset's condition and its criticality should it fail to achieve its required level of performance. In the context of this approach, condition is a measure of the physical integrity of an asset and its required versus actual performance. The condition assessment indicates how much of the asset's operational life remains. The criticality measure is linked to the consequences of asset failure or underperformance in terms of on-time running, reduced asset redundancy, reliability, reputational damage, repair costs, and environmental impact. The risk rating index is used by Sydney Trains to inform renewal and maintenance planning. MetrôRio (Brazil) similarly applies a risk-based investment prioritisation method that includes reliability impact, and the matrix-based output is reviewed annually at director level for the purposes of prioritising investment.

An investment prioritisation example from the non-rail asset manager community is the Risk Trading Model (RTM) developed by the UK National Grid, [Ref. C8]. The RTM involves generating a monetised risk for each asset that can be combined with those of other assets to produce aggregated values at different hierarchical levels within the network infrastructure. The RTM is based upon an asset register which is defined for each Transmission Owner's network. In addition to identifying significant assets, the asset register assigns a Probability of Failure at the start of the evaluation period, alongside a monetised Consequence of Failure and forecast Probability of Failure in the final year of the investment period. In this way, RTM quantifies the impact that different investment plans have on the monetised risk for individual assets, major asset groups, and the complete distribution network when considered over the investment period. This enables direct comparisons to be made between competing investment plans such that spend can be directed to the plan with the lowest monetised risk.

4.2.12 Asset Condition Forecasting

The weighted scoring evaluation in Appendix A revealed that approximately half of the 21 methodologies examined included an effective method for predicting the future condition of assets. The utilities asset managers scored higher than those of other sectors in this regard, possibly due to the distributed nature and national importance of these infrastructures, although the same could be said of railways.

Of the asset managers whose methodologies take account of future asset condition for the purposes of forecasting investment needs, a spectrum of approaches was evident ranging from simple degradation models based on percentage of asset life used to more sophisticated predictive techniques built on reliability engineering principles. An example in the latter category is the Common Network Asset Indices Methodology [Ref. C1] which employs Weibull-based mathematical models to describe the rates and patterns of condition deterioration for asset groups in power distribution networks. The approach is designed to model assets whose conditions degrade at different rates, and it is possible to tailor condition degradation characteristics across different phases of an asset's lifecycle. The advantage in this and similar 'physics of failure' type approaches reviewed in the literature is arguably that their predictive power is enhanced by inclusion of more of the real-world variables that influence changes in asset condition over time and usage. Their disadvantage is that they require specialist knowledge to compile and update. As a counterpoise, other asset managers including US rail freight network operator BNSF [Ref. C19] use simpler linear depreciation models that assume a more-or-less constant degradation rate over the remaining life of an asset. BNSF and others improve the predictive power of their methodologies by adjusting degradation rates based on physical inspection findings, anticipated changes in duty cycle, and planned renewal actions. An advantage of the straight line depreciation method with periodic adjustment is that the underlying approach will be more transparent to senior decision makers, particularly those with a commercial background.

4.2.13 Method Transferability

The approximate level of effort and cost that would be required to construct and implement each potential alternative measurement method was evaluated in the weighted scoring criterion "Adaptation Effort" in the worksheets presented in Appendix A. Of the 21 alternative candidate methodologies assessed, 13 scored within the "low" to "minimal" difficulty scoring bands (4 and 5 respectively), although of these, 8 were from the rail sector, and none had an overall weighted score that exceeded that of CSI. SSL concludes from the review and assessment that a number of alternative approaches exist that could be implemented without major changes to the existing CSI data collection process or the need to develop complex techno-economic models, but that the gains in capability offered by these alternatives does not justify the change.

4.2.14 Logistical Considerations

In addition to comparing the relative performance of the CSI to potential alternatives using the weighted scoring evaluation, the choice of policy option should be tempered by the following logistical considerations.

- Condition assessment methodologies that are capable of projecting the future health of assets, including CSI, are dependent on the accrual of data on condition trends over a number of years. The implications for the continued validity of this data becomes an important consideration if a replacement or radical overhaul of an existing methodology were to be undertaken, and options would need to be explored in order to avoid the need to 'reset the clock to zero' in terms of condition trend data accrued to date.

- The following change management implications would also need to be considered if a substantially different condition measurement methodology were to be selected:

    - Costs and skills required to replace or re-engineer the existing methodology, including the theoretical knowledge underpinning any new degradation models, and the skills to design, test, and validate software tools.

- o Training needs for ORR and NR operational and maintenance staff in the capture and processing of data required by the new methodology.

In view of the limited advantage to be gained in moving to a radically different methodology, as indicated by the weighted scoring matrix results, SSL's opinion is that major change to the CSI approach would be difficult to justify given the procedural and administrative impacts listed above.

4.2.15 Future Trends in Asset Measurement Indices

Taking the totality of the literature review inclusive of both complete methodology descriptions and technical references applicable to specific assets or degradation models, SSL found a high level of commonality in the approaches adopted by rail asset managers, and these approaches appear to have changed little over the past 5 to 10 years. More variation was evident between the different sectors such as utilities and defence, though the underlying calculations and variables used in measuring asset health show much in common. There are also discernible clusters of methodologies where their user organisations share a regulatory framework, and an example of this is the State Of Good Repair (SOGR) and Facility Condition Index (FCI) metrics that are shared by asset managers in the defence and utilities sectors. Aside from the obligation to report asset health and investment needs in accordance with practices laid down by a regulatory authority or funding body, some asset managers have sought to align their methodologies and reporting formats with the ISO 55000 suite of asset management standards. This may reflect the increasing tendency of regulators to require that asset managers accredit their organisations to this standard in order to demonstrate having reached a recognised standard of rigour in asset stewardship.

On the basis of research performed on behalf of HS2 and the literature reviewed as part of this project, SSL expects the pace of change in asset measurement methodologies to remain at the incremental levels described above, though the following variables may have a bearing on the types of methodologies employed over the short, medium, and longer terms:

- Short-term:
  - o The continued evolution of track and lineside infrastructure inspection technologies such as video feature extraction and laser scanning may present opportunities to increase the granularity and frequency of condition data collection, which may consequently improve the accuracy and timeliness of asset condition metrics.
  - o Technology change, particularly in terms of signalling and telecommunications, will require a shift in focus from measuring physical degradation to assessing obsolescence risk and key skills shortages.
  - o As a counterpoise to the rise in automated or semi-automated inspection capabilities expected in the coming years, budgetary pressures that influence the scope, depth and frequency of manually-derived asset condition data may have a negative influence on the timeliness and accuracy of condition metrics.
- Medium-term:

- Changes in the volume and speed of rail traffic will impact how quickly track, civil structures, and OLE deteriorates.

- Changes in rolling stock type, particularly with respect to axle loads, wheel profiles, and suspension, will have a bearing on track useful life and the rate with which it is consumed.

- Continued electrification will introduce new assets to degrade, but potentially reduce deterioration of existing assets due to lower vehicle weights and a reduction in corrosive diesel fumes.

- Medium to Long-term:

  - Climate change may need to be considered as part of future developments in the methodologies, though the politicised and uncertain nature of its true effects make it likely that some form of contingency-based funding approach will be applied in preference to quantifying the effects. A reasonably balanced study of the effects of climate change on infrastructure asset maintenance, including those applicable to the rail sector, was commissioned by Infrastructure Australia [Ref. I13] in 2015. Based on extreme climatic events attributed to climate change over the years 2009 to 2011, the report identifies the following as potential climate-induced impacts:

    - Maintenance and renewal costs associated with flood risk mitigation, such as redesigned or re-sized drainage systems to accommodate increased rainfall.
    - Increasing costs of system maintenance to manage extreme heat events (e.g. track buckling and telecommunications/signalling equipment heat loads).
    - Implications of increased average frequency and severity of storms on OLE, lineside ecology, and exposed infrastructure in coastal environments.

  - In time, it is likely that remote condition monitoring technologies will continue to evolve such that they supplement or even replace existing inspection and Non-Destructive Testing (NDT) techniques. If and when such technologies become ubiquitous and cheap enough, they may permit asset condition to be measured in real-time and with a greater level of discrimination than is currently possible using manual or semi-automated inspection methods. Despite the considerable development effort that these technologies will require, SSL expects continued interest in remote condition monitoring given the desire to reduce the exposure of personnel to the trackside environment by NR and the Rail Safety and Standards Board (RSSB). The practical implications of these technologies for asset measurement methodologies include reducing the time and cost required for inspection data capture, and a wider range of asset condition variables.

In summary, SSL does not expect radical changes in the short term that will impact asset condition reporting in any fundamental way, but recommend that a watching brief is maintained on the areas listed above so that advantage can be taken of emerging capabilities that may be of benefit.

5 CONCLUSIONS AND RECOMMENDATIONS

This section describes the conclusions drawn from the weighted scoring evaluation of alternate infrastructure asset condition measurement methodologies identified for comparison with the CSI, and the qualitative review of the literature informed by feedback from SYSTRA personnel with experience in overseas IM asset management practices. A set of recommendations is made to assist the ORR and NR in selecting the most appropriate policy option for the CSI.

5.1 Conclusions

The conclusions below address the key questions posed in the ORR project brief as interpreted in the report scope outlined in section 2.3 of this report. The conclusions are based on a synthesis of the quantitative assessment and qualitative review findings from sections 4.1 and 4.2 respectively.

1. While the weighted scoring matrix results in section 4.1 revealed two specific areas in which some alternate methodologies scored higher than the CSI, the overall scores suggest that none of the 21 alternatives evaluated would offer an advantage great enough to justify its replacement. This conclusion is supported by considerations on the logistical impacts of CSI replacement in section 4.2.14.

2. The use of composite indices to summarise infrastructure asset condition was found to be widespread among both rail and non-rail asset managers. Of the 21 trans-sector methodologies reviewed, approximately 75% employ some form of composite index. The large majority also report asset condition and investment needs at a lower hierarchical level, typically presenting data by asset class or organisational subdivision. Evidence and examples to support this conclusion are given in section 4.2.7. and Appendix A.

3. The multi-sector literature review and feedback from SSL staff with overseas rail IM experience revealed that changes in infrastructure asset condition measurement methodologies have been incremental since the CSI's inception in 2014. Clusters of well-established methodologies predominate, driven largely by established practice and reporting requirements defined by regulatory authorities. Evidence to support this conclusion is presented in section 4.2.6. and in the similarities between methodologies described in the scoring matrix in Appendix A. Future developments that may influence asset condition methodologies in the short, medium and longer term are listed in section 4.2.15.

4. Asset present and future condition assessment methods employed by asset owners fall into three broad categories: risk-based, condition-based, and depreciation-based. The latter method was found to be the most commonly used among railway IMs, and is the simplest but least evidence-based. The risk-based methodologies are preferred by utilities and give a more inclusive view of degradation or failure cost that considers consequences for end-users. The disadvantage of risk-based methods is their theoretical complexity. Further details underpinning this conclusion are provided in section 4.2.9.

5. In the wider asset management context, SSL notes from recent periodic review supplementary documents [Ref. I7], [Ref. I8], and [Ref. I9], and project meetings with the

ORR asset management team, that CSI is supplemented in both breadth and depth by other sources of data and KPIs. Measures which complement the strategic view include the Composite Reliability Index which takes a shorter-term tactical view of network asset reliability trends against a 2013/14 baseline, and Service Affecting Failures (SAFs) that gives sight of infrastructure assets with the greatest effect on network punctuality and reliability. Supporting information beneath the strategic tier of CSI includes NR annual engineer's reports by route and asset type, and NR management data on planned and delivered renewals volumes.

5.2 Recommendations

SSL's recommendations based on the evidence accrued from the weighted scoring matrix and the qualitative review of alternate asset measurement methodologies is summarised as follows.

1. SSL's opinion based on the evidence presented in this report is that the most appropriate policy option would be to retain the CSI, but consider implementing the targeted improvements listed in recommendation 2.

2. SSL's opinion is that the following targeted improvements would be beneficial to the CSI in improving the scope of infrastructure assets covered and the inclusivity of cost categories that define the investment need as presented to senior stakeholders. The changes may be considered for implementation in an incremental fashion so as to spread the workload and minimise disruption in the reporting cycle.

    - Improve output scope by incorporating a simplified measure of monetised risk into the composition of CSI. Relevant alternate methodologies are highlighted in the scoring matrix results in section 4.1., Table 4. Also of relevance are the National Grid Asset Risk approach [Ref. C8] and the Sydney Trains (Australia) risk rating index [Ref. C12] described in overview in section 4.2.11. It is further recommended that the risk metric should consider failure and degradation cost impacts for all major stakeholder groups, including railway end-users.

    - Improve the asset inclusivity of the CSI through use of the specific asset degradation models described in section 4.2.5. These references address the asset classes that are excluded from the current version of the CSI. Asset inclusivity is the second of two categories in which some alternate methodologies score higher than CSI (see highlighted methodology in Table 4, section 4.1.).

    - SSL's opinion based on the literature review is that the CSI should continue to be supported by a breakdown at individual route level. Although the majority of alternative methodologies used a breakdown by asset class, there were notable exceptions such as the National Grid, whose reporting at the level of individual TOs is the best fit to funding and reporting boundaries within their infrastructure.

    - Review the SICA process to determine whether supplemental metrics are needed to reflect factors that drive investment needs in modern computer-based signalling systems. Examples to consider include obsolescence timescales and continued skills availability. Guidance from the literature review includes section 3.5 and Appendix 25 of the Wales and Western methodology [Ref. C9], which gives a brief description of how obsolescence risk is factored into the organisation's Health Index metric.

- In close cooperation with NR, maintain a watching brief on technological, operational, and environmental factors listed in section 4.2.15. so that opportunities or challenges that may drive a need to adapt the CSI are identified early. In conjunction, and based on best practice derived from the literature review, conduct a joint NR and ORR review of CSI methodology annually to plan incremental improvements and assess the need for future changes.

- Consider providing a simple indication of the level of confidence in the data used to underpin the CSI network and route scores to inform stakeholder audiences of the levels of uncertainly that are present. An example of a methodology that presents data confidence levels in simple graphical form is given in section 4.2.2. It is recognised that the ORR already places ISO 8000 derived data quality requirements on NR for the core asset data used in decision making.

- Consider graphical methods of reinforcing the investment message in terms of impact and prioritisation. The graphical presentation approaches judged to have the greatest clarity and impact among the literature reviewed are listed in section 4.2.4.

6 ACRONYMS AND ABBREVIATIONS

Acronym	Meaning
AR	Asset Risk (UK National Grid metric)
BAH	Base Asset Health (measurement index)
BCCI	Building Component Condition Index
BCR	Benefit to Cost Ratio
BDI	Building Deterioration Index
BIM	Building Information Modelling
COST	Capital Optimisation Support Tool
CSI	Composite Sustainability Index
DEFRA	Department for Environment, Food, and Rural Affairs
DNO	Distribution Network Operator
FCI	Facility Condition Index
GAO	Government Accountability Office (US)
HI	Health Index
IM	Infrastructure Manager
ISO	International Standards Organisation
KPI	Key Performance Indicator
LU	London Underground
M&E	Mechanical and Electrical (asset class)
MDU	Maintenance Delivery Unit

Acronym	Meaning
NDS	National Delivery Service
NOMs	Network Output Measures (UK National Grid)
NR	Network Rail
OLE	Overhead Line Equipment
ORR	Office of Rail and Road
RCM	Reliability Centred Maintenance/Remote Condition Monitoring
RSSB	Rail Safety and Standards Board
RTM	Risk Trading Model
RUL	Remaining Useful Life
SAF	Service Affecting Failure
SICA	Signalling Infrastructure Condition Assessments
SOGR	State Of Good Repair
SSL	SYSTRA Scott Lister UK Ltd
TfL	Transport for London
TO	Transmission Owner (UK electrical utilities)
TP	Track Paralleling
UIC	International Union of Railways
WFCI	Whole Facility Condition Index

7 REFERENCES CITED

Ref No.	Description
C1	"DNO Common Network Asset Indices Methodology", DNO Working Group technical report version 2.0, dated 1ts September 2020
C2	"Capital Asset Condition Assessment Report", Regional Transport Authority of Northeast Illinois report dated 1st December 2014
C3	"Asset Health – Our Approach" technical report, United Utilities Water Ltd document reference S4001 dated 2018
C4	"Defence Infrastructure – Actions Needed to Strengthen Utility Resilience Planning", report to the US Senate Committee on Armed Services, US Government Accountability Office (GAO) dated November 2016
C5	"Facilities Management Handbook", Los Angeles World Airports (LAWA) policy handbook release 2 dated 16th June 2016
C6	"Business Case Development Manual" technical manual, TfL Programme Management Office version V101 dated May 2013 [Note: a partially redacted copy released under the Freedom of Information Act (FoI) is available in the public domain]
C7	"Amtrak 5 Year Infrastructure Asset Line Plan", strategic planning document, Amtrak, version 10.2 dated 7th February 2019
C8	"Network Output Measures (NOMs) Methodology Issue 18", policy document, UK National Grid, version 6, dated 14th June 2018
C9	"Business Plan 2013 – 2021: Part B6 – Asset Strategy", business plan, Wales and West Utilities dated November 2011
C10	"Condition Assessment of Water Infrastructures: Application to Segura River Basin (Spain)", technical report, Urrea-Mallebrera, M, et al, Segura River Basin Authority, dated 27th April 2019
C11	"Articulating the Effects of Infrastructure Resourcing on Air Force Missions", technical report, RAND Corporation on behalf of the US Air Force, dated 2017

Ref No.	Description
C12	Information on Sydney Trains' asset methodology elicited through liaison with staff at SYSTRA Australia offices, Sydney, 21/09/2020
C13	"Queensland Rail Annual and Financial Report 2018-19," annual financial report, Queensland Rail, issued 2019, (https://www.queenslandrail.com.au/about%20us/Documents/Queensland%20Rail%20Annual%20and%20Financial%20Report%202018-19.pdf), web page accessed 21/09/2020
C14	"Public Transport Victoria Annual Report 2018-19," network annual report, Public Transport Victoria, issued 2019 (https://www.ptv.vic.gov.au/assets/default-site/footer/data-and-reporting/annual-report/6b8c2cff5a/PTVH4043-Annual_Report_2019-A4-v1_ONLINE.pdf), web page accessed 21/09/2020
C15	"Deutsche Bahn 2019 Integrated Report," network performance report, Deutsche Bahn, issued 2019 (https://ir.deutschebahn.com/fileadmin/Englisch/2019e/Berichte/IB19_e_web_02.pdf), web page accessed 21/09/2020
C16	Rapport financier du groupe SNCF Réseau, SNCF Réseau, financial performance report issued 31st December 2019 (https://www.sncf-reseau.com/sites/default/files/2020-03/Rapport%20Financier%20SNCF%20RESEAU%202019%20Sign%C3%A9_0.pdf), web page accessed 21/09/2020
C17	ProRail B.V. Jaarverslag 2018,' ProRail, network performance report issued 2018, (https://www.prorail.nl/sites/default/files/prorail_jaarverslag_2018.pdf), web page accessed 22/09/2020
C18	Information on Amtrak depreciation and impairment methods obtained from a range of public domain sources such as audited accounts, e.g. https://www.amtrak.com/content/dam/projects/dotcom/english/public/documents/corporate/financial/Amtrak-Management-Discussion-Analysis-Audited-Financial-Statements-FY18.pdf web page accessed 22/09/2020
C19	BNSF Railway Company Consolidated Financial Statements for the period ended December 31, 2019," BNSF Railway Company, 21st February, 2020 (https://www.bnsf.com/about-bnsf/financial-information/pdf/rail-financials-ye-2019.pdf), web page accessed 23/09/2020
C20	"Union Pacific Railway annual investor's report", issued February 2020 (https://www.up.com/cs/groups/public/@uprr/@investor/documents/investordocuments/pdf_up_10k_02072020.pdf), web page accessed 25/09/2020

Ref No.	Description
C21	Outline of MetrôRio asset status risk matrix methodology obtained via SYSTRA Scott Lister UK staff with experience in Brazilian railway operations
I1	"Guidance on Determining Asset Deterioration and the use of Condition Grade Deterioration Curves", guidance document, UK Environment Agency and DEFRA dated May 2009
I2	"Public Infrastructure Management Frameworks – Development and Implementation Guide", guidance document, Secrétariat du Conseil du trésor, Québec, dated 2019
I3	"Asset Sustainability Index: A Proposed Measure for Long-term Performance", technical report reference FHWA-HEP-12-046US, Department of Transportation, dated July 2012
I4	"Key Cost Drivers in Railway Asset Management", technical report, International Union of Railways (UIC), dated July 2015
I5	"Risk-Based Maintenance Management of US Public School Facilities", Dickerson, D, et al, technical paper for the International Conference on Sustainable Design, Engineering and Construction, dated 2016
I6	"Determining Health Index of Transmission Line Asset using Condition-Based Method", Hashim, R, et al, Tenaga Nasional University, Malaysia, technical paper dated 21st March 2019
I7	"Network Rail Monitor", Office of Rail and Road report on UK railway network performance, 4th December 2017
I8	"2018 periodic review final determination supplementary document - Review of Network Rail's proposed costs", Office of Rail and Road report dated October 2018
I9	"2018 periodic review final determination supplementary document: Scorecards and requirements", Office of Rail and Road report dated October 2018
I10	"State of Infrastructure Report", CH2M Hill on behalf of the Corporate Asset Management office of London, Toronto, Canada, technical report dated 2013
I11	"Drainage asset data and risk management", design manual CD535, Highways England, revision 1 dated January 2020
I12	"City of Chula Vista Drainage Management System Asset Management Plan", Kayuga Solutions' asset management plan produced for the metropolitan authorities dated 2016

Ref No.	Description
I13	“Infrastructure Maintenance – A Report for Infrastructure Australia”, climate change impact assessment on infrastructure maintenance including rail report by GHD on behalf of Infrastructure Australia, dated March 2015

APPENDIX A: MEASUREMENT METHODOLOGY SCORING MATRIX

This appendix presents the scoring matrix worksheets used to evaluate the 21 alternate asset condition measurement methodologies alongside the CSI.

					Criteria Weighting Values									
					2	2	3	4	3	3	5	4	5	5
REF	**Sector**	**Originating Organisation**	**Model Name**	**Brief Description**	**Portfolio Differences**	**Asset Diversity**	**Model Maturity**	**Ease of Data Collection**	**Transparency**	**Asset Inclusivity**	**Future State Inc.**	**Composite Index**	**Output Scope**	**Adaptation Effort**
C0	Rail: Conventional	ORR/NR	Composite Sustainability Index	CSI Baseline for Comparison	5	4	4	4	4	3	5	5	4	5
C1	Utilities: Electrical	UK Distribution Network Operators (DNO), 2017	DNO Common Network Asset Indices Methodology	Risk-based method using Probability of Failure (PoF) as common index in place of fractional change in value. Note: condition assessment metrics for HV electrical equipment may offer potential for development of CSI assets in 'Electrical Power' category. Strengths include 'value to society' of asset health, and ability to refine future aging characteristics to specific assets and life cycle phases	3	3	3	3	4	3	5	3	4	2
C2	Metropolitan Transport Systems	Regional Transport Authority, NE Illinois, 2014	COST' model	Good examples for the graphical representation of asset RUL are provided in section 3 of the report, including trend line representation of cumulative investment backlog and percentage of replaceable assets exceeding useful life	3	5	3	4	2	4	5	5	5	1
C3	Utilities: Water	United Utilities Water Ltd, 2018	Base Asset Health (BAH) indicator	Remaining asset life metrics are the driving criterion in the model, but the effects of asset criticality and available mitigations are also factored in	2	3	2	4	4	4	5	5	5	4
C4	Defence: Facilities	US Government Accountability Office (GAO), 2016	Facility Condition Index (FCI)	The FCI provides a general measure of a building's or structure's condition at a specific point in time. It considers required repair costs and plant replacement value	2	3	3	4	4	3	3	5	3	4

					Criteria Weighting Values									
					2	2	3	4	3	3	5	4	5	5
REF	**Sector**	**Originating Organisation**	**Model Name**	**Brief Description**	**Portfolio Differences**	**Asset Diversity**	**Model Maturity**	**Ease of Data Collection**	**Transparency**	**Asset Inclusivity**	**Future State Inc.**	**Composite Index**	**Output Scope**	**Adaptation Effort**
C5	Airports	Los Angeles World Airports, 2016	Facility Condition Index (FCI)	FCI is expressed as a ratio of the cost of remediating maintenance and repair backlog to the Current Replacement Value. It provides a method of measurement to determine the relative condition index of a single facility, a group of facilities, or an entire airport's portfolio. FCI is a KPI that provides a facility manager with a corresponding rule of thumb for the annual reinvestment rate (funding percentage) to prevent deferred maintenance accumulation	3	4	3	4	4	3	3	5	3	4
C6	Rail: Sub-Surface	London Underground Ltd (LUL), 2013	Benefit to Cost Ratio (BCR) approach	This investment prioritisation method considers the balance between cost of asset renewal, additional maintenance cost if the renewal work is not done, and the cost of passenger disbenefits, including resulting revenue loss. A variation on the approach is used to assess different renewal cycle strategies	4	4	3	4	4	3	5	3	5	4
C7	Rail: Conventional	Amtrak, 2019	Asset Condition Assessment used to determine State Of Good Repair (SOGR)	The condition-based methodology has been derived by Amtrak to achieve compliance with U.S. 49 CFR § 625 which requires that assets are regularly assessed as being fit for purpose. The scoring method uses a Condition Assessment Matrix that includes asset age, visual condition, reliability, measured condition, and maintenance condition	5	4	4	4	3	4	5	1	4	2
C8	Utilities: Electrical	National Grid, 2018	Asset Risk (Licensing condition on UK Transmission Owners (TOs))	Asset Risk as applied in this methodology is the sum of the expected values of each failure consequence associated with a particular asset group, and a function of the probability of each failure mode occurring	3	3	2	3	4	5	5	3	4	2

					Criteria Weighting Values									
					2	2	3	4	3	3	5	4	5	5
REF	**Sector**	**Originating Organisation**	**Model Name**	**Brief Description**	**Portfolio Differences**	**Asset Diversity**	**Model Maturity**	**Ease of Data Collection**	**Transparency**	**Asset Inclusivity**	**Future State Inc.**	**Composite Index**	**Output Scope**	**Adaptation Effort**
C9	Utilities: Gas	Wales & West Utilities, 2011 (Note: SOGR using similar principles observed to be in use as at 2019)	Health Index (HI)	Health Index is a representation of where an asset is along its useful life from commissioning through to the end of its life, where its likely performance level would not meet prescribed requirements. It is tailored by asset class and includes visual condition, environment, duty cycle, asset life, fault history, and obsolescence risk. Note: criteria considered in HI are almost identical to those listed in the SOGR model used by Amtrak as at 2019 (see reference C7 above)	2	3	4	3	4	4	5	5	4	3
C10	Utilities: Water	Segura River Basin Authority & Technical University of Cartagena, Spain, 2019	Asset Sustainability Index (ASI)	ASI is the ratio between the Cumulative Amount Budgeted for infrastructure maintenance and preservation over the whole life-cycle of the infrastructure and the total Amount Needed to achieve a specific infrastructure condition over the whole life-cycle of the infrastructure. The amounts include all maintenance actions that contribute to retaining or restoring the asset to a satisfactory state	2	3	2	4	4	3	5	5	4	4
C11	Defence: Facilities	RAND Project AIR FORCE (PAF), 2017	Infrastructure Project Prioritization Model modified adjusted for Mission Criticality	Proposed approach combines existing US DoD facilities metrication variables of Probability of Failure, Consequences of Failure, and Cost Saving, and proposes new methods for taking account of Mission Dependency. Included as a potential means of incorporating Service Affecting Failures and line closures into a modified or existing CSI metric. Good congruence to ISO 55000 principles of AM	3	4	1	2	2	3	5	3	3	2

					Criteria Weighting Values									
					2	2	3	4	3	3	5	4	5	5
REF	**Sector**	**Originating Organisation**	**Model Name**	**Brief Description**	**Portfolio Differences**	**Asset Diversity**	**Model Maturity**	**Ease of Data Collection**	**Transparency**	**Asset Inclusivity**	**Future State Inc.**	**Composite Index**	**Output Scope**	**Adaptation Effort**
C12	Rail: Conventional	Sydney Trains (Australia)	Structured risk rating	A risk rating index for not replacing an asset is determined based on asset condition and criticality (impact of asset failures). Condition is a measure of the physical integrity of an item and its ability to deliver the required performance. It indicates how much of the asset's operational life remains. Criticality is linked to the consequence of asset failure in terms of On-Time-Running, asset redundancy, reliability, reputation, costs and the environment. The risk index is used to inform renewals and maintenance planning, though should not be used for comparisons between asset classes	5	4	5	3	3	4	3	1	2	3
C13	Rail: Conventional	Queensland Rail (Australia)	Accountancy depreciation & impairment	Straight line depreciation over useful asset life used for railway infrastructure assets and buildings. Different assets are assigned different useful lives ranging from 6 years (for some telecommunications assets) to 100 years (for some civil works). Useful life and residual value (after useful life) are reviewed on an annual basis. Assets are also reviewed on an annual basis for impairment to identify cases where book value exceeds actual value, e.g. due to damage beyond repair in a natural disaster	5	4	5	5	5	3	3	5	3	5

					Criteria Weighting Values									
					2	2	3	4	3	3	5	4	5	5
REF	**Sector**	**Originating Organisation**	**Model Name**	**Brief Description**	**Portfolio Differences**	**Asset Diversity**	**Model Maturity**	**Ease of Data Collection**	**Transparency**	**Asset Inclusivity**	**Future State Inc.**	**Composite Index**	**Output Scope**	**Adaptation Effort**
C14	Metropolitan Transport Systems	Public Transport Victoria (Australia)	Accountancy depreciation & impairment	Straight line depreciation over useful asset life used for railway infrastructure assets and buildings. Impairment is also accounted for. Limited specific details are available in the public domain	4	3	5	5	4	3	3	5	3	4
C15	Rail: Conventional	DB Netz (Germany)	Accountancy depreciation & impairment	Straight line depreciation over useful asset life used for railway infrastructure assets and buildings. Different assets are assigned different useful lives ranging from 3 years (for some fittings and fixtures) to 100 years (for some civil works). The appropriateness of the chosen depreciation method, useful life, and the residual value (at the end of useful life) are reviewed on an annual basis. Impairment is carried out in accordance with International Accounting Standard (IAS) 36	5	4	5	5	4	3	3	5	3	4

					Criteria Weighting Values									
					2	2	3	4	3	3	5	4	5	5
REF	**Sector**	**Originating Organisation**	**Model Name**	**Brief Description**	**Portfolio Differences**	**Asset Diversity**	**Model Maturity**	**Ease of Data Collection**	**Transparency**	**Asset Inclusivity**	**Future State Inc.**	**Composite Index**	**Output Scope**	**Adaptation Effort**
C16	Rail: Conventional	SNCF Réseau (France)	Accountancy depreciation & impairment	Straight line depreciation over useful asset life used for railway infrastructure assets and buildings. Different assets are assigned different useful lives ranging from 5 years (for some telecommunications assets) to 100 years for built infrastructure. Useful life assignments and usage rates are updated based on regular inspections and tests	5	4	5	5	4	3	3	5	3	4
C17	Rail: Conventional	ProRail (Netherlands)	Accountancy depreciation & impairment	Straight line depreciation over useful asset life used for railway infrastructure assets and buildings. Different assets are assigned different useful lives ranging from 3 years (for some communications assets) to 120 years (for some civil works). An annual impairment assessment is also carried out to identify any cases where the value of an asset is below its book value	5	3	5	5	4	3	3	5	3	4
C18	Rail: Conventional	Amtrak (USA)	Accountancy depreciation & impairment	Straight line depreciation over useful asset life used for railway infrastructure assets and buildings. Periodic external studies are carried out to review depreciation rates. Limited details were found in the public domain on Amtrak's depreciation and impairment approach, but additional information on condition-based indices are given in reference C7 above	4	3	5	5	4	3	3	5	3	4

					Criteria Weighting Values									
					2	2	3	4	3	3	5	4	5	5
REF	**Sector**	**Originating Organisation**	**Model Name**	**Brief Description**	**Portfolio Differences**	**Asset Diversity**	**Model Maturity**	**Ease of Data Collection**	**Transparency**	**Asset Inclusivity**	**Future State Inc.**	**Composite Index**	**Output Scope**	**Adaptation Effort**
C19	Rail: Conventional	BNSF (USA)	Accountancy depreciation & impairment	Straight line depreciation over useful asset life. BNSF conducts depreciation studies, generally every three years for equipment and every six years for track structures and other railway property. These studies form the basis of the company's depreciation rates and take account of statistical analysis of historical use and retirement patterns, evaluation of expected changes in operation, technical advances and changes to maintenance practices as well as expected salvage value	4	3	5	4	3	3	5	5	3	4

					Criteria Weighting Values									
					2	2	3	4	3	3	5	4	5	5
REF	**Sector**	**Originating Organisation**	**Model Name**	**Brief Description**	**Portfolio Differences**	**Asset Diversity**	**Model Maturity**	**Ease of Data Collection**	**Transparency**	**Asset Inclusivity**	**Future State Inc.**	**Composite Index**	**Output Scope**	**Adaptation Effort**
C20	Rail: Conventional	Union Pacific (USA)	Accountancy depreciation & impairment	Straight line depreciation over useful asset life used for assets meeting 'minimum units of property' criteria. On high-density traffic corridors, depreciation is based on gross tonnage; on other lines it is based on time. Union Pacific has more than 60 depreciable asset classes, which are grouped where they have similar characteristics. Union Pacific conducts depreciation studies, generally every three years for equipment and every six years for track structures and other railway property. These studies form the basis of the company's depreciation rates and take account of statistical analysis of historical use and retirement patterns, evaluation of expected changes in operation, technical advances, and changes to maintenance practices as well as expected salvage value	4	3	5	4	3	3	3	5	3	4
C21	Rail: Metro	MetrôRio	Asset Status Risk Matrix	A risk grade and textual consequence analysis of failure is provided for each asset. The risk grade is based mainly on currently reliability, and the availability of spare parts, both in stock and on the market. The risk matrix is annually reviewed by the board of directors to prioritise investments	4	3	4	2	2	3	3	1	2	3

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