It is not rocket science: A sharper focus is required for New Zealand’s road bridges.

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Plagiarism Statement

In submitting this assignment, I agree to the terms of Massey University's plagiarism policy. I have acknowledged and referenced anybody else's ideas in this work that are not my own. I confirm this work is original and entirely my own.

Abstract

Bridge collapses due to age and external events occur all over the world, and New Zealand is no exception. Two recent bridge collapses in New Zealand have been attributed to adverse weather events. The ability of bridges to withstand environmental events is based on the quality of the bridge inspection regime and the resulting repairs and maintenance. This research aims to investigate the inspection regime of road bridges in New Zealand. Using case studies, it analyses how bridges are inspected, data is managed and the role of the asset manager in determining repair and maintenance programmes. Influencing factors including bridge age and the inspection practices and procedures of councils are compared to the bridge inspection guidelines published by the New Zealand Transport Agency. This paper will also investigate if New Zealand is ready to address the large number of bridges that are nearing the end of their useful life and will soon either require replacement or substantial remediation. The results show that local authorities are using the official guidelines as a guide rather than a minimum standard. The research and its findings are expected to allow for a better insight into decision making and priority setting for asset managers working in bridge management.

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1. Introduction

Bridge collapses are happening all over the world. The most recent major collapse occurred in Aulla, Italy, in April during the Covid19 lockdown. The virus is credited with saving lives, as the 260-metre concrete bridge is part of a busy provincial network between the coast and Parma. The collapse highlighted the continuing poor state of repair of Italy's road network, occurring only two years after the 2018 collapse of the motorway bridge in Genoa that killed 43 people.

There are some 300 Italian bridges at risk of collapse. The World Economic Forum 2019 ranked their quality of road infrastructure at 54 from 140 countries. However, collapses are not exclusive to any one country. There have been over 120 collapses since 2000, with the majority in the United States which is ranked 11. The situation in the United States is considered very poor by the American Society of Civil Engineers who predict major problems in the near future. New Zealand does not score highly in road infrastructure either with road quality was rated by the forum as 4.7 out of 7 in 2018 and ranked 39 from 140 countries in 2019.

New Zealand's most significant bridge collapse was the Tangiwai disaster when the Whangaehu River rail bridge collapsed because a bridge pier (pile) was swept away after the tephra dam on the lip of the Ruapehu crater disintegrated. Other recent New Zealand bridge collapses include the Wairoa Bridge (1988), Te Rata Bridge with the loss of one life (1994), Birchville Bridge (2015) and the Waiho Bridge (2019).

New Zealand has more than 18,000 bridges and large culverts managed by either the New Zealand Transport Agency (agency) or local authorities (councils). They use similar bridge management techniques to many of the highly ranked countries in the forum survey.

The literature review shows that concern about bridge inspection techniques and management practices are similar around the world. All countries grapple with the most effective and efficient way to manage their bridge assets.

Fundamentally, the management of a bridge consists of four elements: the bridge inspection; the collection of data; the analysis of that information; and the maintenance decision of the asset manager. Researchers have studied all four components over many years.

The literature review found that since, 1998, studies have focussed on the need for regulated standards of bridge inspections and the appropriate collection, storage and analysis of data. These studies have highlighted a range of concerns including: the variance between individual inspectors; an absence of non-destructive testing (NDT) at the general inspection cycle; lack of useful management information; and the reliance on visual inspections (VI).

The literature suggests that VI's are not enough - additional tools are needed to support visual observations, including NDT and knowledge of the original design and construction information (Rapaport, 2016). The importance of considering structural, design and maintenance records means that the inspection can provide a more robust and quantitative platform to assist asset managers in decision making (Hearn, 2007; Hirsch, Armstrong and Engelsted, 2017).

The basis of this study is underpinned by the concern that bridges in New Zealand are as susceptible to failure as bridges in any other country. This paper will use secondary analysis of bridge records including age and current inspection periods and surveys regarding data storage and reporting protocols. A mixture of participant and expert interviews was chosen to best reflect both the community and expert positions on bridge repair and maintenance.

The ethical considerations of this study include accuracy, fairness and balance. All interview request will be accompanied by an explanation of this research and an informed consent form. Interviewees will be treated with respect and any information gained during an interview will be reported accurately and in the correct context. With the exception of door knocking the interviewee will be provided with the relevant questions in advance of the interview.

This paper argues that the current standard of bridge inspection in New Zealand is open to interpretation by councils and that the data collection and management practices do not always provide the quality of information required to make informed decisions.

2. Long form journalism

It is not rocket science – A shaper focus is required for New Zealand's bridges

Birchville is a small settlement comprising of 70 properties on the Bridge Road side of the Hutt River. It is a peaceful place with a close-knit community boarded by native bush on one side and a riverbank on the other. The settlement is accessed by a one-way bridge across the Hutt River.

Residents were dismayed when the middle pier of the 139-year-old bridge slumped, pulling the deck of the bridge down with it. There is no other road into the suburb. The alternative is a half-hour slog through the bush along a narrow walking track. For five weeks residents walked this over the track carrying groceries and supplies while dodging mud and falling rocks until a vehicle track was constructed.

The collapse occurred in October 2015, but the memories are still raw. The morning of October 29, 2015, it was a cold, wet day in Upper Hutt. The river was up, but residents did not think it was unusually high and certainly did not think it was a flood.

Terri Fordman was in her car driving back from work. A white car was stopped at the entrance to the bridge, blocking her way across. A man was standing by the car in the rain. He came over and told her the bridge was not right and they shouldn't cross. Fordman says, "I just wanted to go home, I could see my front door across the river." Daisy, her 12-year-old dog, was at home, waiting for her.

It was awful she says, "I didn't have a raincoat, just a coat and shoes. People who lived on the town-side of the bridge asked me in for a cup of tea. They were lovely, gave me lunch, let me gather my thoughts and lent me a coat and gumboots to walk home over the Totorua Park walking track."

Fordman recalled the first few days. She put buckets in the garden to collect the rainwater and stored it for washing and boiled it to drink. There was no gas and it was cold. She says, "You can do everything out of a bucket for a day, but longer is terrible."

Sometimes, Fordman walked out twice a day to feed her horse and go to work. She considers that she was lucky because her car was on the other side. She could go away, but she couldn't go grocery shopping, the groceries were too heavy to carry back.

Fordman doesn't really think about what would have happened if the man in the white car hadn't stopped her. At the time she was driving a four-wheel drive she thinks she would have probably kept going, "I knew the pier was strong even though it was on a lean. Daisy was waiting at home, and I was more worried about her." Her neighbours were sheltering from the rain under big umbrellas on the other side of the bridge. She remembers shouting to them "I want to come home."

Birchville residents had been concerned about the bridge for years. They complained to the Upper Hutt City Council about the pooling of water on the deck and the movement it made when logging trucks went over it. Fordman recalls that they would call the council and tell them about the puddles, the movement and the growing gaps at either end of the deck. Men would come and fill up the gaps with tar and go away again.

The bridge is located close to the confluence of the Akatarawa Stream and Hutt Rivers. The structure is one of the remaining artefacts of early settlement in the area. It is a combination of old and older. The bridge was built in 1881 and upgraded in 1954 when the original wooden trusses and decking were removed and replaced with a prestressed concrete deck. The new deck was built over the existing wooden bridge supports and the 139-year-old central pier.

The impact of the flood on the central pier of the Birchville Bridge was catastrophic. Due to the ferocity of the water, the riverbed experienced heavy scouring, resulting in a hole 1.5metres deep on the east side of the mid-pier, extending 1m below the bottom of the pier.

The bridge failure report provided to the council and obtained under the Local Government Official Information and Meetings Act (LGOIMA) noted no indications that riverbed levels had declined. However, measurements of the riverbed were not taken during any inspection between 2008 and 2015, and all inspection reports relied on visual inspections and limited photographic evidence.

The bridge was inspected three months before the collapse. The engineer found that the movement reported by the residents was probably caused by vertical expansion of the concrete beams at mid-level. The inspection recommended the removal of flood debris upstream and around the pier so further scour investigations could take place. The debris was not removed, and three months later, the bridge collapsed.

The 2015 bridge inspection report noted that no remedial work was undertaken since the last inspection, and recommended that flood debris be cleared from upstream and around the bridge pier. If any scour was revealed the situation would then be reviewed.

Fast forward to 2019 and the scene is the same. It is raining, the Waiho River is up, but nothing spectacular. Muddy greywater is flowing under the Waiho Bridge. The 170-metre-long structure connects the Fox and Franz Josef townships. It is the arterial route for locals, businesses and the million-plus tourists that cross the deck every year.

Tim Gibbs has a first-hand view of the river because he drove the last vehicle across before it collapsed on March 29, 2019. He didn't hear or see anything unusual. He says, "They had no concerns - they had seen bigger floods."

On the Franz Josef side of the river concerned locals stopped traffic because they were worried about the bridge. Gibbs stood on the riverbank with tourists and other locals and watched the structure across the grey, swirling waters. A tourist standing beside him said the bridge had been making a bit of a weird noise.

Gibbs saw the north end just peel off and float away. "I watched it wash away. It was all a surreal experience," he says. "It left a bit of a taste in my mouth."

The Waiho Bailey Bridge is a giant Meccano™ set straddling a narrow spot on the Waiho River. It is made of steel and held together by millions of bolts. It was swept away by the increased speed and volume of the water which dug a deep scour and undermined the rock protection in front of the northern abutment. When the abutment failed and lost its footings the bridge teetered like a drunken dancer, while the water pummelled the piers which were never built to resist lateral flooding.

The Waiho Bridge is a state highway structure managed by the New Zealand Transport Agency (NZTA). Regular inspections and measurements are undertaken by NZTA, its consultants and the National Institute of Water and Atmospheric Research (NIWA).

One of NIWA's responsibilities is to measure the height between the riverbed and the soffit just below the deck. This is important as the bridge deck must be kept above the water; otherwise there is a risk of floating debris collision or excessive lateral water pressure. In correspondence obtained under the Official Information Act, it was found the distance was incorrectly recorded by 1.35m for an unknown number of years before being corrected in 2012.

The area where the bridge was built was once a gorge. Over the decades, the constant wash of gravel from the glacier and neighbouring hillsides has filled it in. To compensate for the continued rising level of gravel the bridge deck was raised over 9m in 90 years, but the aggressive, aggrading river still threatens it.

In 2017 a tender was issued to raise the bridge by another 2m. The bid was not awarded because the submissions were considered too expensive. The New Zealand Transport Agency believed the riverbed was stable even though the riverbed data they held was only accurate since 2012.

Cost

Franz Josef local business owner Logan Skinner believes he has every reason to be annoyed about the loss of the Waiho Bailey Bridge. He could not believe the photo that popped up on his phone. "I thought it was a joke until I went down to the river bank." The bridge was all but gone, the steel twisted sideways into the water.

The previous day Skinner attended a meeting about future river management. Everyone was there: local community groups, the council, NZTA, and OPUS. He estimates there were 20 people in the room. There were lots of ideas but Logan says he left the meeting with no confidence, and the rain started to fall. He is resigned, "We have had lots of meetings, and there is a momentum of identified actions coming from these meetings but nothing gets done."

The bridge collapse was a disaster for Skinner as it was for every business in the Franz Josef and Fox Glacier regions. He believes that tour companies cancelled tours to the West Coast after the bridge collapse because they were sick of being stuck there. They just turn left and go to the Catlins. Skinner knows that when the tour companies go their advertising goes as well. That is a blow for the smaller operators who piggyback off their promotion of the area. They just fall off the radar.

Even when the bridge was rebuilt Skinner says that visitors do not immediately return. “It is not like turning the tap back on. People are suspicious, and misinformation swirls around the tourist population, and they don’t come.” He believes it will take years to recover.

Skinner is passionate about the Franz Josef township and is a keen observer of the river because it influences every part of his life. He was so concerned about the Waiho River he emailed NZTA on March 24 at 4.20pm:

‘Just got a call from a concerned person, apparently with the channel works above the bridge the river is pointed towards the North Bridge abutment and some rocks are missing. They said it was not critical now but may be an issue if we get a good rain. DOC emailed saying we were getting rain tomorrow I think.’

At 10.00am March 25, NZTA replied:

‘There was a temporary bank put in upstream of the bridge to divert the channel while they repaired the groins on the north bank, and that is probably disappearing, which is what is supposed to happen to it. The groins have been repaired now, so all should be fine, hopefully for a while. First test coming now, by the sounds of things.’

The Waiho Bridge was washed away the next day.

It was an economic disaster for the businesses in Franz Josef and Fox Glacier townships. Skinner says April is usually their best month, “It’s when the bills are paid and whatever you earn is a profit, even though it is a skinny profit. The bridge collapsed in the last week of

March 2019, and tour companies recalibrated their 2020/21 New Zealand itineraries and dropped the Coast because they were sick of being stuck here."

The West Coast Regional Council chief executive officer Michael Meehan says, "The council has spent years consulting with the Fox Glacier and Franz Josef communities and stakeholders." He is hopeful that the work done to-date will help with the current recommendation. The council is asking central government for funding to strengthen the stop banks and raise the bridge as part of the road infrastructure project. He has confidence in NZTA's management of the bridge and just wants to make sure the banks of the river can perform when needed as the Waiho River is the most dynamic in the country.

It took 21 days to build another Bailey bridge costing $6.5 million. However, the cost to the West Coast region was far higher and estimated to be between $42 and $63m. Andrew Elphick, a local accountant, felt for his clients and the people of the Coast. They were cut off from food supplies, banking and medical facilities. If the locals and thousands of tourists in Franz Josef wanted to go south, they detoured hundreds of kilometres, driving around the Aoraki Mt Cook National Park and through Arthurs Pass - roughly a 12-hour journey. When the bridge was operational it took 25 minutes to drive south from Franz Josef to the Fox Glacier.

The Birchville community does not have a commercial base, its residential housing. The residents cannot estimate how much they lost during the 18 months it took to replace the one-lane bridge. However, businesses were financially hurt and destroyed.

The cost to the NZTA and the Upper Hutt City Council, including the $600,000 for the temporary road was $3.68m. Two-thirds of the construction cost was funded through NZTA subsidies.

According to the 2008 Upper Hutt City Council replacement and depreciation values obtained under the Local Government Official Information and Meetings Act (LGOIMA), the bridge's depreciated value was $1.9m with a remaining economic life of 46 years. The replacement was planned for 2054 because the depreciation value records the bridge as being constructed in 1954 rather than the 1881 construction date of the pier.

The age of a bridge and external events have a definite impact on bridge structures and should be considered when making asset decisions. The use of depreciation to assess the remaining useful life of a bridge leaves asset managers with a false impression that the bridge is younger than its parts. The depreciation values were last updated in 2008, although the replacement value continued to be annually updated. This is an example of inconsistent data collection and management.

We will never know if the bridge raising would have saved the Waiho or if the removal of the debris would have uncovered scour around the pier at Birchville. What we do know is that globally bridges are getting older and some of them are collapsing because of age and external events.

Bridge collapses happen all over the world. The most recent major failure occurred in Aulla, Italy, in April 2020 during the COVID19 lockdown. The virus is credited with saving lives, as the 260m concrete bridge is part of a busy provincial network between the coast and Parma. The collapse highlighted the continuing poor state of repair of Italy's road network, occurring only two years after the 2018 collapse of the motorway bridge in Genoa that killed 43 people.

There are some 300 Italian bridges at risk of collapse. The World Economic Forum 2019 ranked their quality of road infrastructure at 54 from 140 countries. However, collapses are not exclusive to any one country. There have been over 120 collapses since 2000, with the majority in the United States which is ranked 11. The situation in the United States is considered very poor by the American Society of Civil Engineers who predict major problems in the near future. New Zealand does not score highly in road infrastructure either with road quality was rated by the forum as 4.7 out of 7 in 2018 and ranked 39 from 140 countries in 2019.

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New Zealand is lucky that the two recent bridge collapses did not result in loss of life. The 1953 Christmas Eve Tangiwai disaster killed 151 people. On that wet Christmas Eve night in the shadow of Mount Ruapehu Cyril Ellis tried to stop the train but the trains brakes did not catch in time and five train carriages tumbled into the cold water. The man in the white car at Birchville and the locals at the Waiho Bridge were successful stopping the traffic and warning people of the danger.

Bridges are kept safe through regular inspections by qualitied personnel. New Zealand has more than 18,000 bridges and large culverts managed by either NZTA or councils. Bridge inspections are a little bit of wisdom mixed with a little bit of science.

Inspections

Both the Waiho and Birchville bridges were inspected within four months of collapse. Bridge inspection guidelines are developed by NZTA and managed by either the agency for state highways or by the local government (councils). However, the guidelines are just that; they are not enforceable and merely serve as a minimum standard.

An NZTA spokesman says they have a good relationship with councils and they help when they can. "Some of the gaps in knowledge at the council level are because of change in staff. In the past few years, many councils have lost experienced staff and the new staff do not know how to lay their hands on information quickly." This may also be a sign of poor bridge management systems at the council level.

The first inspection of a bridge is visual, using the professional knowledge of the inspector; looking for cracks, recommending flood debris is moved, fixing broken rails, tightening bolts and removing severely rusted and broken elements.

Visual inspections are the thin end of an inspection wedge, and are perceived as old fashioned by some academics and impossible to do without by others. Regardless of which camp people sit in, the need to visually inspect a structure is the first and sometimes the most effective way, to inspect the condition of a bridge.

An NZTA spokesman says much of the bridge network is inspected visually and a change of condition can almost always correspond with a change of inspector. They consider that the findings of an inspection boils down to the experience of the inspector. Most councils do not want a bridge issue, and as a result, inspectors are usually conservative in their assessment to make sure they catch any problems.

The science is based around the use of devices to test the assumptions of the visual inspection. More modern non-destructive measuring methods include acoustic, electromagnetic, electrical and radiological techniques. The NZTA believes that the use of handheld non-destructive instruments is not particularly helpful. They would rather inspectors use the specified techniques of inspection and live load testing. They stress the need for the bridge inspector to be clear on what they are looking for before using instruments. It is about focussing on defects and identifying any changes in the bridge.

This position is endorsed by Hastings District Council Bridge engineer Anu Ileperuma. She says, “Non-destructive testing works in some situations but not all circumstances. The most crucial factor is to make sure you know what you are looking for.” The NZTA believes that making the same inspection on a regular basis is sufficient at the supervisor level.

Germany is recognised as having the best bridge inspection regime in the world and uses non-destructive testing on all levels of bridge inspections except for the three-month superficial visual inspections. The results provide useful and repeatable information which can support the findings of a visual inspection and possibly give the visual findings more credibility. In New Zealand, visual assessment is the most common technique used for bridge inspections.

Bridge inspections are divided into three basic categories, an annual routine inspection, bi-annual general inspection and a six-yearly detailed principal inspection. The NZTA publish detailed inspection guidelines and qualification requirements for councils to follow. However, an investigation by the author shows that there are still variations in inspection periods utilised by different councils compared to NZTA guidelines. Masterton District Council‘s response to a LGOIMA request concerning bridge inspection frequency was that they carry out the routine and general inspections but only conduct a principal inspection based on the results of the general inspection.

Masterton District Council Manager assets and operations manager, David Hopman, responded to a further request for clarification on the inspection regime in writing. ‘The response to the LGOIMA request was not intended to imply that Masterton District Council does not conduct inspections to the standard of a “Principal” inspection, as defined in the NZTA policy for bridges on the State Highway network (NZTA S6: 2019).’ He continues, ‘While this policy does not specifically cover bridges on roads outside the State Highway network, i.e. those for which MDC has responsibility, this document provides a guideline for council inspections.’ Hopman noted that the council does not, in practice, use the terms adopted in the NZTA document, which defines the terms “general” and “principal” for different levels of inspection.

Hopman emphasised that all inspections of Masterton District bridges are carried out by a structural engineer, and they are able to get within 3m of an acceptable percentage of the bridge.

The written response confirmed that bridges within Masterton District are inspected every two years, unless they carry a weight restriction, in which case they are inspected every year. This reflects the practice of other councils identified in the authors investigation where the general bi-annual inspection is undertaken but it is not clear that a specific principal six yearly inspection is conducted.

Principal inspections are comprehensive, designed to investigate the structure in more detail and may include an engineer’s report. A bridge may be considered safe under a general inspection but need repair under a principal inspection. The lack of six-yearly robust principal inspection combined with a bridges age may put New Zealander’s at risk without anyone being aware.

Age

The estimated life of a bridge in New Zealand is 100 years and one of the longest in the world. There are seven bridges built on state highways that were built before 1900. State Highway 2 runs the length of the North Island winding through the Bay of Plenty, Hawkes Bay and the Wairarapa, ending in Wellington. The average construction year for bridges on State Highway 2 is 1966 with an average age of 54 years. However, when reviewing a section of State Highway 2, the average year of construction is earlier. In the Wairarapa region, between the Remutakas and Woodville, there are 18 state highway bridges with an average construction age of 57-years, four built before 1931 and one between 1931 and 1940.

The physical age of the structures suggests that five bridges in the Wairarapa will require either replacement (if they are at the end of their useful life) or remedial work to extend the life of the bridge; four in the next 10 years and one in the next 20 years.

The Masterton District Council is responsible for 179 bridges; 24 built between 1900 and 1930 with another 49 constructed between 1931 and 1940. Disregarding any bridge replacement programme for the balance of the country, in the Wairarapa NZTA will potentially replace four bridges in the next 10 years and one in the following 10 years. They will also contribute to the construction to a further 24 bridges managed by the Masterton District Council by 2030 and an additional 49 bridges by 2040.

Bridge age can be manipulated using depreciation. The Birchville Bridge Road bridge collapse is an example of the different live spans of different components. The bridge's depreciated age was 46 years based on the deck age rather than the 139-year-old pier.

The unreliability of the pier only became apparent because of a flood. Although a flood cannot be forecasted, it can be planned for by actioning the bridge inspection recommendations and remembering that the structure was towards the end of its useful life and potentially requiring closer inspection.

Upper Hutt City Council Roading Manager Patrick Hanaray says, "The collapse of the Birchville Bridge Road bridge was the result of a weather event. It was localised heavy rain that caused a flood triggering the failure of the central pier." He points out that bridge construction is different now, with internal reinforcement for abutments and piers. When the council recently replaced three bridges on Akatarawa Road, they took a core sample to make sure the concrete pour was good. Those procedures and checks were not available 139 years ago.

Hanaray is satisfied with the process for inspection and maintenance because it is well established and proven. He says, "They have not changed any procedures since the collapse. They have good systems and electronic records of bridge information including design and construction plans. The council has spent a considerable amount of money making sure they have the information they need for its bridge assets."

Asset management

An investigation by the author shows that there are possible conflicts between asset management and best practice especially for bridges of mixed construction ages. New Zealand Transport Agency spokesman Jason Morgan says, "There is currently a bit of a bow wave of older bridges but that is part of an asset managers processes from a financial rating perspective."

The 1912 Waihenga Bridge in the Wairarapa is a good example of extending life. The NZTA has spent over $1million for concrete repairs to bring the bridge up building code standard. The NZTA are confident that their management plans reflect the correct priorities.

However, an investigation by the author into bridge inspection and management of New Zealand bridges found that our bridges are susceptible because of varying standards of bridge management and inspections. These variations are not new. The New Zealand Office of the Auditor General (NZOAG) 2010 State Highway network review found that there was no effective model for monitoring bridge condition and deterioration, and the data collected for bridges was not as good as that collected for roads. The review also stated that while the NZ maintenance for road pavement planning practices is well developed, bridge asset management systems require real improvement.

The NZOAG followed up the 2010 report in 2014 with a review concentrating on how local authorities (councils) manage water and roads. They found that councils use the guidelines as a template and then adapted them to their requirements. Investigations by the author has found that this practice continues today. Because the NZTA manuals are guidelines, there is no direct oversight of the methods and measurements used in council bridge inspections.

The Carterton District Council, and South Wairarapa District Council undertake an annual general inspection of 50 per cent of their bridges and one-third of those will then have a more structural inspection within that year. Therefore, all bridges have a general inspection every two years, which fits within NZTA guidelines. Masterton District Council also conduct a general inspection every two years.

These results show that there is variance in the inspection periods utilised by different councils compared to NZTA guidelines, and that the Carterton District Council and the South Wairarapa District Council's may inspect too regularly. This is costly in both money and time. The decision by the Masterton District Council to only conduct general inspections suggests that flaws may be missed because the six-yearly principal inspection is more comprehensive, designed to investigate in more detail and may include an engineer's report. A bridge may be considered safe under a general inspection, but need repair under a principal inspection. The lack of the six-yearly principal inspection, combined with a bridges age, may put the public at risk without anyone being aware.

It is the inconsistency of data that leads to a suspicion that many councils around the country do not have the best interests of the New Zealand travelling public front of mind and a greater focus on minimising cost. They can do it because NZTA does not audit the bridge inspections carried out by council consultants. Principal inspections are expensive to conduct and although all councils are given funding by NZTA councils have other calls on their funds.

There is a real monetary cost to taxpayers when expensive remedial action needs to be taken, and a personal financial and emotional cost for residents when something goes wrong. However, there is another way. Upfront investigations and community involvement have saved the Hastings District Council millions of dollars and made council bridges safer.

The Red Bridge straddles the Tukituki River. It is a vital arterial route for farming, forestry and vineyards. In 2016, a visual inspection as part of the principal inspection found wide cracks on the bridge. There were several options available to make the bridge safe: reduce the speed limit for stability, reduce the weight on the bridge by separating trucks and trailers during the crossing, or close the bridge and impose a 10 kilometre detour over a narrow windy road.

It was estimated that the increased volume and weight of the traffic deviation would cause premature pavement failure and incur more costs. The non-urgency of the situation, combined with the extreme and costly options, encouraged the Hastings District Council to consult with local business owners and stakeholders on the repair options.

The wider consultation, led by the council's engineering team and the council, engaged with the community to discuss options for repair. At the same time, a detailed investigation into the capacity of the bridge using various non-destructive testing methods was undertaken. Testing included crack monitoring and load testing, as well as visual inspections for reinforcement corrosion. Non-destructive testing has been around for a while but not used extensively.

The civil engineering undergraduate curriculum at the University of Canterbury does not cover non-destructive testing. The postgraduate course touches on it, but it is not a taught subject. University of Canterbury Professor Alessandro Palermo is optimistic that the new generation of non-destructive tools will become more widely used because they support the analysis and assessment of bridges. He is encouraged by the integration with digital platforms that can deliver consistent measurements.

Although the Hastings District Council engineers use non-destructive testing, this was after the initial principal inspection. Council engineer Anu Ileperum says, "The most important thing is to identify the changes in the bridge; are they moving or deteriorating and then deciding the best way to monitor the situation." Council inspectors inspect their bridge alongside the contractors who will carry out the work. This means that ideas can be shared and options considered.

After the initial flaw was identified additional special inspections were undertaken using both visual and non-destructive testing methods to provide options for maintenance and repair. An additional benefit was that the detailed investigation showed that the bridge can handle much higher loads without further strengthening.

The use of depreciation to assess the remaining useful life of a bridge leaves asset managers with a false impression that the bridge is younger than its parts. Because of the number of ageing bridges in the country we are building up to a perfect storm bridges nearing the end of their useful lives, an increase in extreme events combined with variations in inspection frequency, councils who translate guidelines to fit their own requirements and a history of patchy data collection and storage.

Many of the identified shortcomings are common sense. When recommendations are made, they should be carried out in a timely manner; ageing bridges need special treatment to continue their useful lives; inspection frequencies should be adhered to; and principal inspections should be carried out. NZTA needs to strengthen their guidelines and make sure councils adhere to them. And finally, the bridge management system should be uniform for councils and NZTA.

These points were raised with the agency, and NZTA spokesman, Barry Wright, says it is hard to dictate exactly how long after an inspection the actions should be carried out. The decision on when, for example, debris should be cleared is based on the amount of risk they pose. He says, "What is really important is that the actions are not lost in the paperwork. No one wants the next inspection to come around only to find that previous recommendations have not been actioned. The asset manager should make decisions around prioritisation and keep watch that the recommendations are carried out."

Nowhere is this more important than with ageing bridges. The inspection records for the Birchville Bridge show that recommendations were not actioned between one inspection and the next.

The NZTA regional bridge manager for the Wellington region, Terry McGavin, says, "Bridges aged over 40 years cannot be bought up to new bridge standards, and they are managed using the building code." He is confident that consultants will know the code and can apply it to their bridge structures. Bridges are rated low-or-high probability and should be managed accordingly.

Bridge inspections happen all over the country every day. Inspectors use the guidelines and their experience and knowledge to make assessments on bridge condition and the frequency of bridge inspections. Some bridges may be inspected more often than the guidelines recommend and others less depending on their condition or financial reasons. What is usual says NZTA spokesman Barry Wright is that, "Worldwide a principal inspection is usually carried out every five to six years as part of the bridge management regime."

The inspection regimes are set out in NZTA's Inspection and Maintenance Manual (S6). However, the recommendations are not compulsory and could be merely considered a platform for councils to develop individual bridge inspection regimes as shown in the NZOAG 2014 review. The bridge engineers at NZTA believe that the guidelines and S6 identify the minimum requirements of a bridge inspection balanced against a reasonable level of risk management.

Councils are not required to report to the agency regarding bridge inspections, although, they do provide annual achievement reports for local roading and information. In addition, a sample of councils are audited every year to check on highway support. NZTA spokesman Jason Morgan says the majority exceed the requirements set out in the audit. The NZOAG review into council road management was six years ago, and the driving public deserves a more robust system of checks and balances now.

The easiest way to have checks and balances is by using a standard bridge management system. Currently, councils use a mixture of paper and computer-based systems which leads to inconsistent data collection and narrows the decision-making process. The agency is in the process of developing a new bridge management system. It will include all the bridge data plans, design drawings and inspection reports. The NZTA regional bridge manager for the Wellington region Terry McGavin says there is no reason why they could not run a combined bridge management system with councils.

Age, asset management, reporting and oversight, data management and storage are all tools to increase the safety probability of a bridge. University of Canterbury Professor Alessandro Palermo says nothing can be guaranteed as safe because it is a very broad term. When an engineer is designing a bridge, they look at safety and the coefficients linked to a probability of failure. He says, "Once the bridge is built, it is the maintenance programme established by the council that is instrumental in reducing the risk of a bridge collapse."

It is time that NZTA stopped chipping away at the edges of a preferred level of bridge maintenance. Investigation by the author found the most significant shortcoming is the disconnect between the expected regime of inspection and what actually happens. The NZTA need to take control of the inspection process to ensure councils are not over or under inspecting bridges. The guidelines and policies can be standardised and enforced. Councils have to understand that the funding from NZTA and its ratepayers is not about taking the money and running, it is about making the best decisions based on the best information they have available.

The crucial six-yearly principal inspection should be undertaken by NZTA consultants alongside the local contractors to ensure that the best solution is agreed on at the time of inspection. This practice has proven successful for the Hastings District Council.

Patchy data collection practices can be addressed by making the new NZTA bridge management system available to all asset managers. The use of a common program will ensure that minimum standards are achieved by asset managers.

Another shortcoming is around the need to make hard decisions based on more than cost. Community value of an entire region or a small community is dependent on a reliable and safe transport network. The need to maintain bridges to their best potential is vital for the public of New Zealand, and bridge maintenance practices should reflect this.

Although the inspections and maintenance are carried out by qualified engineers and consultants, they get to go home at the end of the day. For the residents of Birchville and Franz Josef, that was difficult. It was either a 45 minute walk over a narrow walking track dodging rocks and puddles or a 12 hour detour. The collapse of the bridge had an enormous ongoing impact on their daily lives.

Saving money by ignoring the actual age of a section of a bridge becomes fraught with danger as a structure creeps towards its hundredth year or even surpasses it. The 1912 Waihenga Bridge in the Wairarapa is an example of successfully extending the life of a bridge by doing the right thing fixing it rather than ignoring it.

The possibility of extreme weather events is becoming more likely. Floods stress and strain bridge structures in ways that are hard to anticipate because everything happens underwater in adverse conditions. New Zealand, like every other country in the world, faces challenges with older bridge stock and extreme weather. Bridge officials at local and national government level need to make the right decisions at the right time. Even so, improvements in inspection protocols may not be enough to eliminate future failures.

3. Literature review

New Zealand (NZ) has longer road lengths and freight (tone-Km) per person or GDP than most developed countries. Therefore, the importance of efficient, modern and safe road network is paramount to the NZ economy.

The two most costly components of road systems are pavements and structures; they are typically more expensive to build, and maintain, and require special attention in any road management program. NZ legislative documents such as the Local Government Act 2002, and the Land Transport Management Act 2003, focus on the development of a proper management process for all network assets.

Underlying the proper management of the NZ road network is the unspoken understanding by the public that our roads and bridges are safe to drive over. Although the Oxford English Dictionary defines 'safe' as "free from danger and secure', in contrast an engineer's definition is not an absolute. Engineering design factors concentrate on keeping the risk of failure to acceptably low levels based on a probabilistic basis. From time to time, there will always be events that result in structures being loaded beyond the limits prescribed by standards, and at times result in collapses.

For a bridge, that may mean it is designed for a one in a 500-year earthquake loading derived by statistical means, or a one in a 100-year flood based on historical records. Although traffic loadings are prescribed, they can be altered from time to time and the load factors applied in the design also allow for some latitude being taken by say, truck operators.

If a failure occurs from any type of loading beyond the design limits, then that is, in a sense, acceptable in general terms. However, for building structures at least, engineers aim to design so that once a building exceeds its design loading limits, that the mode of failure tends to be ductile and progressive, rather than brittle and precipitate. That principle is also applied to bridges to some degree. This study will examine the layers of bridge management in NZ and compare current practice against the definition of probabilistic safe.

This chapter examines the terms 'visual inspection' and 'non-destructive testing' and the evolution of road bridge inspections. Including the change in focus from expensive software development to low-cost visual inspections and the impact this has had on inspection regimes, reporting, and data collection and retention.

3.1 Background on the topic

Globally, bridge inspection standards have become more critical because of ageing bridge stock and increasing maintenance costs. There are more bridge failures around the world because of the age of the bridge and the ferocity of floods than any other reason (Dikanski, Imam, Hagen-Zanker, Avery and Castlo, 2016). Therefore, each bridge must have the best chance to weather a flood event through regular bridge inspections, timely and appropriate maintenance, sufficient budgets and knowledgeable asset management.

The focus of bridge research has moved from costly high-tech solutions to low-tech, moderately-costed options concentrating on maintenance and lifecycle practices with an emphasis on visual examinations (Gkoumas, Marques Dos Santos, van Balen, Tsakalidis, Ortega, Grosso, Haq, & Pekár, 2019).

The growth and direction of the research was driven in part by the increasing costs of infrastructure. In 2019, the Economic Union (EU) Joint Research Centre published a review of the requests for bridge research project funding through the Transport Research and Innovation Monitoring and Information system (TRIMIS). They found that research into bridge assessments had changed emphasis from technical to visual inspections (Gkoumas et al., 2019).

The term visual inspection (VI) refers to a qualitative process of examination and data collection on structures and components using the naked eye aided by simple mechanical enhancements such as magnifiers and dental picks (Bush, Omenzetter, Henning & McCarten, 2013). The practice of VI is globally recognised as an economically simple way to check the condition of a bridge and provide data to registries and databases (Reynolds, 2018; Hearn, 2007).

There are several issues related to VI, including accuracy, repeatability and a lack of quantitative information on loads and their effects on the structure. Defects can be located in inaccessible or difficult-to-detect areas, and the literature recommends that bridge asset managers should consider the appropriateness of relying solely on VI for high-risk bridges (Bush et al., 2013; Gkoumas et al., 2019; Hajdin, 2018; Luís, Neves, Frangopol & Petcherdchoo, 2006; Siviero, 2018; Quirk, Matos, Murphy & Pakrashi, 2018).

The purpose of this review is to ascertain if there is compelling evidence that the current inspection standards used to inspect NZ's bridges fall short of best international practice. It will demonstrate that although the NZ bridge inspection regime may be considered adequate, there are shortcoming around the reliance on visual inspections, lack of technology use, timeliness of inspections and fragmented data management systems.

3.2 Comparison of New Zealand standards

Similar to Germany, United Kingdom and Sweden, many of NZ's bridges are now nearing the end of their projected lifespan (Taplin, Deery, van Geldermalsen, Gilbert & Grace, 2013). As bridges age, their maintenance and repair needs change due to the gradual deterioration of the original materials. This means that engineers should use a variety of different technologies and methods to keep the ageing infrastructure reliable and capable of supporting the increasing volume and weight of vehicular traffic (Rapaport, 2016).

New Zealand uses similar protocols, methods, and standards of inspection to those practised by some foreign countries (Appendix A). However, accelerating climatic events are starting to expose the shortcomings of the current inspection standards in many countries. Over the past five years, the NZ road network has experienced bridge collapse due to severe weather and floods including the Birchville Road bridge, Upper Hutt, and the Waiho bridge on the West Coast.

Therefore, it is timely to undertake comparative research into NZ's visual bridge inspection standards against other counties which have similar terrain, aged bridges, and funding sources. This research will show if there is compelling evidence that our current bridge inspection regime is equal to or below the standard of inspections in those comparable countries.

3.3 Overview of the research

Results from the 2019 EU, TRIMIS review showed that although many research projects focused on improved bridge inspection procedures, there was a weak link between the research recommendations and the widescale adoption of the techniques, or even a common standard of bridge inspection (Gkoumas et al., 2019). These findings are not restricted to the EU, as studies undertaken in the United States by Hearn (2007) show a similar pattern of research recommendations that are yet to be implemented.

Many of these recommendations centre on the current reliance on visual inspections, Hajdin (2018) says;

> Bridge management practice differs quite significantly from country to country, but the most common denominator is that it relies on visual inspections. The visual inspections are – if performed by a qualified structural engineer – cost-efficient and a very valuable source of information. (p.70)

Hajdin (2018) recommended the incorporation of forecasting into bridge inspections for both the assessment process, and safety and transparency. This is in direct contrast to the New Zealand Transport Agency's (agency) lifecycle management of bridges policy which states that bridge asset management practices should not consider forecasting, and concentrate on only doing sufficient investigations to allow the maintenance option to be undertaken (New Zealand Transport Authority (NZTA), 2018a).

There seems to be a disconnect between what the literature is recommending and current bridge inspection practices in many countries, and NZ is no exception.

3.4 Literature research

Recent studies have compared various countries' bridge inspection standards and procedures (Siviero, 2018; Liao, Mustapha, Yau, Jiang, Huang, Su, & Chen, 2017; Hearn, 2007). They found that there were significant variations in the frequency of inspections (ranging from daily to biannually), discrepancies between the methods, and that design documentation was not part of the inspection process.

Comparison of international bridge inspection methodologies and evaluation to Taiwan's current inspection practice by Liao et al., (2017) found the strategy of focussing on data recording did not flow through to a notable improvement in maintenance efforts. The report recommended that engineers refine their inspection and assessment techniques. The drive for standardisation is not unique to Asia, the EU also suffers from multiple standards and inspection regimes.

Research undertaken by Siviero (2018) recommended the adoption of a four-level hierarchy assessment process across all EU countries. The research used case studies to justify knowledge and confidence factors, and to illustrate how EU members could utilise a standard inspection regime.

> The possibility of harmonising these type[s] of procedure[s] is needed in Europe, together with a completely new plan of infrastructure renewal.
> (Siviero, 2018, p.1185)

Research into the standardisation of inspections regimes was also undertaken across the fifty American States and the combined results compared to eight foreign practices (Hearn, 2007). The results showed that visual inspections varied significantly across the states, and compared to foreign practices, had extended periods between inspections.

Country comparisons were also undertaken by Scutaru, Comisu, Boaca, and Taranu (2018), who investigated the strengths and weaknesses of bridge inspections, maintenance and methods in diverse countries. Results show that although all countries seek to provide the same information, the way it is collected and analysed differs significantly (Appendix A). Germany was considered to have the most complete system for assessing management structures because they use non-destructive tests (NDT) at all levels of inspections except the three-month superficial visual inspection.

Non-destructive testing refers to using non-destructive methods to test strength, loads and structures that may change over time by using acoustic, electromagnetic, electrical and radiological methods. Increasingly, the equipment is software-based and uses sophisticated mathematical algorithms and artificial intelligence to allow for more comprehensive inspections, for example, thermography to test the condition of the steel inside concrete

(Hearn, 2007). NDT causes no damage to the structure, can be completed to a considerable depth and easily repeated (Schabowicz, 2019). In contrast, NZ uses simple mechanical enhancements such as magnifiers, dental picks and suchlike for one- and two-year inspections (Bush et al., 2013).

The TRIMIS report highlighted a promising future for NDT. In particular, the development of new technology solutions from university incubation labs (Gkoumas et al., 2019).

> New solutions and technologies are being explored to develop low-cost, large scale and easily deployable systems that could contribute to the monitoring of the large number of civil structures that are at present, missing dedicated supervision. (Gkoumas et al., 2019, p. 31)

New solutions can be driven from necessity, Hirsch, et al., (2017) used NDT to inspect 1200 bridges in Fiji. They were not hampered by the transition between old and new systems because there were few construction plans and no historical bridge inspection records. The use of modern technology meant that they could quickly build a database of each structure.

Jager, Pape, Shaw and Heywood (2018) also recommend that a bridge's structural plans should be available to ensure the assumptions created by visual inspections aligned with the operation of the bridge. They investigated assessment decisions on 84 bridges across the Australian road network examining for unrecognised defects. At the time of the assessment, all the structures were functioning satisfactorily. They found that the adoption of NDT, including reliability-based assessments to measure material and actual vehicle weight in motion testing, ensured bridge owners had a more accurate appreciation of the risks associated with the ongoing management of their structures.

The amount of information provided before an inspection also has a significant impact on the assessment results. Research by Quirk et al., (2018) provided three levels of bridge information to inspectors before an inspection - no information; perfect information; and imperfect information. Perfect information would incorporate the different bridge lifecycle data sets including management risk models, operational and capital investment planning. The different levels of information influenced the result, with prior knowledge about the asset significantly improving the inspection result.

The agency (2018) recommends that inspectors use the lifecycle plan to identify, review and develop individual bridge plans and use the lifecycle plan as a living document:

> The steps in the plan are not rocket science; it is about having a good knowledge of the bridge network, sound engineering principles, following good management practices and documenting outcomes.
> (NZTA, 2018, p. 9)

In a perfect world, this data would create a decision-making framework providing a sharper focus for high-risk bridges, with more data collected for analysis, and less data collection for lower risk bridges (Bush et al., 2013; NZTA, 2018). Linking the asset management approaches to data collection would ensure that appropriate data was available, which in turn, strengthens the decision-making framework while safeguarding the safety of the bridge, and identification of repairs and defects (Hearn, 2007).

Asset management also needs to change focus as the structure ages, because of the gradual deterioration of the original materials. This means that engineers have to find new technologies and methods to keep the ageing infrastructure data reliable at a time when the volume and weights of vehicular traffic are continually increasing (Rapaport, 2016).

The literature shows that the more design and assessment information known before an assessment necessitates fewer assumptions about the state of the bridge. The literature repeatedly shows that solely relying on visual inspections leads to poorer maintenance decisions and impacts the accuracy of data collection.

Finally, although international research on this subject abounds, evaluative studies on the effectiveness of bridge inspections in New Zealand are comparatively scarce. This paper includes relevant examples of international studies, and it can be said at the outset that the dearth of such studies in New Zealand needs to be addressed by the research community.

3.5 Themes that emerged from the literature

Numerous papers have compared different inspection regimes and standards in an attempt to identify best practice, and some papers show that even the best compliance standards can fall below the standard required for safety and hazard protection (Jager et al., 2018; Liao et al., 2017; Scutaru et al., 2018). This is, in part, because of the number of bridges built shortly after WWII with a designed life span of 75-100 years that are still operational, and in some cases there is a question mark about their safety performance (Gkoumas et al., 2019). There is a significant difference in the amount of funding required to support a bridge nearing end of its useful life compared to building a new bridge. However, the reverse is also true, so there is a cycle between keeping a bridge in a safe condition and replacing it. This has led to a change in research focus.

The TRIMIS report concludes that over the five years preceding it, there is increasing emphasis on maintenance, lifecycle and visual bridge inspections in academic papers. Data collected from the SCOPUS citation database confirms this finding, showing that the number of bridge maintenance research papers were fewer than 100 in 2010, and as the researchers refocussed on bridge structural health and maintenance, almost 500 papers were published in 2017 (Gkoumas et al., 2019).

The move towards structural health and maintenance, and more intelligent ways of collecting data, was addressed in the 2015-2018 TRIMIS BRIDGE SMS project. The project focussed on the development of standardised methods for bridge assessment, scour inspection procedures for the erosion of riverbanks or beds and bridge management systems including using mobile devices to collect and analyse data.

The use of technology allowed for increased collaboration and productivity, and reduced the likelihood of errors and lost data. The Fijian initiative shows how easy it is to standardise inspections and incorporate bridge design and construction information into the inspection process while also providing bridge inspectors with information that encourages informed decisions (Hirsch et al., (2017). The addition of NDT tools to the inspection process means that the inherent guesstimate factor is removed from maintenance assumptions. It also showed that as technology becomes cheaper, the opportunity to harness technical solutions becomes simpler and more advantageous.

3.5.1 Methodologies

Similar to country comparisons research by Gkoumas et al., (2019), bridge inspection methodologies and evaluation criteria in Taiwan were compared with other foreign practices by Liao, et al., (2017). They found that although there are different procedures between countries for bridge degradation assessment, they all seek to provide the same information which supports the research undertaken by Scutaru et al., (2018) and Gkoumas et al., (2019).

Scutaru et al., (2018) investigated the strengths and weaknesses of bridge maintenance strategies, inspection practices and methods between countries including Australia (which shares the same inspection standards as NZ). They found that the most common methodology for monitoring the technical condition of bridges were visual inspections confirming the findings of Gkoumas et al., (2019) and Liao et al., (2017).

Recommendations from the Scutaru et al., (2018) study included the development and implementation of data collection, processing and storage programmes to make it easier for bridge inspectors to access all the available data on a management system. This, in turn, leads to a more efficient design and execution of maintenance and repair work.

Comprehensive data collection for older bridges is necessary because regular visual inspection methods do not identify flaws that are internal to the structure. Rapaport's (2016) research identified that an increasing number of bridge collapses pointed to a lack of understanding of the behaviour of ageing structures.

In conclusion, inspection procedures have to identify flaws using all the information available as well as factoring in the age of the bridge. Around the world, bridges are nearing the end of their lifecycles, and budgetary constraints mean that the method of bridge inspection can lower the cost of inspections. Although researchers attempt to identify a gold standard of bridge inspection practice, the current standard is still below what could be considered safe and hazard-free.

3.5.2 Current bridge rating systems and inspection frequency

The United States, Germany, Sweden, Denmark and the Britain were compared to NZ because they assign short-medium-and-long-term inspection regimes, and non-interval special or project-level inspections. All of those countries have two-road authority branches, experience environmental events through floods and storms and Taiwan experiences earthquakes (Appendix A).

The most notable difference in the six-country comparison is the protocol for inspection frequency. New Zealand lags behind all comparable countries because the first 'inspection' is the annual inspection. In contrast, all other comparable countries practice more regular inspections regimes ranging from weekly to monthly visual checks of the upper part of the bridge (Scutaru et al., 2018; Liao, 2017).

The other notable difference are the rating scales - the majority have a single measure response while only two offer a multicriteria approach (Appendix B). Multiple options allow for idea elaboration, which is more effective because it breaks down the evaluation into less complex sub-tasks (Riedl, Blohm, Leimeister, & Krcmar, 2013). The multicriteria options provided by the UK (extent and severity) and Sweden (physical and functional) allow inspectors to make more considered decisions using the marking criteria.

The six-country rating comparison shows the range in selection options (Appendix B)
For instance, Germany has a precise six-stage rating scale while the USA has ten options. These may reflect the different intervals for inspection - the United States inspect their bridges every two years, while Germany inspects their bridges every three months. Sweden also practices a short interval between inspections, and uses a multicriteria scale to allow a more precise response.

Although the commonality between the countries may seem reassuring, the overall standards of inspection are still below the standard required to keep the bridges safe. The results of a 2001 BRIME review of highway bridges in France, Germany and the UK found that they all presented deficiencies at rates of 39, 30, and 37 per cent respectively, with the leading cause being the corrosion of reinforcement (Gkoumas et al., 2019). Recent publications echo these concerns after several bridge failures and structural collapses were attributed to material degradation and lack of maintenance.

In conclusion, it is evident from the inspection intervals that the United States, Denmark, Britain, Sweden and Germany all inspect their bridges on a more frequent basis compared to NZ and the Britain (Appendix C). Sweden and Britain also use a multicriteria questionnaire to further break down the evaluation criteria into subtasks. Although it could be argued that the more frequent inspections are only visual, the process of checking literally every day brings the bridge condition to front-of-mind compared to the annual visual inspection carried out in New Zealand.

3.5.3 Assessment practices that lead to doubts of credibility

Asset owners and managers play an essential role in deciding on the maintenance and replacement plans for bridges under their jurisdiction. They rely on the civil engineering profession to help them understand the risks (Jager et al., 2018). As bridge structures age, the cost of strengthening, and the need to carry heavy loads, increase the need to manage lifecycles. Jager et al., (2018) research suggests that bridge owners need to understand the requirements and the inherent outputs of bridge assessments before making decisions.

Many international codes have adopted a reliability-based, and risk-informed, approach to balance the often-conflicting demands between asset preservation and maintaining operational access, particularly when there is a high expenditure component (Jager et al., 2018). If the assessor understands the bridge construction, the behaviour of the bridge and the loading, then a smaller operating margin can be accepted.

Internationally, the plausibility gap is addressed by the adoption of a reliability-based and risk-informed assessment methods (ISO 13822: 2010). The standard considers the reliability of the individual bridge combined with its target reliability level and ultimate and serviceability states. The ISO standard acts as a plausibility check to review any discrepancies between the real-life condition, the performance of the structure and the assessment based on past performance.

Australia and NZ operate under the requirements set out in the Australian Standards (AS 5100., 2017) which allocates a design life of 100 years to road bridges - one of the longest design-lives in the world (Geiger, Wells, Bugas-Schramm, Love, McNeil, Merida, Meyer, Ritter, Steudle, Tuggle, & Valasquez, 2005). America and Canada both emphasise the difference between design and assessment reviews, and allocate a 75-year design life for highway bridges. The Australian standard used for rating existing bridges is largely based on design principles combined with capacity reduction and road factors. Some capacity reductions are allowed if certain factors are exceeded, along with the bridge design philosophy, serviceability and ultimate condition states (Siviero, 2018).

Jager et al., (2018) define capacity as the ability to support a load. They state that the major contributing factors to sheer failure (failure from structural cracking) are increased loading, conservative analysis and assumptions, inappropriate use of standards, condition deterioration, design, and construction errors. These findings support the view that the variability of bridge assessments is based on inspection assumptions, and the review methodologies that underpin that assessment (Scutaru et al., 2018; Quirk et al., 2018).

Without an appreciation of those assumptions, the asset owner can be left questioning which assessment should be applied to their management strategies. If a conservative design assumption or methodology is applied, it can indicate that a significant number of structures are operating at a reduced margin, which does not correlate with the behaviour of the structure leading to a plausibility gap. International standards address this issue by applying a framework that allows specific bridge assumptions based on observational behaviour and material strength. However, there is no specific guidance to engineers in Australia (and by association NZ) as to the specific process or assumptions incorporated under the international standard (Jager et al., 2018).

The lack of specific guidance was first evidenced in the 2010 New Zealand Office of the Auditor General (NZOAG) review which found that the agency needed specific improvement. There was no effective model for monitoring bridge condition or deterioration and the data collected for bridges was not as good as that obtained for roads (NZOAG, 2010).

A General Bridge Inventory survey was undertaken by the agency in 2012 to provide a baseline of usual practice. It found that NZ councils did not use a standardised method for the storage of bridge data or the type of data collected. It also showed that, across the network, there was a high quality of inventory and bridge data collected. However, the collection process was less developed for element data and poorly developed for component data (Bush et al., 2012). Component data is essential because it registers the defect at the component level, meaning that targeted maintenance can be carried out (McCarten, 2018).

The survey results showed that councils did not store bridge data or assessment details electronically, including load capacity and seismic activity. It did confirm that most councils undertook general and detailed inspections, and a majority aligned with the recommended inspection cycle. However, some had moved from the six-year detailed cycle to a two-yearly general inspection. In another case, the council had moved the recommended two-year general inspection to every three years. No reason was given - the report assumed that the move was cost-related as more time is needed to set up a detailed inspection, and local authorities do not have sufficient funds (Bush, Omenzetter, Henning & McCarten, 2012).

In addition to the credibility gaps identified by Bush et al., (2012) the survey also highlighted that neither the maintenance nor investment program and planning process aligned with current practice. Also, risk decision making did not align with government or community expectations, supporting similar findings by McCarten (2018) who identified credibility gaps between asset managers' decisions and the impact of an event on the community.

There are three types of credibility gaps: first, community and agency acceptance of maintenance; secondly, bridge planning alignment with current practice: and thirdly, risk decisions aligning with government or community expectations. McCarten (2018) cites the flooding caused by cyclone Bola, and the subsequent collapse of the Wairoa bridge in 1988, as examples of credibility gaps in risk management.

The replacement cost of the Wairoa bridge was 6.9 million and other infrastructure costs (direct and consequential) amounted to 3.4m. However, when the additional road user costs caused by a four-month detour were factored-in, the total cost of the bridge failure was 18m (McCarten, 2018). He concludes that this is a good example of inadequate risk management and a lack of balance between community needs and investment programmes.

3.6 Significance of this research

As discussed, different countries have divergent bridge inspection practices, and a common denominator is a reliance on visual inspections, which researchers consider to be substandard.

The use of NDT provides a quantitative measurement to support qualitative visual inspections while minimising the risk of delayed maintenance or missing a camouflaged defect because of previous repair (Hajdin, 2018).

Hajdin (2018) believes that the current bridge management cycle undergoes a form of 'amnesia' where design and construction data is not available or is only stored in paper form. The need for high-quality information to deal with gradual degradation, growing traffic demands, and increased frequency and magnitude of natural hazards are an important part of the bridge management process allowing for better exploration of inspection results. This, in turn, allows for improved decision making regarding in-depth investigations and maintenance interventions while ensuring the safety and serviceability of the bridge (Hajdin, 2018).

Quirk et al., (2018) also articulates this position. Their research studied the influence of human imperfections on the conclusions of bridge inspections. They proposed that VIs cannot easily be translated into data analysis because the visual review is based on qualitative reckoning in contrast to the quantitative measurements used in the planning and construction of bridges. Therefore, there is a lack of robustness around the perceived benefits of a visual inspection because the explicit information regarding the mechanical properties and structural components are unavailable.

Luis et al., (2006) also questioned the practice of using VI as a start to maintenance actions because they can be detrimental to structural safety. They defined a VI as a type of condition index, whereas safety was a structural analysis. If VI are used, the asset manager receives one deterministic optimum maintenance plan rather than a structural analysis plan that provides multi-maintenance solutions. They researched the options of using preventive actions compared to a rebuild allowing for a broader of feasible solutions. Unsurprisingly, the rebuild option was the best option for providing greater flexibility in design, environmental fit and an excellent safety rating (Luis et al., 2006). Limitations to this research were that only two conditions were investigated. The study would be more robust if it had also included an NDT quantitative measurement option which would improve the data gathered and provide a measurable and repeatable test without demolishing the bridge.

The literature shows that moving from a qualitative reckoning to a quantitative measurement can be achieved if NDT and design history are part of the assessment process. The growth in technology options and the strength of cloud-based technology means that countries can skip high-cost technology platforms and manage cloud-based data from anywhere in the world via an internet connection (Hajdin, 2018).

To conclude, the change in focus from reactive analysis to combining qualitative with predictive quantitative analysis provides the asset manager and the bridge inspector with the best possible information to enable informed decisions and consider multiple maintenance options.

3.7 Shortcomings of this research

This review looks at the current reliance on visual inspections and the use of NDT to make bridge inspection data more quantitative. However, there is a lack of research papers that illustrate how the addition of technology can limit conservative and often expensive defect remedies. Only Germany practises a comprehensive inspection regime that incorporates NDT as of right in the annual or bi-annual inspection. Most countries use a combination of visual and NDT when the defect warrants further investigation.

The review has not covered specific inspections regarding weight loading, inspections after an external event, the types of inspections required for specific design structures or the affect different types of soil materials has on a structure. Nor the levels of transparency between local councils and the agency, or between the bridge inspector and the asset manager. It is believed that the level of transparency will become apparent after the interviews with agency specialists and academics.

3.9 Research goal

Clearly, additional research is needed. Compared to other countries, NZ is not as thorough in the one- and-two-year inspection cycles, and as a result bridges may be deteriorating without anyone knowing. Further research will show that the reliance on visual assessments in early bridge inspections is not best practice, and the use of NDT in the one- and two-year inspection cycle allows for a quantitative review and analysis.

In addition, the literature suggests that the social and community aspects of bridge inspections are not fully factored into maintenance decisions and the impact of bridge failure.

As noted in regards to the cyclone Bola and Wairoa bridge collapse, there are real consequences for the local community if a bridge fails (McCarten, 2018).

3.11 Literature review conclusions

All of the above shows that the current bridge inspection regimes around the world are conflicted with financial constraints and ageing infrastructure while relying on simple inspection techniques.

Inspection methods have to change to ensure that the safety of a bridge, and the people who travel over it are front and centre in asset managers' mind.

This literature review has identified three broad research questions:

1. What place do visual inspections and NDT have in NZ bridge inspection regimes?

2. What other factors influence bridge safety, management and protocols?

3. How well do New Zealand asset managers systems work compared to best practice?

4. Methodology

The literature review suggests that the reliance on visual inspections without detailed knowledge of design and construction elements or the support of NDT technology leads to assumptions that may be conservative or incomplete. In addition, the age, management and impact of external events influence the safety of a bridge.

This research aims to investigate the current visual bridge inspection regime in NZ and determine whether there is a gap, and possible remedies, but not qualify to what extent this may or may not apply to the entire NZ bridge population. A combination of qualitative research tools is appropriate to this research.

Qualitative research enables the researcher to look deeper and wider into the data but generally allows for less control over the research. It allows for observations that cannot be quantified, or expressed in numerical form, and is suited when a researcher is not attempting to generalise the population, rather than generalise the theory. Quantitative research might look at the “how many” whereas qualitative researchers consider the diversity of meanings, or the “how and “why” (Wienclaw, 2019).

There are many approaches open to qualitative researchers, including observation, interview and secondary analysis. Brennen (2017) says qualitative researchers often incorporate triangulation, the use of multiple methods, to increase the rigour of their analysis and to develop in-depth understandings.

This research will use secondary analysis of bridge records including, age and current inspection periods and surveys regarding data storage and reporting protocols, plus a mixture of participant and expert interviews. Interviews were chosen to best reflect the community and expert positions on bridge repair and maintenance. Questions will be open-ended and face to face where possible.

Interviews with residents from the Waiho and Birchville areas will explore how they were affected by the collapse of the bridge; if they observed problems before the collapse, and what, if any, action was taken to warn authorities.

Leading academics, local government officials and agency spokesmen and practitioners in the civil engineering space will be interviewed to measure current practice and investigate if alternatives to visual inspections are required.

Evidence for cross-case synthesis of archival records, government reports, will also be collected under the Official information Act (OIA) and Local Government Official Information and Meetings Act (LGOIMA) requests for information and possibly for interview access to council personnel. Requested data will include age data on all bridges under the supervision of the agency and some councils plus data storage, tender documents, and bridge inspection regimes for specific councils.

The study will consider five case studies: three investigating specific bridge inspections and the condition of the bridge after the inspection; the fourth reviewing the ages of NZ bridges in a particular region, and the fifth reviewing bridge inspection and asset management.

The multiple case study design will compare the inspection methods of three NZ bridges. The bridges are notable because two collapsed soon after an inspection while the findings of the third inspection led to strengthening work. This case study will test if the inspections were adequate, and if the collapses were predictable.

Various documents including the respective bridge collapse reviews and the previous five years inspection and maintenance reports will be requested under the OIA and LGOIMA from the agency, the respective councils and interviews with bridge managers will be conducted. The case study findings will be collated with the interviews to test transparency, draw conclusions and develop policy implications.

The literature review suggests that VI inspections do not recognise threats to bridge structures or alternately the asset manager did not act in a timely way to warnings or physical signs of deterioration.

The fourth case study will compare the age of bridges on a section of a State Highway to the corresponding local council's bridges to see if there is a difference in ages between the two authorities. This will test if there are an unequal load and expectation of maintaining older bridges owned by councils compared to the agency and test the asset management plans for replacement or strengthening. Information will be gathered by OIA and LGOIMA requests to agency and council for detailed official records.

The literature review suggests that as bridges age, they require different maintenance and repair and this study will show if ageing bridges are planned for in the respective agency and council planning documents.

The fifth case study will compare bridge asset management of a small number of councils. The case studies will be an amalgamation of questionnaire results to test current methods of inspection frequency, reporting and data management and storage. The cross-case synthesis will be compared to the current guidelines published by the agency. In particular, adherence to the procedures of the schedule of inspections.

The literature review suggests that there are varying methods of inspection, storage and management of data. This study will test if selected NZ councils follow the guidelines set of the agency.

The case study on the age of NZ bridges is suitable because NZ has a large number of ageing bridges with an expected useful life of 100-years. The literature review showed that ageing bridges and their corresponding deterioration are a world-wide problem. This study will compare the age of bridges on a section of State Highway 2 compared to a local council within the same region. Comparisons can be drawn between the respective bridge ages under the jurisdiction of the two authorities and predictions made regarding bridge replacement or major refurbishment.

The asset management case study will compare different councils against the specific guidelines from the agency for bridge inspections, including inspection frequency, reporting and oversight, and data management and storage. The results will show if the councils are following the prescribed guidelines or reflect the practice of manipulating the guidelines to fit local budgetary or timing constraints which was identified in the literature.

The case study method is well suited to this research because it allows comparison of both similar and contrasting results. The commonality of information from different sources within a case study will show some theoretical interest (Yin, 2014). It is expected that the case studies will reveal new information about how asset managers manage their bridges.

The use of case studies to compare and contrast information is relevant for this study because they allow the research to build a series of questions and answers based on the study database. The answers to the questions can be compared to each other and the wider research community (Yin, 2014). The research questions will be addressed using the five case studies because they explore the role of impact of VI and NDT, identify other factors that may influence bridge safety and review the practice of asset managers compared to best practice.

Because this research uses interviews, approval was sought from Massey University's human ethics committee; application ID 4000022231 was approved on February 24, 2020. The study is considered low risk because the nature of harm was considered to be no more than that encountered in normal daily life. The investigation will gather the information from government documentation, publications and interviews. It is not envisioned that any participant will experience any more than discomfort. The informed consent form will be provided to all interviewees and discussed before the interview commences.

4.1 Ethical Considerations

This study is considered low risk because information gathered from face to face interviews and accessing official documentation. All interviewees were given informed consent forms and the content was discussed before the interview commenced, including the right to decline to answer questions, that participation was voluntary and the interviewee could withdraw at any time. At no time was an interview undertaken without full disclosure.

The only foreseeable risk to this study was one of discomfort because the interviewee is being asked questions that expose poor bridge inspection techniques. There are no risks of physical, financial, psychological or cultural impact as part of this study. In addition, there are no interventions, vulnerable participants, or illegal activities undertaken as part of this study. Funding for any part of this study has not been sought, offered or accepted

As this study involved human participants, human ethics approval was gained through the institutional processes. This approval (Massey University, Ethics Committee reference number 4000022231) enabled interviews with specialists and residents who volunteered to participate in this study.

5. Discussion

This chapter answers the critical question: are NZ bridges are safe? To do that, I first examined the use of VI's and NDT in NZ bridge inspection regimes. Afterwards I move on to analyse other factors that could influence bridge safety and review the standard of NZ asset management compared to best practice.

5.1 What place do visual inspections and non-destructive testing have in NZ bridge inspection regimes?

It became apparent that this study started with an anti-VI standpoint and concluded with the recognition that VI identified flaws in the three bridge case studies.

This research has found that visual inspections can successfully identify flaws and have a place in the NZ bridge inspection regime. This finding is contrary to the literature review, and suggests that international researchers did not give due consideration to what techniques are needed to support the findings or the value given to the VI data by the asset manager.

The Birchville and Waiho bridge case studies show that, ideally, there would be widespread use of NDT techniques to support VI and add quantitative weight to repair and maintenance recommendations. The Red Bridge case study shows the value of using NDT alongside VI, supports the suggestion that it is the actions of the asset manager that has the most significant impact on the condition of the bridge (Bush et al., 2013; Gkoumas et al., 2019; Hajdin, 2018; Luís, et al., 2006; Siviero, 2018; Quirk, et al., 2018).

To illustrate the role NDT pays in bridge inspections and asset management, this study reviewed the decisions around the repair of the Red Bridge. The use of NDT allowed the manager to consider a number of maintenance options and make decisions based on quantitative and qualitative data (Hearn, 2007; Hirsch et al., 2017).

5.2 What other factors influence bridge safety, management and protocols?

The is study has shown that the Waiho and Birchville collapses were due to flooding; an unforeseeable external event which Dikanski et al. (2016) identified as the main cause of bridge failure. However, because of the nature of the failure it is difficult to absolutely claim that additional NDT or timelier action on the recommendations would have influenced the outcome.

Age and external events have a definite impact on bridge structures, and should be taken into consideration when making asset decisions (Rapaport, 2016). In particular the reliance on depreciation tables complemented by incomplete data and poor historical record keeping. New Zealand has a large number of ageing bridges. If the depreciation tables on even half of ageing bridges missed a similar 139-year-old pier the cost of replacement would be more than councils or the agency could easily afford. The agency recommends that asset managers recognise that older bridges require skilled maintenance and supervision. However, if the age of the bridge is not obvious is difficult to apply good advice.

The Birchville inspector carried out the correct pre-inspection review of design documents however the depreciation records show the bridge to be 73 years younger than its oldest component. Although the failure report states the collapse was due to a one-off weather event you could argue the inspection report incorrectly identified the flexing of the spans rather than the movement of the pier. If the cause of the movement had been inspected more thoroughly using NDT the damage to the pier may have been recognised and possibly rectified before the extreme weather event.

The use of depreciation to assess the remaining useful life of a bridge leaves asset managers with a false impression that a bridge is younger than its parts. An increase in extreme events combined with variations in inspection frequency, councils who translate guidelines to fit their own requirements and a history of patchy data collection and storage suggest we are building up to a perfect storm and no one wants another Tangiwai.

This study found that there are significant gaps in inspection standards and the inspection regimes of councils. Furthermore, the longer maintenance is delayed, and poor data collection continues, the more unsafe bridges will become. There is an immediate need for the agency to become proactive by setting standards rather than guidelines, and actively mentoring councils to improve their performance. These findings confirm the research undertaken by bridge Scutaru et al., (2018) and Liao (2017).

This study found that inaction by the asset manager can have extreme consequences. The results showed that councils practice differs from the recommended inspection guidelines and although these variations were first identified in 2010. There has been a low shift by the agency towards a high quality of data collection and asset management.

Based on the results of this study, the asset management of a bridge by the agency has not significantly changed since 2010. In addition, the 2014 NZOAG review of bridge management at council level also found that its systems were also less than satisfactory (NZOAG, 2014). It took two years after the 2010 report for the agency to survey the councils to gauge the extent of the problem and launch the REG initiative to measure management systems across agreed quartiles. The REG initiative has been reporting results to councils for four years, and there has been a small (eight per cent) increase in compliance.

Because the agency issues guidelines rather than standards there is an ongoing impact on bridge safety because councils are manipulating the polices to fit their agendas. If the correct inspections are not being made, data is not being collected. As a result, asset managers are making decisions based on assumptions rather than actuals. This is of great concern as more bridges near the end of their useful life

5.3 How well do NZ asset managers systems work compared to best practice?

This research shows the standard of management systems is below best practice. The REG radar charts showing the wide variation in the quality of data collection supports the finding of this study (Appendix D). Even if the councils applied the agency's standards and policies as the minimum requirement, NZ falls below the gold standard of bridge inspections. The literature shows that Germany, which is considered the best practitioner, only scored 37 per cent compliance on the BRIME review of highway standards.

The results show that if standards are not enforced, councils will continue to deviate from the required minimum. Visual inspections will continue to be used without the support of NDT, and asset managers will either undervalue the data or not have quality data. This will lead to bridges falling behind their maintenance schedule and either falling short of the 100-year

useful life or become increasingly dangerous to the NZ public. Post event reports including the bridge failure reviews of Birchville and Waiho show that there are many opportunities to learn from past practice. However, the Birchville failure report was written in support of the insurance claim arising from the failure of the bridge in a storm event (Hampton Jones, 2016)
.

The LGOIMA and the OIA responses suggest that as a country, we are working towards best practice without any audit oversight. Although NZ has a national guideline, it is not compulsory, and the ratings generated by REG merely serve as snapshot of a minimum standard. In practice, we are comparable to the practices of individual European countries with different standards of inspection which may or may not meet a perceived gold standard of bridge inspection (Siviero, 2018).

The results of this research show that it is not the age of bridge but the decisions of the asset manager in regards to repair and maintenance that have the most impact on the useful life of a bridge. To protect NZers and the roading network this research recommends that the agency has to take a more active role in the inspection and maintenance of all NZ bridges. The most cost effective and constructive way would be to conduct all principal inspections and set out the repair and maintenance schedules for the respective councils to cost, and manage. This would improve the quality of data collection, bring all councils into the correct inspection regime and ensure that older bridges are maintained correctly.

In addition, the BMS used by the agency should be available to all councils to ensure that data collection is standardised and complete.

The case studies included in this research highlight the how extreme events can adversely impact assets. Because they cannot be planned for it is important that asset managers apply consistent decision making which can only be achieved by quality data and inspection practices.

The methods of secondary analysis and case studies were appropriate for this study. The method enabled a deeper and wider method of examining current procedure against preferred practice. The multiple stands of information from government sources, specialist and bystander interviews allowed a generalisation of the theory that: the current standard of bridge inspection in New Zealand is open to interpretation by councils and that the data collection and management practices do not always provide the quality of information required to make informed decisions.

Although it would be tempting to gather more information by interviewing numerous people within a council there comes a time when the information is merely being repeated. In addition, the smaller councils don't have a large number of people resources. This study interviewed two asset managers, an engineer plus three NZTA bridge engineers. The information gained from the interviews confirmed the information gathered through official requests and investigations and provided real examples to be compared with the findings of the literature review .

Although I should not be concerned about the cost of a council to provide information under the LGOIMA. I was aware that the councils I asked for information seemed to have antiquated information systems and there was a man-hour cost to providing the information. In a small office this means that the usual job of the person answering my request is being side-lined. In addition, the request for age, inspection and data storage information in most cases had to be accessed from hard copies rather than electronic systems. Which illustrates how behind some of these councils are in easily collecting and storing quality data

If the study was to be repeated I would recommend that two or more district councils were survey regarding inspection practices, age and asset management. This would allow for a bigger sample and a better understanding of the state of repair and or despair of NZ bridges. However, based on the information gathered, my suspicion would be that the information gathered in the additional investigation would only confirm the current findings with the exception of cities with large populations, a greater rating base and less rivers. They would show a superior quality of inspection and maintenance practices.

6. Conclusion

The loss of 151 lives in the Tangiwai disaster in 1953 was because of an extreme event. New Zealand is experiencing more extreme events at a time when bridge inspection practices are deviating from the guidelines. New Zealand was lucky that lives were not lost in the Birchville or Waiho collapses.

The replacement of those bridges cost over 10m in construction costs and another 42-63m in community costs to fix foreseeable fixable problems. In comparison the Red Bridge strengthening project saved 2.6m from the original detour and remedial work.

This study used case studies to investigate current inspection techniques, accuracy and standardisation of bridge management systems, and considered the impact age and extreme events had on bridge structures. It used interviews and official documents to measure the quality of bridge inspections in New Zealand.

The studied endeavoured to answer the question 'Are NZ bridges safe?' If the engineer's definition of 'keeping the failure of risk to acceptably low levels based on probability' they are safe but probability is more acceptable as a theory, and becomes challenging when it is a reality.

The minimisation of a probability risk is the establishment of a standards which identify flaws and provide inspection on how to remedy them. The results from this research found that the standard of bridge inspections is reliant on guidelines, rather than standards, and that there is variation in the application of those guidelines.

It is time that NZTA stopped chipping away at the edges of a preferred level of bridge maintenance. The most significant shortcoming is the disconnect between the expected regime of inspection and what actually happens. The agency needs to take control of the inspection process to ensure councils are not over or under inspecting bridges. The guidelines and policies should be standardised and enforced. Councils have to understand that the funding from NZTA and its ratepayers is not about taking the money and running; it is about making the best decisions based on the best information they have available.

The crucial 6-year principle inspection should be undertaken by NZTA alongside the local contractors to ensure that the best solution is agreed on at the time of the inspection. This practise has proven successful for the Hastings District Council.

Patchy data collection practices can be addressed by making the new NZTA bridge management system available to all asset managers. The use of a common programme will ensure that minimum standards are achieved by asset managers.

Another shortcoming is around the need to make hard decisions based on more than cost. Community value of an entire region or a small community is dependent on a reliable and safe transport network. The need to maintain bridges to their best potential is vital for the public of New Zealand, and bridge maintenance practices should reflect this.

Saving money by ignoring the actual age of a section of the bridge becomes fraught with danger as a structure creeps towards its hundredth year or even surpasses it. The 1912 Waihenga bridge in the Wairarapa is an example of successfully extending the life of a bridge by doing the right thing – fixing it rather than ignoring it.

The possibility of extreme weather events is becoming more likely. Floods stress and strain bridge structures in ways that are hard to anticipate because everything happens underwater in adverse conditions. New Zealand, like every other country in the world, is facing challenges with older bridge stock and extreme weather. Bridge officials at local and national government level need to make the right decisions at the right time.

The use of qualitative research to generalise the research question has been successful in discovering gaps in the current methods of bridge management and inspection. I believe that this research method was correct for the topic and investigative process. During this research I discovered that there are many facets to bridge asset management and had to curtail the study to only concentrate on bridge inspections and asset management arising from those inspections.

There are significant opportunities for further investigation. In particular, the councils use of depreciation values when calculating the life of a bridge. The Birchville case study showed that the weighted age of the bridge was calculated on the build year of 1954. However, the oldest (and one could argue the most vital) sections of the bridge (the piers and under deck structure) were built in 1881. It may be that there is a huge backlog of unforeseen maintenance and repair projects just waiting for the next extreme weather event.

A further area of study would be the investigation of multicriteria scoring on bridge inspections, which has shown in the literature to improve decision making. This would improve the quality of the qualitative information, and if it was combined with NDT would add to the robustness of decision making.

A fascinating study would be the difference between the management of bridges in cities to districts. Cities enjoy a greater a larger and usually wealthier rating base, a higher population which would raise the funding from NZTA because there is more risk, and they would usually have less rivers to contend with.

Additional study into the ways that the agency could lift the performance of the councils could include reviewing the use of NDT tools, and the options of implementing a transparent management system that would allow cloud uploading and analysis from the riverbank and the council office. Universities specialising in civil engineering could also introduce NDT as a subject. This would upskill the younger engineers who inspection NZs bridges in more than one inspection technique.

Further study into the gaps between the agency's guidelines and the adherence to them, in particular the role of the agency in supporting the councils, would be immensely valuable. It would provide a better understanding of the current level of performance, which will enable the agency to develop mentoring programmes for councils.

There is an opportunity to investigate the backlog of funding requests from councils to the agency to measure the number of (as yet) unfunded bridge replacements. A longer backlog would show there is a high demand for financial provision, outside the provisional savings of the council.

If bridges are not inspected as recommended, or if identified flaws are not actioned promptly, bridges in NZ will collapse, particularly if they experience an extreme weather event. To minimise the risks of this happening, significant resources have to be developed for councils and the agency. Investment in staff training to use NDTs, and an auditing function to measure actual inspections against the guidelines, would be the first steps to towards ensuring NZ's existing bridges are in a fit state. Ongoing funding for staffing and asset management would also provide a higher standard of proficiency.

The study has shown that the agency has been treading water for ten years by failing to act on the NZOAG recommendations in a prompt and timely manner. By ignoring our ageing bridge inventory, and failing to implement standards for bridge inspections rather than guidelines, the agency is failing NZ and New Zealanders.

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Appendix A

Country comparison of inspection regimes

New Zealand

All bridges in New Zealand require routine visual surveillance undertaken not less than annually, followed by a two-yearly general visual inspection that verifies previous descriptive data. A larger principal inspection must be undertaken every six years by a bridge inspector who is tasked with comprehensively inspecting all inspectable parts of the structure at close quarters. Where that is not possible, and special access equipment is not specified, the remaining elements can be visually compared using binoculars or other optical equipment (NZTA, 2018). At this level, inspection techniques such as hammer tapping are recommended to ensure the visual interpretation reflects actual condition. A six-point rating scale is used to grade the condition of the bridge responses range, from not inspected to structural maintenance required with comment and photo (NZTA, 2020). The current Bridges, Geothermal Structures and other Significant Highway Structures Inspection Policy (2020) contains templates of inspection reports. It is supplemented by numerous publications with clear photos and descriptive text.

New Zealand compared with

Sweden

Sweden's bridge inspections are governed by the Swedish Road Administration (SRA) Bridge Inspection manual 2011. There are five types of bridge inspections; regular: superficial (surface): general: major; and special. (Lindbladh, 1996; Scutaru, et al, 2018). A regular visual inspection is carried out to detect and report any degradation of load-bearing structures, and the safety of road participants. Superficial inspections occur every six months for highways and annually for public roads, while general inspections are every three years including a visual inspection of all structural elements of the bridge and pulse radar measurement for inspection of waterproofing, ultrasonics, radiography and the physical checking of at least 30 per cent of welds (Lindbladh,1996). Special inspections are carried out when the situation requires, and it is assumed there has been rapid degradation that would seriously affect traffic safety.

SRA collects ratings and other data on the condition of bridge components during the general, major and special inspections. The quantity and types of damage are compared to the structural element, material and other considerations with a 0-3 rating - with three being the worst condition with recommendations ranging from 'need repair now' to 'repair after ten years' and a functional condition using the same rating value range with commentary varying from 'service impaired now' to 'service greater than ten years' (Liao et al, 2017).

Britain

Bridge inspections form part of the Inspection Manual for Highway Structures which determines maintenance needs based upon structural adequacy or safety, rather than solely on the condition of the bridge. All inspections are performed under long-term contracts with 20 highways area inspectors throughout the country (Hearn, 2007).

There are four types of inspections for bridges, and they can be used in combination depending on the inspection needs - safety/surface; general; main; and special for assessment and safety. The safety inspection is used to identify obvious deficiencies which represent or might lead to danger to the public and therefore require immediate attention. They are typically carried out by trained highway maintenance staff on an agreed frequency using a slow-moving vehicle or on foot on a weekly or monthly basis (Hearn,2007). General inspections are a visual examination of the structure and the easily accessible parts of the supporting members and riverbed. It is carried out approximately two years after the main inspection or since the last general inspection (Scutaru et al., 2018).

Main inspections are a very precise check of structural elements and inaccessible areas undertaken every six years or up to 10 years for new structures. The timing depends on the results of the general inspection. It is a comprehensive and detailed review of all inspectable parts of the bridge (Scutaru et al., 2018). Special inspections provide detailed information on a particular part, area or defect that is causing concern, which may include repeated visits for visual inspections (Wilson, 2017). All previous inspections can be entered and accessed on an electronic database.

The methodology of the visual inspection in Britain is primarily based on severity or extent as set out in the Highway Agency Manual. Each condition has five definitions for either prescription. Severity defines the degree of damage, while extent measures the length, area, or the number of defects of the bridge element (Liao et al., 2017).

The assessment of bridges adopts a limit state format, with appropriate partial safety factors for condition evaluation. Bridges built after 1965 are evaluated for serviceability and ultimate limit states; bridges built before 1965 do not require assessment for service limit rates (Siviero, 2018). The Bridge Inspectors handbook has multiple diagrams and pictorial representations of the various types of bridges and types of faults to assist with defect detection and descriptions.

Denmark

The Danish Road Directorate inspection regime has three types of bridge inspections - superficial or routine; plus the main inspection carried out every three years but can vary to between 1-6 years. It includes a visual check of all accessible elements of the structure. The special inspection is carried out after the main inspection, and always before regular maintenance or capital works (Scutaru et al., 2018). For each defect reported, the inspector will recommend a repair scheme, year of application and estimated costs. The intervals of inspection can also depend on the age, average daily traffic, location and existing conditions or special features (Liao et al., 2017). The bridge management system was fully computerised in 1988.

Taiwan

Bridge inspections form part of the Manual for Enhancement and Inspection of concrete bridges. There are three types of bridge inspections: daily patrol; a two-year naked eye (visual) and essential tools to examine the overall condition of the bridge and the river course; plus a damage inspection to assess structural damages including floods, typhoons, earthquakes and fire.

The visual evaluation criteria are evaluated using four sections with an integer scale rating of 0-4, with 0 corresponding to non-existing to 4 serious requiring immediate action (Liao, 2017).

Fiji

Hirsch et al., (2017), digital inspection of Fijian bridges championed the use of new technology which is far more sophisticated than those typically adopted in NZ and Australia.

Fiji was a blue-sky project with little or no existing lifecycle documents, which allowed the modern cloud-based approach to provide flexibility and easily accommodate changes. The inspector's familiarity with technology such as mobile apps and online maps allowed for more training to be devoted to understanding of the role of the inspection rather than data entry.

Clipboards were replaced with an external camera, smartphones and tablets all connected to cloud interfaces which were accessible instantaneously anywhere in the world. The data hosting by remote servers rather than in an office means that secure access to data is possible anywhere that has an internet connection. Hosted systems kept things safe and backed up, which minimised the possibility of photos or plans being lost or mislaid. They found that remote access to data in open industry-standard data forms meant that data could be quickly mapped, and analysed, often on-site. The increased ability to leverage the collected data, and the insights gained through the inspections ,helped the BECA team to effectively communicate the state of the assets and the underlying risks to the asset owners.

Germany

The German Highway Research Institute has four inspection types: annual surface inspections; general inspections every three years consisting of visual inspections on all accessible elements; and in exceptional circumstances various in situ non-destructive tests to collect data about degradation evolution and extent (Scutaru et al., 2018).

In addition, a major inspection, including touch-distance tests, is conducted every six years. Everything is inspected including the underwater structures and river bed inspections. Minor tests are undertaken three years after the major test. Minor general tests use the findings from the previous major test and focus on the identified damage and defects without the use of access equipment. All highway structures are visited twice yearly and after significant events such as storms or floods (Hearn, 2007), (Liao et al., 2017). Each state employs inspectors and team leaders who are civil engineers (Liao et al., 2017). To ensure a standardised evaluation approach inspection teams are provided with catalogues containing detailed examples of damage evaluation. A total of six levels of bridge condition ratings are defined with possible ratings graded between 0 (very good) to 4 (inadequate structural condition) (Hearn, 2007).

Appendix B

Comparison of six Bridge Condition Rating System marking codes showing the use of single and multicriteria grading responses

New Zealand	United States	Britain – 2 scales	Denmark	Sweden 2 scales	Germany
0= not inspected 1 = satisfactory 2 = monitor next inspection R = routine maintenance – provide comment S = Structural maintenance (comment and photo) N = not applicable	N = not applicable 9 = excellent condition 8 = very good condition 7 = good condition – some minor problems 6 = satisfactory condition – structural elements show some minor deterioration 5 = Fair condition – all primary structural elements are sound but may have minor section loss, cracking, spalling, or scour 4 = Poor condition – advanced section loss, deterioration, spalling, or scour 3 = Serious condition – loss of section, deterioration, spalling or scour have seriously affected primary structural elements 2 = Critical condition – advanced deterioration of primary structural elements 1 = Imminent failure condition – major deterioration or section loss present in critical structural components, or obvious vertical or horizontal movement affecting structure stability 0 = failed out of service	Extent A = no significant defect B = Slight, less then 5% of length/area affected C = Moderate; 5%-20% of length/area affected D = Wide 20-50% affected E = Extensive = over 50% of surface area/length Severity 1 = As new, or has no significant defect 2 = Early signs of deterioration, minor effect 3 = Moderate, some loss of functionality expected 4 = severe defect and/or element is close to failure 5 = the element is non-functional/failed	0 = Insignificant deterioration; little or no damage 1 = Minor deterioration; damage with a very slow rate of development 2 = damage is at an early stage of development or there are a few fully developed defects 3 = Damage has developed to such a degree and/or extent that it is likely that within a short time the component will no longer fulfil its function 4 = The component is severely deteriorated, such that its capacity to fulfil its function has or will soon disappear. Repair is necessary in the near future 5 = The component has completely deteriorated and can no longer fulfil its function.	Physical condition 3 = repair needed now2 = repair within three years 1 = repair within 10 years 0 = repair after 10 years Functional condition 3 = service impaired now 2 = service impaired within three years 1 = Service impaired within 10 years 0 = Service greater than 10 years	1. – 1.4 very good structural condition 1.5 – 1.9 Good structural condition, but may have less long-term durability 2. – 2.4 Satisfactory structural condition, but may have less long-term durability 2.5 – 2.9 Unsatisfactory structural condition. Traffic safety may be affected. 3. – 3.4 Critical structural condition. Traffic safety is affected 3.5 – 4.0 Inadequate structural condition. Traffic safety is not adequate

Appendix C

Current bridge inspection frequency and routine showing Germany's use of NDT for the three-year inspection cycle

Occurrence	NZ	United States	UK	Denmark	Sweden	Germany
Frequent		Daily	Safety/Surface V	Daily V	Regular V	
3 Months						Superficial V
1 Year	Routine/Superficial V	Routine - extended		Routine V	Superficial V+	
2 Year	General V	Fracture critical, routine,	General V			
3 Year					General V+	General V+NDT
5 Year		Underwater				
6 Year	Principal/Detailed	Principal	Main	Principal	Major	Major
8 years						
Other	Damage, Special, Event	Unscheduled, Special, Technical	Special Safety	Users report Special	Special	Adhoc

(Scutaru et al, 2018; Liao, 2017)

+ additional NDT testing is carried out as part of the inspection

Appendix D

Road efficient Group - Performance measures and asset management data

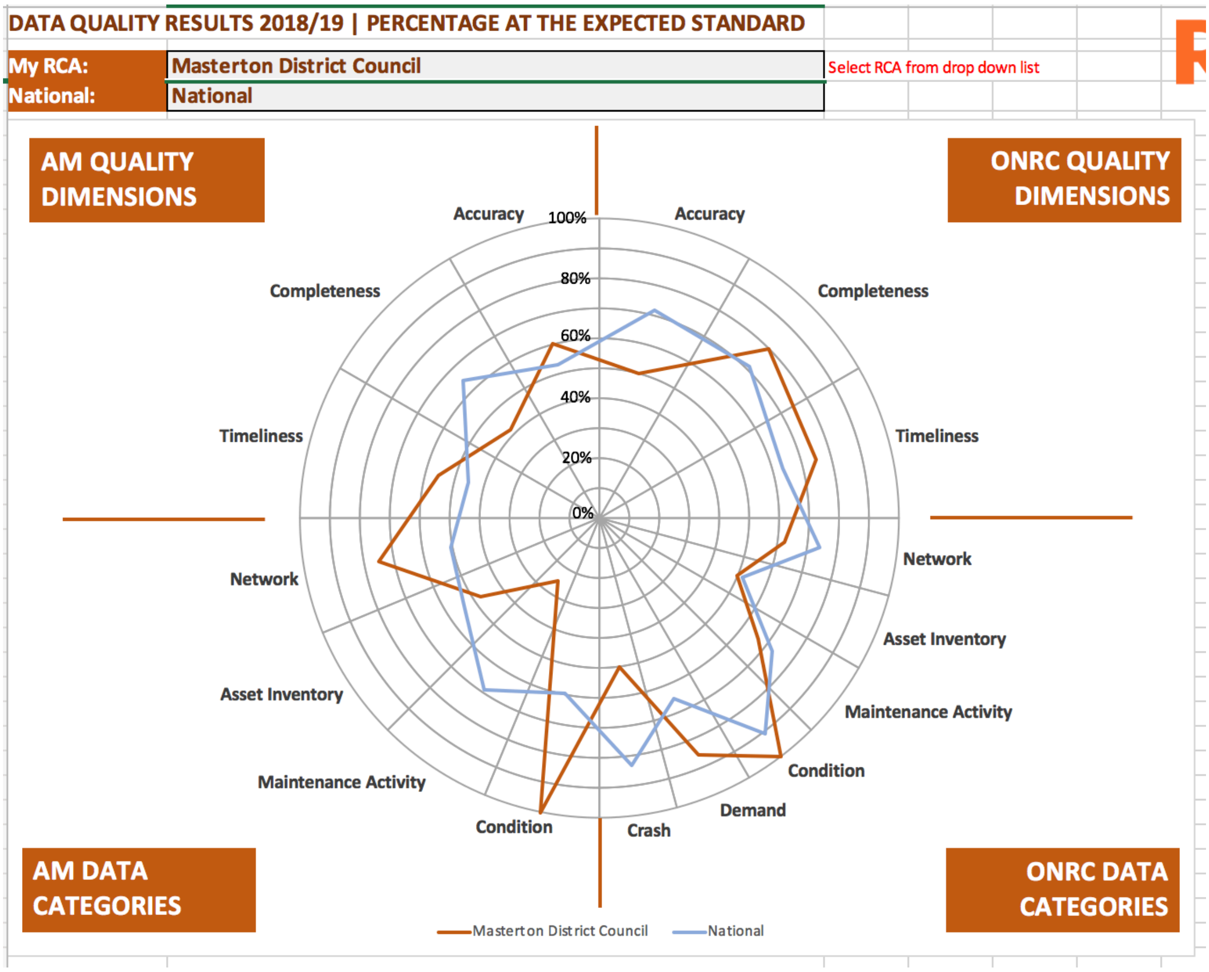
Each spreadsheet summarises the reported annual high-level results for RCA based on an evolving data quality framework of metrics interrogating data for a range of data quality dimensions including completeness, accuracy and timeliness.

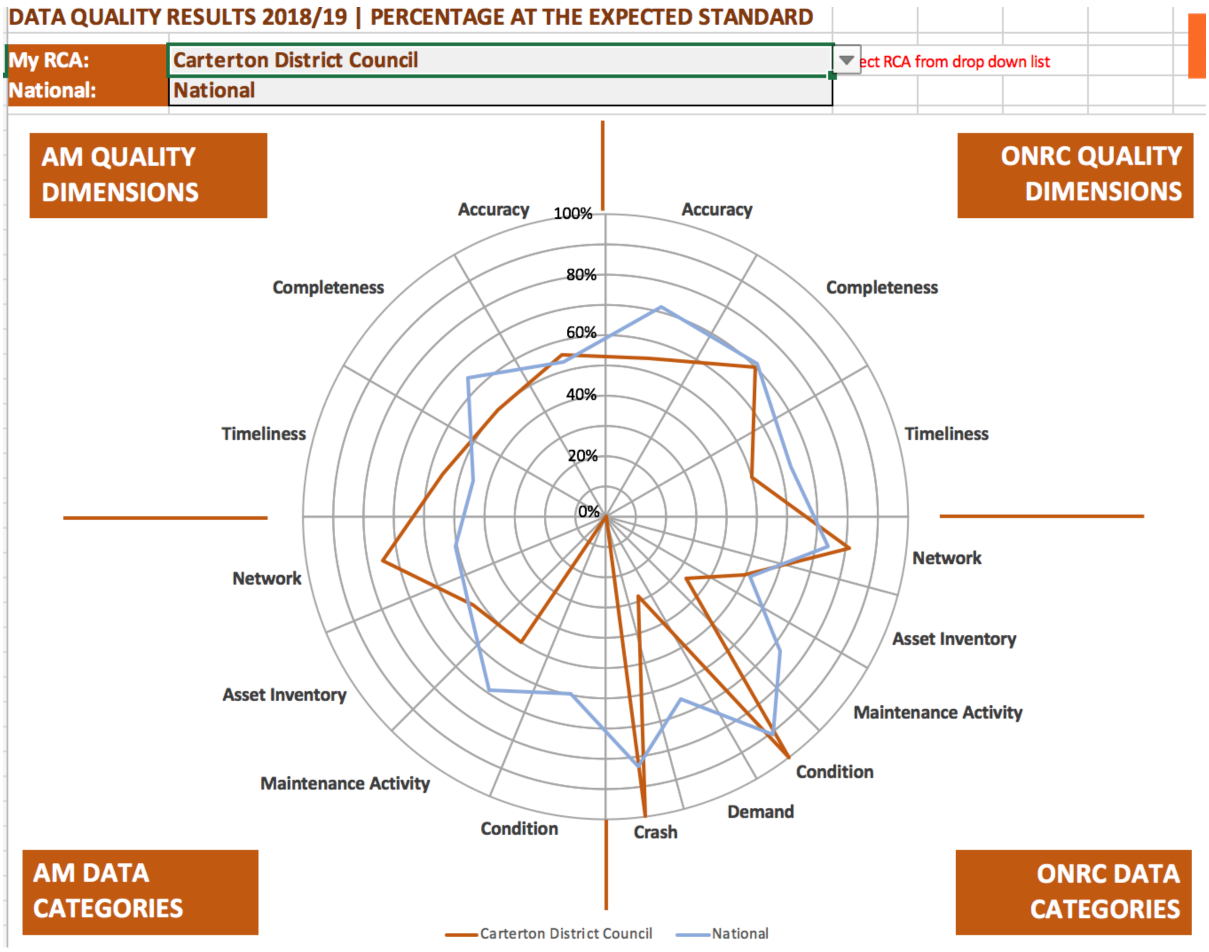
Comparison of data collection by area for South Wairarapa District Council, Wellington City Council , Carterton District Council and Masterton District Council to the national result.

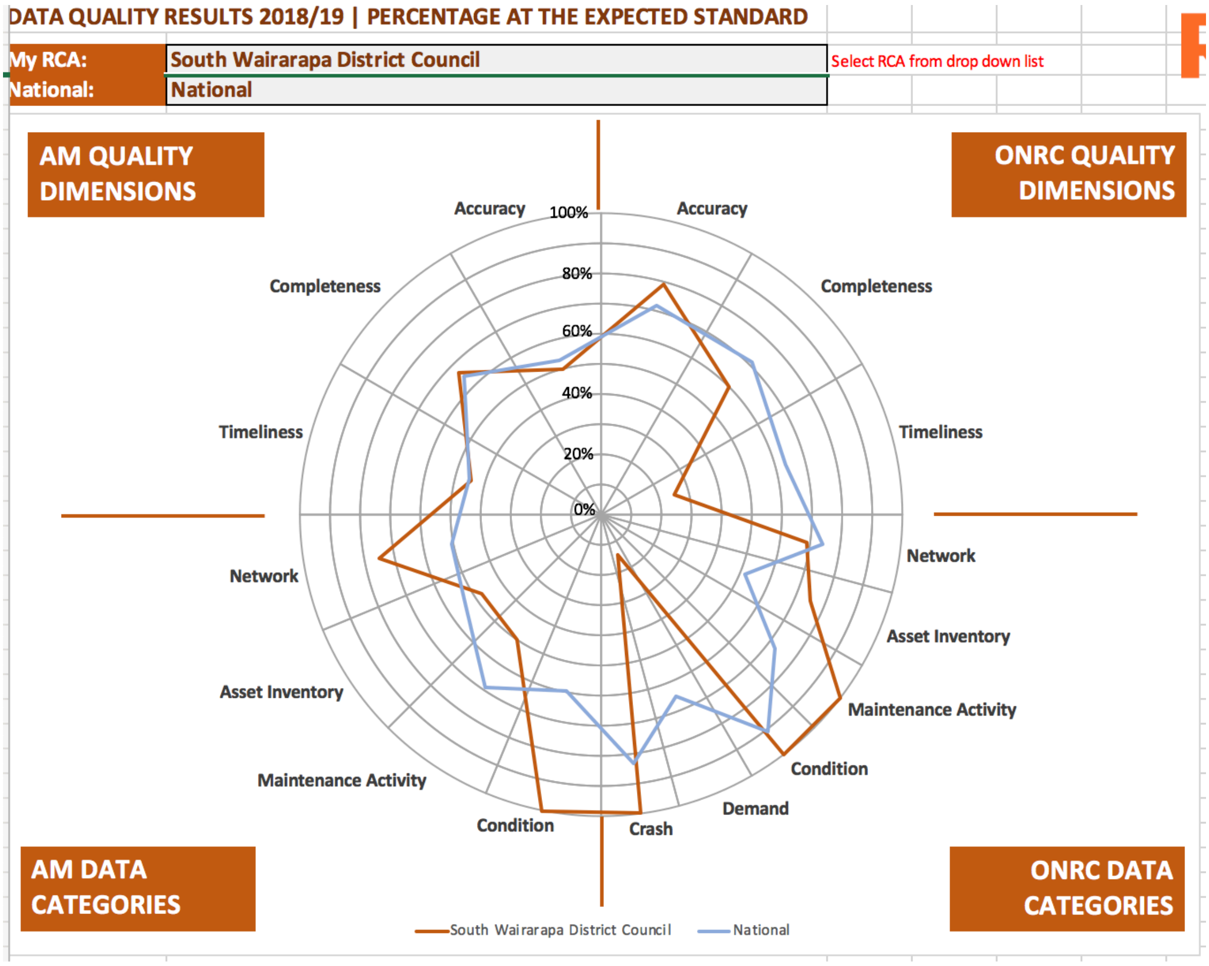
Key

AM = asset management

ONRC = On network road classification




DATA QUALITY RESULTS 2018/19 | PERCENTAGE AT THE EXPECTED STANDARD
My RCA:
Carterton District Council
ect RCA from drop down list
National:
National
AM QUALITY DIMENSIONS
ONRC QUALITY DIMENSIONS
Accuracy
Completeness
Timeliness
Network
Asset Inventory
Maintenance Activity
Condition
Accuracy
Completeness
Timeliness
Network
Asset Inventory
Maintenance Activity
Condition
Demand
Crash
100%
80%
60%
40%
20%
0%
AM DATA CATEGORIES
ONRC DATA CATEGORIES
Carterton District Council
National


DATA QUALITY RESULTS 2018/19 | PERCENTAGE AT THE EXPECTED STANDARD
My RCA:
South Wairarapa District Council
Select RCA from drop down list
National:
National
AM QUALITY DIMENSIONS
ONRC QUALITY DIMENSIONS
AM DATA CATEGORIES
ONRC DATA CATEGORIES
Accuracy
Completeness
Timeliness
Network
Asset Inventory
Maintenance Activity
Condition
Crash
Demand
100%
80%
60%
40%
20%
0%
South Wairarapa District Council
National