GUIDELINES FOR DATA COLLECTION AND MONITORING FOR ASSET MANAGEMENT OF NEW ZEALAND ROAD BRIDGES

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GUIDELINES FOR DATA COLLECTION AND MONITORING FOR ASSET MANAGEMENT OF NEW ZEALAND ROAD BRIDGES

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ABSTRACT

These Guidelines outline a process for data collection and monitoring for New Zealand road bridge asset management. They discuss, firstly, the recent appraisals of the state-of-the-practice conducted by the New Zealand Office of Auditor General and the indicated need to adopt advanced approaches to bridge asset management. The underlying relevant asset management principles are then briefly discussed. The main part of the document describes the recommended process for data collection and monitoring road bridges. The process starts with developing baseline data. Following this, a bridge risk and criticality assessment is undertaken and based on the results, bridges are classified for the core, intermediate and advanced data collection regimes. Detailed recommendations concerning data collection techniques, inspection frequency and the types of data to collect for each regime are provided. Considerations regarding data storage and management are discussed. Finally, a discussion about adapting the strategy to specific network needs is provided.

IMPORTANT NOTE

This document is based on NZ Transport Agency Research Report 475 "Data collection and monitoring strategies for asset management of New Zealand road bridges", February 2012.

The views expressed in this guideline are the outcomes of independent research, and should not be regarded as being the opinion or responsibility of RIMS or the NZ Transport Agency.

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ABBREVIATIONS

AADT	–	average annual daily traffic
ADTT	–	annual daily truck traffic
IGNS	–	Institute of Geological and Nuclear Sciences
LOS	–	level of service
NDE	–	non-destructive evaluation
NIWA	–	National Institute of Weather and Atmospheric Research
NZOAG	–	New Zealand Office of the Auditor General
NZTA	–	NZ Transport Agency
RMS	–	root-mean square
SHM	–	structural health monitoring
TLA	–	territorial local authority
VI	–	visual inspection
WIM	–	weigh-in-motion

GLOSSARY OF TERMS

Advanced asset management: Asset management which employs predictive modelling, risk management and optimised decision-making techniques to establish asset lifecycle treatment options and related long-term cash flow predictions

Best practice: A desired performance level that may or may not be attained by the current management practices

Bridge: The whole bridge asset, including deck, beams, abutments, foundations, handrails and surfacing

Bridge inventory: A physical description of the bridge

Component: A single entity that forms an element of the bridge, eg a specific joint, bearing or bridge beam

Condition data: An assessment of defect or deterioration extent and/or severity using a numerical scale

Core asset management: Asset management which relies primarily on the use of an asset register, maintenance management systems, job/resource management, inventory control, condition assessment, simple risk assessment and defined LOS in order to establish alternative treatment options and long-term cash flow predictions

Criticality: The degree of consequences or impacts that a bridge failure may have on the operation or functionality of a system

Damage: An unfavourable change in the condition of a structure that can affect structural performance

Data: Numbers, words, symbols, pictures etc without context or meaning

Defect data: Details of defects found during the inspection process, including defect description and proposed mitigation actions

Element: A structural or functional section of the bridge, eg deck, bearings, beams, abutments, foundations

Good practice: A performance level that is deemed appropriate taking into account time, budgetary, and operational constraints

Information: A collection of numbers, words, symbols, and pictures that have meaning, i.e. information is data with context

Knowledge: The understanding of information through assessment and analysis that provides a basis for the decisions to be made

Network functionality: The level to which a network delivers on the expected LOS as measured using a series of key performance indicators

Non-destructive evaluation (NDE): The type of testing that does not destroy the test object, typically uses simple tools and techniques, is short in duration, and can be carried out without attaching sensors to the bridge for a long time. NDE needs to be specifically arranged and carried out, and does not provide data or information on demand using automatic data-collecting systems. Typical examples include Schmidt hammer, chloride sampling and cover meter surveys. NDE also includes tests, such as concrete core strength, steel tensile strength or carbonation test, that destroy small samples extracted from the structure but do not destroy the bridge or any of its elements or components

Performance data: Data as measured against defined assessment criteria, relating to the operation of the bridge and its impact on network functionality – includes condition assessment, loading assessment, seismic assessment, scour assessment and other similar data

Risk: The chance of something occurring that will have an impact on objectives, measured in terms of a combination of the consequences of an event and its likelihood

Structural health monitoring (SHM): A type of data collection that provides data or information on demand about structural performance and any significant change or damage occurring in the structure. In the context of this strategy, SHM also comprises automatic data collection on wider network performance and environmental and operations factors affecting a bridge (eg traffic volumes, seismic excitation and river flows) (referred to as network-level SHM)

Validation: An exercise carried out to ensure an asset database is maintained correctly and has all data up to date and free of obvious errors

Verification: A random sampling exercise carried out to confirm the results from an inspection and to assess the accuracy of the data that is held in the bridge inventory database

Visual inspection (VI): The process of examination and evaluation of systems and components by the use of the human sensory systems aided only by such mechanical enhancements to sensory inputs as magnifiers, dental picks, stethoscopes and similar.

CONTENTS

1. INTRODUCTION

1.1 WHY THIS DOCUMENT IS NECESSARY

1.1.1 RECENT APPRAISALS OF NEW ZEALAND ASSET MANAGEMENT PRACTICE

In the period between 2002 and 2010, the New Zealand Office of the Auditor General (NZOAG[1]) produced a number of reports relating to road infrastructure asset management (NZOAG 2004; NZOAG 2007; NZOAG 2010). The reports noted that while local authorities have basic information about their road infrastructure and management plans for assets delivering essential services, these plans and the information being collected were, in general, relatively unrefined. It was found from the NZOAG reports that asset management primarily concentrated on:

- Identifying and quantifying the assets
- Gathering information on the assets' age and defects[2] or condition
- Developing information systems
- Providing forecasts of costs, such as new capital investment, renewals and operational expenditure.

The NZOAG reports also noted that few local authorities achieved an advanced level of asset management, which is characterised by:

- Improved understanding of the desired service levels the community wants the assets to provide
- Improved knowledge of the assets enabling predictions to be made about future performance
- Collection of appropriate data to improve asset management
- A focus on addressing the risks associated with managing the infrastructure.

The need for specific improvements to bridge asset management was further discussed in an NZOAG (2010) audit. The audit observed:

- There was no effective model for monitoring bridge condition deterioration
- There was an overreliance on the key asset management personnel's experience. This was considered to result in a high risk of losing institutional knowledge, which is critical for long-term planning, especially should those people move on
- The situation in bridge asset management was compared to road asset management and the latter found to be utilising more advanced asset management practices.

As a result of the issues raised by NZOAG targeted improvements to New Zealand's bridge asset management practice are being introduced. These *Guidelines* focus on improving the process of bridge data collection – the critical link in asset management. This is important as bridges occur, on average, every 2.5km on the State Highway network and every 5.2km nationally. Their ability to operate effectively and efficiently has a critical role to play in road network's operation.

1 For the list of acronyms see Appendix IV.
2 For the glossary of terms see Appendix IV.

1.1.2 GOVERNING PRINCIPLES OF ASSET MANAGEMENT AND THE ROLE OF DATA

PAS 55-1:2008: *Specification for the Optimised Management of Physical Asset*s (British Standards Institute 2008) defines asset management as:

"Systematic and co-ordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organisational strategic plan."

The PAS 55-1:2008 specifications applicable to these *Guidelines* involve:

- Clearly understanding and articulating the desired current and future function, performance and condition of existing and new assets and asset systems
- Considering the assets' life cycle management requirements
- Taking into account asset and asset-system-related risks and criticalities
- Need for optimal and sustainable management of assets.

The asset management cycle shown in Figure 1includes:

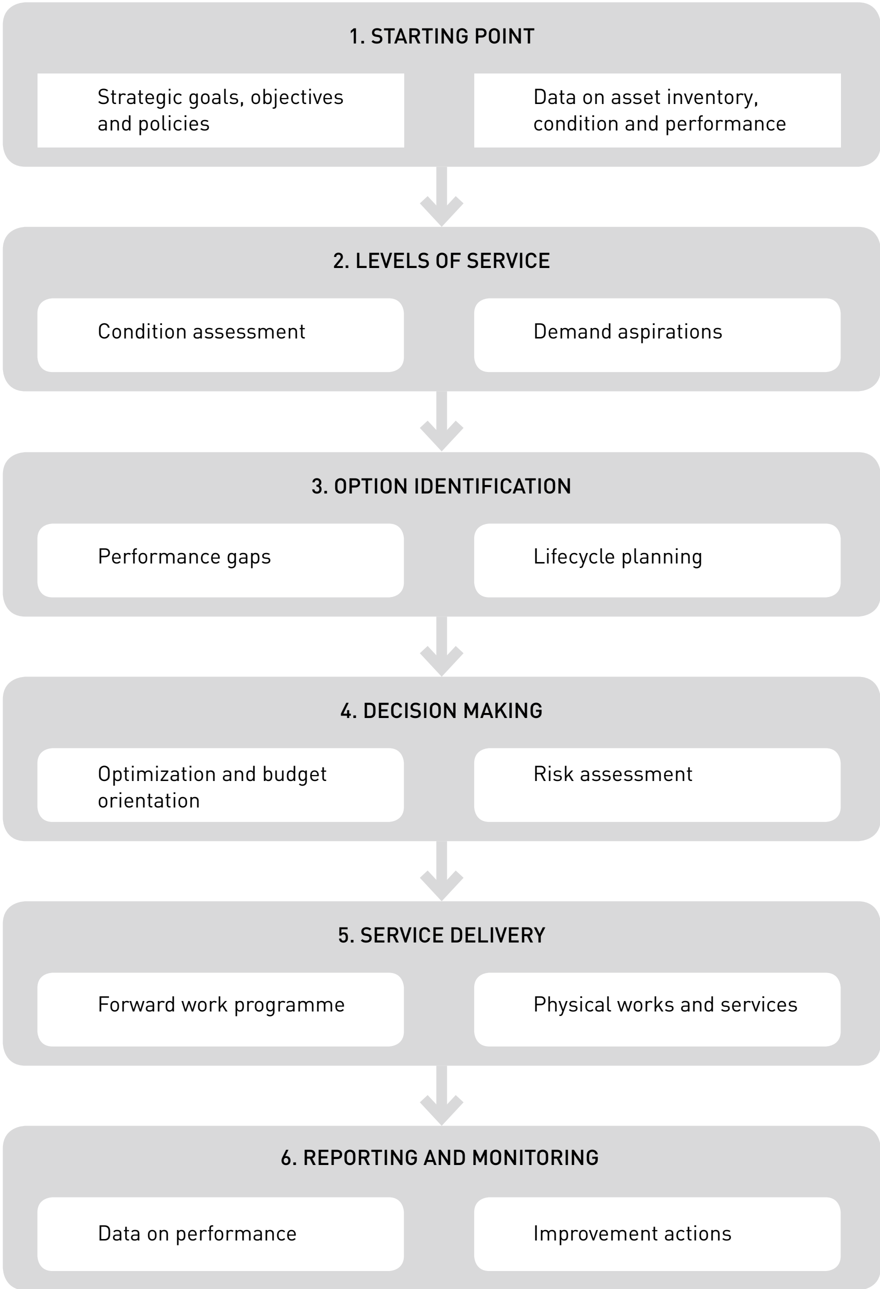
- Identifying strategic goals
- Understanding level service (LOS) delivery via condition assessment and defining demand aspirations
- Identifying options by assessing performance gaps and asset lifecycle planning
- Decision making, including optimisation and budgetary consideration and risk assessment
- Service delivery by planning forward works and their delivery
- Reporting on strategic goal achievement and performance targets.

As seen in Figure 1, data collection on asset inventory, condition and performance appears at the earliest stage within an asset management cycle. At the end of the cycle, when reporting is undertaken, performance data again needs to be gathered to identify any required improvements in the asset state. The data must, therefore be of the appropriate type, volume and quality.

Bridges require specialised asset management. To achieve the expected LOS the underlying data about their performance and deterioration needs to be collected. In contrast to other parts of the network, bridges are:

- Expected to perform for much longer than roads, with service lives in excess of 70 years and design lives of 100 years
- Typically expensive and difficult to replace without affecting network operation , especially in heavily congested areas
- Less easily repaired than roads, usually requiring significant traffic management arrangements for works to be undertaken
- Difficult to upgraded to provide increased LOS to manage, for instance, increases in traffic flow or truck weights
- Critical to the network's ability to function efficiently according to the expected LOS
- Often used as conduits for utilities, so are therefore critical to the utility networks' ability to function efficiently
- Much more complex than roads with respect to their failure mechanisms and have less inherent redundancy against failure.

Figure 1. Asset management cycle (Roads Liaison Group 2005).



When developing a data collection and monitoring strategy, bridge asset managers need to consider:

- The history of the available data
- The bridge data information systems, whether the data is appropriately stored, maintained, updated and validated, and whether it is easily retrievable
- Whether the data can be analysed to provide information about bridge performance
- Whether the bridges are appropriately classified according to their risk profile so they receive the most appropriate management regime
- Whether the bridge management budget is spent in the right areas and the bridge maintenance and renewal outcomes are optimal
- Whether the current asset management regime is aligned with good practice and on par with advancements here and overseas?
- Whether improvements deliver maximum value
- Whether the data, including quality as built records, is available to undertake the advanced asset management expected by NZOAG audits (NZOAG 2004; NZOAG 2010).

The NZOAG audits suggest data gaps exist in the existing asset management practices that have hindered the development of advanced asset management practices. Therefore, if appropriate data is collected and linked with improved decision making, it will significantly improve asset management outcomes. These *Guidelines* aim to help bridge asset managers close the noted gaps.

1.2 THE *GUIDELINES*' PURPOSE

The *Guidelines* are based on the bridge data collection and monitoring strategy developed for NZTA (Bush et al. 2010). This undertook a detailed review of the international practice and surveyed the current New Zealand practice. The *Guidelines* provide a step-by-step description of how to implement the data collection and monitoring strategy recommendations that are sufficiently flexible to meet a wide range of network needs. The objectives are to close the gaps identified in recent NZOAG audits (2004; 2010) and to move current practice towards advanced asset management.

The main recommendations the *Guidelines* address are the need to:

- Acknowledge that not all bridges or networks require the same level of asset management
- Develop a risk-based approach to data collection, so practices can be tailored to specific bridge and network needs
- Develop bridge data collection approaches with strong links to the decision making process and the expected strategic outcomes
- Modify and standardise the type of data collected to ensure there is sufficient for advanced asset management
- Expand the type of data collection techniques used including visual inspections (VIs), non-destructive evaluation (NDE) and structural health monitoring (SHM) to ensure more accurate data is available for long-term planning
- Improve asset management practices, similar to those for roads.

The *Guidelines* aim to provide a data collection framework that enables bridge asset managers to develop innovative and network specific approaches to data collection. The data collection framework provides a risk- and criticality-based process for categorising bridges, where acceptable risk levels would be set according to risk tolerance and available budgets. The *Guidelines* provide specific recommendations for the type of data that should be collected and ways to collect it.

The *Guidelines:*:

- Describe the process of implementing the proposed data collection strategy
- Carefully explain the risk and criticality-based approach used to classify bridges for various data collection regimes
- Provide detailed descriptions of the proposed core, intermediate and advanced data collection regimes for bridges with different risk and criticality profiles, including VI types and frequency and the use of NDE and SHM
- Describe how the collected data links to strategic outcomes in the overall decision making process
- Clarify the requirements regarding the type of data to collect
- Explain the data storing and management requirements
- Discuss data collection strategy review and modification.

2. ROAD BRIDGE DATA COLLECTION AND MONITORING BRIDGES

2.1 PROCESS

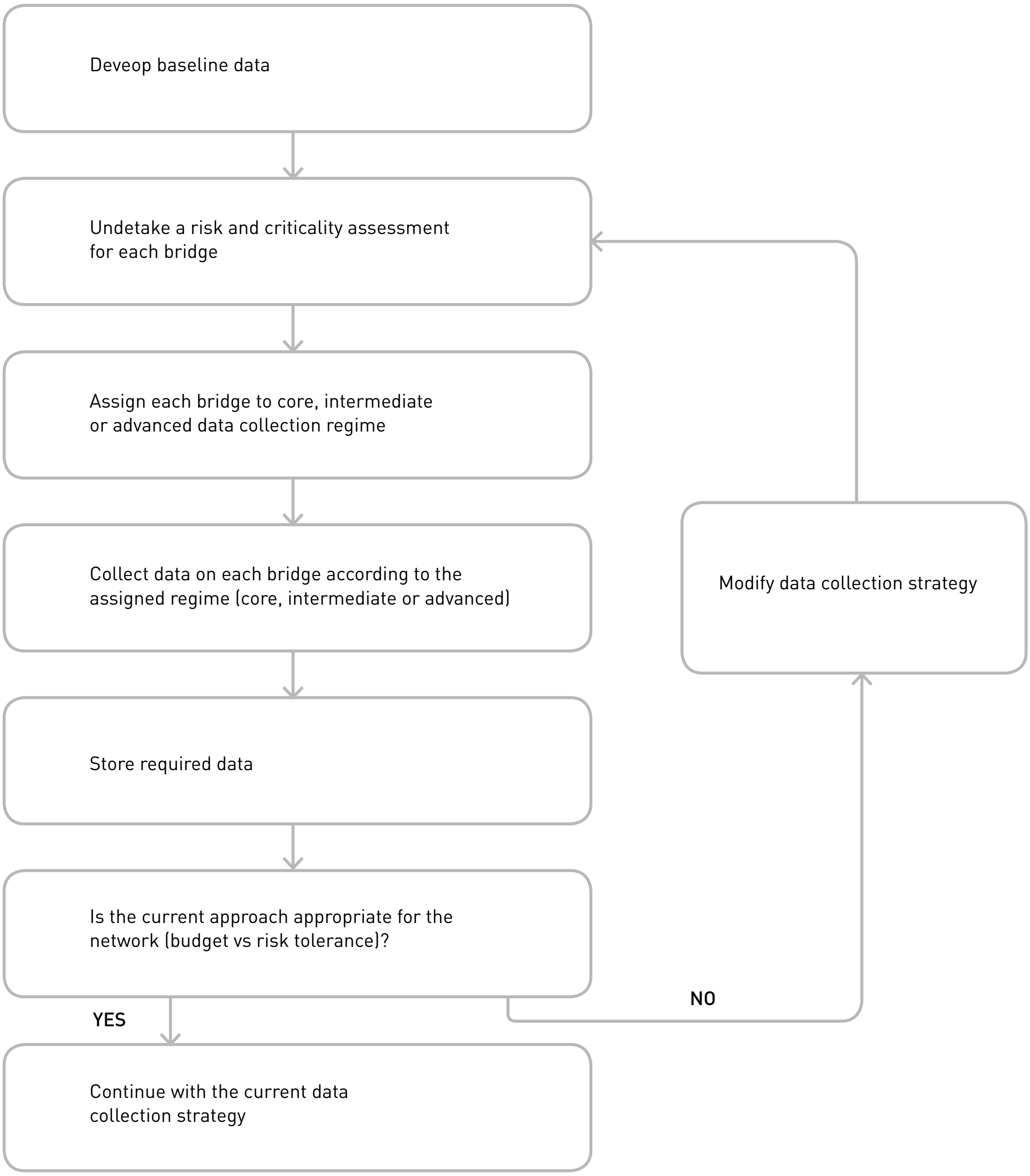
The process for collecting and monitoring data for road bridge asset management is outlined in Figure 2. This section explains the whole process, providing a big-picture view, while subsequent sections describe in more detail its parts.

The main steps are to:

- Develop baseline data
- Besides collecting data on bridge inventory, condition and performance, additional data may be required for the initial risk and criticality assessment discussed in Section 2.2.
- Undertake a risk and criticality assessment for each bridge
- The process of data collection outlined in the *Guidelines* differentiates bridges based on their risk and criticality rating. It calls for different data collection regimes depending on the risk and criticality rating discussed in Section 2.3.
- Assign a core, intermediate or advanced data collection regime to each bridge
- Based on their risk and criticality assessment results, each bridge is assigned an appropriate core, intermediate or advanced regime for specific data to be collected as outlined in Section 2.4.
- Collect data on each bridge according to the assigned regime (core, intermediate or advanced)
- The type, accuracy, quality, frequency and collection techniques for each level are detailed in Section 2.5.
- Store required data
- Requirements for data storage and management are outlined in Section 2.6.
- Decide whether the current approach for the network (budget versus risk tolerance) is appropriate
- The approach proposed in the Guidelines allows for modifications depending on budgetary constraints versus risk tolerance. In some circumstances, for example after the process has been in place for some time and/or when circumstances have changed (eg due to risk and/or budget changes) bridges may be reassigned to different data collection regimes as discussed in Section 2.7.
- Either continue with or modify the current data collection strategy

Regardless of whether the current process is continued or altered, having collected the required data will facilitate better informed decisions.

Figure 2. Data collection process



2.2 DEVELOPING BASELINE DATA

Baseline data is the starting point for the data collection process as it is used in the risk and criticality assessment. The baseline data provides information about the bridges on the network, the roads they support and the likely impacts of any change of performance. As Figure 2 shows, the implementation process is circular: once it has begun, the data it yields can be used to refine the risk and criticality assessment, leading in turn to improvement in data collection.

The baseline data scope is therefore covered by the risk and criticality assessment process requirements outlined in Section 2.3 and Appendix II. It is important to understand these requirements before assessing data quantity and quality. Nevertheless, the following scenarios can be envisaged:

- The available data is of insufficient quantity and/or quality. In these cases, the process can only be implemented for those bridges and/or risk categories, if any, that have appropriate data available. Data gaps have to be addressed before implementation of the data collection strategy is possible.
- The minimum data is available for the whole stock and the process can be implemented in a comprehensive, whole-network and uniform fashion. Subsequent risk and criticality assessment will enable differentiating approaches on a bridge-by-bridge case.
- A mixture a data levels exists, where some bridges have more and/or higher quality data than others. In these cases, comprehensive process implementation is also possible as the proposed risk and criticality assessment methodology addresses such differences by the use of 'uncertainty premium' (see Section 2.3.2).

2.3 RISK AND CRITICALITY ASSESSMENT

2.3.1 RISK AND CRITICALITY APPROACH

Not all the bridges on a given network have the same characteristics and condition, are subjected to the same demands, and have the same importance. Some bridges will require more advanced asset management approaches, while for others, simpler asset management approaches will be adequate. It is logical that more advanced approaches require higher volumes and quality of data and vice versa. The cornerstone of these *Guidelines* is in moving away from the current data collection approach that treats all bridges equally to adopt a systematic approach of tailored bridge asset management and data collection. This is achieved by using a risk- and criticality-based data collection strategy. This section firstly discusses the underlying concepts of risk and criticality, describes a simple methodology for risk and criticality assessment, and then illustrates it by an example involving several bridges.

The commonly adopted definition of risk (R) quantifies it by multiplying the probability of bridge failure (P) with overall consequences (C) (sometimes referred to as impacts or exposures) of the failure (Standards New Zealand 2004):

$R = P \times C$

In these *Guidelines*, 'failure' is any situation when a bridge fails to deliver its performance expectations in a way that affects network functionality. This may, in extreme and rare cases, involve structural collapse or damage but it also includes non-catastrophic failures. Examples are where , vehicle loads or speeds are restricted to manage structural element fatigue or functional deficiency. The overall consequences of failure can be divided into:

- Direct consequences including bridge maintenance, repair or replacement costs
- Wider, whole network or regional level consequences including traffic delays, service interruption, loss of business, lowered community resilience to natural hazards
- The structure's loss of heritage or iconic status.

Even when the likelihood of failure is low, large consequences or impacts can occur, so a different calculation may be needed. Multiplying the probability and consequences may not therefore lead to meaningful risk appraisal and consequences alone govern decisions. The bridges with large failure consequences are referred to as 'critical'.

2.3.2 ASSESSMENT OF BRIDGE RISK AND CRITICALITY

Bridge asset managers will be able to understand which bridges present increased risk and/or are more critical according to the outcome from the risk and criticality assessment process using the baseline data. This knowledge will enable them to decide on the appropriate level of asset management and data collection regime for each bridge.

When choosing and implementing a risk and criticality assessment process the following should be considered:

- Assessment methodology should account for both bridge and network level risks
- Assessment methodology should account for wider performance risk beyond bridge structural failure (eg its effect on traffic, safety, economic impact)
- Outcome from the risk and criticality assessment process should provide sufficient detail to rank bridges and clearly identify those with increased risk and/or criticality.

To determine bridge risk and criticality, the *Guidelines* have adopted the process developed by Moon et al. (2009), see Figure 3. However, bridge asset managers may choose other rational approaches. The general aspects of the process and higher level details are covered in this section and are illustrated via an example using four bridges from the State Highway network. More detailed tables required for risk and criticality scoring are provided in Appendix II. (Note the terminology used in Moon et al. (2009) has been changed in some cases for consistency with the rest of the *Guidelines*.)

Moon et al. (2009) define the following four major risk categories:

- Geotechnical / hydraulic safety
- Structural safety
- Serviceability, durability and maintenance
- Functionality.

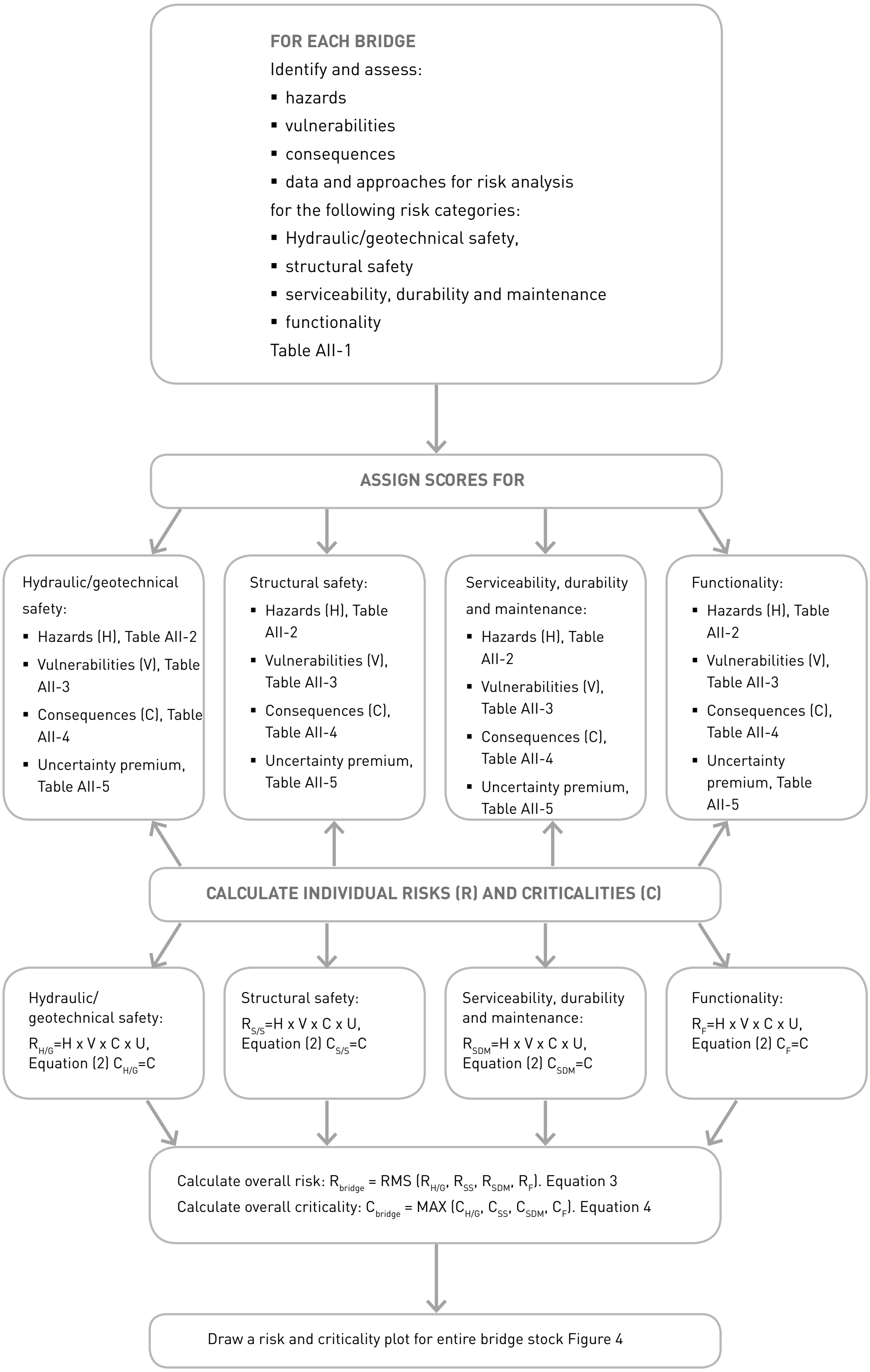
For each of these categories' risk is calculated separately as follows:

$$R = H \times V \times C \times U$$

where:

- H = probability of a given hazard occurrence
- V = vulnerability to a given hazard
- C = consequences resulting from a failure to perform adequately
- U = uncertainty premium.

Figure 3. Risk and criticality assessment process



Tables outlining this risk and criticality assessment methodology in more detail are presented in Appendix II. Table AII-1 provides a list of hazards, vulnerabilities and consequences that need to be considered while assessing the risk in each category. Tables AII-2 to AII-4 provide the scores used in the above risk formula (Equation). The relative scores range between 1 and 3 (or in some cases between 1 and 2) for the first three factors, i.e. H, V and C. For example, the score for hydraulic/geotechnical hazard probability depends on design flood return period at the bridge location, seismic design category, distance from the coast, possibility of vessel impact, scour potential and history of hazard occurrence.

The uncertainty premium, U, takes into account the accuracy of the data available and approaches used for risk analysis and quality control measures employed (see Table AII-5). Five different values are proposed, ranging from 2.5 for assessments based on minimum standard VIs and document review, to 1.0 when best practice VIs and document review are used together with best practice analysis, technical checks and NDE/SHM.

To obtain an aggregate risk for the entire bridge, R_{bridge}, the root-mean square (RMS) of the individual risk category scores is calculated:

$$R_{bridge} = \sqrt{\frac{R^2_{H/G} + R^2_{SS} + R^2_{SDM} + R^2_{F}}{N}}$$

where

- $R_{H/G}$ = hydraulic/geotechnical safety risk score calculated according to Equation using Tables AII-2 to AII-4
- R_{SS} = structural safety risk score calculated according to Equation using Tables AII-2 to AII-4
- R_{SDM} = serviceability, deterioration and maintenance risk score calculated according to Equation using Tables AII-2 to AII-4
- R_F = functionality risk score calculated according to Equation using Tables AII-2 to AII-4, and
- N = number of risk categories considered (N = 4 if all categories are considered).

The use of RMS for the overall risk score ensures that greater emphasis is placed on specific risk issues that contribute more to the aggregated risk. However, for bridges with heightened overall risk it is recommended that individual performance risks are also examined to understand their relative importance.

Bridge criticality is measured by the wider consequences to the network functionality and regional economy resulting from a failure. By separately reporting on criticality, it ensures that the bridge asset manager takes into account those bridges that have a significant impact on network functionality, but because of their low failure probability might not have the same recognition if only a purely risk based outlook were used. The overall bridge criticality score, C_{bridge}, is assumed as the maximum criticality score for the individual risk categories:

$$C_{bridge} = \max (C_{HG}, C_{SS}, C_{SDM}, C_F)$$

where

- $C_{H/G}$ = hydraulic/geotechnical criticality risk score from Table AII-4
- C_{SS} = structural safety criticality score from Table AII-4
- C_{SDM} = serviceability deterioration and maintenance criticality score from Table AII-4, and
- C_F = functionality criticality score from Table AII-4.

As with the overall risk score, for highly critical bridges it is recommended to examine the individual criticality scores.

2.3.2.1 Illustrative example of bridge risk and criticality assessment

Four bridges are used in this example, including a small corrugated-steel culvert, a single-span highway bridge, the Auckland Harbour Bridge, and the replacement Newmarket Viaduct. These bridges were chosen as representative of some of the challenges faced by New Zealand bridge asset managers. All inventory data for the bridges is taken from the NZTA Bridge Data System. The details for the four bridges required for risk and criticality assessment are provided in Table 1.

Table 1. Description of bridges used in the risk and criticality assessment example

BRIDGE	PHOTOGRAPH OF THE BRIDGE	DESCRIPTION
Corrugated-steel culvert		▪ 4m diameter corrugated-steel culvert supports state highway of national strategic importance ▪ Built <50 years ago; overall good condition; only minor corrosion to the barrel; no scour ▪ Replacement cost low; AADT >50,000 vehicles; heavy commercial vehicles 5%; reasonable LOS could be restored within a few days; temporary measures quickly available; alternative routes available with only minor reductions to service level ▪ Data collected via regular minimum-standard VIs
Single-span timber bridge		▪ 12m span timber bridge carrying road of local importance over a small river ▪ Designed to outdated load standards; overall moderate condition ▪ Replacement cost moderate – between NZ$100K and NZ$1m; AADT is 1,000 ▪ Service can be returned after several days, with a temporary bridge installed ▪ Data collected via regular minimum-standard VIs

Table 1 continued

Auckland Harbour Bridge		▪ Key link across a harbour supporting state highway of national strategic importance at the heart of the major economic centre of New Zealand; complex truss bridge with 'clip-on' extensions on both sides ▪ Navigable shipping channel; coastal environment ▪ Known fatigue issues in extensions (heavy vehicles prohibited on extensions); extensions recently strengthened but only limited service life expected ▪ Replacement cost very high >NZ$750M; AADT for extensions >38,000, centre truss >80,000; major service would take >1 year to restore; a detour available for long routes, but nothing available locally; failure will cause significant delays in the region and impact heavily on local, regional, and inter-regional commerce; a national icon ▪ Individual management plan implemented, including best-practice VIs, NDE and SHM
Newmarket Viaduct		▪ Key link supporting state highway of national strategic importance at the heart of the major economic centre of New Zealand; completed in 2011; twin post-tensioned bridges with 12 spans, ~60 m each ▪ Replacement cost very high >NZ$200M; AADT >160,000; service would take >1 year to restore; detours available but failure will cause significant delays in the region and impact heavily on local, regional, and inter-regional commerce ▪ Data collected via best-practice VIs and technical analyses conducted; a University-operated SHM system is in place that could be integrated into management plan

The final criticality and risk scoring outcomes are summarised in Table 2. A more detailed rationale behind the scores assumed for the culvert for structural safety is provided below as an example of the process:

- Hazards (structural safety): There are moderate numbers of trucks on the road section (2,500); this has not resulted in overstressing. The rating is therefore 2.
- Vulnerabilities (structural safety): 50 years or fewer since construction and overall good condition, therefore rating assumed as 1.
- Consequences (structural safety): AADT is more than 10,000, but the replacement cost is low and the detour is easily available, therefore rated as 2.
- Uncertainty premium (structural safety): Assumed to be 2.5 as there are only minimum standard VIs occurring.

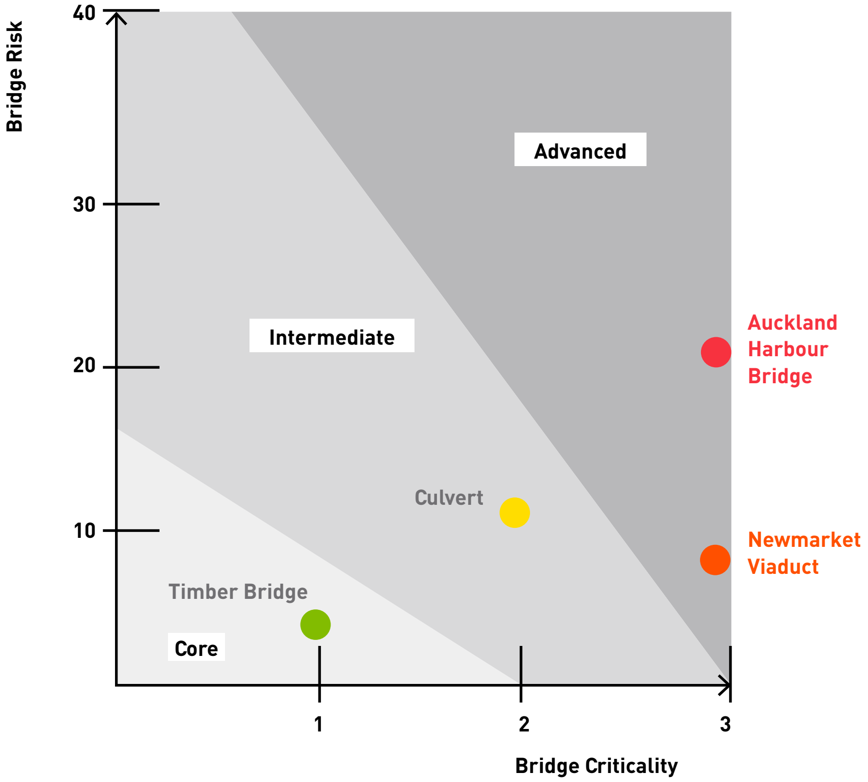
It is also useful to represent the assessment outcome graphically in a risk and criticality plot as shown in Figure 4. The bands in the plot indicated by different shades of grey correspond to the different data collection regimes assigned to the bridges (indicatively at this stage). This is further discussed in Section 2.4.

The first observation that can be made from the example (Table 2 and Figure 4) is that the Auckland Harbour Bridge and Newmarket Viaduct, while having very different risk scores, both have the same criticality rating, which could be anticipated given their relatively similar, and high, importance. Another observation is that the corrugated-steel culvert, while being a relatively simple structure in good condition, nevertheless has a high criticality rating because of the anticipated wider consequences should it fail. More traditional bridge asset management practices might not have differentiated between the bridges or recognized their importance in a similar way as the proposed approach.

Table 2. Risk and criticality assessment of analysed bridges

			Structural safety					Hydraulic/geotech safety					Serviceability, durability, maintenance					Functionality				
Bridge	Bridge criticality	Bridge risk	Hazard	Vulnerability	Consequences	Uncertainty preium	Structural safety risk	Hazard	Vulnerability	Consequeces	Uncertainty premium	Hydraulic/geotech risk	Hazard	Vulnerability	Consequence	Uncertainty premium	Serviceability risk	Hazard	Consquence	Vulnerability	Uncertainty premium	Functionality risk
Culvert	2	10.6	2	1	2	2.5	10.0	2	1	2	2.5	10.0	1	2	1	2.5	5.0	3	1	2	2.5	15
Timber bridge	1	5.7	1	3	1	2.5	7.5	2	1	1	2.5	5.0	1	2	1	2.5	5.0	1	2	1	2.5	5
Auckland Harbour Bridge	3	20.6	3	3	3	1.0	27.0	3	2	3	1.25	22.5	3	2	2	1.0	12.0	3	3	2	1.0	18
New-market Viaduct	3	8.0	3	1	3	1.25	11.3	1	1	3	1.25	3.8	3	1	2	1.25	7.5	3	1	2	1.25	7.5

Figure 4. Risk and criticality plot for analysed bridges



2.4 RISK- AND CRITICALITY-BASED DATA COLLECTION REGIMES

2.4.1 TIERED APPROACH TO DATA COLLECTION AND MONITORING

The asset management process is usually differentiated into the core asset management and the advanced asset management. The advanced asset management is characterized by two capabilities:

- Forecasting condition or risk over time
- Long term investment optimization.

The proposed three-tiered data collection framework that is split into core, intermediate and advanced data collection regimes was based on this philosophy. An extra layer of sophistication was added to data collection regimes, since more detailed investigation and analysis of the most critical or at-risk structures is necessary. Linking explicitly the bridge asset management approaches to data collection regimes will ensure that for high-risk and critical bridges, appropriate data is available to implement the required advanced asset management approach. On the other hand, for less at-risk or critical structures, where core asset management is appropriate, data collection can be simplified. The use of three data collection levels also allows bridge asset managers more freedom in developing bridge specific approaches that can be used to ensure cost neutrality is maintained. In Table 3, the core and advanced asset management levels are juxtaposed with the respective data collection needs and levels. The proposed approach allows bridge asset managers to adapt their data collection regimes depending on the data's ultimate use in the asset management decision making processes, and each bridge's specific information requirements according to its risk and criticality assessment. For the advanced asset management process, appropriate data is sourced from an intermediate or advanced data collection regime. However, advanced data collection is required for more detailed analyses, such as diagnostics at the bridge component level.

The proposed core, intermediate and advanced data collection regimes link directly to the risk and criticality assessment: each bridge in a given network will be assigned to the core, intermediate or advanced regime based on its risk and criticality scores. This is illustrated in Figure 5 using a risk and criticality plot. It is intended that the bridge asset manager will have a degree of flexibility in drawing the boundaries between each regime, taking into account the available resources versus risk tolerance. For example, promoting more bridges into the intermediate and/or advanced regimes will entail collecting more and better quality data for those bridges and will require additional resources. On the other hand, it will lead to a better risk understanding and management. Conversely, keeping more bridges in the core regime will be cheaper as far as data collection is concerned but the risks may be only rudimentarily understood so their asset management may not be appropriate.

In conclusion, while the risk and criticality-based assignment of bridges to the data collection regimes is not prescriptive it does provide a means for relative ranking of the bridge population.

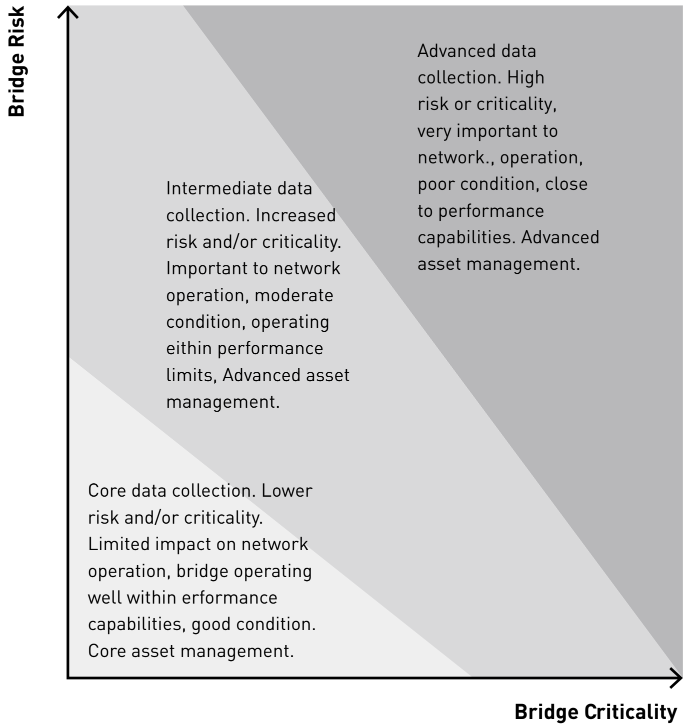
Once the risk and criticality boundaries have been set, a review of all results should be undertaken to decide whether any bridge or bridge type requires further review, ensuring:

- No bridge is out of context when compared to other bridges of its type or similar bridges on the same route
- Bridges on known strategic or critical life-line routes are rated appropriately and have a level of consistency in their risk and criticality ratings
- The risk or criticality is not considered too high requiring further, more detailed investigation to better understand specific risk.

Table 3. Correspondence between asset management and data collection levels

<table>
<tr><th rowspan="2">DATA COLLECTION AND MONITORING LEVEL</th><th colspan="2">ASSET MANAGEMENT LEVEL</th></tr>
<tr><th>CORE</th><th>ADVANCED</th></tr>
<tr><td>Core</td><td rowspan="3">Basic functionality of asset management can be achieved, including valuations and prioritisation of annual budget expenditure.</td><td>Core data may not be sufficient for advanced asset management processes.</td></tr>
<tr><td>Intermediate</td><td rowspan="2">Advanced asset management processes, including network-level analysis, forecasting condition/risk and investment-level scenario analysis can be achieved using intermediate data.
Advanced data is utilised for further analyses at a more detailed level (eg project level) such as diagnostics and more accurate intervention needs and costs.</td></tr>
<tr><td>Advanced</td></tr>
</table>

Figure 5. Correspondence between data collection regimes and bridge risk and criticality



2.4.2 DATA COLLECTION TECHNIQUES AND PROGRAMME

The VI programme is based around general inspections, special inspections and routine surveillance inspections. Current detailed inspections have been omitted as they are not seen as providing noticeable value (Graybeal et al. 2001; Phares et al. 2001). Table 4 outlines the proposed VI cycles.

Bridges with higher risk and/or criticality ratings will have general inspections carried out on a more frequent basis than bridges with lower criticality and/or risk. While developing an altered inspection programme, the asset manager may account for the need to have a 'common denominator' for all inspection cycles, so all the stock is inspected within that time duration. For example, if four years were chosen for the core bridge inspections frequency, a cycle of two years would be appropriate for intermediate bridge inspections.

Special inspections will comprise:

- Special VIs, including principal inspections of large or complex structures
- Monitoring and testing inspections, probably undertaken by specialist contractors (eg specialist testing of steel bridges)
- Posting/loading assessments
- Overload damage inspections
- Bailey bridge inspections
- Post-earthquake event inspections
- Post-flood event inspections.

Routine surveillance inspections are intended to identify any obvious defects that may affect the safety of highway users, or anything else needing urgent attention, eg vehicle impact damage or build-up of flood debris.

Table 4. Bridge VI, testing and monitoring programme

DEVELOPMENT LEVEL	VI, TESTING AND MONITORING PROGRAMME	INSPECTION FREQUENCY		
		General inspections	Special inspections	Routine surveillance inspections
Core	Routine surveillance inspections, general inspections, programmed special inspections, reactive NDE	3–6 years	As identified during general inspection process or as planned by the bridge asset manager (eg access to critical elements or components)	As required by contractual arrangement (eg annual)
Intermediate	Routine surveillance inspections, general inspections, programmed special inspections, reactive and proactive NDE, network SHM data	2–3 years		
Advanced	Routine surveillance inspections, general inspections, programmed special inspections, reactive and proactive NDE, network SHM and bridge-specific SHM	1–2 years		

Internationally, bridge managers supplement VIs with NDE and SHM. VIs have relatively poor repeatability and accuracy issues (Phares et al. 2004) and this has a direct bearing on risk ratings (the uncertainty premium). NDE and SHM should therefore become integrated into the data collection practices.

In the *Guidelines* NDE refers to the type of testing that does not destroy the test object (or possibly only small samples as in the case of concrete coring). It typically uses simple tools and techniques, is short in duration, and can be carried out without attaching sensors to the bridge for a long time. NDE needs to be specifically arranged and carried out and does not provide data or information on demand using automatic data-collecting systems. Typical examples include Schmidt hammer, chloride sampling and cover meter surveys. SHM, on the other hand, is a type of data collection using sensors and data acquisition systems providing data (information) on demand about structural performance and any significant change or damage occurring in the structure. SHM also comprises automatic data collection on wider network performance and environmental and operations factors affecting a bridge, eg traffic volumes, seismic excitation and river flows (referred to as network-level SHM). Table 5 provides a list a most common NDE techniques and their application in bridge data collection. Table 6 lists the most common time frames of SHM application, which could be used irregularly, continuously over short or long-term, or in a regular and cyclical fashion. Tables 7 to 9 provide lists of SHM applications to overall bridge performance issues, and specific issues related to concrete and steel. Table 10 includes examples of data collected by network-level SHM.

Table 5. Types and uses of NDE

NDE TEST	APPLICATIONS
Concrete compression tests	Used to identify the strength of concrete – with a number of tests, statistical models can be developed for the stock or bridge-specific strengths identified, which is useful for performance assessments.
Schmidt hammer	A rebound test that is a measure of hardness and can be used to understand compressive strength of concrete.
Steel tensile tests	Can be carried out on reinforcement or steel sections to understand tensile strength.
Chloride sampling	Used to understand the penetration level of chloride ions, which is an indication of the possibility of corrosion. Can be used to understand maintenance actions such as concrete replacement or application of cathodic protection.
Carbonation tests	Usually carried out with chloride tests to understand the probability of corrosion occurring.
Half-cell potential tests	Usually carried out as an alternative to chloride and carbonation tests to understand corrosion probability.
Cover meter survey	Used to identify reinforcement location and cover depth – considered essential for bridges with no records as it enables strength assessment. Depth to reinforcement can also provide an indication of the time to onset of corrosion, taking into account factors such as the environment, concrete compaction and strength.
Delamination survey	Carried out with a hammer – delamination indicated by hollowness in the concrete, as sound concrete provides a ringing return. A useful test for identifying areas that require repair. Also useful in performance assessments, as delaminated areas may be an indication of loss of bond strength, which may affect member capacity.
Mortar patches or tell-tales	Mortar patches are the older version of tell-tales, but both are used to understand the rate of any ongoing movement that has manifested itself as a crack. May be used to understand the crack propagation before repair is undertaken.
Steel section loss measurement	By measuring the loss of section it is possible to understand the loss of capacity and its overall effect on the bridge.
Decay/damage/ weathering/ delamination	Used to understand section loss and strength loss in timber bridges through rotting, fire damage and ongoing weathering.
Infestation (timber)	Used to understand section loss and strength loss in timber bridges.
Contamination (timber)	Used to understand strength and remaining life of the member.

Table 6. SHM time frames of application

TIME FRAME	DESCRIPTION
Irregular	Used to notify the asset manager when predetermined parameters are exceeded. Examples include storm surge, bridge impact or bridge overload.
Short-term	Monitoring to obtain bridge response information. Examples include load rating, tracking short-term fatigue growth or monitoring for a permitted overweighed vehicle.
Long-term	Monitoring of a new, retrofitted or structurally deficient bridge to track its response, usually over a year or more.
Regular cyclical	Monitoring to assess condition as part of an inspection programme. Likely to follow the same cycle as the inspection programme, eg every two years.

Table 7. SHM General metrics

PARAMETER	PARAMETER DESCRIPTION
Scour	Refers to scour around foundation and abutments based on bed movement
Seismic	Seismic data referring to earthquake intensity
Traffic load	The actual number and weight of vehicles using the bridge; measured using weigh-in-motion (WIM) stations
Acceleration	Acceleration data can be used to assess whether deterioration or damage has occurred
Curvature	The rate of change of curvature along a flexing member can be used to understand increase in live load effects
Displacements	The movement of the bridge under specific loads
Tilt/slope	Angular changes; used to measure distortion in a bridge

Table 8. SHM Concrete metrics

PARAMETER	PARAMETER DESCRIPTION
Corrosion	Defines corrosion rate/total corrosion amount. Used to understand remediation actions for chloride contamination or strength loss through section loss
Cracking	It is possible to detect cracks through acoustic emission sensors. It is also possible to monitor cracks using strain gauges. This will generally apply to larger cracks, as some cracking is expected in concrete sections. See also NDE and tell-tales (Table 5)
Strain	Under normal service loads, strain can be used to understand the stresses in specific sections. This can be useful when run in conjunction with WIM data – member capacity can be understood, and therefore the loading-capacity margin for the member
Tension	Applicable to pre-stressed, pre-tensioned and post-tensioned bridges, as tension in the tendons is directly related to strength. Used to understand the capacity of the member

Table 9. SHM Steel metrics

PARAMETER	PARAMETER DESCRIPTION
Cracking/crack growth	Useful in understanding the fatigue effects on steel bridges, especially for active cracks
Strain	See concrete metrics strain (Table 8)
Tension	Useful for understanding the actual tension loads – eg on tied arches; especially useful if an element/component is operating close to its design load

Table 10. Network-level SHM data

ORGANISATION	AVAILABLE SHM DATA
NIWA	River flow, sea level, air quality, climate change data
IGNS	Natural hazard data including seismic, tsunami, volcanic activity and geological data
TLA	Rainfall, river levels and flows, regional traffic growth data
NZTA/TLA	WIM data, state highway traffic count data

2.4.3 CHARACTERISATION OF DATA COLLECTION AND MONITORING REGIMES

2.4.3.1 Core data collection regime

Core is the lowest data collection level. Core bridges will have a low criticality rating and a low risk rating. These bridges will therefore require a lower level of asset management, with the practices focusing on core asset management.

A core asset management approach is considered appropriate for these bridges: as they will:

- Generally be in good condition
- Have a limited impact on the network if their service level is reduced
- Be operating well within their operational capabilities
- Have structural systems of high redundancy reducing the risk of failure.

Based on this, only limited performance data will be collected. This will mainly focus on known key risks. Collecting this data will facilitate core asset management and the prioritised work programme's development.

The primary method of data collection for these bridges will be VIs, with NDE used in a limited, reactive way to manage issues raised during the inspection programme. VIs will provide key data for condition ratings, defect descriptions, defect risk ratings, maintenance action recommendations and cost estimates.

For core bridges, inspection frequency can be decreased to between one and two inspections in the six-year cycle. This is considered appropriate, as general inspections are supported by both routine surveillance and special inspections after a recognised event (eg flood, storm surge, seismic activity) or for a specific issue such as a posting assessment. In line with current practice, anything untoward identified during a general inspection should be investigated to better understand the issue. This may involve special VI or NDE.

2.4.3.2 Intermediate data collection regime

If the criticality and/or risk ratings increase, the bridge moves from the core to the intermediate data collection regime. Intermediate bridges have an increased impact on network performance if they:

- Fail
- Are in a poorer operational state
- Are operating close to their performance envelope.

Intermediate bridges' structural systems may have less or no redundancy, which increases the risk of failure. A broader understanding of their performance risks and more accurate data collection approach is necessary to ensure the performance risks are adequately managed.

The intermediate data collection regime is expected to provide sufficient data to allow advanced asset management to be carried out, so forward planning and optimisation can be undertaken. Data for these bridges will typically be collected using VIs and NDE. NDE will be used as a greater level of accuracy is required for advanced asset management. This will be supplemented by data from network-level SHM.

For intermediate level bridges, general inspections should be undertaken every two years. However, this may be modified to three years for new bridges or bridges with a lower level of risk – typically, bridges that have performance levels comparable to current design standards. These inspections should be supported by reactive NDE to provide understanding of issues identified as part of the ongoing general inspection process. It is also supported by proactive NDE, which involves undertaking testing in a strategic manner and provides improved data (eg chloride tests for deterioration rates). As with core bridge inspections, intermediate bridge inspections are supported by special and routine surveillance inspections.

Network-level SHM data, such as AADT, truck weights and flood and seismic data will also be used as this data is required for advanced decision making. It is expected this data will be collected from third parties or as part of regional / national programmes.

2.4.3.3 Advanced data collection regime

The advanced data collection level is only for the most critical or high-risk bridges. These bridges will:

- Have a pivotal role in the network's operation
- Be in a poor state of repair, or operating very close to or even beyond their performance limits
- Have structural systems that may lack redundancy

Additional data has to be collected if the risks are to be managed appropriately. It will be cost beneficial to use more advanced techniques to collect the data. Data will be collected to a level where critical components' performance can be understood; using more advanced approaches will ensure the required level of accuracy is achieved.

Advanced-level bridges are visually inspected every one or two years. In common with the core and intermediate bridge inspections, advanced inspections will be supported by special inspections (eg for critical elements or components) and routine surveillance inspections. Inspections will also be augmented by NDE to understand on-going or newly identified issues, and advanced-level bridges will also need some form of SHM. This will enable bridge asset managers to understand the day-to-day performance of these high-risk, high-criticality bridges. Using SHM will also enable proactive management to reliably better, define these bridges' performance limits and optimise their lives. Examples of state highway structures requiring advanced data collection are SH1 Auckland Harbour Bridge, SH5 Mohaka Bridge and SH6 Kawarau Gorge Bridge.

2.4.4 IMPLEMENTATION COSTS

The cornerstone of the *Guidelines'* philosophy is to prioritise data collection depending on risk and criticality. Therefore, while there will be bridges requiring more resources to be directed towards their asset management, including data collection, others may be moved to the core data collection regime, resulting in savings.

The following analysis shows how to assess the costs of involved, using this data collection approach. The same methodology may be used as a template for assessing individual networks.

When undertaking an assessment of likely costs, the following should be taken into account:

- Contractual requirements specific to the network
- The number of core, intermediate and advanced bridges on the network
- The costs of carrying out the current inspection regime on core, intermediate and advanced bridges
- The number of bridges that require special access requirements for detailed inspections, and the breakdown of access costs for core, intermediate and advanced bridges.
- The altered inspection cycle for the proposed regime, following the removal of detailed inspections
- Travel costs resulting from more frequent advanced bridge inspections.

The following assumptions have been made while producing the cost estimates:

- All travel costs are included in the rates
- Under the current practice, all bridges have two general and one detailed inspection in a six-year period

Detailed inspection costs are the same as general inspection costs, other than access charges (for the current practice only). No detailed inspections are undertaken in the proposed regime. For the proposed regime, two core general inspections, three intermediate and six advanced inspections are undertaken in a six-year period for bridges falling into each respective risk and criticality categories.

Results are shown in Table 11. The estimated savings are approximately $60,000 per year for the network considered in the example. These savings are a result of the smaller number of core inspections (assumed to follow a three-year inspection cycle) and the removal of all detailed inspections. The savings could be reinvested into enhanced data collection, including NDE / SHM, for bridges whose risk management can benefit from doing so. In general, the costs will depend on network size, number of bridges and current contract requirements.

Table 11. Estimate of data collection strategy implementation cost

DATA COLLECTION AND MONITORING ESTIMATE							
Structure numbers	Bridges and large culverts	Culverts	Stock underpasses	Retaining walls	Sea walls	Deep drainage pits	Calculation
	177	133	31	40	2	52	a
ESTIMATED PROPORTION OF STRUCTURE TYPE (%)							
Core	40%	90%	90%	50%	50%	90%	b
Intermediate	55%	10%	10%	50%	50%	10%	c
Advanced	5%	0%	0%	0%	0%	0%	d
ESTIMATED PERCENTAGE OF CORE, INTERMEDIATE OR ADVANCED STRUCTURES REQUIRING SPECIAL ACCESS							
Core	10%	10%	10%	10%	10%	90%	e
Intermediate	40%	40%	10%	20%	20%	90%	f
Advanced	90%	0%	0%	0%	0%	0%	g
ESTIMATED GENERAL INSPECTION COSTS (NO ACCESS COSTS)							
Core	$200	$100	$200	$100	$100	$100	h
Intermediate	$500	$200	$300	$300	$300	$200	i
Advanced	$1,000	$500	$500	$500	$500	$300	j
ESTIMATED DETAILED INSPECTION ACCESS COSTS							
Core	$200	$200	$200	$200	$200	$200	k
Intermediate	$500	$500	$500	$500	$500	$300	l
Advanced	$1,000	$1,000	$500	$500	$500	$500	m
CURRENT VI CYCLE							
Number of general inspections in a cycle	2	2	2	2	2	2	n
Number of detailed inspections in a cycle	1	1	1	1	1	1	p
CURRENT PRACTICE COSTS							
Core costs – general	$28,320	$23,940	$1,160	$4,000	$200	$9,360	a*b*h*n
Intermediate costs – general	$97,350	$5,320	$1,860	$12,000	$600	$2,080	a*c*i*n

Table 11 continued

Advanced costs – general	$17,700	-	-	-	-	-	a*d*j*n
Core costs – detailed	$15,576	$14,364	$6,138	$2,400	$120	$13,104	a*b*h*p + a*b*e*k*p
Intermediate costs – detailed	$68,145	$5,320	$1,085	$8,000	$400	$2,444	a*c*i*p + a*c*f*l*p
Advanced costs – detailed	$16,815	-	-	-	-	-	a*d*g*p + a*d*j*m*p
Total VI costs for one cycle of current regime				$367,801			
PROPOSED GENERAL VI CYCLE (GENERAL ONLY)							
Number of Inspections in a core cycle	2	2	2	2	2	2	q
Number of inspections in an intermediate cycle	3	3	3	3	3	3	r
Number of inspections in an advanced cycle	6	6	6	6	6	6	s
PROPOSED VI REGIME COSTS							
Core general inspection costs	$28,320	$23,940	$11,160	$4,000	$200	$9,360	a*b*h*q
Intermediate general inspection costs	$146,025	$7,980	$2,790	$18,000	$900	$3,120	a*c*i*r
Advanced general inspection costs	$53,100	-	-	-	-	-	a*d*j*s
Total VI costs for one cycle of proposed regime				$308,895			
Difference between current and proposed regime				$58,906			

2.5 BRIDGE DATA REQUIREMENTS

This section discusses how bridge data links to strategic outcomes for the transportation sector (Curran et al. 2002; Félio et al. 2009; Maguire 2009; NZTA 2009). It then lists the broad inventory and performance areas in which data collection needs to occur. Detailed data requirements are listed in the tables included in Appendix III.

Figure 6 provides a high level picture of the data entering the decision making process and shows how it is linked to strategic outcomes. As can be seen, it is no longer the case that bridge data solely comprises inventory, geometrical, capacity and condition data. Bridge data has evolved to take into account aspects such as environmental impacts and climate change. There is also a greater level of financial aspect understanding, eg the cost to undertake a project and the economic benefits derived from it. In addition to the broader data there is also an expectation, as required by the advanced asset management approach, that the data will be used to support non-financial strategic and community outcomes.

It is suggested the following bridge data categories are collected:

- Inventory data – network and bridge data
- Condition data – condition rating, raw data from NDE and SHM investigations and benchmark data
- Asset history and planned work data
- Cost data
- Performance data – load-carrying capacity, over weight permit information, traffic, safety, environmental, and risk and lifeline data, and
- Other data: photographs, reports, site records and drawings.

Bridges not only require different amounts of data depending on their core, intermediate or advanced status; there are also differences in the types of data to collect, collection techniques and inspection frequency, and whether collection occurs at the bridge, component or element level.

Figure 6. Data for asset management

GOVERNANCE/POLICY DIRECTIVES: GOVERNMENT STRATEGIC OBJECTIVES

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PERFORMANCE MEASURE/SERVICE LEVEL CATEGORIES (NZTA STATEMENT OF INTENT 2009)

- Better use of capacity
- More efficient use of freight supply chains
- More transport mode choices
- A resilient and secure transport network
- Easing service urban congestion
- Reduction in deaths and serious injuries
- Reduction in adverse environmental effects

↑

PROCESSED INFORMATION: KNOWLEDGE

CONDITION FUNCTIONS	RATING OUTCOME	NETWORK FUNCTION	ECONOMIC FUNCTIONS	COST FUNCTIONS	ENV FUNCTIONS
▪ Service Life ▪ Condition/ health index ▪ Deterioration rate	▪ Reliability index ▪ Bridges posted or restricted ▪ Network impact	▪ Reduction in fatalities ▪ Average speed/ posted speed ▪ Highway (congestion)	▪ Vehicle operating costs ▪ Accident costs ▪ Travel time costs	▪ Agency costs/ revenue ratio ▪ Costs/capita ▪ Project achievement	▪ % recycled materials ▪ Climate impact ▪ Sustainability

↑

PROCESSED DATA: INFORMATION

CONDITION ASSESSMENT	RATING	NETWORK FUNCTIONS	COST FUNCTIONS	ENV FUNCTIONS	SAFETY FUNCTIONS
▪ Condition rating ▪ Critical element condition	▪ Bridge rating ▪ Member rating ▪ Risk rating	▪ Route alternatives ▪ Traffic growth rates ▪ Vehicle composition	▪ Whole-of-life costs ▪ Improvement costs ▪ Asset valuation	▪ Materials consumption ▪ Climate-change protection ▪ Energy use over lifecycle	▪ Compliance with standards ▪ Accident trends

↑

DATA REQUIREMENT FOR PERFORMANCE FRAMEWORKS

INVENTORY DATA	LOS (MINIMUM REQUIRED AND CURRENT)	INSPECTION TESTING AND MONITORING DATA	ASSET HISTORY AND PLANNED WORK DATA	SAFETY	ENVIRON-MENTAL	COST
▪ Highway ▪ Bridge ▪ Element ▪ Component ▪ Drawings ▪ Photos ▪ Detour length ▪ Route importance ▪ Overweight management	▪ Defect extent, severity ▪ Scour/flood ▪ Seismic ▪ Ship/truck impact ▪ Component (eg handrail at height)	▪ Visual inspections ▪ NDE data ▪ Bridge SHM ▪ Vehicle loads ▪ Scour ▪ Vehicle loading data	▪ Maintenance history ▪ Future maintenance ▪ Future renewals ▪ Furutre replacements ▪ Inspection programme ▪ Programme achievement	▪ Vandalism rates ▪ Number and type of vehicle crashes ▪ Strikes: ship/truck collisions ▪ Exposure to hazardous substances	▪ Reduction in GHGs, NOx, SOx and VOC ▪ Vehcile noise ▪ Materials used ▪ Carbon footprint	▪ Maintenance costs ▪ Improvement costs ▪ Replacement cost ▪ Inspection cost

2.6 DATA STORAGE AND MANAGEMENT

Data on bridge inventory and performance is an asset in its own right. Like any other asset, it needs to be appropriately managed. It has to be stored in an appropriate system, updated when required, and subjected to quality checks. The *State Highway Database Operation Manual* (NZTA 2009a) has been used as a basis for the recommendations included in this section.

The expected outcomes from carrying out the exercises recommended in this stage are:

- The asset manager has a full understanding of the data required to measure current and future operational and strategic outcomes
- The asset manager has undertaken a gap analysis to assess what data needs to be collected and where data is no longer required
- A prioritised data collection plan has been created so new data collection requirements meet operational and strategic needs
- Data is stored in a well referenced way so it can be utilised for analysis and decision making
- Data is managed using verification and validation quality assurance techniques to ensure all required data is present and appropriate.

2.6.1 UNDERSTANDING DATA STORAGE NEEDS

Data storage tools may range from a simple spreadsheet through to a complex asset management database depending on the network's complexity and its asset management challenges. Those tools should include functionalities for data examination to help with analyses and decision making. These systems should be modified, if required, so the range and type of data can be stored.

The five key stages to understanding data storage requirements are noted in Figure 7. Once the range of data is understood, an assessment prioritising the data that should be stored should be undertaken. The data should be rated according to its importance to the decision-making process; and should therefore prioritise reporting on the most important strategic outcomes. When considering the range of data to store, the data with the highest priority should be given to the data that can be mapped to important asset management functions. Data with moderate or low importance may be stored in the system depending on the specific need. A register of the data and the location from which it was collected should be maintained so the data can be tracked. Once the data list has been developed, the bridge asset manager should identify how the data is currently stored, and how this may be adapted and transferred to the new storage system once it has been developed. Data management protocols may need to be expanded to achieve this.

Figure 7. Data assessment process used to understand data storage needs

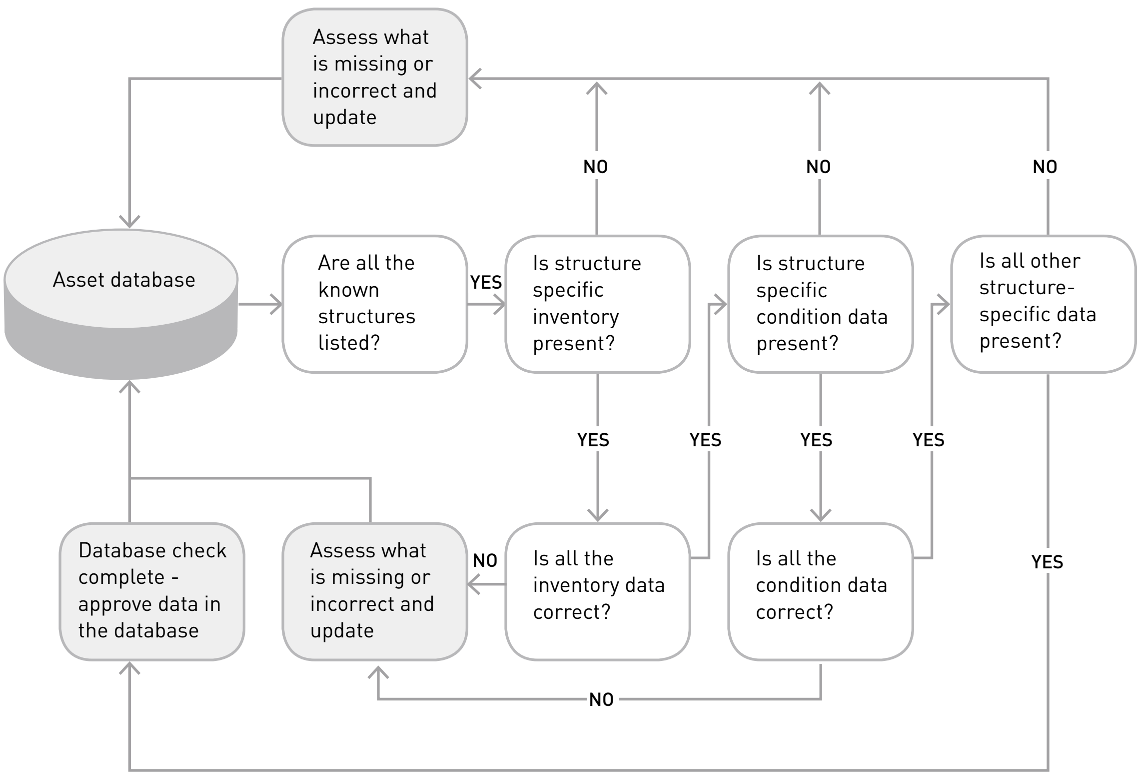
2.6.2 DATA MANAGEMENT

To ensure the data is robust and reliable, it should be quality assured. It is therefore important to that quality control measures are used to check inspections and all data. Good practice involves auditing the data management process, when an assessment is made of the input data and the data already stored in the system. Good practice also recommends verifying the results for consistency and to ensure the data is a fair reflection of reality. Asset validation should be carried out to ensure all bridges, bridge elements and components are recorded in their respective databases. If assets no longer exist or new ones have been vested to the road controlling authority, the database should be updated to reflect this. Future assessments will comprise a check of new or changed data only. In some cases, an asset check may require a complete network drive-over to ensure all assets are present within the system.

Data validation is used to ensure data used in the decision-making process is up to date. It is also a check to ensure the data has no obvious errors, such as zero lengths, or incorrect asset descriptions within the bridge management system. The proposed data validation process is detailed in Figure 8.

To ensure data validation is undertaken regularly, the bridge asset manager should create a validation audit schedule. Field verifications should be carried out to ensure the data collected by the inspectors and input into the system is a fair reflection of reality. Depending on the confidence in the existing database, verification can be based on random sampling, where only a representative portion of the database is checked. Alternatively, a more systematic and thorough approach might be required.

Figure 8. Data validation process



2.7 STRATEGY REVISION AND MODIFICATION

The proposed approach can be applied to specific networks balancing their risk profiles, risk tolerance and available asset management budgets. The boundaries between core, intermediate and advanced bridge categories can be adjusted, while still ensuring the most at-risk and critical structures receive appropriate attention. While some bridges will require more resources to collect their data, other bridges may be moved to a lower regime resulting in savings. Implementing the approach described in the *Guidelines* does not, therefore, have to cost more. By balancing the extra testing and increased VI frequency for some structures with reduced requirements for others, it can be shown to be cost neutral. Financial implications can be studied using approaches modelled on the example in Section 2.4.4.

3. CONCLUSIONS

The recommended process for data collection and monitoring of road bridges starts with developing baseline data. This is required to carry out risk and criticality assessment for all bridges on the network. Four broad categories of risk are considered, namely hydraulic / geotechnical safety, structural safety, serviceability/durability /maintenance, and functionality. Scores are assigned for hazards, vulnerabilities, consequences and data accuracy, and approaches used for risk analysis and quality control measures employed (uncertainty premium) in each risk category, and overall bridge risk and criticality are calculated.

Based on the outcomes of the risk and criticality assessment bridges are ranked and classified for the core, intermediate and advanced data collection regimes. Detailed recommendations concerning data collection techniques, inspection frequency and the types of data to collect for each regime are provided. Bridges classified as core will have less frequent VIs and will require less data to be collected on their performance. For intermediate and advanced bridges, VI frequency will be gradually increased and the type, amount and quality of data broadened and increased. NDE and SHM will be more widely incorporated into the data collection practices for those bridges.

An important aspect of the proposed process is appropriate data storage and management, where all the data needs to be checked for accuracy and correctness and stored in systems that facilitate data retrieval and interrogation for the purpose of analyses and planning.

Finally, a discussion about adapting the data collection strategy to specific network needs is provided. The classification of bridges into core, intermediate and advanced permits the boundaries between those categories to be adjusted based on risk tolerance and budgetary constraints, while still ensuring that structures receive attention commensurate with their risk profiles.

The overall premise of the proposed data collection framework is that it will facilitate adoption of the advanced asset management for the bridging asset while being sensitive to budgetary requirements.

APPENDIX I

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APPENDIX II

CRITERIA FOR RISK AND CRITICALITY ASSESSMENT

Table AII-1. Risk categories and associated hazards, vulnerabilities and consequences (adapted after Moon et al 2009)

RISK CATEGORIES	HAZARDS	VULNERABILITIES	CONSEQUENCES
Geotechnical/ hydraulic safety	▪ Flowing water ▪ Debris and ice ▪ Seismic ▪ Vessel collision ▪ Flood	▪ Scour/undermining ▪ Loss of support ▪ Soil liquefaction ▪ Unseating of superstructure ▪ Settlement ▪ Overtopping	▪ Loss of human life ▪ Replacement and repair costs ▪ Impact of removal from service related to: ▪ Safety (lifeline) ▪ Economic ▪ Social (mobility) ▪ Defence
Structural safety	▪ Seismic ▪ Repeated loads ▪ Trucks and overloads ▪ Vehicle collision ▪ Fire	▪ Lack of ductility and redundancy ▪ Fatigue and fracture ▪ Overloads ▪ Details and bearings	
Serviceability, durability and maintenance	▪ Winter maintenance practices ▪ Climate ▪ Intrinsic loads ▪ Impact (vertical) ▪ Environment	▪ Corrosion ▪ Cracking/spalling ▪ Excessive deflections/ vibrations ▪ Chemical attack/reaction ▪ Difficulty of maintenance	▪ User costs ▪ Maintenance costs: ▪ Direct ▪ Indirect (delays, congestion etc.)
Functionality	▪ Traffic ▪ Special traffic and freight demands	▪ Network redundancy and adequacy ▪ Geometry and roadway alignment	▪ Loss of human life and property (accidents) ▪ Economic and social impacts of congestion

Table AII-2. Hazard assessment scores (adapted after Moon et al 2009)

HAZARDS CONSIDERED		HAZARD SCORES		
		1	2	3
Geotechnical/hydraulic safety	▪ Scour and flood ▪ Debris and ice ▪ Vessel collision ▪ Seismic liquefaction ▪ Settlement	▪ Outside of 500yr flood plain ▪ Low seismic design requirements ▪ Over a non-navigable channel ▪ Located over 500km from coast ▪ No potential for scour ▪ No records of significant earthquake, floods or storms surge etc.	▪ Outside of 100yr flood plain ▪ Moderate seismic design requirements ▪ Navigable channel for mid-sized vessels ▪ Located over 50km from coast ▪ Moderate potential for scour ▪ Records of moderate earthquake, floods or storms surge etc.	▪ Within a 100yr flood plain ▪ High seismic design requirements ▪ Navigable channel for large vessels ▪ Located within 50km from coast ▪ High potential for scour ▪ Records of significant earthquake, floods or storms surge etc.
Structural safety	▪ Seismic effects ▪ Fatigue ▪ Vehicle collision ▪ Overload ▪ Fire	▪ Low seismic design requirements ▪ ADTT less than 500 ▪ Not spanning over a road ▪ Located more than 10km from heavy industry ▪ No history of overloads, collision, earthquake etc.	▪ Moderate seismic design requirements ▪ ADTT less than 10,000 ▪ Spanning over a road with ADTT less than 1,000 ▪ Spanning over a railway line with low train numbers ▪ Located more than 1km from heavy industry ▪ History of isolated overloads, collision, and moderate earthquakes etc.	▪ High seismic design requirements ▪ ADTT more than 10,000 ▪ Spanning over a road with ADTT more than 1,000 ▪ Spanning over a railway line with high train numbers ▪ Located less than 1km from heavy industry ▪ History of repeated overloads, collision, and significant earthquakes etc.
Serviceability, durability and maintenance		▪ No routine use of de-icing salts ▪ Located more than 100km from the coast ▪ Low number of freeze/thaw cycles ▪ No history of overloads etc.	▪ Moderate use of de-icing salts ▪ Located more than 25km from the coast ▪ Moderate number of freeze/thaw cycles ▪ History of isolated overloads and/or low/moderate numbers of permitted vehicles	▪ No routine use of de-icing salts ▪ Located less than 25km from the coast ▪ High number of freeze/thaw cycles ▪ History of repeated overloads and/or low/moderate numbers of permitted vehicles
Functionality		ADTT less than 1,000 AADT less than 10,000 No history of fatal accidents No history of congestion	ADTT less than 10,000 AADT less than 50,000 History of isolated fatal accidents History of moderate congestion	ADTT more than 10,000 AADT more than 50,000 History of frequent fatal accidents History of heavy congestion

Table AII-3. Vulnerability assessment scores (adapted after Moon et al 2009)

VULNERABILITIES CONSIDERED	VULNERABILITY SCORES		
	1	2	3
Geotechnical/ hydraulic safety	▪ Deep foundations or founded on bedrock ▪ Meets current pier impact and scour protection standards ▪ No history and no evidence of scour or settlement ▪ Superstructure 600mm above 100yr flood level ▪ No tilt of sub-structure elements	▪ Founded on shallow foundations on cohesive soil ▪ Evidence of minor scour/undermining during underwater inspections ▪ Pier protection system in good condition ▪ Superstructure above 100yr flood level but less than 600mm ▪ Minor tilt of sub-structure elements	▪ Founded on shallow foundations or on non-cohesive soil ▪ Evidence of moderate to significant scour/ undermining during underwater inspections ▪ Pier protection system missing or in poor condition ▪ Superstructure below 100yr flood level ▪ Significant tilt of sub-structure elements
Structural safety	▪ Meets all current design standards ▪ Structure displays bi-direction redundancy ▪ 20yrs or fewer since construction or major renewal ▪ Low fatigue susceptibility ▪ No history of structural damage ▪ No history of excessive displacements or vibrations etc.	▪ Simply-supported system with transverse distribution capabilities ▪ 50yrs or fewer since construction or major renewal ▪ Moderate fatigue susceptibility ▪ Onset of structural damage on the critical load path ▪ Clearance within 150mm of current standards ▪ History of significant displacements or vibrations etc. ▪ Substructure within 10% of vertical (i.e. no or limited rotational movement and/or within construction tolerance)	▪ Non-composite \ construction ▪ Simply-supported constructed with minimal transverse distribution capabilities ▪ 50yrs or more since construction or major renewal ▪ High fatigue susceptibility ▪ Structural damage on the critical load path ▪ Exposed pre-stressing strands ▪ Pin or hanger details ▪ Clearance below current standards ▪ Evidence of structural damage ▪ History of excessive displacements or vibrations etc.
Serviceability, durability and maintenance	▪ No visible cracks ▪ No evidence of reinforcement corrosion ▪ Joints in good condition ▪ Paint in good condition ▪ Good ride quality on the approaches ▪ No rutting on the deck and approaches	▪ Minor local cracking ▪ Some evidence of reinforcement corrosion ▪ Paint in moderate condition ▪ Joints with minor evidence of leaking ▪ Moderate ride quality on the deck and approaches ▪ Approaches with minor rutting	▪ Extensive evidence of cracking and spalling ▪ Evidence of wide spread reinforcement and structural steel corrosion ▪ Paint in poor condition ▪ Exposed pre-stressing strands ▪ Failed expansion joints ▪ Poor ride quality on the deck and approaches ▪ Approaches with significant rutting

Functionality	▪ Roadway approach alignment and bridge geometry up to standards ▪ Guardrail and road markings in good condition ▪ Good ride quality on the deck and approaches	▪ Lane width within 300mm of current standards ▪ Guardrail and road markings in fair condition ▪ Posted for more than 90% of legal truck weight ▪ Moderate ride quality on the deck and approaches ▪ Minor rutting of the pavement	▪ Lane width less than 300mm compared to current standards ▪ Guardrail and road markings in poor condition ▪ Posted for less than 90% of legal truck load ▪ Poor ride quality on the deck and approaches ▪ Significant rutting of the pavement

Table AII-4. Consequence assessment scores (adapted after Moon et al 2009)

CONSEQUENCES CONSIDERED	CONSEQUENCE SCORES		
	1	2	3
Geotechnical/ hydraulic safety	▪ AADT less than 10,000 ▪ Replacement cost less than $2M ▪ Not on a critical/life-line route ▪ Detour less than 5km	▪ AADT less than 50,000 ▪ Replacement cost less than $10M ▪ Not on a critical/life-line route ▪ Detour less than 10km	▪ AADT more than 10,000 ▪ Replacement cost more than $10M ▪ On a critical/life-line route ▪ Detour more than 10km
Structural safety			
Serviceability, durability and maintenance	▪ Low maintenance costs ▪ AADT less than 50,000	▪ High maintenance costs ▪ AADT more than 50,000	▪ Not applicable
Functionality	▪ No history of congestion ▪ AADT less than 25,000 ▪ ADTT less than 10,000	▪ Average peak hour delays of more than 10mins ▪ AADT more than 25,000 ▪ ADTT more than 10,000	▪ Not applicable

Table AII-5. Risk assessment uncertainty premium (adapted after Moon et al 2009)

LEVEL	ASSESSMENT APPROACH	QUALITY ASSURANCE	UNCERTAINTY PREMIUM
1	VI and document review	Minimum standards	2.5
2	VI and document review	Best practice	2.0
3	VI and document review, analysis and technical checks	Minimum standards	1.5
4	VI and document review, analysis and technical checks	Best practice	1.25
5	VI and document review, analysis and technical checks and use of NDE/SHM	Best practice	1.0

APPENDIX III

DETAILED BRIDGE DATA REQUIREMENTS

INVENTORY DATA

Bridge inventory comprises four levels – network, bridge, element, and component data (see Figure AIII-1). Network data relates to the route or corridor section that the asset is located on; bridge data defines the individual bridge as an entity; element data provides more detail on bridge elements such as deck, bridge beams or bearings; and component data provides specific details on areas such as single bearings or bridge beams.

In the following tables the inventory data required for core, intermediate and advanced bridges is covered. It is expected that in the advanced data collection regime more detailed inventory, up to the component level, will be available.

Figure AIII-1. Inventory hierarchy

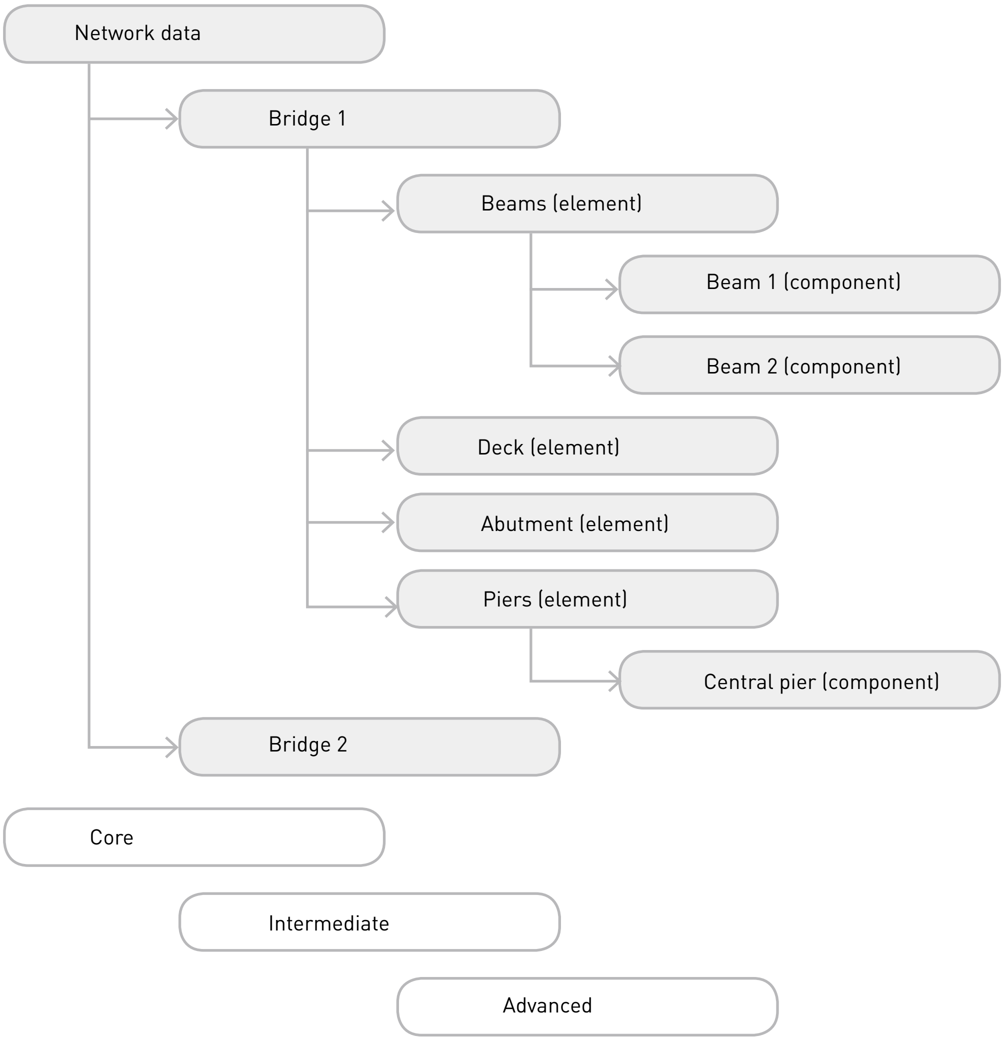

Table AIII-1. Network inventory data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Road name/road no.	Road name or number	x	X	X
Road designation	Road of national significance, arterial road	x	X	X
RAMM Section ID	Allows the bridge and pavement databases to be interfaced	x	X	X

Table AIII-2. Core and intermediate bridge inventory data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Structure number/ structure ID	Unique identifier assigned to the bridge	x	x	X
Structure location (grid ref)	6-figure grid reference	x	x	X
Structure location GPS	A unique GPS location point	x	x	X
Distance	Distance along the road section	x	x	X
Obstacle crossed	River, stream, highway, road, railway etc	x	x	X
Structure name	Name used to identify the bridge	x	x	X
Route position/ location	Location position on the route	x	x	X
Construction year	Overall age of the bridge	x	x	X
Structure type	Description of structural form	x	x	X
Construction material	Description of structural material	x	x	X
Overall length	Overall length of bridge or structure	x	x	X
Width	Bridge width	x	x	X
Element type	Name of the element group	x	x	X
Element name	Name of the element, eg handrails, bearings, joints, foundations, piers, barriers, guardrails	x	x	X
Importance weighting	Used to assign risk ratings for condition or performance	x	x	X

Table AIII-2 continued

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Geometrical data required	As defined by design standards and used to assess compliance, eg guardrail heights	x	x	X
Element material	Construction material	x	x	X
Age (linked to change history)	Age of the element	x	x	X
Approach alignment	Defines the alignment of the bridge	x	x	X
Clearance (min and max)	Min and max clearance to the obstacle crossed	x	x	X
Number of spans and lengths	Individual span lengths	x	x	X
Number of lanes	Number of lanes crossing the bridge	x	x	X
Ownership	Who is responsible for bridge management	x	x	X
Utilities	Lighting, emergency phones, gas/ irrigation pipes, fibre-optic cables, power cables, sewer pipes, sign gantries, water-supply pipes, other utilities	x	x	x

Table AIII-3.Advanced bridge inventory data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Component name	Name of component, eg bearing 1, pier 1, joint 1			X
Component type	Name of the component group			X
Importance weighting	Used to assign risk ratings for condition or performance			X
Geometrical data	Dimensional data			X
Component material	Construction material			X
Age (linked to change history)	Age of the component			x

CONDITION DATA

Condition data is a numerical rating stored in the bridge management system. Under this heading, raw NDE/SHM data is also included, along with benchmarking data. Benchmarking data is collected at the point of commissioning the bridge. This data will provide a baseline for developing long term deterioration models, to be in turn used when developing long term financial plans.

Table AIII-4. Condition-rating data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Condition ratings (severity and extent)	Bridge (overall weighted average for bridge)	x		
	Element (severity and extent of defect on inspected element)		x	
	Component (severity and extent of defect on inspected component)			x
Collection methodology	Noted as collected by VI, NDE or SHM	x	x	x
Actions	Stored as planned work	x	x	x
Condition models	See performance data		x	x
Programme	Inspection programme	x	x	x

Table AIII-5. Raw NDE/SHM data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Raw NDE/SHM data	Raw NDE and/or SHM systems outputs	x	x	X

Table AIII-6. Benchmark data for inspection, testing and monitoring strategies

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Cover levels	Used when developing deterioration models. Other data may be stored as required by bridge manager		x	x
Chloride levels			x	x
Environment description			x	x
Paint thickness			x	x
Concrete core strengths			x	x
Reinforcement strengths			x	x
Critical element stresses				x
Timber grade			x	x
Timber treatment level			x	x
Timber type			x	x

ASSET HISTORY AND PLANNED WORK DATA

Asset history data is used to understand actual replacement/renewal durations. It can also be used when developing long term forecasts.

Table AIII-7. Asset history data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Bridge data	Amendment history at bridge level, eg work carried out and date completed	X		
Element data	Amendment history at element level, eg work carried out and date completed		x	
Component data	Amendment history at component level, eg work carried out and date completed			x

Table AIII-8. Planned work data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Work ID/bridge ID	Stored in road work database	x	x	x
Work description	Amendment history at element level, eg work carried out, date completed		x	
Programme	Estimated commencement date	x	x	x
Programme development process	Prioritisation and optimisation	x	x	x
Cost	Cost of the planned work			x
Bridge	Level at which the data is available	x		
Element			x	
Component				x

COST DATA

Cost data can be broken into economic costs and agency costs. Cost data facilitates understanding of network performance in terms of how much it costs to maintain and improve the bridge stock (agency cost). It also facilitates understanding of network performance on the benefits the bridge provides in terms of, for example, lowered vehicle-operating costs and lowered travel times (economic cost) as a result of the bridge providing a shorter route.

Table AIII-9. Cost data

DATA CATEGORY	DATA ITEM	COMMENT	DEVELOPMENT LEVEL		
			CORE	INT	ADV
Valuation data	Replacement cost	As detailed in the valuation	x	x	x
	Annual depreciation	A function of condition/remaining-life model or age	x	x	x
	Depreciated replacement cost	Linked to remaining-life and/or condition models	x	x	x

Table 9 continued

DATA CATEGORY	DATA ITEM	COMMENT	DEVELOPMENT LEVEL		
Maintenance cost data	Initial estimates	Include all costs including design, procurement, construction, and construction management. It is recommended that these are stored such that a time aspect is added, eg maintenance undertaken now may be relatively inexpensive, however, if deferred this could escalate to a more major issue. Short-, medium- and long-term solutions should therefore be accounted for. This will improve the risk planning process.		x	x
	Planning estimates			x	x
	Construction estimates			x	x
	Construction costs		x	x	x
Improvement cost data	Initial estimates	All costs including design, procurement, construction, and construction management (linked to the historical and planned work data)		x	x
	Planning estimates			x	x
	Construction estimates			x	x
	Construction costs		x	x	x
Other costs	Studies	Other costs incurred as part of the bridge management process (stored at bridge level)		x	x
	Inspections			x	x
	Miscellaneous costs			x	x
Economic data	Vehicle operating cost	Basic data to undertake economic analysis, eg an assessment of the benefits gained from widening a bridge and allowing more traffic to flow, thereby lowering journey times		x	x
	Travel-time costs			x	x
	Safety costs			x	x

PERFORMANCE DATA

Performance data is any data that provides information on the *in-situ* performance of a bridge. This includes its loading capability, seismic strength, impact on traffic flows, or environmental data such as channel clearance or scour susceptibility, etc. While condition data is also performance data it has traditionally been reported separately (see above); this practice is maintained in this *Guideline*.

Table AIII-10. Load carrying capacity assessment data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Assessment date	When the assessment was undertaken	x	x	x
Assessor	Who carried out the assessment	x	x	x
Vehicle load design standard	The design loading used by the highway authority	x	x	x
Current vehicle load capacity (gross weight and axle limit)	Loading limit at bridge level (critical element noted)	x		
	Loading capacity at element level		x	
	Loading capacity at component level			x
Posting data	Restricted Y/N, restriction (speed limit, weight limit)	x	x	x
Seismic capacity (design/ assessment)	Assessed capacity relative to design or assessment loading		x	x
Seismic capacity (current)	Elements noted that limit capacity		x	x
Over-height impact capacity (design/ assessment)	The design or assessment loading used by the highway authority		x	x
Over-height impact capacity (current)	Assessed capacity relative to design or assessment loading (rating)		x	x
Pier impact capacity (design/ assessment)	The design or assessment loading used by the highway authority		x	x
Pier impact capacity (current)	Assessed capacity relative to design loading			
Foundation capacity (design/ assessment)	The design or assessment load used by the highway authority to assess foundation capacity		x	x
Foundation capacity (current)	Current capacity compared to required capacity		x	x
Barrier impact capacity (design/ assessment)	The design or assessment loading used by the highway authority to assess impact capacity		x	x
Barrier impact capacity (current)	Assessed capacity relative to design loading		x	x
Other performance data	Other performance data required by strategic, national or regional programmes		x	x

Table AIII-11. Traffic data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
AADT over the bridge	Used for economic assessment and risk management; also used in network level modelling	x	x	x
ADTT over the bridge		x	x	x
Site-specific traffic count data	Lane counts, vehicle types; used in bridge-specific loading assessment			x
Traffic growth rate	Stored in RAMM database	x	x	x
Traffic capacity	Used to assess performance gap		x	x
Current capacity	Based on number of lanes		x	x
WIM data	Used to understand truck loading and configurations		x	x

Table AIII-12. OPermit: permitting system data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Permitting system data	Influence line, beam, V-beam, timber deck, and transom, models, deck capacity factor, restrict X (increasing), restrict X (decreasing), comments		x	x
Assessor	Who carried out the assessment		x	x
Date updated	When the assessment was undertaken		x	x

Table AIII-13. Safety data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Crash statistics	Stored to assess economic impact and to identify black spots	x	x	x
Over-height strikes/ impacts	Number of vehicles impacting the bridge		x	x

Table AIII-14. Environmental data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Flood/sea-level clearance	The clearance between design/assessment sea levels (eg 1 in 100 year return period flood or sea levels) and the soffit of the bridge. Expected clearance between 500 and 600mm		x	x
Sustainability data	Use of recycled material (recommended and achieved)		x	x
Noise (network and sites)	Noise compliance of vehicles on the network and site compliance (recommended and achieved)		x	x
Resource consents	Data to cover details of resource consents including geometrical extent of consent, expiry/renewal date, and brief description of coverage	x	x	x

Table AIII-15. Lifeline assessments/network risk data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Compliance	Safety and environmental compliance	x	x	x
Loading	General bridge compliance	x		
	Specifically identified element risks		x	
	Specifically identified component risks			x
Flood/scour	Based on assessment: for core bridges desktop and document review; for intermediate/advanced bridges assessment based on additional data (eg NDE/SHM)		x	x
Tsunami			x	x
Volcanic risk			x	x
Assessor	Who carried out the assessment	x	x	x
Date updated	When the assessment was undertaken	x	x	x

OTHER DATA

Other important data, such as photographs, reports, site records and drawings, is included in this category.

Table AIII-16. Other data

DATA ITEM	DESCRIPTION AND COMMENT	DEVELOPMENT LEVEL		
		CORE	INT	ADV
Photographs	Inspection photographs	x	x	x
Reports	Any reports written regarding the bridge	x	x	x
Construction reports/site records	Details of work carried out on the bridge	x	x	x
Drawings	Drawing numbers, names, coverage descriptions, locations	x	x	x