Performance indicator analysis and applying levels of service

June 2013

TFP Henning, University of Auckland
SB Costello, University of Auckland
M Tapper, Beca, Tauranga

NZ Transport Agency research report 529

ISBN 978-0-478-40766-2 (electronic)
ISSN 1173-3764 (electronic)

NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

Beca Infrastructure was contracted by NZTA in 2010 to carry out this research

Henning, TFP, SB Costello and M Tapper (2013) Performance indicator analysis and applying levels of service. *NZ Transport Agency research report 529.* 141pp.

Dr. Theunis FP Henning, Department of Civil and Environmental Engineering, The University of Auckland, Private Bag 92019, Auckland 1142, New Zealand.

Keywords: benchmarking, failure risk, performance monitoring, roughness, rut index, strength indices trend monitoring,

An important note for the reader

The NZ Transport Agency is a Crown entity established under the Land Transport Management Act 2003. The objective of the Agency is to undertake its functions in a way that contributes to an affordable, integrated, safe, responsive and sustainable land transport system. Each year, the NZ Transport Agency funds innovative and relevant research that contributes to this objective.

The views expressed in research reports are the outcomes of the independent research, and should not be regarded as being the opinion or responsibility of the NZ Transport Agency. The material contained in the reports should not be construed in any way as policy adopted by the NZ Transport Agency or indeed any agency of the NZ Government. The reports may, however, be used by NZ Government agencies as a reference in the development of policy.

While research reports are believed to be correct at the time of their preparation, the NZ Transport Agency and agents involved in their preparation and publication do not accept any liability for use of the research. People using the research, whether directly or indirectly, should apply and rely on their own skill and judgement. They should not rely on the contents of the research reports in isolation from other sources of advice and information. If necessary, they should seek appropriate legal or other expert advice.

Acknowledgements

The NZTA is recognised for its funding of the research project. Also the full research team and steering group are acknowledged for their respective contribution towards this research. They are:

Research Team: F. Jooste, S. Bush, M. Schlotjes, S. Perera, D. Gunawardena, N. Smith and L. Bargh

Steering Group: M Hendry (Research Manager), J Brass, G Morrow, C Thew, J Chisnall. M McMinn

Contents

Executive summary

Background to the research

The NZTA has been using performance indicator analysis and levels of service (LOS) reporting for some years to assist with funding allocation, monitor the application of funds and ensure they are spent appropriately. Undertaking performance reporting assists in the funding decision process by utilising:

- **Trend monitoring**. The NZTA uses trend monitoring to validate the appropriateness of funding requests.
- **Benchmarking/relative comparisons**. Trend monitoring by itself cannot establish appropriateness of funding levels. The LOS of one authority may be at an unaffordably high level, and a reduction in condition levels for such an authority would be acceptable.
- **Cost-effectiveness measurement**. It would be unreasonable to expect all authorities to maintain the same level of service for their road networks. The LOS needs to be adjusted based on socio-economic factors, population size and vehicle numbers using a network.

Objectives of the research

The tender for this research project specified:

> *Investigate effectiveness of current performance indicators with a view to improving the way NZTA tracks value for money and the potential to define a fundable level of service. This should tie into the activity management framework being developed currently by NZTA.*

Review of performance indices

The review of existing performance measurements resulted in a suite of indices summarised in table E.1. This report documents the fundamental background to the new indices, whose robustness was demonstrated during the research through testing on full networks or a sample of networks.

Table E.1 Recommended performance measures for road pavements

Performance area	Performance measure	Notes/recommendation
Pavement structural health	Rutting index (RI)	A combination of the actual rut depth and the change in rut depth during the past three years. Testing of the index revealed that it is sensitive to the network change; however, appropriate weightings for the index need confirmation following intensive use.
	Wavelength	The wavelength spectrum energy levels can be reported in terms of their absolute value and the incremental change over time. Both reporting mechanisms displayed useful result for the understanding of the profile changes. The results also highlighted that roughness changes were different for different speed environments. This needs to be incorporated into future reporting, especially relating to STE.
	Roughness (IRI)	The limitations of the IRI are well understood. However given the significant historical context of the IRI its use should continue. The use of NAASRA should cease.
	Smooth travel exposure (STE)	STE is used for exception reporting and should therefore be supplemented with a distribution plot of IRI. Additional recommendations include: • STE should be reported separately for different speed zones

Performance area	**Performance measure**	**Notes/recommendation**
		• an STE for trucks should be used on the basis of the truck ride index.
	Pavement integrity index (PII)	The PII should be phased out as soon as the other pavement indices are adopted.
	Structural indices (SIs)	Four SIs are recommended. These represent the four main failure modes of New Zealand pavement types including: • SIRut – based on a subgrade failure criteria • SILflex – based on cracking characteristics of the pavement • SIShear –based on the shear properties of upper pavement payers • SIRough –based on the differential deflection longitudinally to the road. The research demonstrated both the robustness of these indices and their value in performance monitoring. Good correlations were established with actual performance and explainable results were obtained on network level. It should be noted though that the SIs are contextual indices as they neither indicate actual performance nor do they take traffic loading into account.
	Failure risk index	A probability of pavement failure was developed for three condition items including rutting, cracking and shear. Pavement strength, physical carriageway and pavement composition plus current condition date are considered for determining the failure index. Positive testing results were obtained from this index. Further work is required to refine the index, especially on urban networks.
Surface health	Surface condition index (SCI)	The current SCI was reviewed on the basis of other research findings (Jooste et al 2009). It was also assessed on the basis of network results. In conclusion, there are no recommended changes to the make-up of the SCI. However, some improvement to the index may result from improvements to the data collection –manual rating system. In addition the SCI should report separately on asphalt and chip sealed roads. Significant cracking exists on asphalt compared with chip seal surfaces and reporting the results together skews the results.
	Survival curves	In order to identify the poor performance of surfaces, the use of survival curves is recommended as a comparative measure between networks. This overcomes the limitation of considering either the distribution of current seal or the past performance of surfaces in isolation.
	Total surface thickness	Top surface reporting is an effective way to monitor the resurfacing practices of councils. Total surface thickness above 40mm may be prone to flushing which warrants the monitoring on a network level. It is recommended to use this index on a tactical level only.
Economic efficiency/ economic measures	Efficiency frontier	Efficiency frontier can be developed for any of the performance measures. By normalising the condition parameter and plotting it against the cost of addressing a particular performance measure, one can plot an efficiency frontier that summarises the gains realised for a given investment level.
	Vehicle operating cost index (VOCi)	The VOCi is a ratio between the vehicle operating cost and the VKT travelled on a network. It is therefore a normalised index that indicates the relative cost of travelling on different networks. Testing of this index has revealed that it is very effective in assessing the efficiency of network investment in terms of reductions in user costs.

The full scale testing of the measures proposed for bridge structures and traffic service fell outside the scope of this research project.

Further work

John Maynard Keynes once said:

> *The difficulty lies, not in the new ideas, but in escaping from the old ones which ramify . . . into every corner of our minds.*

This summarises the challenge in the adoption of new performance monitoring concepts. The new frameworks and associated performance measures will significantly improve the status quo. However, most of these concepts are new and relatively little experience exists for most of them. Therefore, they should be used, refined and changed where needed. It is only through using a concept that the true learning can occur.

It is recommended that the NZTA considers a forum to take ownership of the monitoring process, to capture learning and to execute required changes. Potential bodies may include RCAs and/or the Road Information Management Support Group.

Further research work should also consider examining:

- sustainability indices to asset management and whether current maintenance treatments are providing technical and environmental benefits
- whether data frequency can be even less
- rates of changes in rut depth roughness and SIs so that treatments can be better applied or estimated.

Once the operations performance measures have been tested and fully adopted the remaining components of the monitoring framework such as the tactical and strategic measures can be developed.

Abstract

The NZTA has been using performance indicator analysis and levels of service reporting for some years to assist with funding allocation, monitoring the application of funds and ensuring these are spent appropriately. Undertaking performance reporting assists in the funding decision process by utilising:

- trend monitoring to show the network ‘health’ of an authority
- benchmarking/relative comparisons with similar networks, as trend monitoring by itself cannot establish the appropriateness of funding levels.

Historical indicators, however, have struggled to give an absolute measure of spending efficiency or network health, ie is the network in good health or at risk. This report presents the outcome of a NZTA research project that included a complete review of the current performance framework. It assessed the limitations to performance measures such as the surface condition index, smooth travel exposure and the pavement integrity index.

It also introduced new performance measures including structural indices, a rutting index, longitudinal profile wave lengths and a failure risk index. The value of the performance framework is demonstrated using a network level example. This report will be of value for all roading asset managers, as it provides a framework for condition performance monitoring that can be applied at both local and national levels.

1 Introduction

1.1 Background to the research

The NZTA has been using performance indicator analysis and levels of service (LOS) reporting for some years to:

- assist with funding allocation
- monitor the application of funds and ensure they are spent appropriately.

Undertaking performance reporting assists in the funding decision process by utilising:

- **Trend monitoring**. The NZTA uses trend monitoring to validate the appropriateness of funding requests.
- **Benchmarking/relative comparisons**. Trend monitoring by itself cannot establish the appropriateness of funding levels. The LOS of one authority may be at an unaffordably high level; therefore, a reduction in condition levels for such an authority would be acceptable.
- **Cost-effectiveness measurement**. It would be unreasonable to expect all authorities to maintain the same level of service for their road networks. The LOS needs to be adjusted and based on socio-economic factors, population size and the number of vehicles using a network.

1.2 Objectives of the research

The tender for this research project specified:

> *Investigate effectiveness of current performance indicators with a view to improving the way NZTA tracks value for money and the potential to define a fundable level of service. This should tie into the activity management framework being developed currently by NZTA.*

The main goals in achieving this objective were to:

- Review existing performance indicator analysis and LOS application, focusing on:
  - statistical techniques and tools
  - some performance indicators in conjunction with the latest research findings.
- Link LOS to cost effectiveness:
  - The link between LOS and cost remains the ‘holy grail’ in asset management. Performance indicator analysis needs to follow a holistic approach incorporating physical performance, costs and an element of risk/uncertainty before a comprehensive decision can be made on the appropriateness of investment levels for infrastructure.
- Introduce new performance indicators. Currently there are two main areas of weakness in the existing performance indicator framework:
  - Although the overall health of the pavement surface is well understood, the same level of confidence does not exist for understanding the network’s performance in terms of its pavement structural capacity. Increased focus is required due to the new 50-tonne rule for axle load and axle configuration.

  - A useful addition to the current performance framework would be the incorporation of indices related to the risk of failure and uncertainty measures around data items.
- Incorporate other asset items into the performance and LOS framework. With the lessons learned from the review mentioned in section 1.2, the framework could be expanded into the areas of:
  - Bridges. No national level performance monitoring is currently being undertaken for structures on the New Zealand road network. This limitation needs to be addressed urgently as a large number of New Zealand bridges will be reaching their expected, or designed, life over the next 10 to 20 years. In addition to that, increased load limit legislation will push traffic loading closer to the limits of the design capability of most structures in New Zealand.
  - Other traffic services.

1.3 Scope and research process

Although the performance framework would be closely linked to a higher strategic level of the NZTA's performance monitoring, the initial focus of the research project was aimed at the tactical level of being able to provide condition monitoring of pavements (surfaces and pavement structures), economic efficiency of maintenance work and monitoring of bridges and other asset groups (traffic services). The focus for bridges and traffic services would be to recommend a data framework as limited performance data exists for these asset types. The following areas were excluded from the research:

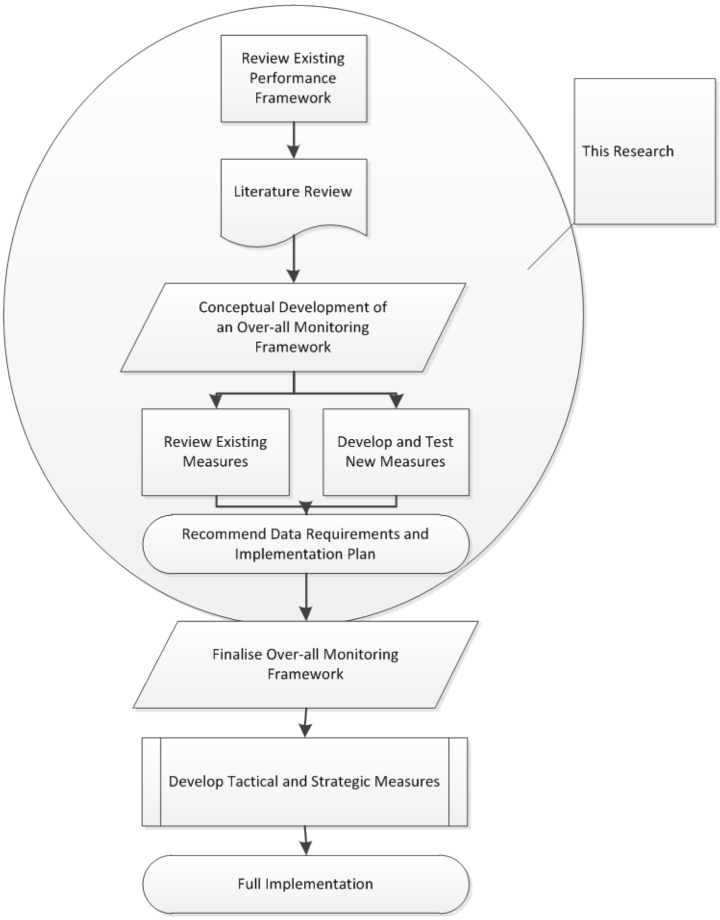
- gravel roads
- road safety monitoring
- road capacity/flow aspects
- road customer satisfaction aspects.

As the development of a complete condition performance framework would be a lengthy project it was decided at the Steering Group meeting that the greatest need was for a review of operational performance measures. In order to do this it was necessary to develop a conceptual framework for an overall monitoring system (refer to figure 1.1).

It was important to define a process that would see enhancements being recommended through the following stages:

1. Theoretical/fundamental development involving the fundamental development of new indices or review of existing indices. We aimed at capitalising on historical research outcomes and adopting them within the project and also envisaged there might be 'new' development needs that could result from the research.
2. Proof of concept using some limited data such as long-term pavement performance (LTPP) data. Following on from the initial development, the second step considered the performance measure on a small dataset. The aim of this step was to investigate any practical issues in relation to the available data. Most importantly, it had to assess the value of the measure in terms of the 'story' it could convey through meaningful results.
3. Full-scale test to check any implementation issues and confirm the usefulness and value of the measures on a large scale.

Figure 1.1 Development stages of the performance monitoring framework

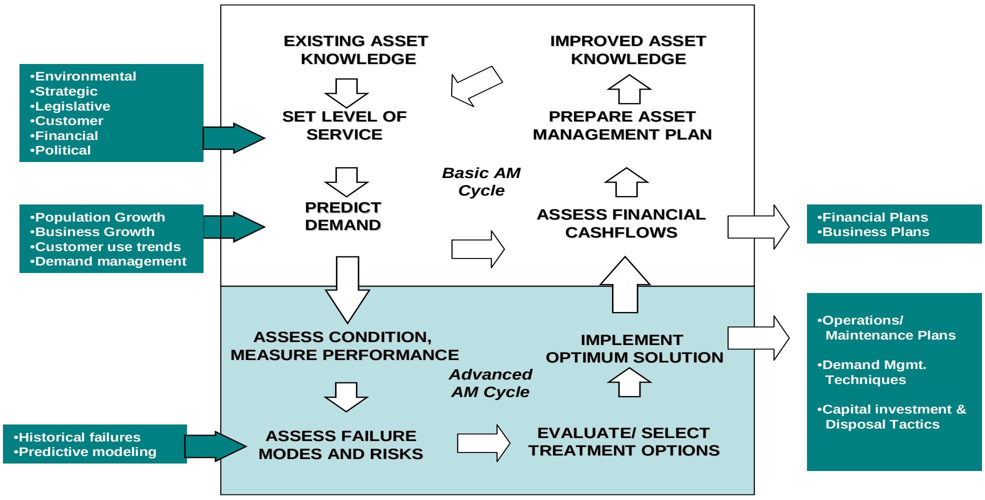


2 Literature review

2.1 Background

Performance monitoring is not only important for the funding organisation; it is also a crucial component of the asset management cycle of any infrastructure agency. Figure 2.1 illustrates the asset management cycle defined by NAMS (2006). This figure shows that asset knowledge and performance management are key functions within both the core and advanced asset management cycles.

Figure 2.1 Core and advanced asset management cycles (NAMS 2006)



The aim of this literature review is to benchmark New Zealand practice against international performance management frameworks. Further detail and technical aspects in relation to performance measures are presented in the relevant sections of this report.

2.2 Experience from the United Kingdom

2.2.1 Performance requirements

Local authorities in England are required to report on 198 national indicators (NIs) which span areas such as transport, education and housing. This is a significant reduction from the 1200 best value performance indicators (BVPIs) required prior to 2008/2009.

Of these, only two relate to highway infrastructure. These are listed below and further detail is provided in section 2.2.3:

- NI 168: Principal roads where maintenance should be considered.
- NI 169: Non-principal roads where maintenance should be considered.

An additional two indicators are of interest from the superseded BVPIs. These are listed below and further detail is provided in appendix B:

- BV 224b: Condition of unclassified roads (unclassified roads where maintenance should be considered).
- BV 187: Condition of surface footway.

Other transport indicators relate to road safety, congestion and public transport. These are included below for information but are not considered further in this report:

- NI 47: People killed or seriously injured in road traffic accidents.
- NI 48: Children killed or seriously injured in road traffic accidents.
- NI 167: Congestion – average journey time per mile during the morning peak.
- NI 175: Access to services and facilities by public transport, walking and cycling.
- NI 176: Working age people with access to employment by public transport (and other specified modes).
- NI 177: Local bus passenger journeys originating in the authority area Y.
- NI 178: Bus services running on time.

The NIs are linked to the departmental strategic objectives (DSOs) of the various government departments. The Department for Transport (DfT) has three DSOs. These are listed below along with the relevant NIs:

- DfT DSO: To sustain economic growth and improved productivity through reliable and efficient transport networks – NI 168, NI 169, NI 177, NI 178, also NI 167 (actually linked to a public service agreement but included here for simplicity).
- DfT DSO: To enhance access to jobs, services and social networks including for the most disadvantaged – NI 175, NI 176.
- DfT DSO: To strengthen the safety and security of transport – NI 47, NI 48.

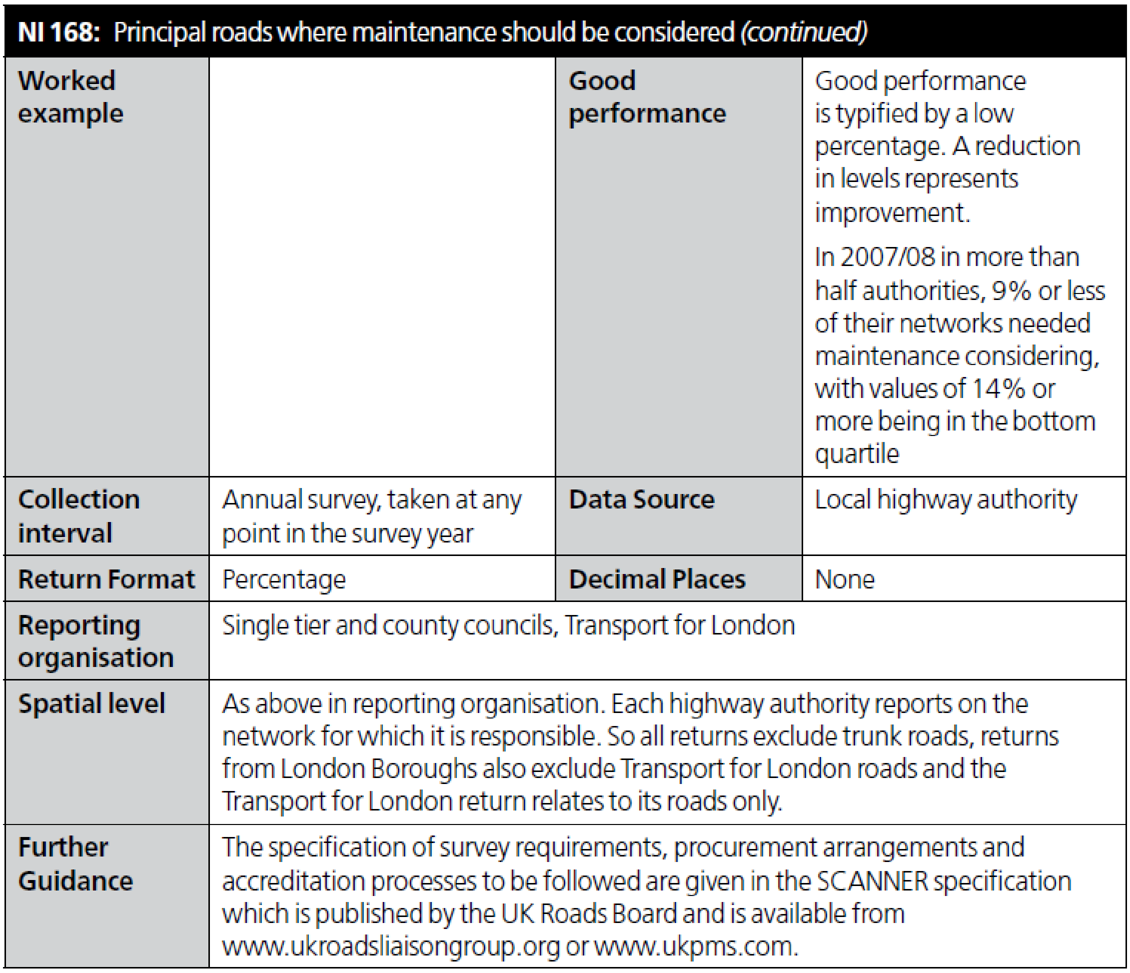
2.2.2 Relevant items of interest

The NIs incorporate a number of characteristics that are of interest to us:

- *The recognition that authorities use different data collection methodologies for different road hierarchies*: NI 168 and NI 169 refer to classified roads on the network whereas BV 224b refers to unclassified roads. All indicators measure the same thing – the percentage of the network that requires maintenance. However, the classified network requires measurement by a surface condition assessment for the national network of roads (SCANNER), which is a high-speed data (HSD) collection device, and the unclassified network by a coarse visual inspection (CVI).
- *Using the lowest common denominator where required*: The option also exists to use a detailed visual inspection to estimate the percentage of the unclassified network that may require maintenance; however, it needs to be converted to a CVI equivalent before the NI calculation takes place.
- *The recognition of the need for sampling especially at lower hierarchies*: For A and B class roads 50% of the network is required to be surveyed in any one year (typically 100% in one direction or 50% in both). For C class roads, 50% of the network is required to be surveyed in one direction. For the unclassified network 25% is required to be surveyed each year but in this case by CVI.
- *The indicator itself*: The indicator is interesting in that it does not report a condition as such but the possibility of treatment derived from measures of condition (converted to a road condition index (RCI) in the case of SCANNER data) and pre-set interventions. It is therefore essentially a measure of the funding required. The calculation is strictly controlled through the UK Pavement Management System (UKPMS) specification and has to be calculated by UKPMS compliant software systems, regardless of whether the calculation is based on SCANNER or CVI data.

2.2.3 Examples of UK performance measures

<table>
<tr><th colspan="4">**NI 168:** Principal roads where maintenance should be considered</th></tr>
<tr><td>**Is data provided by the LA or a local partner?**</td><td>**Y**</td><td>**Is this an existing indicator?**</td><td>**Y**</td></tr>
<tr><td>**Rationale**</td><td colspan="3">Provides an indication of the proportion of principal roads where structural maintenance should be considered. This is a significant indicator of the state of the highways asset.</td></tr>
<tr><td>**Definition**</td><td colspan="3">This indicator is an updated version of the former best value performance indicator (BVPI) 223 (formerly BVPI 96). The indicator measures the percentage of the local authority's A-road and M-road network where maintenance should be considered.
The performance indicator is derived from a survey of the surface condition of the local authority's classified carriageway network, using survey vehicles that are accredited as conforming to the SCANNER (Surface Condition Assessment for the National Network of Roads) specification and processing software that is accredited as conforming to the UKPMS (UK Pavement Management System) standards.
Results are reported for either (a) 100% of the network surveyed in one direction; or (b) 50% of the network surveyed in both directions. Roads not surveyed in the previous year must be surveyed in the present year.
All road surface types should be included (including principal motorways). Surveys should physically cover the required network lengths; grossed-up figures from shorter surveys are not permitted.</td></tr>
<tr><td>**Formula**</td><td colspan="3">The indicator is the length of carriageway identified as having a condition indicator greater than or equal to 100, as a percentage of the total length surveyed.
$$\left(\frac{x}{y}\right)*100$$
where
x = length of carriageway surveyed identified as having a condition indicator greater than or equal to 100;
y = total length of principal roads surveyed.
Results are calculated automatically by the UKPMS software.</td></tr>
</table>



NI 168: Principal roads where maintenance should be considered *(continued)*

Worked example		**Good performance**	Good performance is typified by a low percentage. A reduction in levels represents improvement. In 2007/08 in more than half authorities, 9% or less of their networks needed maintenance considering, with values of 14% or more being in the bottom quartile
Collection interval	Annual survey, taken at any point in the survey year	**Data Source**	Local highway authority
Return Format	Percentage	**Decimal Places**	None
Reporting organisation	Single tier and county councils, Transport for London		
Spatial level	As above in reporting organisation. Each highway authority reports on the network for which it is responsible. So all returns exclude trunk roads, returns from London Boroughs also exclude Transport for London roads and the Transport for London return relates to its roads only.		
Further Guidance	The specification of survey requirements, procurement arrangements and accreditation processes to be followed are given in the SCANNER specification which is published by the UK Roads Board and is available from www.ukroadsliaisongroup.org or www.ukpms.com.		

2.3 Experience from South Africa

2.3.1 Outline

This section contains observations on the measurement and documentation of the condition of road networks in South Africa, specifically pertaining to national toll road networks. The observations are based on experience gained in the analysis and reporting related to two toll road networks, and as such cannot claim to be a complete summary of road condition measurement practices in South Africa.

2.3.2 The N3 and N4 toll networks

These toll roads are known as the TRAC N4 and N3 toll roads, and are respectively operated by Trans African Toll Concessions (Pty) Ltd and N3 Toll Concession (Pty) Ltd. Details of these two networks are contained in two papers (Jooste et al 2008; and Judd and Jooste 2010) published at the 2010 ARRB Conference in Melbourne. Brief details of these two toll networks are:

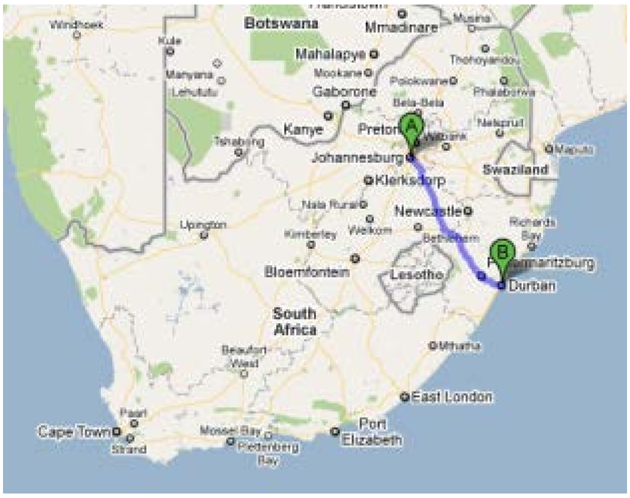
- TRAC N4 network (see figure 2.2):
  - a major corridor linking Pretoria and Maputo (thus spanning South Africa and Mozambique)
  - total length is approximately 560km

  - pavement structures are mostly flexible, consisting of unbound granular base over cement stabilised subbase.

Figure 2.2 TRAC N4 road network

- N3TC network (see figure 2.3):
  - a major corridor linking the outskirts of Johannesburg with the port of Durban
  - total length is approximately 415km
  - pavement structures are mostly thick asphalt base pavements. Some parts of the network consist of concrete pavement
  - a distinguishing feature of this network is that it carries very heavy traffic of up to 2800 heavy commercial vehicles per day, per direction.

Figure 2.3 N3TC road network



2.3.3 Data measurement on N3TC and TRAC networks

The concession contracts for the N3TC and TRAC N4 networks specify compliance requirements with respect to the functional and structural condition. These compliance requirements are determined by the South African National Roads Agency. It is of interest to note that the requirements have changed over the years as new concession contracts have been initiated and more experience gained from prior concessions.

Current *functional* parameters measured annually on the N3TC network are (Judd and Jooste 2010):

- road roughness (or riding quality) expressed in terms of the international roughness index (IRI)
- rut depth
- surface texture, expressed by means of the mean profile depth (MPD).

Structural condition is determined by falling weight deflectometer (FWD) measurements as well as visual assessment of the pavement condition. Primarily, the obligation on the concessionaire is to maintain the road pavement structure with sufficient structural capacity to carry the traffic safely and comfortably during the concession period. It is a condition of the contract that at the end of the concession period, there is a minimum remaining structural pavement life according to the different road categories (Judd and Jooste 2010).

Skid resistance (measured by the sideway-force coefficient routine investigation machines (SCRIM) vehicle, and expressed in terms of the sideways force coefficient (SFC) was originally specified as part of the concession compliance requirements on the TRAC N4 network. However, this requirement is no longer formally monitored owing to problems in the consistency of measured skid resistance data on this network. Texture depth is also measured on the TRAC N4 network and is currently used as a surrogate indicator of skid resistance trends, although it is not a formal requirement.

On both the TRAC N4 and N3TC networks, the condition data is currently measured by the concessionaire every year, even though it is not always formally required (in the case of the TRAC N4 network, the specifications require that HSD only needs to be measured every second year and FWD data only every third year). In the latter case, the concessionaire opted for a higher frequency of data measurement mainly to facilitate a more reliable assessment of network deterioration trends. This has proved invaluable for identifying problems on the network and for calibrating deterioration models.

2.3.4 Concession requirements – measurement and method of reporting

The concession requirements for functional parameters are based on measurements taken with high-speed laser based technology. Data is reported for every 10m of roadway. HSD is typically measured only in the slow lane, but in recent years measurements have also been taken in the fast lane.

In general, the approach to HSD on concession contracts is to group it over segments of a specified length (eg 1km). The grouped data is analysed and specific percentile values are calculated. These percentiles are then compared to specified limits.

For rutting, the 10m data is analysed statistically over 1km segments. Typically, the use of the 10m left wheel path rut depth is specified. The rut data over each 1km segment is used to determine the percentiles shown in table 2.1. This table also shows the limiting rut depth for each percentile. Thus, for example, if the 95th percentile rut depth on any 1km segment is greater than 20mm, then that 1km segment is deemed to be non-compliant.

Table 2.1 Typical concession contract requirements for rutting (Judd and Jooste 2010)

Limiting rut depth (mm)	Maximum length of each 1km segment with rut depth above limiting value
15	10% (ie the 90th %ile rut depth should be below this value)
20	5% (ie the 95th %ile rut depth should be below this value)
25	0% (ie the maximum rut depth should be below this value)

Roughness (measured in terms of the IRI) is reported every 10m. The 10m values are averaged over 100m lengths, and these 100m averages are then analysed over either 5km segments (for the TRAC N4 network) or 1km segments (for the N3TC network). As with rut depth, the 1km or 5km segment's IRI data is analysed and percentiles are calculated and compared with compliance requirements such as those shown in table 2.2.

Table 2.2 Typical concession contract requirements for roughness (Judd and Jooste 2010)

Limiting IRI for		Maximum length of each 1km segment with IRI above limiting value
Road category 1	**Road category 2**	
3.2	3.5	20% (ie the 80th %ile IRI should be below this value)
3.5	3.8	5% (ie the 95th %ile IRI should be below this value)
4.5	4.9	0% (ie the maximum IRI should be below this value)

According to South African legislation, there must always be an alternative route to a toll road. Therefore, the N3TC concession contract requires the concessionaire to construct a parallel route to an existing road with poor geometry in a mountain pass. In this instance, there are different IRI requirements for categories 1 and 2 roads. Category 1 refers to the mainline highway, and category 2 refers to those highway sections that will be replaced by the new route and therefore have less stringent condition requirements due to lower traffic volumes. The TRAC N4 network has a similar categorisation of roads on the network, but in this case the TRH4 guidelines' (COLTO 1998) categories (categories A and B) are used to distinguish between roads of different standards.

On the TRAC N4 network, texture depth, or MPD (also measured using high-speed lasers and reported every 10m) is typically also analysed over 1km lengths and the 15th percentile is reported as an indication of lower percentile macro-texture. On the N3TC network, texture depth is first averaged over 100m, and the minimum 100m average occurring in each 1km segment is then reported. MPD values lower than 0.4mm trigger an investigatory level site and require active management of skid resistance in that area.

Visual condition measurement is currently performed on an annual basis on the TRAC N4 network. Visual assessments for flexible pavements are performed in accordance with the South African TMH9 manual (COLTO 1992) for visual assessments. In general, this manual requires, for each visual segment, that distresses are rated in terms of a degree and extent rating. These ratings range from 0 to 5, with 0 indicating no distress (for degree and extent) and 5 indicating a severe degree of distress or widespread extent of the distress, depending on the rating.

For each distress, the degree and extent rating provides an indication of the most prevalent severity of the distress, and also how widely spread the distress is over the measurement segment. For network level surveys in South Africa, a 1km segment length is generally used. Distresses reported in the TMH9 assessments include:

- aggregate loss
- bleeding or flushing
- transverse cracks
- longitudinal cracks
- crocodile/alligator cracks
- pumping
- rutting

- shoving
- potholes
- patching.

The completed TMH9 rating for all distresses is used to calculate a visual condition index (VCI) for the segment in question. This index ranges from 0 to 100 with 100 being indicative of a segment in perfect condition. For this network, the concession requirements are such that visual assessments are only evaluated in the last three years of the concession period.

Table 2.3 shows typical requirements with respect to FWD maximum deflection. Similar requirements are specified for other FWD deflection bowl parameters such as the base layer index and middle layer index.

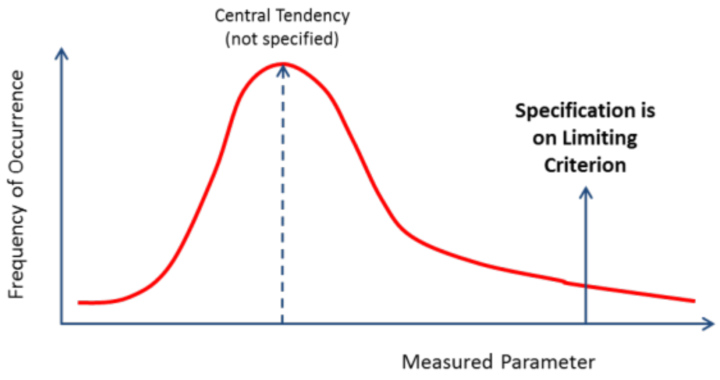
Table 2.3 Maximum deflection criteria for last three contract years

Base type	Limiting value for 90th percentile of maximum deflection (micron)	
	Road category A	Road category B
Granular base	<370	<500
Asphalt base	<320	<450
Stabilised gravel base	<280	<400

2.3.5 Observations and discussion

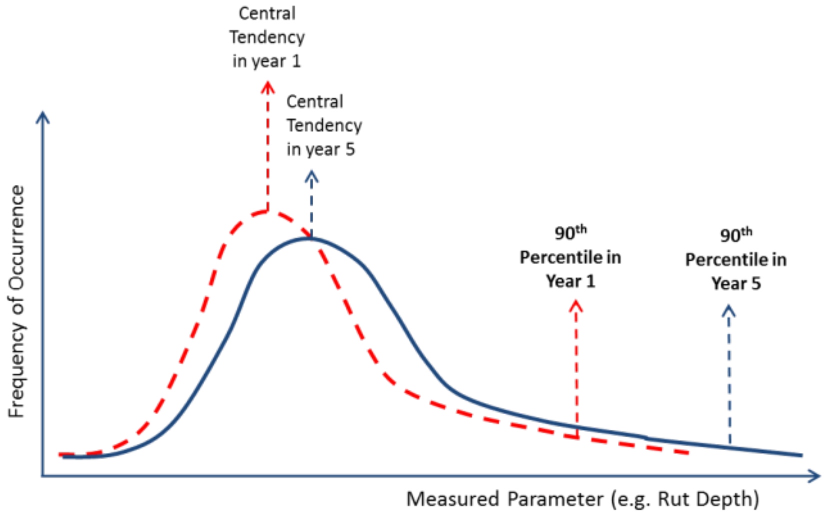
It will be noted that the concession requirements discussed in the preceding paragraphs are all centred around upper percentile (in the case of rutting, roughness and FWD measurement) or lower percentiles (in the case of texture depth). Thus, if one considers that the measured data pertaining to a specific parameter comprises a statistical distribution, then it is of interest that the requirements are mainly based on the tails or width of the distribution and not on the central tendency, as shown in figure 2.4.

Figure 2.4 Condition indicators – central tendency versus outer percentiles



Experience has shown that the use of a limiting criterion on the upper or lower percentiles, as opposed to the central tendency, is a worthwhile consideration. As road networks deteriorate in the absence of proper maintenance, the distribution changes in two ways (see figure 2.5). First, it slowly moves right (or in the case of texture depth – left). Second, it slowly widens as a greater length of the network moves into an unsatisfactory condition. It is believed that this second tendency is a) a more sensitive indicator of road deterioration than a central tendency, and b) more aligned with public perception of road condition.

Figure 2.5 Impact of road deterioration on condition parameter distribution



Based on experience gained in the analysis and documentation of road network condition in South Africa, Malaysia and New Zealand, it is believed that the use of a central tendency parameter such as a mean or median value can mask true network deterioration effects for some time before problems start to become apparent. By contrast, the use of an upper limit indicator (such as a 90th percentile value, or the percentage of data with a rut greater than 15mm) appears to be a more sensitive indicator which could identify deteriorating condition at an early stage.

Another factor to consider is the sensitivity of condition indicators to measurement errors. Even with the best efforts towards calibrating and validating condition measurements, experience in several countries has shown that significant systematic errors can still occur in network level surveys. Such errors may falsely suggest that a network has rapidly deteriorated in a specific year, which often results in costly investigations before the true source of the apparent change in network condition is detected. It is therefore important to include some method of post-survey validation and/or include a confidence rating for processes that are applied towards quality assurance (QA) improvements.

One way to deal with this effect is to make use of a long-term best fit line. Such a best fit line can be used to identify when a new survey has departed significantly from the historical long-term trend (see, for example, Byrne and Parry 2010). This best fit line equation can be updated each year as new data becomes available and can then be used to obtain a trend-corrected or adjusted indicator for the network condition.

2.4 Canadian performance management framework for core public infrastructure

2.4.1 Background

Through an initiative from the National Round Table on Sustainable Infrastructure (NRTSI) and the National Research Council (NRC) a model framework was developed for the assessment of state, performance and management of Canada’s core public infrastructure (CPI). It is described as follows: (NRC and NRTSI 2009)

> *The Model Framework is a decision-support tool that will help to uniformly – across services and jurisdictions – assess the state, performance and management of Canada’s core public infrastructure at the strategic, tactical, and project levels. In addition, the development process of the Model Framework helped identify challenges to its implementation (e.g.*

availability of data) and activities that would improve the assessment or performance of CPI systems (assets or services).

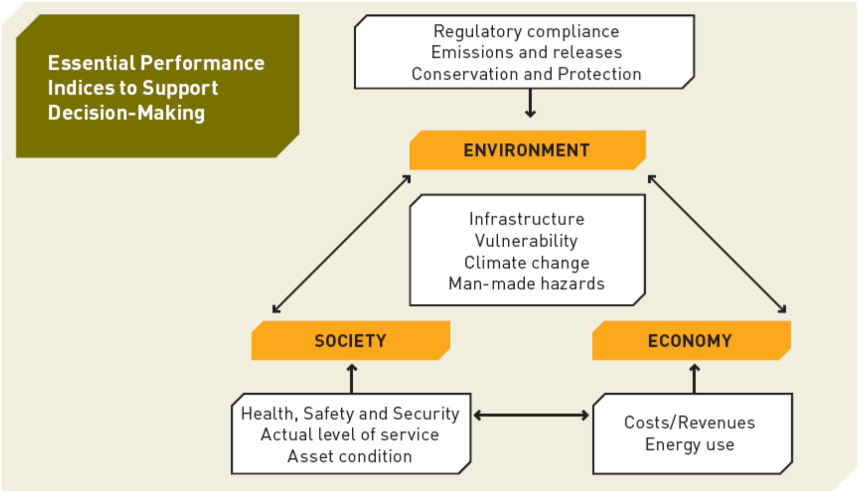
2.4.2 Framework overview

The Canadian framework covers two areas namely assets and service, which are defined as follows (NRC and NRTSI 2009)**:**

> *ASSET· ·: a physical component of an infrastructure system or network that contributes to providing a service to users. Assets can be linear (eg roads, water pipes, subway tunnels), rolling stock (eg buses for public transit) or point assets (eg bridges, water/wastewater treatment plant).*
>
> *SERVICE· ·: a public service provided by the core public infrastructure systems, such as: (i) moving people and goods through transportation infrastructure or public transit; (ii) delivery of potable water and collection and treatment of wastewater.*

This approach differs significantly from other international frameworks which primarily focus on one of these two areas. For example, the current NZTA framework focuses on outcomes which are defined at customer level. In addition to that the Canadian framework was developed in the context of triple bottom line reporting as illustrated in figure 2.6.

Figure 2.6 Performance framework for core public infrastructure (NRC and NRTSI 2009)

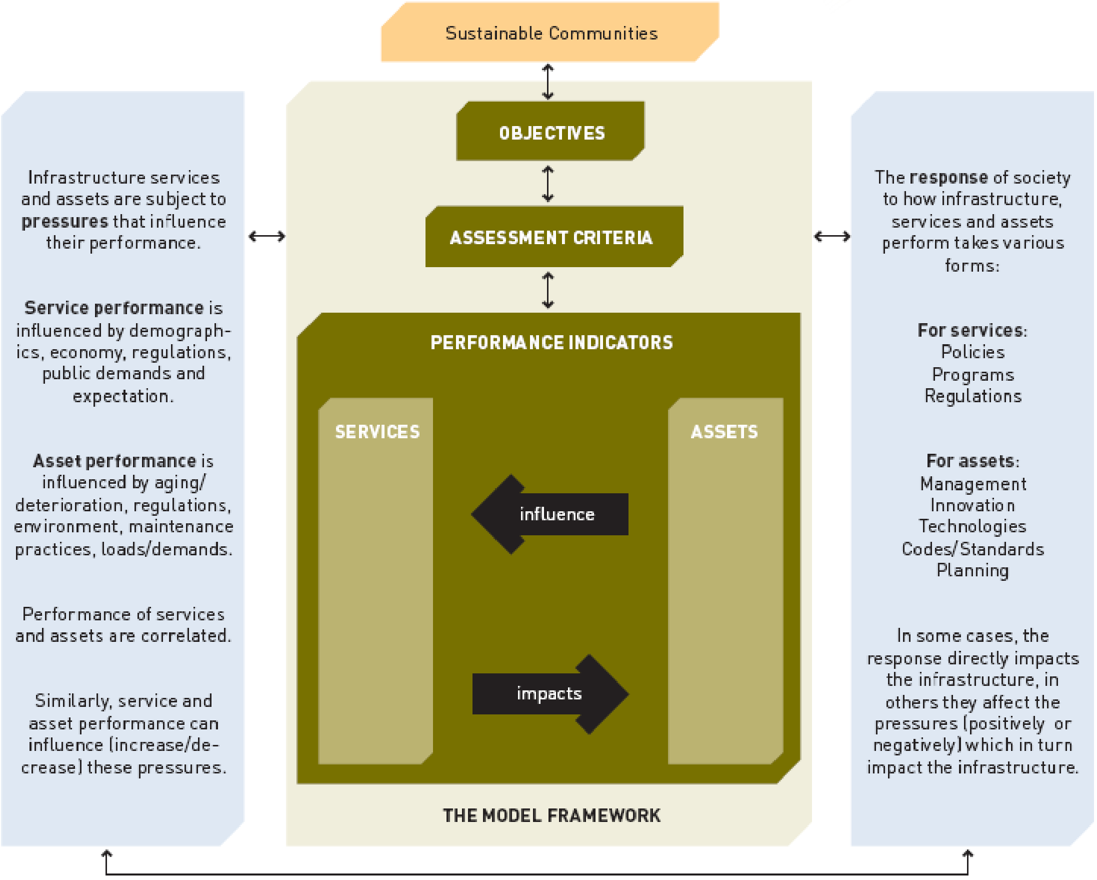


The framework is further defined at three tiers including:

- objectives
- assessment criteria
- performance indicators.

This is demonstrated in figure 2.7.

Figure 2.7 CPI model framework with externalities (pressures, responses) (NRC and NRTSI 2009)

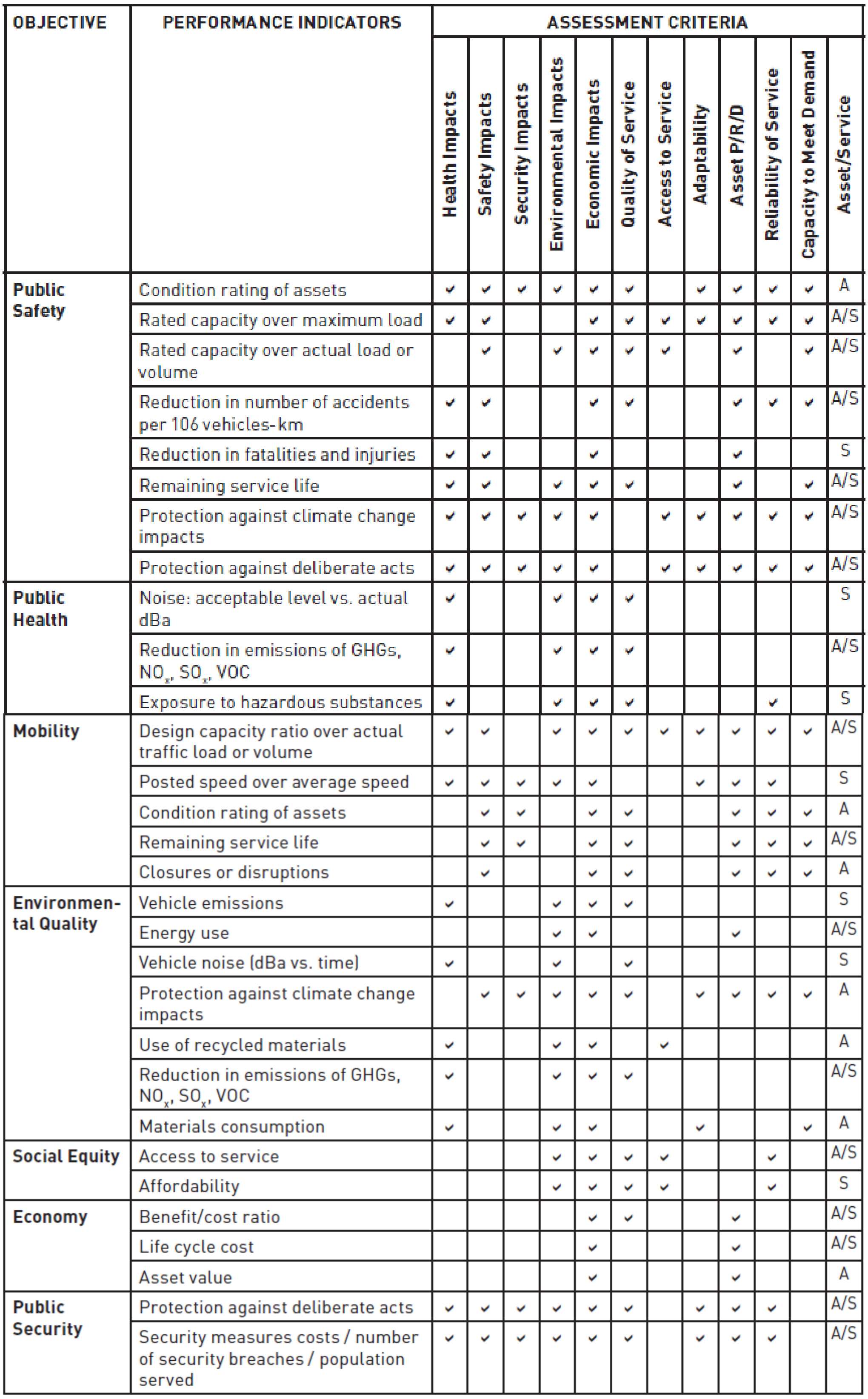


2.4.3 Performance indicators

Given the model framework application in different asset areas, not all assessment criteria and performance measures are relevant to all cases. For example, figure 2.8 illustrates the criteria and measures relevant in the transportation area. It also shows the emphasis on measures in the areas of environment, public health and public security. These areas are still absent from frameworks in New Zealand. The criteria listed in figure 2.8 further show the prominence that transport has in terms of economic impact, while condition, capacity and security concerns dominate as performance measures.

The framework in figure 2.8 is strongly supported by an implementation plan that includes the release of tools that allow for easy data and information exchange. Such an example includes Zimmerman et al (2010).

Figure 2.8 Key performance indicators for transportation infrastructure (NRC and NRTSI 2009)



OBJECTIVE	PERFORMANCE INDICATORS	ASSESSMENT CRITERIA											
		Health Impacts	Safety Impacts	Security Impacts	Environmental Impacts	Economic Impacts	Quality of Service	Access to Service	Adaptability	Asset P/R/D	Reliability of Service	Capacity to Meet Demand	Asset/Service
Public Safety	Condition rating of assets	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	A
	Rated capacity over maximum load	✓	✓			✓	✓	✓	✓	✓	✓	✓	A/S
	Rated capacity over actual load or volume		✓		✓	✓	✓	✓		✓		✓	A/S
	Reduction in number of accidents per 106 vehicles-km	✓	✓			✓	✓			✓	✓	✓	A/S
	Reduction in fatalities and injuries	✓	✓			✓				✓			S
	Remaining service life	✓	✓		✓	✓	✓			✓		✓	A/S
	Protection against climate change impacts	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	A/S
	Protection against deliberate acts	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	A/S
Public Health	Noise: acceptable level vs. actual dBa	✓			✓	✓	✓						S
	Reduction in emissions of GHGs, NO_x, SO_x, VOC	✓			✓	✓	✓						A/S
	Exposure to hazardous substances	✓			✓	✓	✓				✓		S
Mobility	Design capacity ratio over actual traffic load or volume	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	A/S
	Posted speed over average speed	✓	✓	✓	✓	✓			✓	✓	✓		S
	Condition rating of assets		✓	✓		✓	✓			✓	✓	✓	A
	Remaining service life		✓	✓		✓	✓			✓	✓	✓	A/S
	Closures or disruptions		✓			✓	✓			✓	✓	✓	A
Environmental Quality	Vehicle emissions	✓			✓	✓	✓						S
	Energy use				✓	✓				✓			A/S
	Vehicle noise (dBa vs. time)	✓			✓		✓						S
	Protection against climate change impacts		✓	✓	✓	✓	✓		✓	✓	✓	✓	A
	Use of recycled materials	✓			✓	✓		✓					A
	Reduction in emissions of GHGs, NO_x, SO_x, VOC	✓			✓	✓	✓						A/S
	Materials consumption	✓			✓	✓			✓			✓	A
Social Equity	Access to service				✓	✓	✓	✓			✓		A/S
	Affordability				✓	✓	✓	✓			✓		S
Economy	Benefit/cost ratio					✓	✓			✓			A/S
	Life cycle cost					✓				✓			A/S
	Asset value					✓				✓			A
Public Security	Protection against deliberate acts	✓	✓	✓	✓	✓	✓		✓	✓	✓		A/S
	Security measures costs / number of security breaches / population served	✓	✓	✓	✓	✓	✓		✓	✓	✓		A/S

2.5 Monitoring framework for bridges

In earlier NZTA research, Bush et al (2011) discussed the status of bridge performance monitoring sufficiently and this will not be repeated in this document. We have, however, described relevant information we have learned from the international experience.

The difficulty with bridge structures is that they are mostly managed according to two differing philosophies:

1. This involves a very detailed structural design approach to bridge management, concerned about the status of the bridge at the component level.
2. The bridge is viewed as a single entity within a larger system of structures on the network with hardly any detailed accounting of the true health of the bridge. For this approach a network-wide risk process is used to assess the overall performance of the bridge.

Obviously the main challenge with both the above approaches relates to the data collection framework required to make the performance monitoring valuable. The New Zealand performance framework is largely based on the US Federal Highway Administration (FHWA) proposed monitoring framework as documented by Ghasemi et al (2009). Figure 2.9 shows the monitoring of bridges from the perspective of both their condition/structural integrity and their functional aspects. The framework also recognises that not all bridges require the same data collection regime but this will be adjusted according to the priority of the bridge.

Figure 2.9 FHWA bridge performance framework (Ghasemi et al 2009)

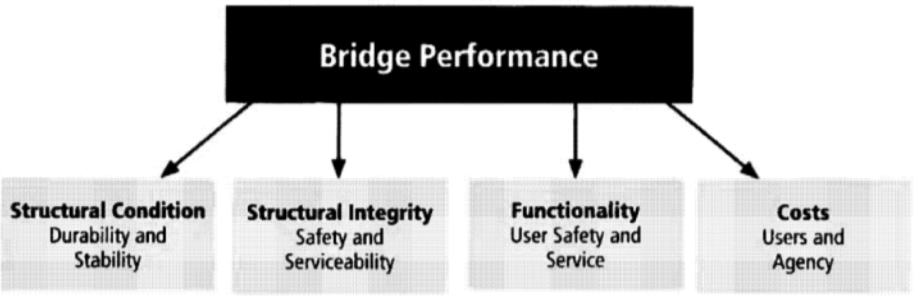
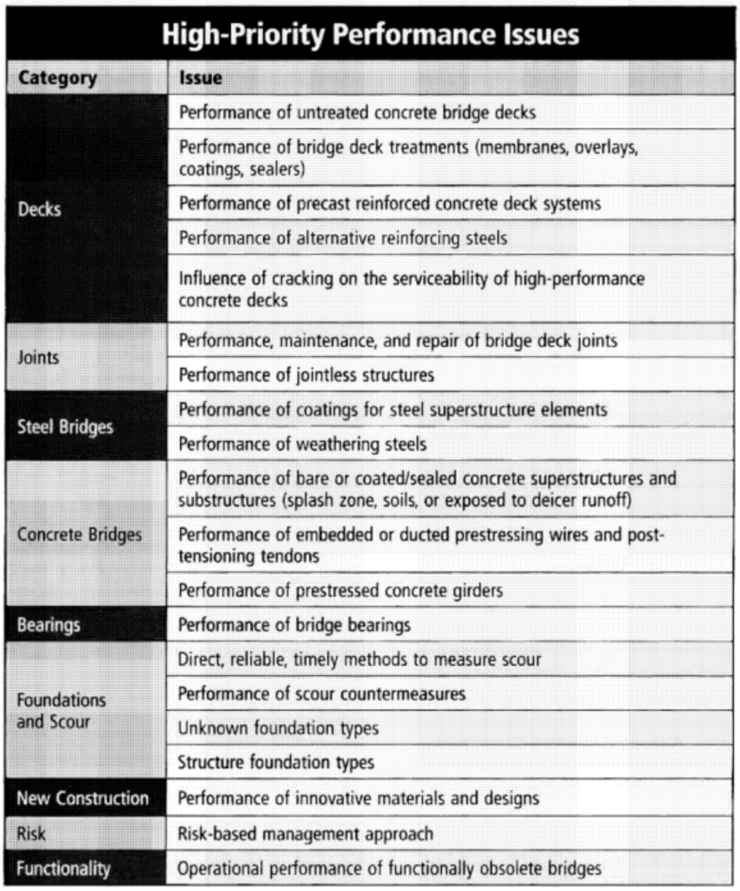


Figure 2.10 shows the performance issues that would be assessed for high-priority bridges. It is noted that although detailed data is required for these structures, not all the information would be required for all structures.

Figure 2.10 High priority bridge performance issues (Ghasemi et al 2009)



High-Priority Performance Issues

Category	Issue
Decks	Performance of untreated concrete bridge decks
	Performance of bridge deck treatments (membranes, overlays, coatings, sealers)
	Performance of precast reinforced concrete deck systems
	Performance of alternative reinforcing steels
	Influence of cracking on the serviceability of high-performance concrete decks
Joints	Performance, maintenance, and repair of bridge deck joints
	Performance of jointless structures
Steel Bridges	Performance of coatings for steel superstructure elements
	Performance of weathering steels
Concrete Bridges	Performance of bare or coated/sealed concrete superstructures and substructures (splash zone, soils, or exposed to deicer runoff)
	Performance of embedded or ducted prestressing wires and post-tensioning tendons
	Performance of prestressed concrete girders
Bearings	Performance of bridge bearings
Foundations and Scour	Direct, reliable, timely methods to measure scour
	Performance of scour countermeasures
	Unknown foundation types
	Structure foundation types
New Construction	Performance of innovative materials and designs
Risk	Risk-based management approach
Functionality	Operational performance of functionally obsolete bridges

Chapter 8 discusses the developed data collection framework for New Zealand and the proposed performance monitoring framework.

2.6 Summary of relevant findings from literature review

A summary of the main findings from the literature review is presented in table 2.5.

Table 2.5 Summary of findings from the literature review with recommendations for this research

Topic area	Description of observations from literature	Recommendation
Statistical consideration	Give consideration to outlier performance	Allow for appropriate reporting levels
Data collection	Measures should be independent of collection techniques	Develop an index concept for the New Zealand framework
	Use a sampling method that differs for road hierarchies	Investigate processes currently being used in New Zealand

Another aspect noticed in this review was the Canadian approach which included both physical asset performance measures and service level performance measures in their framework. This overcomes some of the issues associated with placing too much emphasis on either asset performance or customer performance areas. Although this aspect falls outside the scope of this project, it is a concept that could be considered by the New Zealand roading industry.

3 Performance framework review

3.1 Background to the problem

The development of a performance framework was the core of the project. Once the framework was established, it could be expanded to include new key performance indicators (KPIs) and KPIs for expanded asset groups. The main questions investigated at this stage included:

1. What are the perceived and real **gaps in the current framework (coverage)?** This question was answered largely through consultation with the NZTA and industry on the adequacy of the current approach.
2. Are all **statistical analysis**, summarisation and reporting techniques statistically sound, and are they well understood and applied by users? Some specific items for consideration included the loss of detail in averaging, stratification of data, and different reporting needs for trend analysis and benchmarking between peer authorities.
3. Does the current framework **provide sufficient information to assist decision makers** in the optimisation of investment?

At the time of the research, the individual indicators did not give a clear overall picture of network condition, the measures were not understood at a high level, and at a detailed level analyses did not explain observed trends. We have proposed a new framework for the NTZA to overcome some of these limitations. This chapter highlights some improvements in both the areas of 'what we report' and 'how we report'.

3.2 A tiered reporting framework

A number of performance management frameworks and benchmarking processes recognise the value of reporting on the basis of a tiered system (NRC and NRTSI 2009; Henning et al 2011). Managers at an executive level sometimes find it difficult to relate to detailed technical measures and prefer reporting at a higher level. At this level, they are looking for information that answers some of the more pertinent questions such as: are the NZTA's investments targeting the right/best outcomes? Mid-level managers in an organisation, such as the NZTA, require more detailed technical level information such as what impact is their investment achieving, what is the rate of change, where are early signals of risks?

There is a need to have high-level indicators for high-level reporting, but these need to be backed up with a clear understanding of the composition of the indicators thereby enabling determination of the true network performance from a variety of perspectives. We proposed to do this using a tiered/hierarchy system as set out below to give the NZTA the best of both worlds. In terms of this research's outcomes, KPIs must fulfil the information requirements for each of the reporting levels. Figure 3.1 sets out a proposed reporting approach as suggested from within the NZTA (Hendry and Brass 2010).

3.2.1 High-level indicators (strategic level)

High-level indicators comprise a figure derived from mid-level descriptive indicators. This indicator summarises as best as possible the key weighted effects and importance of the mid-level indicators for the network in question.

3.2.2 Mid-level indicators (tactical level)

These indicators are designed to describe the road structure from various perspectives including the condition of the pavement/surface, construction/design quality, and also user aspects delivered. A number of indicators for each of the main categories (surface/pavement/user) are used to frame the road's performance from various angles and feed up into the high-level indicators, eg:

- outright condition
- indication of construction quality, eg based on shortened life, early faulting
- ride quality based on road roughness profiles rather than on a selected roughness value.

It is important that the indicators are able to adapt to possible changes in operating conditions within the road environment such as traffic volume, volume of heavy vehicles, hierarchy and road use. This could be built into the formulas.

3.2.3 Low-level indicators

Low-level indicators are the basic measures/faults or data collected and analysed to form the mid-level indicators (eg alligator cracking, potholes, rutting, roughness). This information will likely be of more interest to maintenance engineers programming routine maintenance, sealing and pavement works, but may also point to trends in emerging issues on a network or around the country. Collection of these measures overlap with the condition rating research, so it is important that any low-level information requirements for performance indicators are factored into the condition rating review

Figure 3.1 Transport performance indicator structure (Hendry and Brass 2010)

	AUDIENCE	INDICATOR	USE
	Executive/strategic level	**Long term/overview**	**Network**
	Politicians/industry lobby groups/governing organisations/legislation/Treasury Infrastructure Unit	Community and government outcome statements	Long-term funding requirements/long-term trends, direction and goal setting
LINKAGE	Policy/strategic documents	Levels of service dashboard: • safety/efficiency/environmental quality/road classification	Affordability debate/defining customer expectations/consultation/risk management processes/modal option scenarios
	Management/tactical level	**Medium term/descriptive**	**Corridor/sub-network**
	Asset managers/funding organisations/industry steering groups/researchers	Performance indicators, eg network efficiency indexes/asset condition indexes/travel performance measures/customer satisfaction ratings/environmental performance indicators	Activity prioritisation process/programme decision making/performance monitoring/gap analysis/budget allocation
LINKAGE	Asset management plans/financial plans	Performance monitoring dashboard: • tracking performance measures/construction achievement/road profile/system use/cost of delivery	Minimising lifecycle costs Maximising benefits
	Technical/operational level	**Short-term/detail**	**Project**
	Engineering/contract/research/audit	Parameters/faults/data quality indication	Contract KPIs/budget tracking/customer service systems

3.3 Linking with the NZTA's outcome areas

Table 3.1 lists the top priority impact areas as defined by the NZTA (2011a). The table also indicates the relative importance of the various output classes that were identified as being relevant for this project (note larger circles suggest higher importance).

Table 3.1 Output and impacts areas for the NZTA (based on NZTA 2011a)

Output class	Desired long-term impacts							
	Better use of existing transport capacity	More efficient freight supply chains	Resilient and secure transport network	Easing of severe urban congestion	More effective vehicle fleets	Reduction and deaths and serious injuries from road crashes	More transport model choices	Reduction in adverse environ-mental impacts
Management of the funding allocation system	•	•	•	•	•	•	•	•
Renewal of local roads		●	●	•				
Maintenance and operation of local roads	•		•	•		•		
Maintenance and operation of state highways	●	●	●	•		•		•

Note: Only output classes relevant to this project are indicated

As indicated in the table, the areas of greatest importance from the perspective of this project primarily relate to more efficient freight supply chains, and a resilient and secure transport system.

Of the entire NZTA 2011 budget of $2,555,639 million, $819,100 million was invested for the operation, maintenance and renewal of New Zealand roads. This equated to more than a third of the NZTA's budget, emphasising the importance of protecting the investment through robust monitoring and planning.

In terms of linkage to the performance framework from the output class and impact areas plus the stated value of the assets, it was clear that the emphasis should be on monitoring:

- pavement health
- surface condition
- effectiveness and efficiency measures of maintenance programmes.

3.4 Monitoring performance at different reporting levels

The first issue that needs consideration in setting up a hierarchical reporting system is the aggregation or ‘rolling-up’ principles required to report measures at higher levels. These can be divided into two categories:

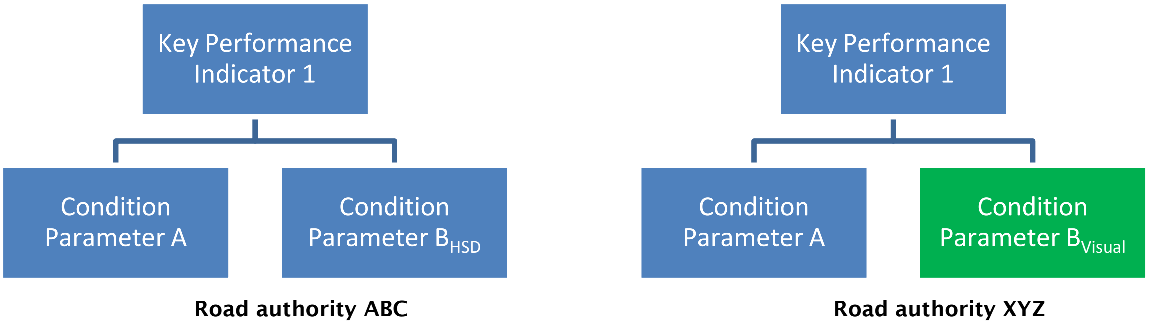
1. There are some measures that remain unchanged as they are reported at a higher level. For example, in the safety area the number of fatal or serious car crashes is well understood by all audience levels and is equally valuable at all hierarchies in its ‘raw’ format.
2. There are some technical measures that need to be changed when reported at a higher level. For example, engineers understand roughness reported in IRI, whereas this is a difficult concept for non-engineers to comprehend. In this regard, the target audience only needs to know whether roads are rough or smooth.

The ideal situation is to have the same KPIs for all road authorities and road hierarchies. Issues arise where different data collection methodologies are in place in each authority or for different road hierarchies. However, the ideal situation poses some challenges as explained in the following sections.

3.4.1 Issue 1: Not all authorities use the same processes to collect data

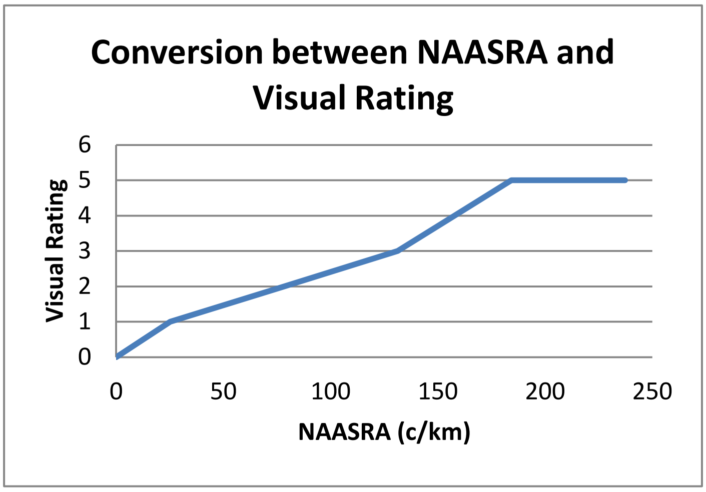
Referring to figure 3.2, the same performance indicator, KPI1, needs to be calculated for both road authorities. Both authorities collect condition parameter A using the same process, but for condition parameter B, authority ABC uses HSD and authority XYZ uses a visual rating with different units (say a 0–5 rating with 0 being perfect and 5 the worst condition) to determine the same condition parameter.

Figure 3.2 Aggregating data from different collection methods



In this case, there needs be a way of converting both to a common denominator when calculating the KPI. One way to convert them could be via a transfer function as shown in figure 3.3. For example, a NAASRA count of 130 equates to a visual rating of 3.

Figure 3.3 A common scale for different techniques



The relationship can be any shape but should ideally be determined from a comparison of both methods of measurement on a number of common roads over a range of values. Alternatively, 'expert opinion' can be used to determine the relationships.

This technique is not new and to a certain extent is already being used with the composite index approach that combines different measures into a single indicator. For example, the surface condition index (SCI) takes different surface-related indices and combines them into one overall index. This approach provides two opportunities for the framework, allowing:

1. The use of a single measure for condition items that are collected using different techniques (eg roughness)
2. A methodology of aggregating different indices into composite indices such as pavement and surface indices.

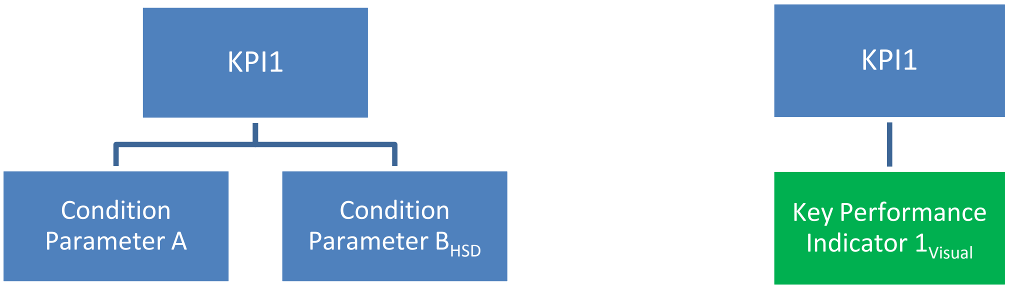
Note that other statistical practices recommended in this report are also relevant to indices. For example, the mean should always be reported in conjunction with other statistical measures such as standard deviation and some percentile measure such as 95th percentile values.

3.4.2 Issue 2: Accuracy and confidence issues

If the same condition parameter is collected using the same units of measurement – for example rutting from HSD in mm and rutting from a straight edge in mm then there are two options. Either both can be entered directly into the calculation for the KPI or, if it is known that one overestimates the value, an offset can be introduced to that value to determine an equivalent rut depth measured by the 'more accurate' method. Therefore it is possible for a 'correction' factor to be introduced to measures calculated this way.

In the example given in figure 3.4, none of the condition parameters required to calculate KPI1 are collected by road authority XYZ, which could mean a sub-network of low significance. In that case KPI1 could be estimated directly by a visual rating (eg windscreen survey, video footage, on foot). Issues about accuracy, subjectivity and confidence level would need to be understood. Otherwise, by having a common index, one may easily assume, incorrectly, that the same confidence level applies to both, thus emphasising the importance of having confidence levels assigned to the measures based on their origin.

Figure 3.4 Two authorities reporting different measures



Road authority ABC **Road authority XYZ**

3.4.3 Issue 3: The absolute value does not tell the whole story

In the development of a general framework for network level condition measurement and reporting, the following suggestions could perhaps be considered. First, to completely summarise the condition with respect to a specific measure, two general aspects need to be reported:

1. The current absolute value for that parameter (for example, the 90th percentile value for rut depth on a given sub-network). This value can be used to answer comparison questions such as 'which network is currently the worst or best?'
2. The current rate and direction of change for that parameter. These indicators could be used to answer questions such as 'which networks have deteriorated with respect to rutting in the last year', and 'which networks have showed the most rapid improvement over the last five years'.

Without both the position and rate of change indicators, a comprehensive and rational comparison of network condition and network performance is not possible.

For example, rutting is an importance measure from two perspectives:

1. It may be an indication of safety concerns. If the rutting increases above 15mm, the risk of potential water ponding and associated consequences of vehicle aquaplaning would reach unacceptable levels.
2. Rutting is also a strong indicator of pavement structural capacity of unbound based pavements, thus indicating the overall health of the pavement layers and subgrade. For example, many design methods accept 15mm as a structural failure point of a pavement.

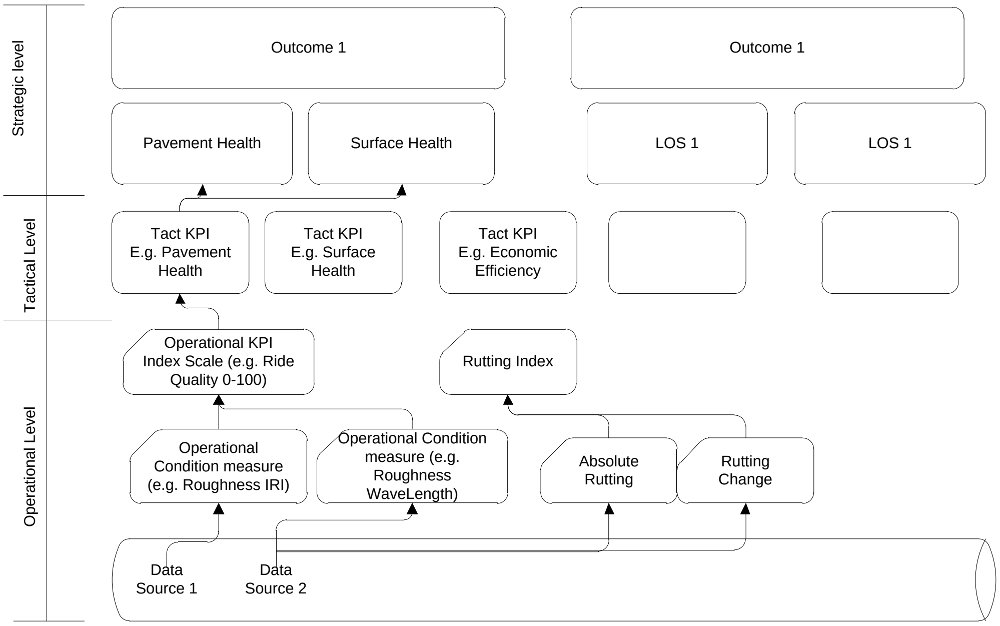
However, the absolute rutting value does not give a complete understanding of the situation of pavements on a network level. For example, there may be some pavements with say 12mm rutting that only increases by 0.1mm/year and other pavements may have 8mm of rutting that increases by 1.5mm/year. In this example, the pavements in the latter category are of greater concern, despite the fact that their current absolute value is lower than the other pavements on the network. Therefore, for some condition items, such as roughness and rutting, the combined effect of the absolute value and the rate of change of the measure need to be considered at tactical reporting level. However at a strategic level combining these effects into a composite index would be more appropriate.

3.5 Recommended performance management framework

Based on the information at hand, a generic framework recommended for the NZTA asset management area is illustrated in figure 3.5. The main characteristics for the framework are as follows:

- At a strategic level, the NZTA has defined the outcome areas and this framework needs to feed directly into these outcome areas. The way in which the LOS reporting will occur has not yet been finalised, but it may well include a star rating system similar to that used for safety issues.
- At a tactical level the overall health of the pavement and surface, and economic efficiency are reported.
- At an operational level, detailed technical measures should be reported at different levels of aggregation.
- The framework allows for composite indices as a reporting technique.

Figure 3.5 Recommended generic performance framework – concept only



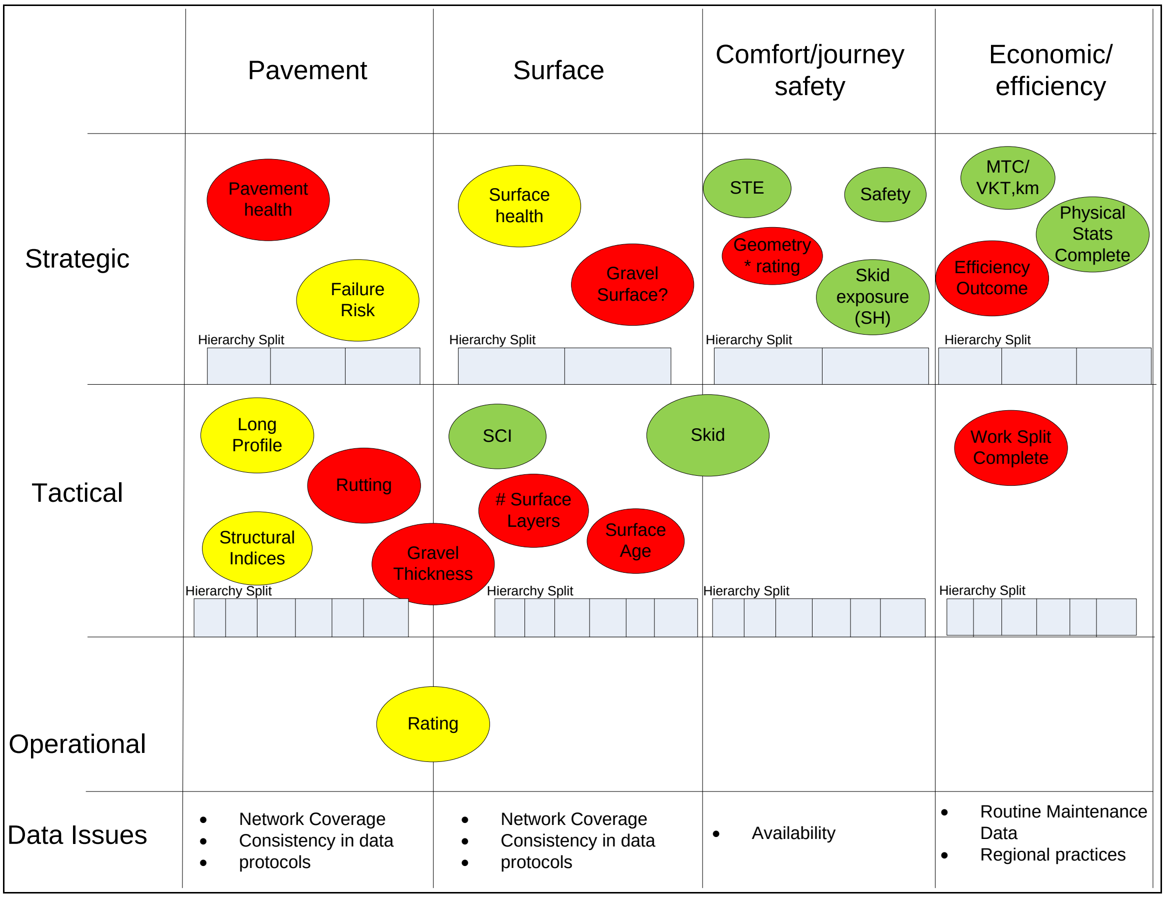
The focus of this research project was primarily in getting all data and lower reporting levels working properly. The next stage, the aggregation and 'roll-up' to the higher levels, was simpler and easier to achieve.

4 Development of new condition performance indices for road pavements

4.1 Overall status of performance measures

In order to sufficiently populate the proposed performance framework, a number of performance measures were considered. The suggested measures for the road network monitoring are presented in figure 4.1, classified according to their current development/use status. Note, in terms of the scope for this project, the comfort/safety area was excluded due to targeted work being undertaken in the safety area external to this research project. Also, unsealed roads were excluded from the research.

Figure 4.1 Development status of performance measures



Note: Red – new index needed

Yellow – some index exists but may need refinements

Green – no change required

The selected performance measures were based on the following three considerations:

1 Historical research projects were reviewed in order to identify opportunities for improving the utilisation of data for quantifying network condition.

2. Each performance stream, such as pavements, surface and economic efficiency, needs to be sufficiently populated with performance measures that ‘tell a comprehensive story’ regarding the particular area under consideration.
3. For each measure the available data was considered. Where data was not readily available to report on the given measures, the potential value of the desired information was weighed against the cost to collect it, before a decision was taken to include it.

It is clear from the figure that the weak areas of the performance measures are in explaining the pavement status and the economic efficiency of maintenance. Most of the surface-related indices exist but may need some refinement, or existing measures and techniques may not be in use. As a result, these were the primary focus areas of this research work. This chapter discusses the development of the new pavement indices suggested in the figure 4.1 and chapter 6 discusses economic efficiency.

4.2 Structural indices

4.2.1 Fundamental background

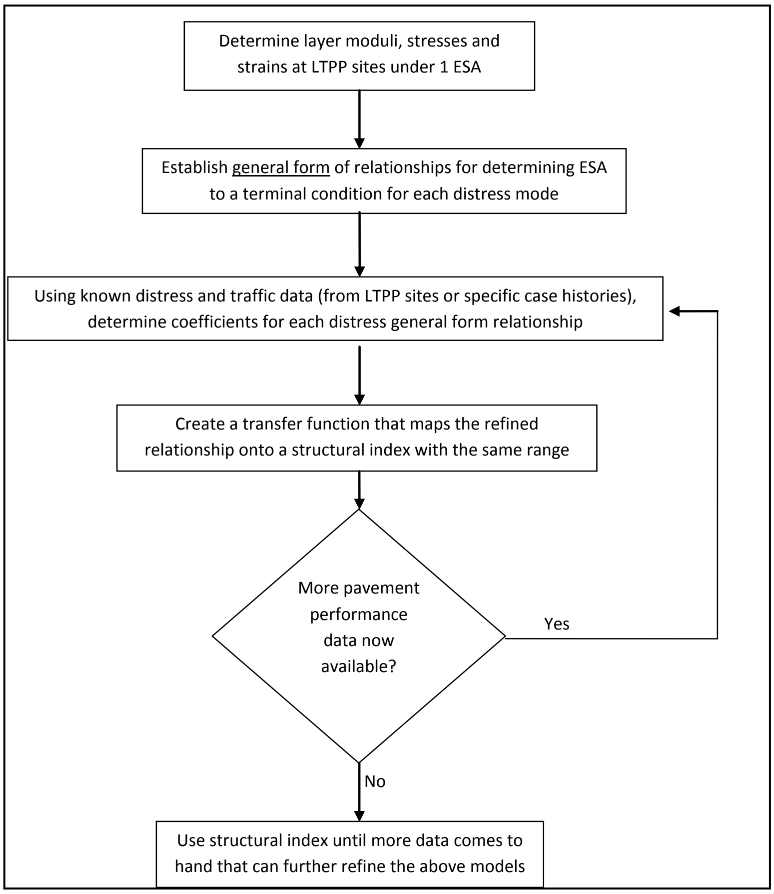
Any diagnostic process that determines the maintenance and rehabilitation of pavements requires correct pavement thickness data and structural capacity models for performance assessment. Pavement structural capacity is generally measured worldwide by the adjusted structural number (SNP). However, the SNP is unable to provide an indication of how a particular pavement structure would behave for a given layer configuration. For example a thin pavement constructed with stabilised layers may have the same SNP as a thick unbound pavement. Although the SNP for these pavements may be equal, their expected life may differ significantly.

As a replacement for SNP, Salt et al (2010) proposed an alternative structural parameter, termed structural index (SI). For each of the recognised structural distress modes (ie rutting, roughness, cracking and shear) a corresponding SI was developed. Salt et al (2010) investigated the process of refinement of partly derived SIs for rutting, roughness, cracking and shear. Analysis was carried out using sample network level data from the pavement network in Hastings district and known failure information stored in the road assessment and maintenance management (RAMM) software. The ability of SIs to enhance the accuracy of decisions related to the field of pavement asset management through improving the network level predictions of pavement performance was also examined.

Each SI is mechanistically derived and has the same range (1 to 8) and general distribution as the traditional SNP. As the amount of data from LTPP sites grows, the improved mechanistic understanding of pavement performance can be readily incorporated by refining (or redefining the basis of) the SI for each distress mode. Provided the base (raw FWD deflection) data remains stored in RAMM, updated SIs may be readily generated at any future time for any network

Figure 4.2 illustrates the process of determining the respective SIs. A normalisation process is involved where the expected life of each pavement (for a given failure mode such as rutting) is scaled to a predetermined range (say 0 to 100, or 0 to 8). If a pavement scores 50 (on a 0 to 100 scale) on the rutting index (RI), it means that this pavement is exactly in the centre of the expected life for the network on the basis of the subgrade failure mechanism. If this pavement also has a flexure index of say 30, a roughness index of say 60 and a shear index of say 55, then because the flexure index is the lowest, it means that this pavement would most probably fail due to cracking.

Figure 4.2 Process of determining structural indices (Stevens et al 2009)



4.2.2 Proof of concept

Salt et al (2010) tested the concept in the modelling area:

Since the index was based on the same scale as the SNP it was proposed that it could simply replace the SNP in all pavement deterioration models. The first test was undertaken on the crack initiation models developed by Henning (2009). The probability of cracking is forecast for pavements by considering the composition of the pavement, traffic loading and the age of the surface. The testing was done in two steps:

1. The SIs for current pavement deterioration models were applied by directly replacing the SNP with the SI. This test had a negative outcome and resulted in progression to the next step as the SI was fundamentally different from the SNP, thus suggesting a simple replacement was not valid.
2. The SIs were incorporated in the model development stage, ie they were included as independent variables in the regression analysis. This test had a promising outcome showing that the indices were more significant indicators than the SNP.

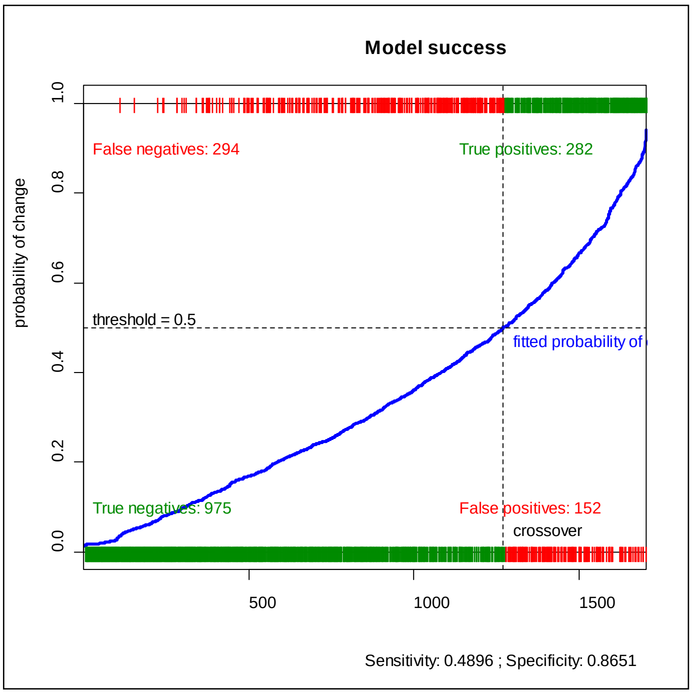
It was expected that the latter approach would yield a better correlation to the data, since the model coefficients were changed due to the inclusion of a different structural component. Two observations were made from these tests (Salt et al 2010):

- The multi-variant analysis confirmed that the SI was indeed a better forecasting factor than the structural number. As expected, this also led to a far better model outcome as depicted in figure 4.3.

The figure displays the number of occasions where the model correctly forecast the true behaviour (correctly predicted the cracked or non-cracked status) against occasions where the forecast was wrong (ie predicted a section as being cracked when it was still uncracked and vice versa.

- What was not expected, though, was the significant difference in the outcome from comparing the two methods, thus suggesting that the SNP could not simply be replaced in the pavement models by the SI. A full calibration of the models would be required using the SIs.

Figure 4.3 Crack probability model containing $\mathrm{SI}_{\mathrm{flexure}}$ (Salt et al 2010)



Note: The sensitivity is defined as the ability of the model to find the 'positives', ie sites that actually cracked: Sensitivity def = (true positives)/(total positives). In this case 282/(282+294) = 0.4896.

Specificity is the proportion of 'negatives' that are correctly predicted, which is:

Specificity def = (true negatives)/ (total negatives). For this case it is 975/(975+152) =0.8651.

The model is good at finding sites that did not crack (975 out of 1127), and is average at finding sites that did crack (282 out of 576).

The next step was evaluating the usefulness of the SI as a direct indicator of maintenance need. While this showed expected trends in the results, it did not have a one-to-one relationship with the field decisions. This could have been because the SIs were not available as part of the field validation process. However, in reviewing the results, it was noted that the indices were extremely helpful in making appropriate decisions. For example, the low indices for rutting and shoving highlighted that some scheduled resurfacing was not appropriate, which suggested a need for rehabilitation.

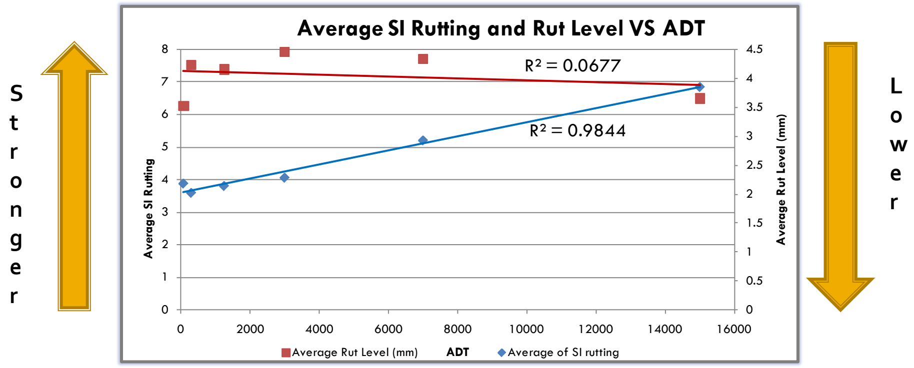
This research confirmed the value of the SIs, but it recommended that a full network level analysis was required prior to accepting the SI concept for wider adoption in New Zealand.

4.2.3 Network level reporting

On the basis of results obtained in previous research, a research project was undertaken to discuss the applicability of the SIs at a network level (Perera and Islam 2010).

These studies compared the four SIs with the performance on the road network and the maintenance programme. Figure 4.4 shows a comparison between the RI and actual rutting, both plotted against traffic volume. Figure 4.5 depicts the time to crack initiation for given ratios of traffic load divided by the power of the SI (note that this ratio is used in the HDM -4 crack initiation model).

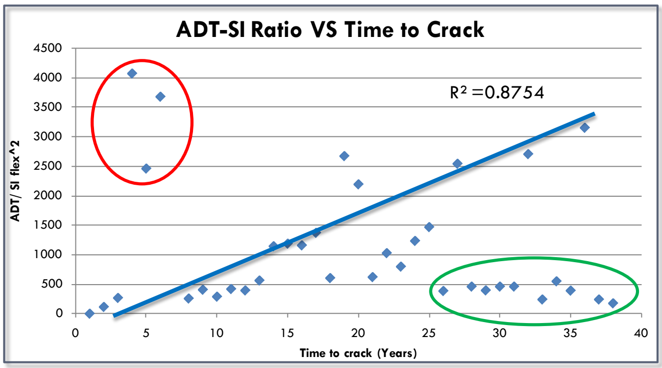
Figure 4.4 Rutting structural index compared with actual rutting



As traffic volume increases:

- Average SI rutting increases
- Average rut levels decrease

Figure 4.5 Flexure (cracking) index compared with actual crack initiation



- Red oval represents weak pavements
- Green oval represents over strengthened pavements
- The linear trend represents well designed pavements

Observations of these two graphs include:

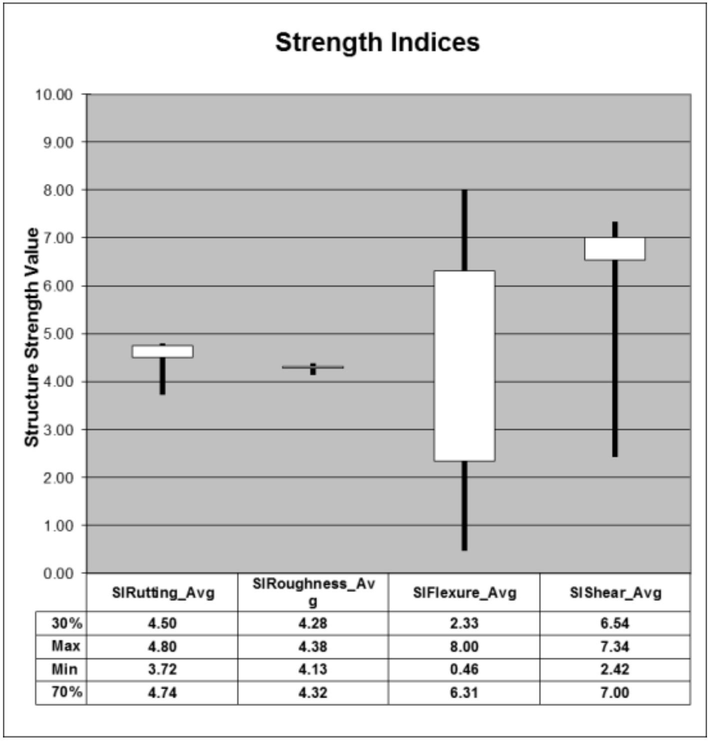
- The RI produced expected results, with higher volume roads normally having a higher RI. In order to achieve this, stronger pavement designs were used.
- The crack initiation comparison with the structural flexure index gave surprisingly good results. Although initially it appeared to have a weak correlation, with further investigation a strong correlation was found by removing the outliers. Weaker pavements (for its relative traffic) took longer to crack. Most of these weaker pavements failed due to rut mechanism as it mostly consisted of unbound granular pavements that were not prone to cracking. However, there were clear zones in the outliers representing over-designed and under-strength pavements with the resulting long and short lives according to when the cracking began.

Likewise, the results obtained for roughness and shear also gave expected results thus confirming the value of SIs to indicate actual behaviour of pavements (refer to Salt et al 2010).

The network tests also involved a comparison between strength data and actual maintenance decisions. The results gave unexpected outcomes and further procedures are being developed to take account of SIs in the development of maintenance programmes. We would recommend, at this stage, using the SIs as measures for monitoring network health only.

Following the confirmation that the SIs had a reasonable correlation with actual performance, a sample of a network (8km) was analysed and a distribution of the respective indices is depicted in figure 4.6. This figure shows plots where the 30th and 70th percentiles are the boundaries of the boxes and whiskers and represent the minimum and maximum values. Most of the indices' values are well above a level of 2.5 with only the flexure index having values below that. Both the SIs for rutting and roughness have high values well above 4. The largest variation occurred within the SIFlexure thus suggesting that this sample road would most probably be prone to cracking rather than rutting, roughness or shear issues.

Figure 4.6 Structural index distributions for a sample of the Wellington network

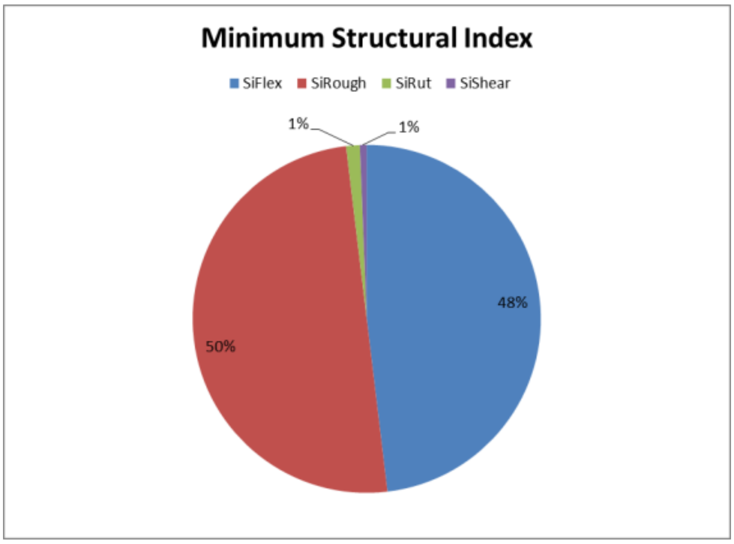


	SIRutting_Avg	SIRoughness_Avg	SIFlexure_Avg	SIShear_Avg
30%	4.50	4.28	2.33	6.54
Max	4.80	4.38	8.00	7.34
Min	3.72	4.13	0.46	2.42
70%	4.74	4.32	6.31	7.00

The information conveyed in the figure correlates very well with the expected outcome for a road of this nature. This road length is a piece of motorway consisting of an asphalt surface constructed on a relatively stiff pavement structure, which has inflexible/stiff layers on top of a relatively strung sub-structure. It would be expected that where an imbalance in stiffness exists (ie a very stiff layer on a very flexible layer), there would be a significant cracking risk. The figure supports this behaviour and some isolated areas were identified with possible cracking issues. Other indices such as roughness and rutting are not an issue on this relatively strong pavement.

The proportion of the network with the lowest SI values was considered on a strategic level. Figure 4.7 illustrates the lowest structural values for the same length of motorway. This figure shows that for approximately 50% of the network SIRoughness is the lowest index value with SIFlexure very close at 48%. Comparing this result further with figure 4.6 reveals that cracking may be an issue in isolated areas but roughness is not an issue for this network given its relatively high value. The figure therefore illustrates that the network portion on its own may give misleading information in terms of the issues occurring on the whole network. Information from this section should be supplemented by data from a portion of the network where there are issues for the given indices. For example based on this road length, it is estimated that there may be cracking on only 30% of the network, despite the fact that 48% of the surface has a minimum SI flexure value.

Figure 4.7 Proportion minimum values for structural indices



4.2.4 Application discussion

The SIs show promise as an indication of the network pavement structural capacity. However, it should be kept in mind that this does not necessarily correlate with actual performance. Also, it should always be jointly considered with the traffic loading, as a low SI may indicate a weaker road section. However, if this road is subjected to low traffic loading only it may be performing according to its design. Some strong points and limitations to these indices are:

Strong points:

- SIs give indications of the pavement structural capacity of road lengths in terms of specific failure modes.
- SIs are capable of highlighting network performance issues that may not yet be visible, ie the indices give an indication of potential risk aspects on a network. For example, if a network has low SI rutting values, this may be an indication that it is prone to rutting if suddenly trafficked by heavily loaded trucks.
- SIs provide strong supporting evidence for the type of rehabilitation/maintenance considered.

Limitations:

- SIs cannot be used in absolute comparisons as pavement capacity is also a function of traffic loading.
- SIs are processed from FWD data which can sometimes be variable due to moisture conditions during surveys.
- Ranges of poor performance are not well defined as performance can be affected by different material types (ie a low structural number on one subgrade material type may indicate a different performance

from the same value on a different subgrade material. For example on pumice subgrades, FWD tests normally suggest high deflection of the pavement, which does not necessarily mean it will rut.).

The recommended use of SIs is summarised in table 4.1.

Table 4.1 Recommended application of structural indices

Item	Recommendation
Tactical level	
Reporting format	Report all four strength indices according to box-and-whisker plots. Historical trends can also be considered; however, FWD surveys are not undertaken on a regular basis as with HSD surveys and trends would only of value for longer analysis periods.
Value of the indices (the story it tells)	SIs are useful for quantifying the load-carrying capacity of a network. In particular they will highlight specific performance issues associated with a network (eg rutting or cracking). They cannot be used in absolute comparisons, without also comparing traffic loading.
Expected ranges	Since the SIs indicate capacity they must be interpreted within the context of the network use (ie traffic loading) and the actual performance (ie current performance). Therefore, SI values do not have a definitive range but rather expected ranges for a given network or traffic use. The following ranges may be of some use: • 0–1.2 – very low values expected of weak pavements or pavements that are failing • 1.21–1.8 – low volume road spectrum, only light traffic • 1.81–2.5 – typical for most New Zealand rural road networks, some higher volume roads • 2.51–3.5 – stronger chip seal pavements –relatively new • 3.5–5 – higher volume asphalt surface pavements • >5 motorways.
Strategic level	
Reporting format	At a strategic level the SI can only be used as a contextual index. Proportions of the minimum values of networks should be displayed (refer to figure 4.7). This figure can be further enhanced by colour coding problem portions of the network.
Value of the indices (the story it tells)	The network proportion distribution indicates the minimum SIs provide context to network use, actual condition and maintenance needs. For example, if a network shows high potential for cracking (low SIFelxture values) will typically associated with network with high cracking and/or higher resurfacing requirements.
Expected ranges	No expected ranges are available.

4.3 Rutting index

4.3.1 Fundamental background

- The goal of this research was to develop a rutting index (RI) that could effectively quantify the structural performance and behaviour of a pavement. Rutting is an important measure as it gives an indication of safety issues. Deep rut depths may be associated with aquaplaning issues under certain geometric road conditions. Rutting is also an important indicator of pavement structural capacity, especially of thin flexible chip seal pavements.

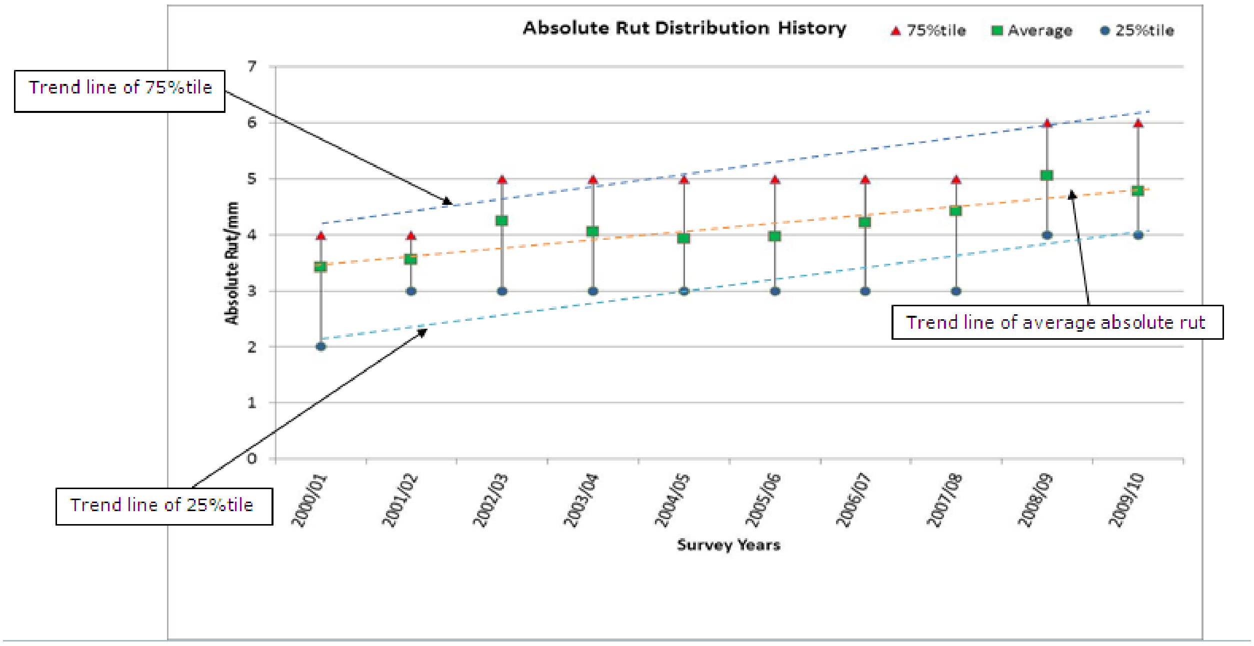
As a starting point, network statistical reporting of rutting was investigated (refer to figure 4.8) using data contained in both the RAMM database and from LTPP site data. There are a number of observations that can be made from this figure including:

- The rutting on this network has increased, although the level of increase has been relatively small, for example, the average rutting increased from 3.5 to approximately 4.8 mm. Note this also included a technology shift during 2001 and 2002 when all reported rut levels increased.
- The distribution of rutting has changed. Note that the rate of change is different for the 25th, average and 75th percentiles.
- There was an overall increase in the higher rut levels (75th percentile) over time.

Based on the observations and recommendations from the literature review it is evident that rut reporting should take account of:

- the entire rut level distribution for effective trend monitoring (change over time)
- both the rut levels and the rut rates for relative comparisons.

Figure 4.8 Historical rutting trend on a road network



It was decided to establish an index with a scale ranging from 0 to 100 where a RI of 100 indicated the ideal performing pavement with no evidence of both absolute rut and incremental rut. A RI of 0 on the other hand indicated the worst pavement performance (refer to table 4.2 for an idea of condition ranges within the RI scale). Hence on the basis of this along with the two performance indicators we developed our base RI:

$$Rutting\ Index = 100 - (x\ \times Absolute\ Rut + y\ \times Incremental\ Rut) \qquad \text{(Equation 4.1)}$$

The parameters x and y are the relative importance of the two key performance parameters. The importance weighting of incremental rut should be greater than the importance weighting for absolute rut (ie y >x). However, relative weightings between these two could not be established subjectively, as they would vary between networks, and it was therefore decided to base the weightings on terminal/failure criteria. It was deemed that for an absolute rut of 20mm and an incremental rut of 2mm a rut index of roughly 30 would be expected. By applying this to the above formula with several iterations it was possible to back calculate x and y to be 2 and 15 respectively. Therefore our initial index became:

$$Rutting\ Index = 100 - (2\ \times Absolute\ Rut + 15\ \times Incremental\ Rut) \qquad \text{(Equation 4.2)}$$

The next step was to manipulate the local authority or state highway data in a way that normalised both absolute rut and incremental rut to the same scale. Therefore each normalisation constant for each performance indicator was determined based on its respective maximum value. Hence, through calculation, it was determined that in order to normalise absolute rut the constant is 3 and for incremental rut the constant is 27.5. The following procedure depicts the process in order to determine a rut index for a given pavement:

$$Normalised\ Absolute\ Rut = \left\{\frac{AbsRut_i}{max(AbsRut_i\ to\ AbsRut_n)}\right\} \times 27.5 \qquad \text{(Equation 4.3)}$$

$$Normalised\ Incremental\ Rut = \left\{\frac{IncRut_i}{max(IncRut_i\ to\ IncRut_n)}\right\} \times 3 \qquad \text{(Equation 4.4)}$$

$$Rutting\ Index = 100 - (2\ \times Normalised\ Absolute\ Rut + 15\ \times Normalised\ Incremental\ Rut) \qquad \text{(Equation 4.5)}$$

Where: Absolute rut: $AbsRut_i$ is the absolute rut

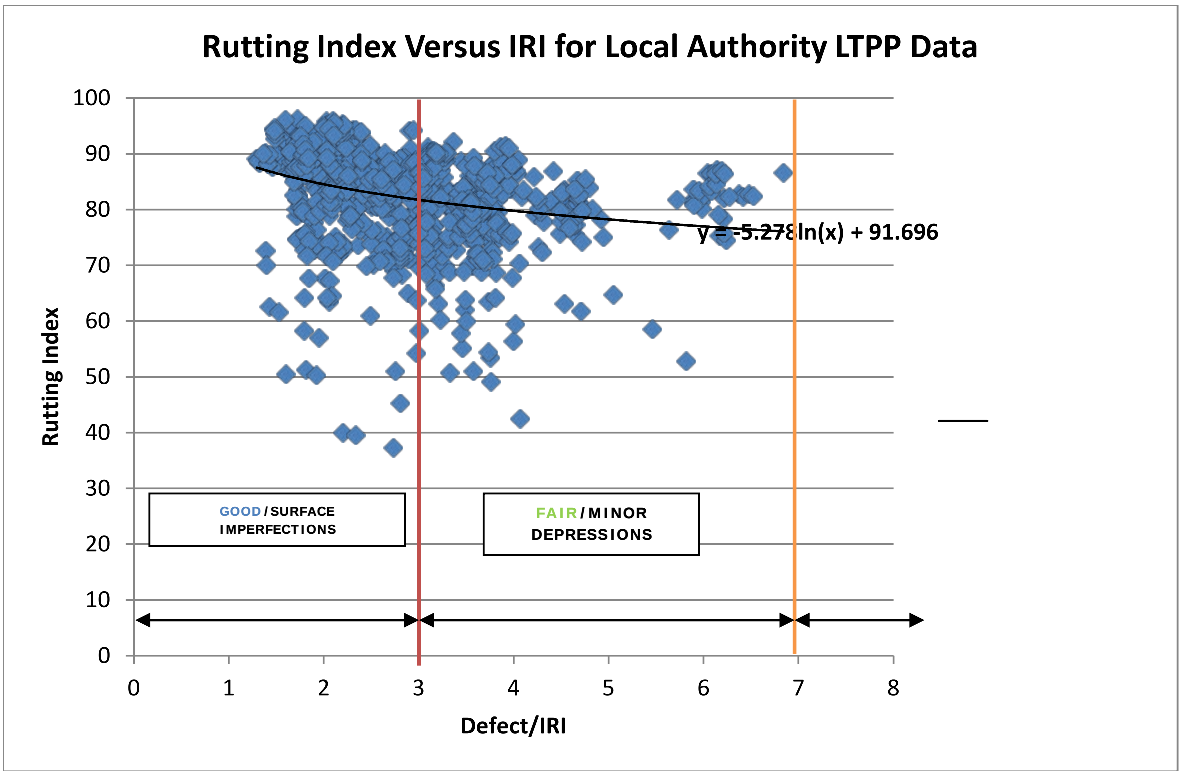
$IncRut_i$ is the incremental rut.

4.3.2 Proof of concept

The RI was calculated for both network data and LTPP data and meaningful distributions were obtained for both these datasets. It was, however, observed that the full integer reporting of rutting on a network level caused some difficulty in the calculation of incremental rut depth since the incremental rutting is normally a portion of a millimetre. It is therefore recommended that rutting be stored and reported to one decimal point in order to assist in the calculation of the RI.

In order to develop an understanding of the index, it was plotted against IRI, used as an independent measure of the defectiveness of the pavement. Although a direct relationship between IRI and rutting is not expected, it is generally accepted that older pavements would have both these defects in increasing levels. The graph (see figure 4.9) does show the expected trend; with increasing IRI a gradual decrease in the RI, indicating the transition from a good performing pavement to a poorly performing pavement, is evident. Note the ranges in conditions are indicative only. In order to categorise the pavements in terms of good, fair and poor, an IRI scale was used (note the ranges in conditions are indicative only). It is observed that the distribution of the RI follows the expected coverage of the range with the majority of the pavements having low stable levels of rutting corresponding to an index range between 80 and 95. However, there are also indications that on poorer pavements the values start decreasing below levels of 70 with some extreme cases having RIs as low as 30.

Figure 4.9 Rutting index versus IRI for local authority LTPP data network reporting



4.3.3 Network reporting

Figures 4.10 and 4.11 illustrate the rut depth change over time for the state highway network. It is evident from these graphs that the rut depth has increased slightly, despite regions reporting that rutted sections were targeted and the increased rut was not perceived to be an issue.

Figure 4.10 State highway rutting trends (rut > 10mm) (NZTA 2009)

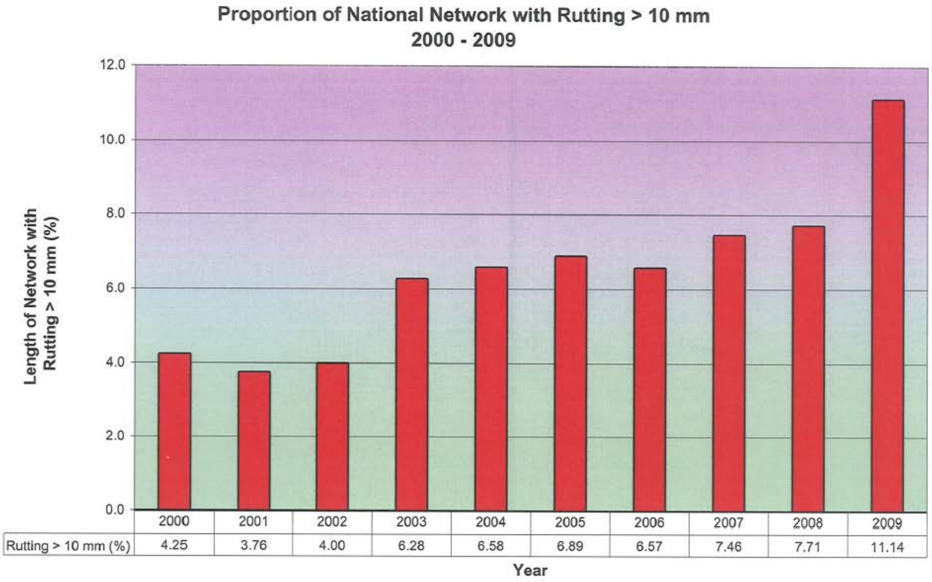
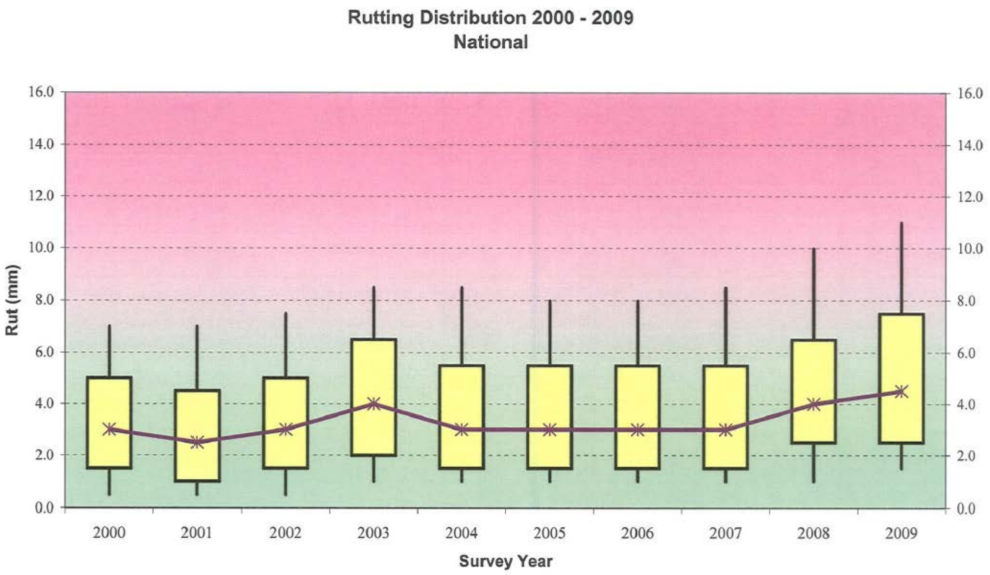


Figure 4.11 State highway rutting distribution trends (NZTA 2009)



These absolute rut changes can be compared with the RI results presented in figures 4.12 to 4.14. Note that where NZTA (2009) summarises ruts in all lanes, the figures only report the outside lane rut depths. In the box-and-whisker plots for the RI, the boxes include the 30th to 70th percentiles and the whiskers include the 10th and 90th percentiles. Significant changes were observed in these graphs including:

- There was a slight reduction in the left wheel path RI between 2008 and 2009. For example, the 30th percentile reduced from a RI of 76 to 71.
- The RI for the right wheel path displayed a significant improvement with the 30% percentile improving from a RI of 78 to 88.
- The lane average (both wheel paths) also showed some improvement, which was probably due to the improvement in the right wheel path.

Figure 4.12 Rutting index changes for the state highway (left wheel path)

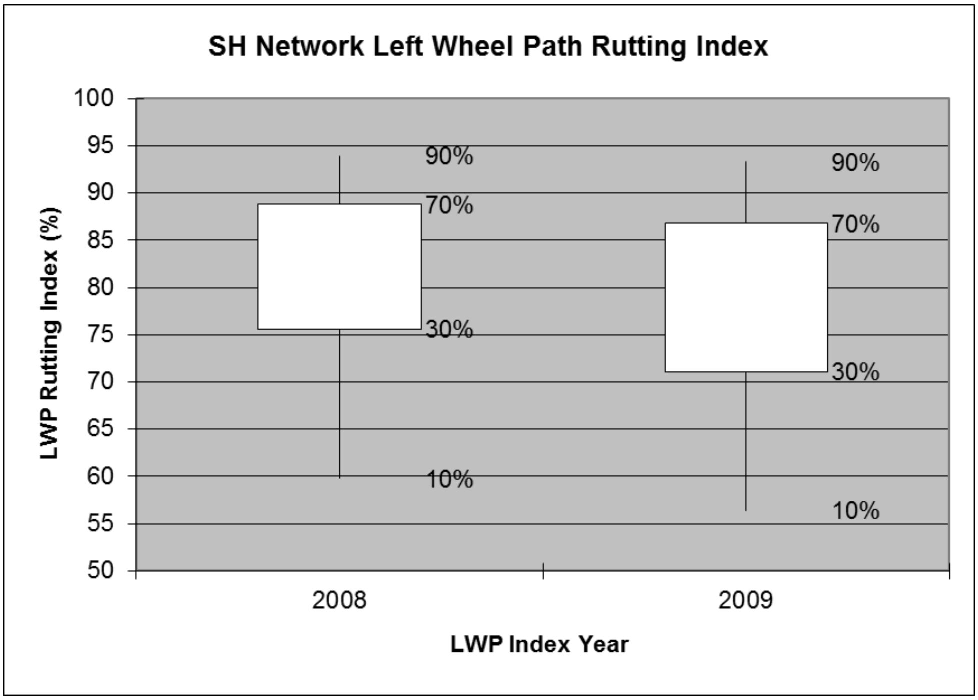


Figure 4.13 Rutting index changes for the state highway (right wheel path)

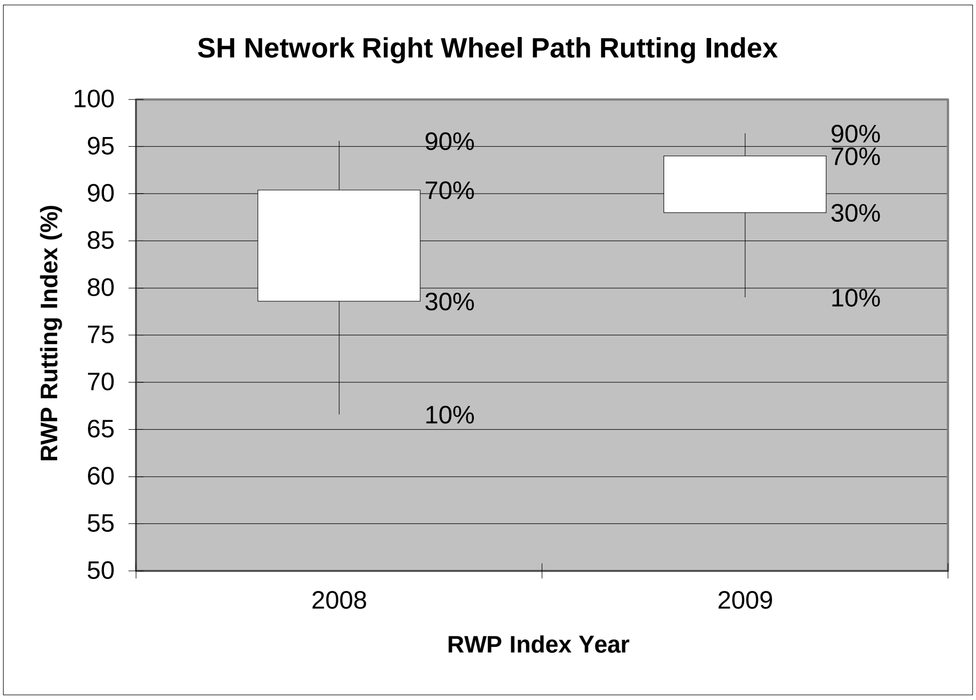
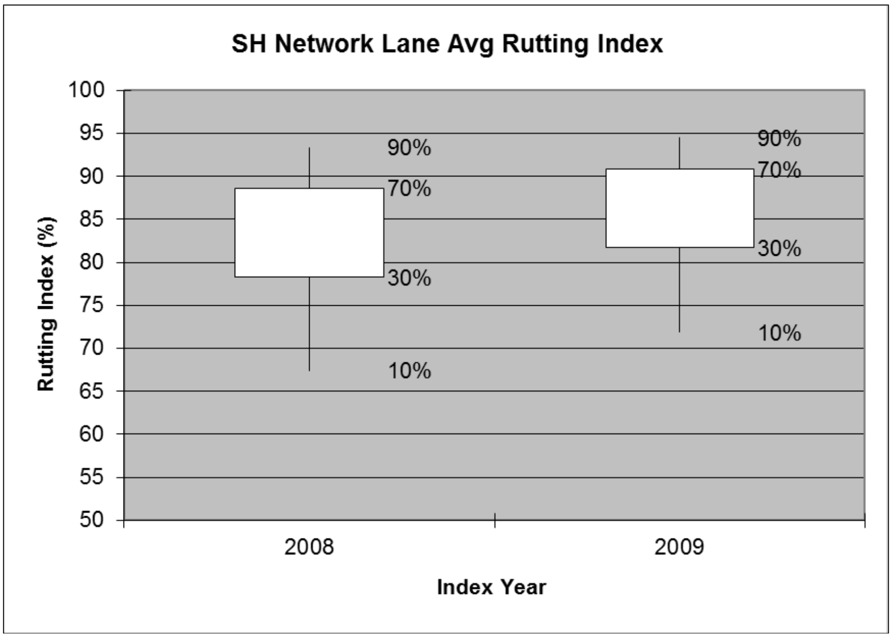


Figure 4.14 Rutting index changes for the state highway (both wheelpaths)



The outputs from the graphs suggest the RI is sensitive to changes in rutting on the network. At this stage it was not yet determined whether the sensitivity of the RI was appropriate as it was still functioning on full digit measurements. In addition, the weightings assigned to the absolute rut depth versus the change in rut depth would require some adjustment on the basis of more experience with the indices.

4.3.4 Application discussion

It is believed that the RI will provide useful information for network managers as it considers both the actual and change in rut depth. The index seems to be functioning as intended but more experience is required to refine it to a state where it provides the appropriate trends. For that reason it is advisable to report it in conjunction with the absolute rut trends.

Table 4.2 Recommended application of rutting indices

Item	Recommendation
Tactical level and strategic level	
Reporting format	Report according to box-and-whisker plots, presented for at least the past three years.
Value of the indices (the story it tells)	The RI gives an understanding to the rut trends on networks. Since it combines the absolute rut and rut change, it gives a better overall picture of the network structural status.
Expected ranges	• RI >75 minor rutting with minor deterioration • RI = 50 to 74 notable rut depth with some deterioration (eg 8mm rutting changing at 1mm per year ->RI = 69 • RI =30 to 49 significant rutting and/or rut deterioration (eg 15mm rutting changing at 2mm per year ->RI = 40 • RI<30 – failed section.

4.4 Road longitudinal profile changes

4.4.1 Fundamental background

Current road roughness deterioration modelling and analysis tends to focus on the prediction of roughness progression in terms of the change in IRI over time. Since IRI simulates the response of a specific type of vehicle (quarter-car) with certain damping characteristics, it masks the actual profile change of the road pavement. Understanding the true deterioration of roads in terms of the actual profile change and identifying the actual mode of road roughness deterioration will help road controlling authorities (RCAs) refine their specifications on road roughness requirements for road design, construction and maintenance, to reduce their adverse influence on roughness.

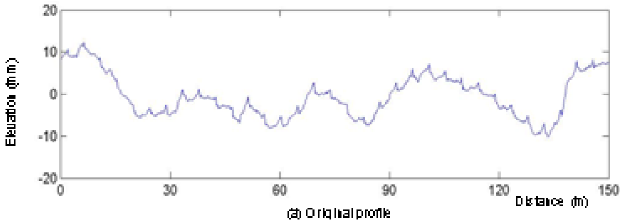
A recent research project, titled 'Identifying pavement deterioration by enhancing the definition of road roughness' (Brown et al 2010), looked at an alternative method for analysing and defining the roughness of different pavement sections of the New Zealand road network by analysing the characteristics of the longitudinal profile of the road surface using wavelet analysis.

The analysis used the longitudinal profile data collected on the New Zealand LTPP programme over the past eight years and processed it using wavelet decomposition to split the longitudinal profiles into a number of wavebands and then calculated the relative energy within each wave band. Techniques for such analysis included Fourier transform, digital filtering (lowpass filtering to remove noise or highpass filtering to remove trend) and wavelet transform.

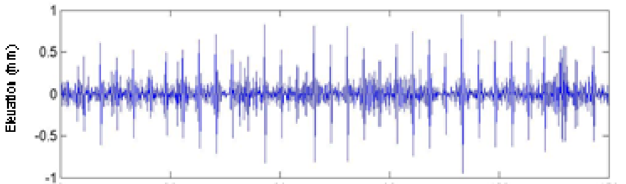
Fundamentally, the wavelet analysis offers the use of wavelet functions to satisfy certain mathematical requirements to represent data or other functions. Using wavelet transforms, researchers are able to decompose signals into different frequency components and present each component with a resolution matched to its scale. Finally, this results in a collection of time and frequency representations of the signal in different resolutions (refer to figure 4.15).

The major advantage offered by wavelet analysis is its ability to perform local analysis whereby it allows researchers to analyse the localised area within a larger signal. Therefore wavelet analysis is able to reveal some key aspects of data that other signal analysis techniques overlook. In terms of road roughness analysis, these key aspects include trends, localised surface irregularities such as surface ravelling caused by pavement distresses, potholes, surface heaving and bumps, breakdown points, discontinuities in higher derivatives and self-similarities (Liu et al 2005).

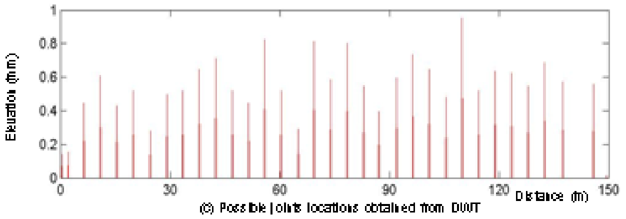
Figure 4.15 Profile of a road pavement (Lui et al 2005)



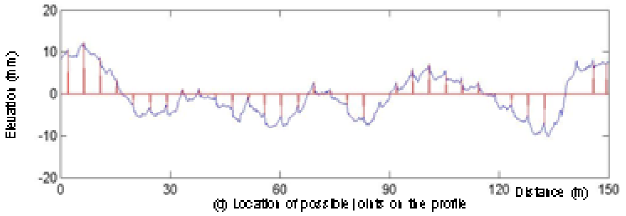
(a) Original profile



(b) Detail sub-band d_1 of DWT



(c) Possible joints locations obtained from DWT



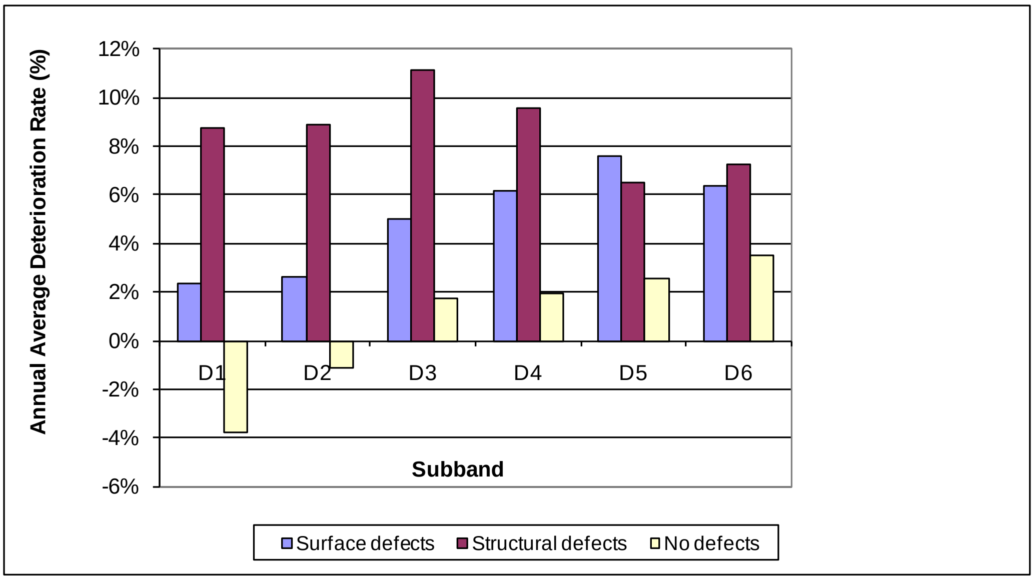
(d) Location of possible joints on the profile

For the purpose of the network analysis, LTPP data was classified into three failure states (no defect, surface and structural). This classification was used to investigate the deterioration within each sub-band and the outcome is depicted below in figure 4.16.

Some significant observations from this figure include:

- The three different failure mechanisms follow completely different patterns for the respective wavelength distributions.
- New sections or stable sections (no visible defect) show a wavelength energy reduction for the short wavelengths (D1 and D2 or <2m). It is suspected that this trend is mostly influenced by the change in texture during the earlier years of pavement and surface life. Furthermore, initial densification due to traffic loading, takes place in the first couple of years after construction. This densification also leads to a smoothing action of the pavement surface and helps explain network trends that indicate an initial reduction in roughness on new and rehabilitated sections.
- Sections displaying structural defects mostly result in roughness changes in the shorter wavelengths (D1 to D4).
- Sections displaying surface defects have more effect on the long wavelength spectra (D3 to D6), although this trend was not observed in all sections.

Figure 4.16 Deterioration patterns for different failure mechanism states (Brown et al 2010)



The results depicted above potentially have promising applications and should be explored further. For example, if these patterns are universal for typical New Zealand roads, they could be used as an indicator of the structural integrity of pavements. It is therefore recommended that this concept is tested further on network level data. The trends match current roughness deterioration theory, as follows:

- Initial densification of flexible pavements and re-orientation of chips of thin chip seals, will have an expected roughness reduction during the initial years following construction. Given the nature of these changes most of the reduction will take place in the short wavelengths rather than in the longer wavelengths.
- For most of the stable phase of pavement deterioration a slow increase in roughness is expected in the longer wavelengths. The pre-dominant factors for this roughness increase will be caused by environmental impacts.
- One of the signs of advanced pavement deterioration includes a significant variation in support from both the subgrade and the pavement layers. These variations are noticed in FWD tests. Therefore, a significant relative increase in roughness for the shorter wavelength sub-band will be more evident during these stages of deterioration.

The research was also successful in demonstrating the effectiveness of isolating different deterioration patterns for different networks. For example, it has been identified that rural and urban roads deteriorate in different parts of the wavelength spectrum. Note, that although this difference was not significant for IRI, a statistical significant difference (95% confidence) was observed for the wavelengths (refer to table 4.3).

Table 4.3 Statistical comparisons between urban and rural sections

Sub-band		**d1 (05-1.0)**	**d2 (1-2)**	**d3 2-4)**	**d4 (4-8)**	**d5 (8-16)**	**d6 (16-32)**	**ΔIRI (m/km/year)**
Urban vs rural	p value	0.22	0.09	0.08	0.02	0.05	0.08	0.1746
	Significant difference	No	Yes	Yes	Yes	Yes	Yes	No

The conclusion from the research was that the wavelet analysis showed promising results in terms of its value as a performance measure. Certainly some of the limitations associated with the IRI were overcome. There were, however, a couple of implementation questions left unanswered, as follows:

- How practical is it to process large quantities of data, for example for an entire network at a time?
- Does the reporting offer useful information at a network level?

These questions are investigated in the following section.

4.4.2 Network reporting

Wellington SH1 road profile roughness was analysed using wavelet analysis. The wavelet energy spectra were produced for three different road classes of the Wellington state highway network with the aim of investigating the value from the outputs. The results from this analysis are depicted in figure 4.17.

Figure 4.17 Change in roughness sub-band energy levels in Wellington SH1 road network (Deng and Henning 2013)

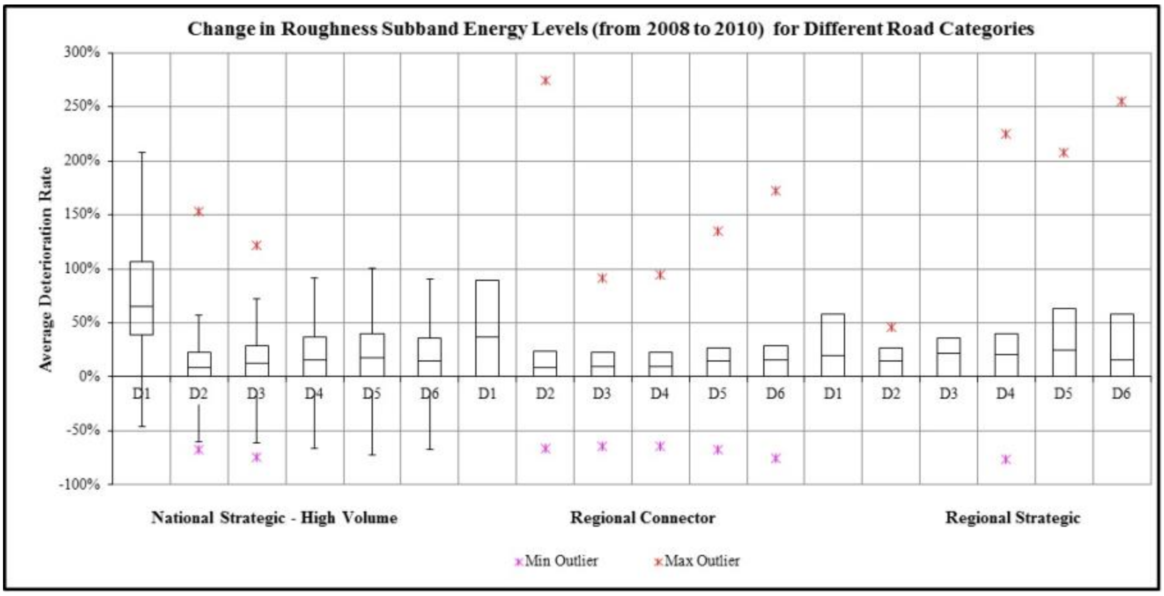
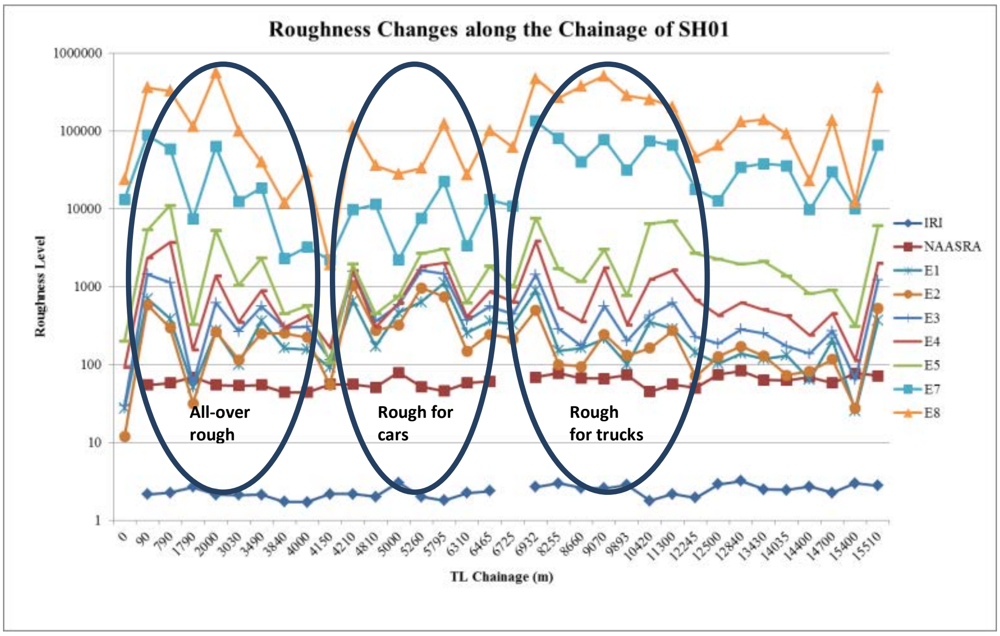


Figure 4.17 indicates that the sub-band D1 deteriorates at a faster rate compared with other sub-bands across all road classes. The energy in this sub-band reflects the profile changes to the surface defects, which normally occur in the first stage of pavement deterioration. Sub-bands D2 and D3 have the lowest average deterioration rates. Longer wavelength features in sub-bands D4 to D6 are associated with the structural defects. Therefore national strategic sections deteriorate faster than regional strategic and regional connector sections, due to the heavier traffic on these roads. National strategic sections and regional strategic sections deteriorate at approximately the same rate, in sub-bands D4 to D6. This could be explained by the allocation of more maintenance funds to these road classes.

Long wavelength spectra energy (often associated with the underlying geological terrain) does change, and this change is more obvious on the state highways and local authority sites with high traffic volumes (Wellington SH1). However, there are no obvious visible signs or changes to the calibration sites that could be associated with this change or used to identify this occurrence. It was established that IRI is most influenced by the short and medium wavelength roughness; changes in the short and medium wavelength spectra have a corresponding change in IRI and are the only wavelength energy that can be seen to directly correlate to changes in IRI. Therefore a significant portion of sites have had little or no visible change in condition or IRI, while demonstrating a significant change to the long wavelength spectra energy.

It is also useful to view the wavelets for a specific length of road. Figure 4.18 illustrates the wavelets for a length of state highways. The figure illustrates three distinct areas along the road. The first portion has an area where most of the wavelength energy is relatively high, thus suggesting an overall high roughness. For the second area most of the shorter wavelength energies are high but the longer wavelet energies are relatively lower. It is expected that this area would give cars a rougher ride. The last length has higher energy levels for the longer wavelengths which suggests a rougher ride for trucks.

Figure 4.18 Wavelet energy levels for a length of road

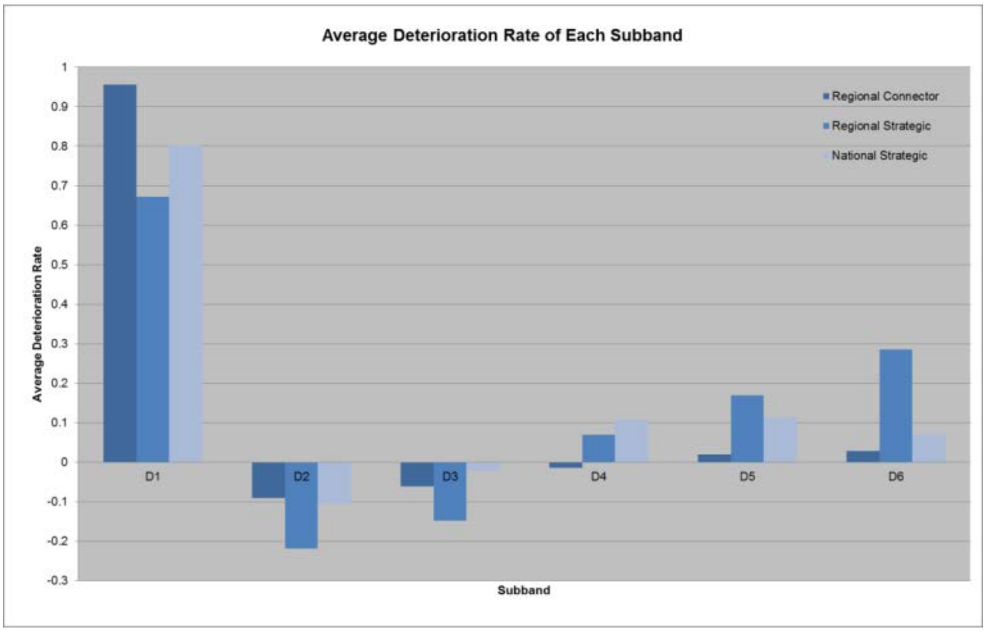


It is evident that wavelet analysis can be used as an analytical tool to determine pavement deterioration and maintenance needs. This research provided early indications that wavelength energy would be useful in determining the state of a road length, thus indicating potential surface and/or pavement-related problems.

4.4.3 Application discussion

Although there is still much to be learned from the process of longitudinal profile analysis, it already has some application potential. For example, the longitudinal profile change could be used to compare the change in condition for different road classes as illustrated in figure 4.19. Ignoring D1 (very short wavelengths), it can be seen that the regional connector roads have changed only slightly whereas a prominent change is observed for the regional strategic roads. Although some of the shorter wavelengths have showed some smoothing, the longer wavelengths are getting rougher. This change pattern is often associated with roads that are starting to deteriorate from increased rutting.

Figure 4.19 Deterioration rate per sub-band wavelength energy



The recommended application of profile energy levels is summarised in table 4.4.

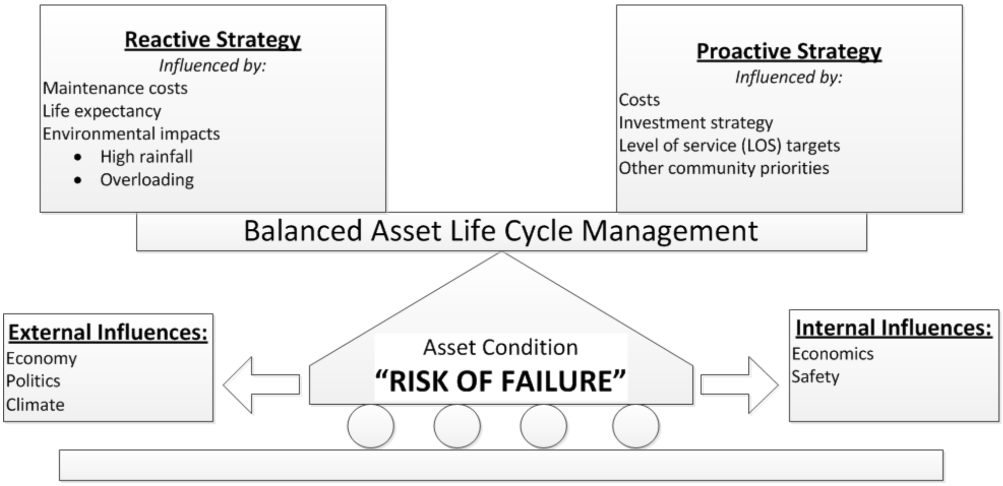
Table 4.4 Recommended application of profile energy levels

Item	Recommendation
Tactical level	
Reporting format	Present the average change per wavelength level as a portion of the prior value (refer to figure 4.19). The result can be produced for the average three-year trend and can be presented for separate road classes. Absolute energy levels can also be compared for inter-network benchmarking.
Value of the indices (the story it tells)	The value promised by the analysis of the wavelength spectrum for roads is twofold. First, the change in the longitudinal profile can be reported more accurately, thus overcoming the limitations in the IRI reporting. Second, it seems there are definite patterns of deterioration for different road age profiles, ie roads requiring rehabilitation will have a certain road roughness profile. Therefore this reporting could assist in better understanding maintenance requirements of networks.
Expected ranges	More work is required to better understand the actual energy values. However, the different wavelength energy change will have the following impacts: • roughness experience by car drivers: D6 • roughness experienced in trucks: D6, D7 and D8 • surface defects: D1–D2 • pavement defects: D4–D5 • subgrade movement: D7–D8.
Strategic level	
Reporting format	Qualitative reporting at strategic level is recommended. For example reporting could indicate the wavelengths changing and the general trend observed for a given network say: • shorter wavelengths (roughness for cars) – improving • longer wavelengths (roughness for trucks) – deteriorating.

4.5 Pavement failure risk

Understanding the risk to failure profiles on road networks is becoming an important consideration, especially under highly constrained funding levels. Schlotjes et al (2009) suggested that the consequences of varying investment levels on pro-active maintenance strategies would be observed in the long-term condition of the network and would have an immediate impact on the routine maintenance cost (refer to figure 4.20). A third impact area that engineers are unable to quantify at this stage is the probability of pavement failure. Reduced rehabilitation and resurfacing also lead to an increase in the failure probability of a network. It is well known that an aging network becomes more vulnerable as primary defects, such as cracking, start emerging, resulting in increased moisture conditions of road pavements (Hussain et al 2011).

Figure 4.20 The asset management balancing act (based on Kyle 2005)



Section 4.5.1 documents the development of a failure risk index based on PhD research at the University of Auckland (refer to Schlotjes at al 2009; 2011).

4.5.1 Fundamental background

Initial work on this research project suggested the risk of pavement failure is a function of multiple factors including (Schlotjes at al 2009):

- road pavement physical attributes such as lane width, pavement composition
- the current age and condition of the pavement, for example has it started to crack yet?
- the current use of the pavement such as heavy vehicle loading
- geological and climatic factors within a given region.

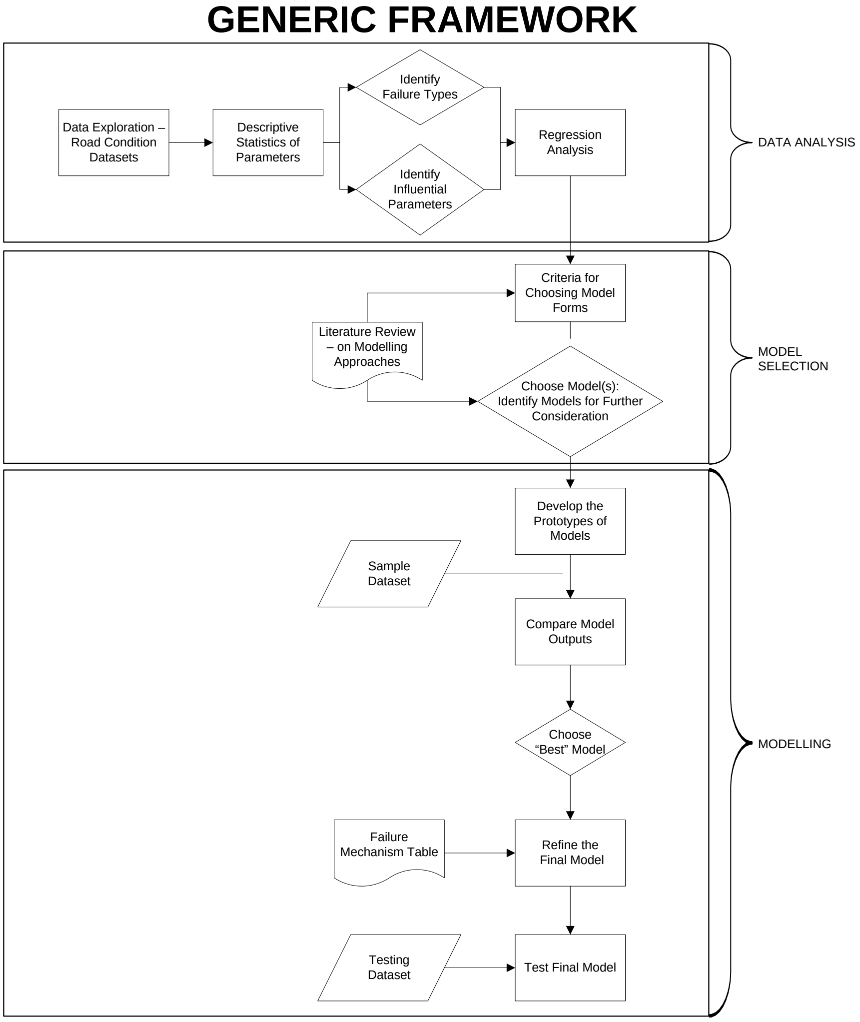
Under each of these headings there is an array of factors that influences each pavement to a varying extent. Quantifying the probability of failure is therefore complex in its nature. This research was based on the following assumptions:

- An overall failure risk index can only be developed on the basis of first knowing the specific failure mode most likely to apply to a given pavement.
- There are a number of probabilistic model formats that can be utilised for the analysis. Therefore, a large part of this research is about establishing the most appropriate model format for the problem at hand.

- Data availability is likely to vary from one application to another, therefore the forecast methodology needs to have the ability to predict failure with the best information at hand. For example, if the resulting model is dependent on five factors but only three of these are available for a given authority, it should be able to do a forecast on these three variables – accepting that the confidence of the prediction may reduce.
- With these issues addressed, the research needs to have a comprehensive and representative sample that will yield the best model.

The full research project followed the last point above and is illustrated in figure 4.21. Potential failure patterns were developed for three primary failure modes: rutting, cracking and shear. Roughness was also considered but it was believed to be a secondary defect stemming from some of the primary defects that work in isolation or in combination. For each of the primary failure modes, different potential failure paths were identified (refer to figures 4.22 and 4.23). For example, rutting (figure 4.22) may be a result of either excessive strain or deformation of the pavement layers or subgrade. For each of these failure modes, a number of failure paths were defined. For example, according to the red failure path in figure 4.22, water may have entered the pavement and affected some specific materials, which resulted in the deformation of a layer within the pavement.

Figure 4.21 Developing a pavement failure risk index



Note: Model refers to the risk indices to be developed.

Figure 4.22 Cause of rutting failure

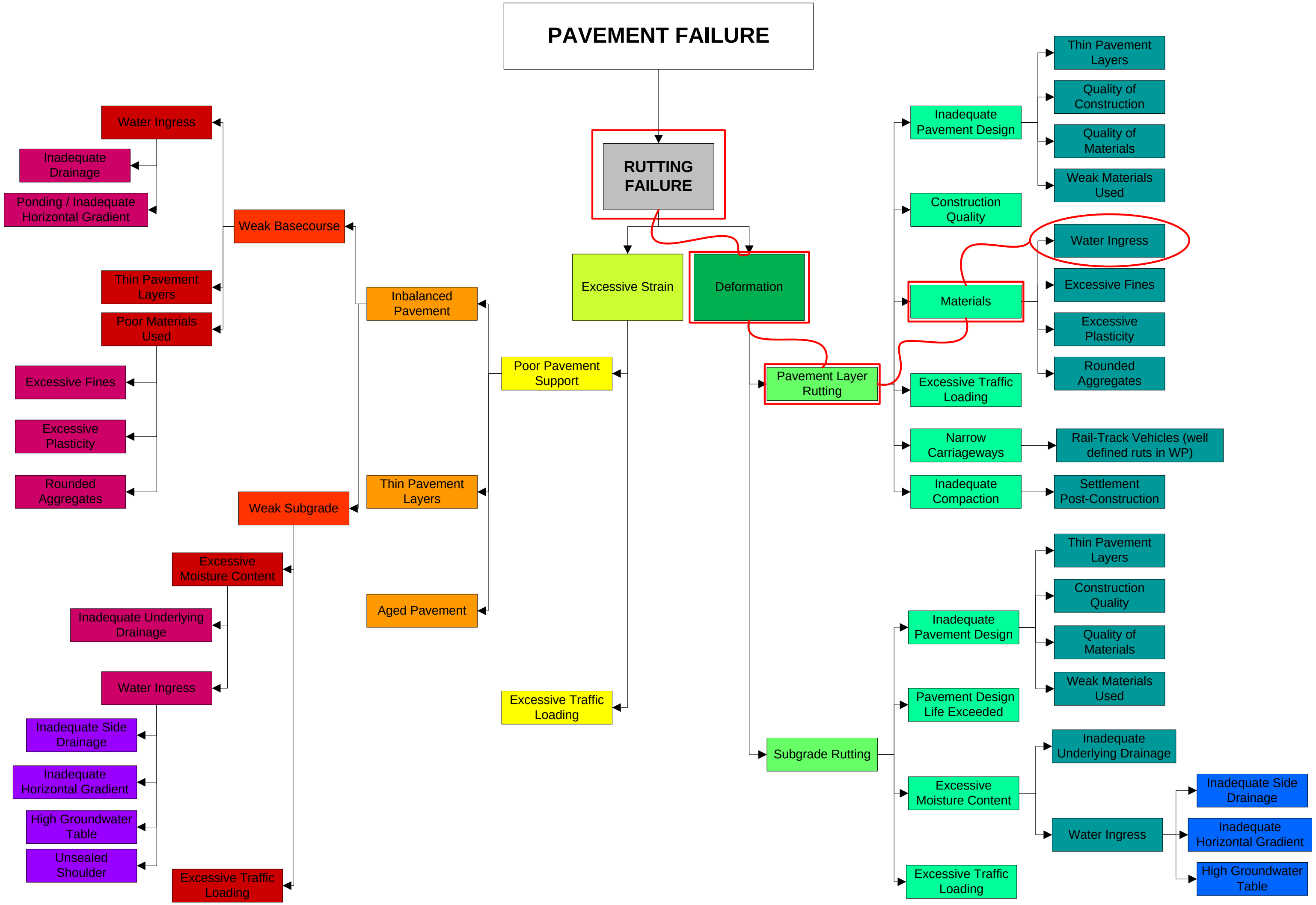
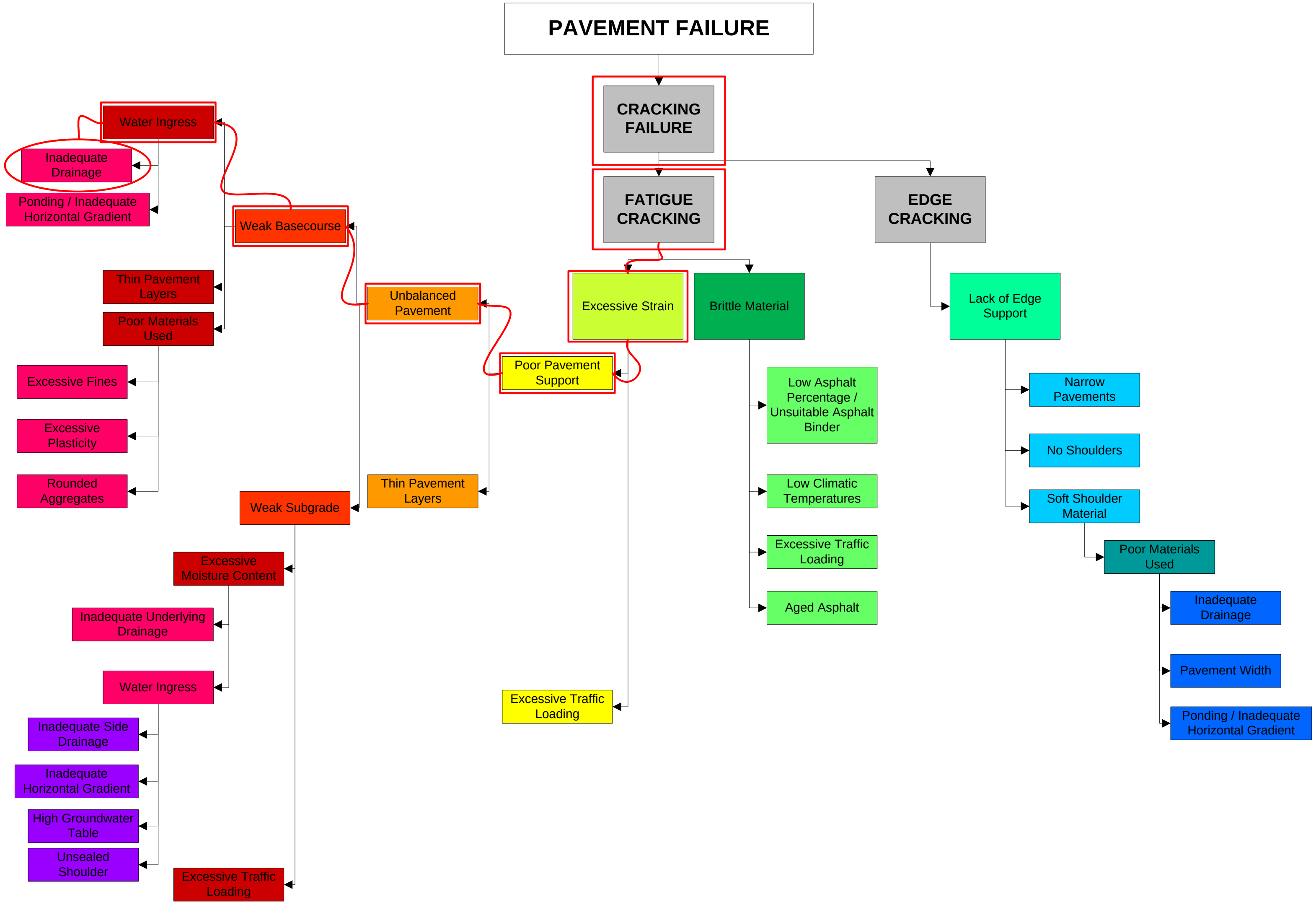


Figure 4.23 Cause of cracking failure



One of the main outcomes of the research, from an academic perspective, was to determine the most effective modelling approach for identifying the failure risk of pavements. Some of the techniques considered in the research were (Schlotjes 2011):

- logistic regression
- neural networks
- support vector machines
- probability (decision) trees
- genetic algorithms
- Bayesian statistics.

The assessment of these models is still under investigation. Some of the preliminary results of using logistic regression are presented in section 4.5.3.

4.5.2 Proof of concept

Tables 4.5 and 4.6 present some of the analysis results produced using the logit model format on the New Zealand LTPP dataset for rutting and cracking respectively. Table 4.5 shows results in two categories, those with a misclassification error equal to zero and those with a misclassification greater that zero. A zero misclassification suggests factor combinations with an equal ability for predicting failure of the pavement. The misclassification errors greater than zero suggest that listed combinations were not able to statistically forecast failure probability.

The results presented in both tables confirm the multi-factor influence on the failure modes that include environmental pavement composition and condition items. Where some of these factors were considered in isolation, the models were unable to predict failure, thus resulting in high miscalculation errors.

Table 4.5 Results from the rutting failure logistic regression models (Schlotjes et al 2011)

Trial number	Rutting failure Factor combinations	Misclassification error (%)	Number of data points
33	Composition + strength + condition	0	4512
43	Traffic + composition + strength + condition		
52	Composition + strength + environment + condition		
54	Composition + strength + condition + sensitivity		
56	Strength + environment + condition + sensitivity		
57	Traffic + composition + strength + environment + condition		
59	Traffic + composition + strength + condition + sensitivity		
62	Composition + strength + environment + condition + sensitivity		
63	Traffic + composition + strength + environment + condition + sensitivity		
5	*Condition*	*41.71417*	*4512*
21	*Condition + sensitivity*	*40.18259*	

Table 4.6 Results from the cracking failure logistic regression models (Schlotjes et al 2011)

Trial number	Cracking failure Factor combinations	Misclassification error (%)	Number of data points
24	Traffic + composition + condition	0	1183
33	Composition + strength + condition		
43	Traffic + composition + strength + condition		
45	Traffic + composition + environment + condition		
52	Composition + strength + environment + condition		
57	Traffic + composition + strength + environment + condition		
59	Traffic + composition + strength + condition + sensitivity		
63	Traffic + composition + strength + environment + condition + sensitivity		
14	*Composition + condition*	*31.87521*	*1183*
37	*Composition + condition + sensitivity*	*31.62654*	
47	*Traffic + composition + condition + sensitivity*	*70.50216*	

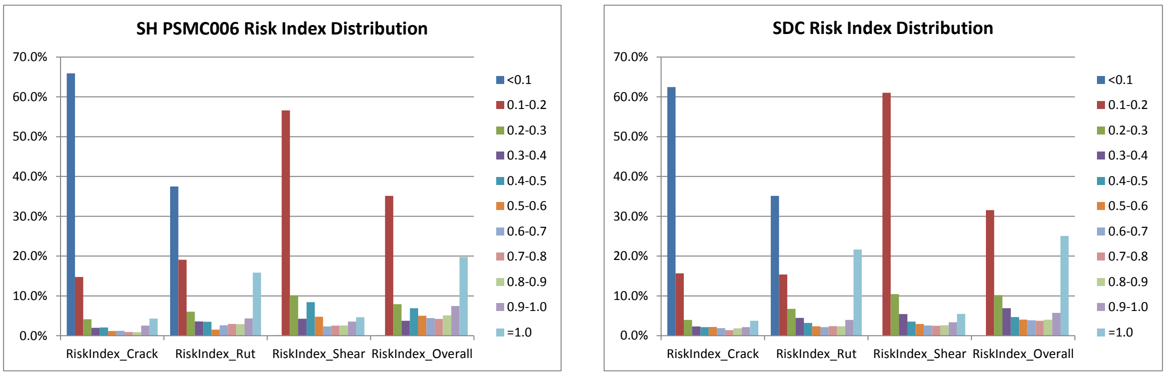
From the perspective of proving that forecasting a failure probability is in fact possible, the results presented here are promising. The next stage for the research was to establish: a) the best modelling approach and b) the final model using representative data.

4.5.3 Network application

The following is an extract from subsequent index testing performed by Deng and Henning (2013). This testing was commissioned by the NZTA to investigate the full-scale implementation recommended as a result of the research. The indices were tested on five networks: PSMC 006, Auckland motorway, and Southland District, North Shore and Manukau City Councils.

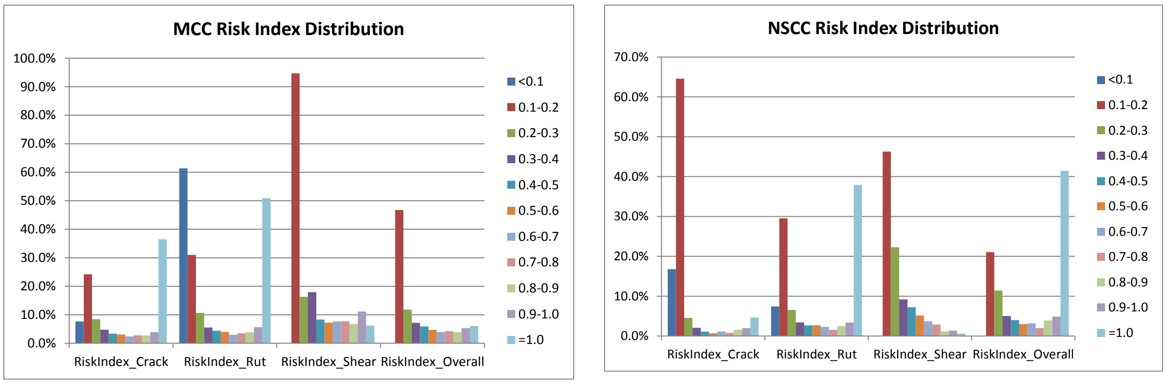
Figure 4.24 illustrates the failure risk profile for all three failure mechanisms and a combined failure risk based on the maximum risk amongst the three failure mechanisms. Note that the current failure risk index is only valid on roads with traffic volumes below 10,000 veh/day. The Auckland motorway results were therefore omitted. Also note that results for both Manukau and North Shore should be used with care as they may include a number of roads carrying heavier traffic than the applicable range for the failure risk index.

Figure 4.24 Failure risk indices for the respective network during 2012



Pavement failure risk PSMC006 (2010)

Pavement failure risk (2010)



Pavement failure risk (2012)

Pavement failure risk (2012)

Observations from figure 4.24 include:

- The risk profiles for PSMC006 and Southland are fairly similar with Southland having a slightly higher risk for rutting failure compared with the PSMC006 network. This is an interesting outcome given that the actual rutting of the PSMC006 network is slightly higher. The result is acceptable given the typical profile and pavement compositions common to the Southland network that may suggest higher risk levels compared with the PSMC006 network. Likewise, the PSMC006 network has a much lower risk profile for crack failure.
- The comparison between the North Shore and Manukau suggests that North Shore has slightly higher risks for all the failure modes, except for cracking. The results suggest that although failure risks are higher on the North Shore network, the Manukau network may be more prone to cracking due to its pavement types. Note that the North Shore FWD coverage is not as intensive as the Manukau network.

Some alternative reporting formats are presented in figures 4.25 and 4.26. Figure 4.25 compares the cracking failure risk between the networks while figure 4.26 summarises the failure split for the PSMC006 network for sites with a failure probability greater than 0.5.

Figure 4.25 A comparison of the cracking probability for the study networks

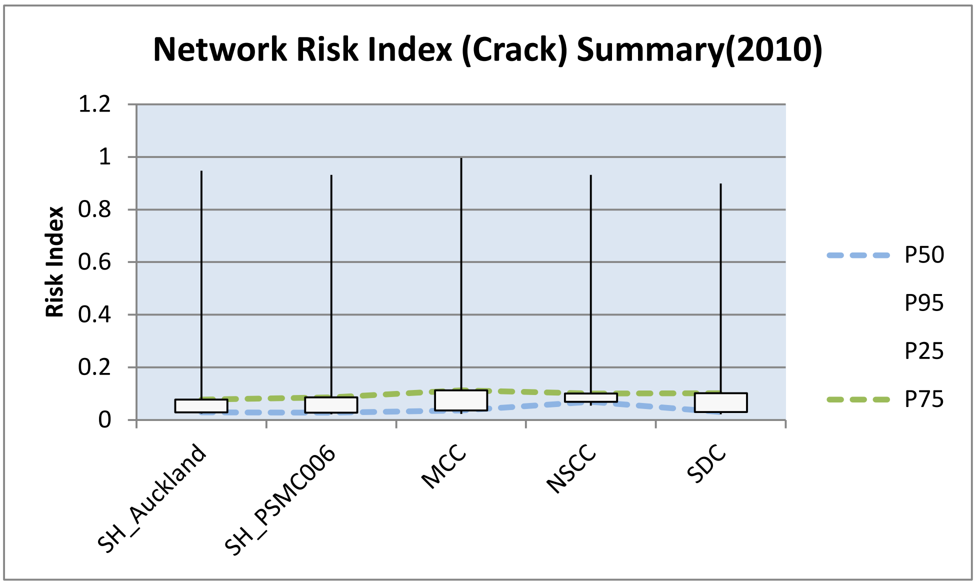


Figure 4.25 suggests that the Manukau network has the highest probability for cracking followed by the Southland network.

Figure 4.26 Probable failure split between failure mechanisms on the PSMC network

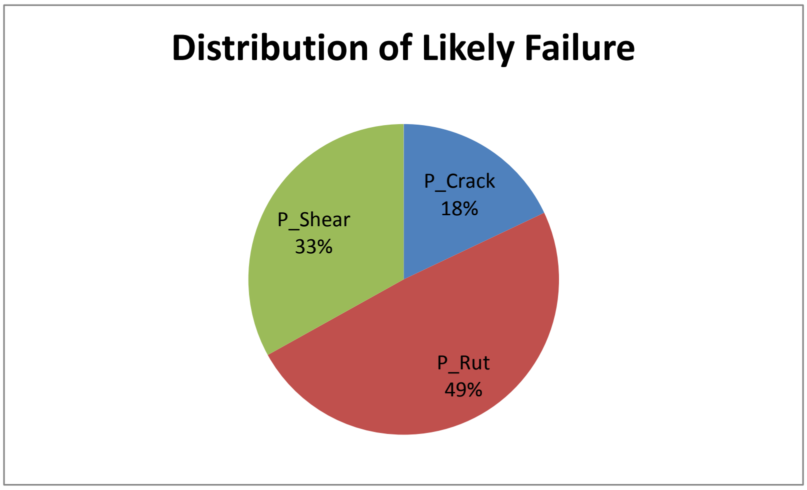


Figure 4.26 suggests the PSMC 006 network is mostly prone to rutting, which has traditionally been a major issue on the network. The formation of potholes is the second largest risk with a fairly small portion of the network being prone to cracking.

4.5.4 Failure risk index limitations, application and recommendations

Development of the failure risk index was completed during September 2012. Despite being a relatively new index, it promises some significant value in understanding the New Zealand road network failure profiles. The failure risk index uses actual pavement composition information, environmental conditions and current performance to forecast failure risk for a number of potential failure paths. As demonstrated in this section, the results are both meaningful and also fit expected outcomes for the networks under consideration. It is therefore recommended that the failure risk index be further tested prior to it being adopted for standard reporting of New Zealand networks.

The main limitation of the failure risk index is that its robustness is dependent on the available data. Although the processing of the failure risk index deals with missing data items, it becomes more meaningful if sufficient data is provided, especially strength information.

Also, based on discussions with network managers, we are aware there are some limitations in using this concept on high-volume roads such as motorways. The failure risk index gives an estimate of likelihood to fail ‘today’. Given the structural strength of motorways and their maintenance programmes, it is expected that this risk will be low.

5 Refinement of existing road condition performance measures

Another of this research project's tasks was to review the status of existing performance measures that were being used effectively, and would therefore remain within the recommended performance framework. The subsequent sections discuss these performance measures.

5.1 Surface health

5.1.1 Surface condition index

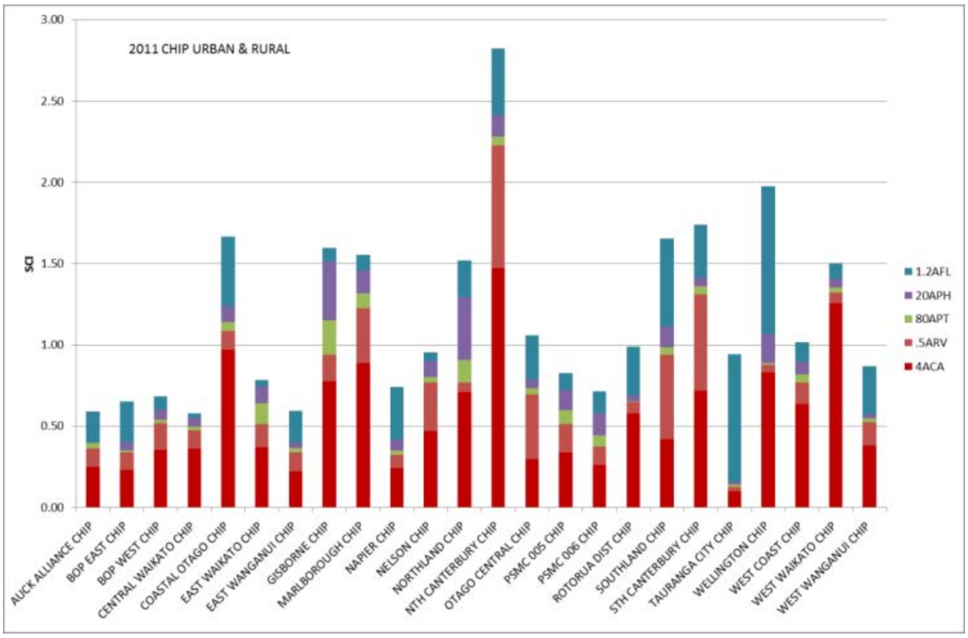
The surface condition index (SCI) has its origins in the surface integrity index (SII), which was developed for the NZ dTIMS project (Fawcett et al 2001). In essence, these two indices are similar, with the main difference being that the SII has incorporated an age index which was adopted to cover the aging factors of bitumen surfaces. The SCI also had an age index that caused some difficulty as a performance indicator. This study confirmed that the SCI should exclude this term as it was purely a function of the actual surface condition. Other indices are proposed to account for the surface life-cycle aspects.

The areas included in the SCI are (Jooste et al 2008):

- cracking
- ravelling
- potholes
- patches
- flushing.

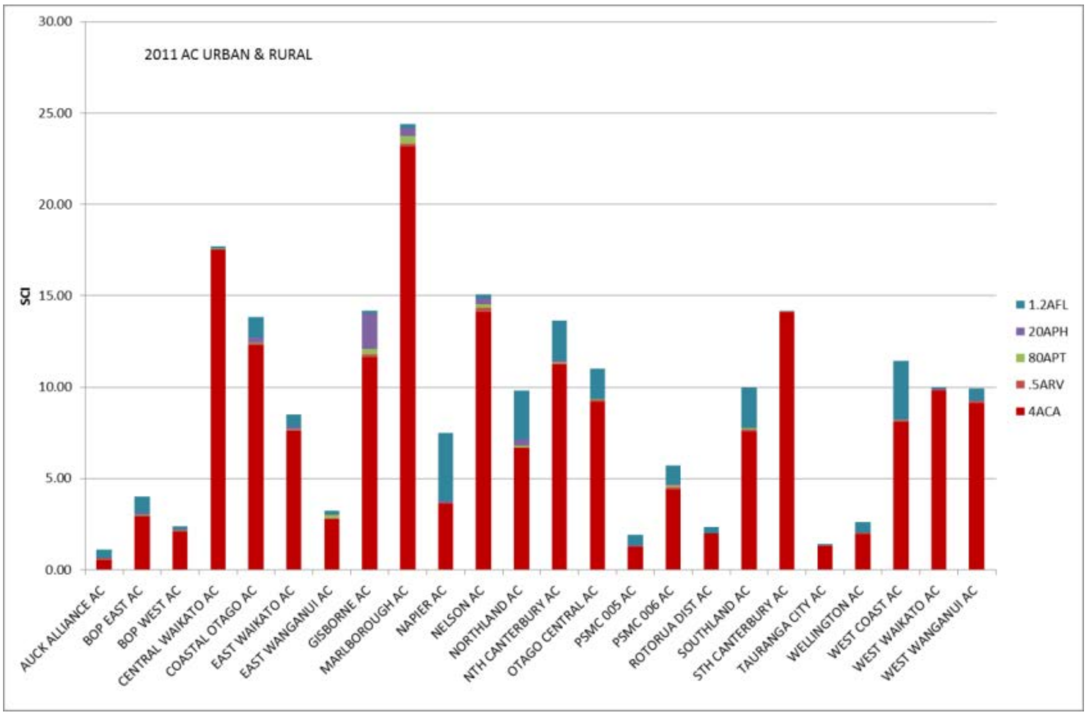
Of the above, cracking and potholes dominate the outcome of the index. Figure 5.1 illustrates the SCI summarised per state highway maintenance area. The bars also indicate the make-up of the SCI in terms of the contributing factors. It is observed that cracking would contribute 30%–50% of the SCI in most cases. This is considered to be appropriate given the importance of keeping road surfaces watertight in the New Zealand climatic environment.

Figure 5.1 SCI for state highway maintenance areas (chip seals) (NZTA 2011b)



One of the difficulties in interpreting network comparisons on the basis of the SCI is that there is a vast difference in SCI between chip seal and asphalt roads. Figure 5.2 presents the SCI for asphalt-surfaced pavements on state highways. Comparing this graph with figure 5.1 shows that the SCI on asphalt surfaces is almost an order of magnitude higher than the SCI for chip seals.

Figure 5.2 SCI presented for state highway asphalt sections (NZTA 2011b)



The figure also shows that the difference in SCI between chip sealed and asphalt surface roads is explained by the extent of cracking on asphalt surfaces. It is understandable that SCI reporting on networks would be overshadowed by the high results for asphalts. As a consequence, it is recommended that SCI should be reported separately for asphalt surfaced and chip sealed roads.

The observed trends do highlight some concerns about the performance of asphalt surfaces in New Zealand and further research may be warranted to address this issue.

Based on experience of using the SCI as a performance measure, it has proven to be one of the most valuable measures thus far. Known issues, especially robustness of this index, are solely governed by the quality of the rating data and some inconsistencies in this area also affect the outcome of the SCI. It is believed that the improvements to the rating method would also result in a more robust SCI. No further improvements to the SCI are recommended, but if significant changes are incorporated in the rating method, the impact on the SCI should be investigated.

5.1.2 Life-cycle performance of surfaces

It is common practice for authorities to resurface 8%–13% of their network on an annual basis. These resurfacing rates equate to a resurfacing cycle of between 7 and 13 years. This is a high resurfacing rate when compared with countries such as South Africa and Australia. There are two factors contributing to high resurfacing rates in New Zealand including:

- Due to the type of material used in pavement structures, combined with the climatic conditions, pavements have to be kept as dry as possible.
- New Zealand follows a high skid resistance standard which results in both texture and skid being a primary driver for resurfacing, especially on state highways (Kodippily et al 2010).

Although these reasons are well understood, there are some authorities that may follow practices resulting in surfaces not lasting as long as they should, or simply use excessively high resurfacing quantities (Fletcher and Theron 2011). The SCI is an effective measure to identify poor performance of surfaces, but it is unable to detect life-cycle issues associated with resurfacing cycles. In addition to that, considering the age distribution of surfaces is also not very effective as two authorities may have the same surface age profiles, but one may follow sound resurfacing practices and the other does not. The only way to understand resurfacing cycles followed by authorities is to investigate how long surfaces last. Unfortunately, retrospective reporting of surface replacement ages also gives a skewed perception of the network as it tends to be biased towards poor performing surfaces. In addressing this shortcoming, it is recommended to use survival statistics that consider both past surface ages and the status of the current network. An example of such a plot is presented in figure 5.3.

Figure 5.3 Survival graphs for chip seal surfaces (Abeysekara 2010)

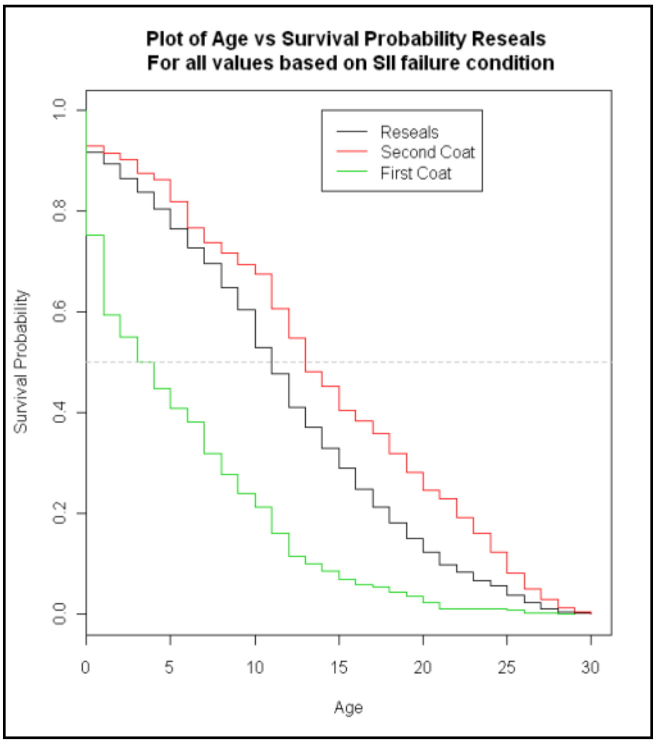


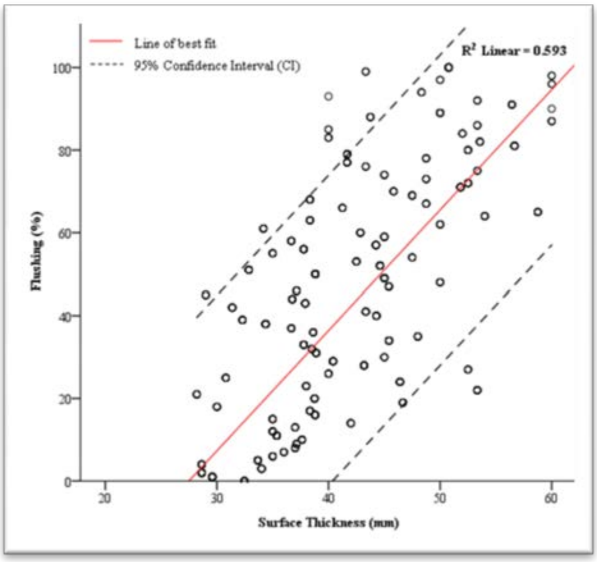
Figure 5.3 shows the probability of a surface lasting a certain number of years. For example, on this network, a second coat seal has a 50% probability of lasting 14 years.

5.1.3 Total surface depth of chip seals

Flushing of chip seal surfaces is a major driver of resurfacing and rehabilitation as it impacts significantly on skid resistance. For that reason, it is important to keep track of this in order to understand the overall surface health of networks. For example, a network may seem to be in a good condition on the basis of the SCI, but it may well have been following an intensive resurfacing maintenance regime that resulted in significant build-up of surface layers. This in return will result in a significant reduction of expected surface life and high flushing potential. It is therefore wise to monitor the trend of surface thicknesses to ensure a practical split between the amount of resurfacing and rehabilitation on networks.

Flushing is a difficult condition parameter to monitor. NZTA operations have ceased monitoring flushing on the basis of rated data given its high variability. In addition to indications of flushing from HSD, texture data could also be misleading as smaller chip sizes may appear to have flushed when they have not. However, there is a strong relationship between flushing and the total surface thickness. Based on research performed on the New Zealand LTPP, Kodippily et al (2011) found a strong correlation between these two parameters (refer to figure 5.4). This figure shows the percentage of flushing as a function of the overall surface thickness. It can be observed that above a total thickness of 40mm, more than 50% of a site will display flushing. Other research has also indicated that above 40mm, the surface performance reduces significantly. For example, Henning (2009) demonstrated that surfaces thicker than 40mm crack much faster than thinner surfaces. It is consequently recommended that the NZTA monitors a distribution of total surface thickness for networks in New Zealand, with particular interest in portions of the network with a surface thickness greater than 40mm.

Figure 5.4 The relationship between surface thickness and flushing (Kodippily 2011)



5.1.4 The reporting of surface health

In order to obtain a thorough understanding of surface health we recommend the asset managers report on:

- the SCI – in order to understand the physical condition of surfaces
- survival statistics – in order to understand the efficiency of reseal practices
- the number of surface layers for chip seals – to understand potential flushing issues that may arise on a chip seal network.

In addition to that, it is recommended that for the first two points above, reporting is done separately for asphalt and chip seal surfaces.

5.2 Pavement integrity index

Unfortunately, despite the perceived value of the SCI, the same cannot be said about the pavement integrity index (PII). We advise not to use the PII in its current format. There are two fundamental flaws associated with the PII:

1. Whereas the SCI robustly covers all expected defects in relation to surface issues, the PII does not adequately cover the overall performance related factors of pavements.
2. Since the PII incorporates both surface-related items and only rutting and roughness items to represent pavement behaviour, the latter two factors are heavily weighted in the index calculation which leads to some instabilities of the index. This is further aggravated by the known issues of using only absolute rutting and IRI as performance measures.

Potential techniques for addressing these two factors are discussed in the following section.

5.2.1 Questioning the value of monitoring pavement performance using a composite index

There are three factors that indicate the overall health of a pavement:

1. Its theoretical structural capacity – section 4.2 presented the new SIs as a way ahead in monitoring pavement structural capacity. The strength of these indices is in their ability to indicate the strength of the pavement in relation to likely failure mechanisms. It is believed these indices are effective in quantifying the pavement structural capacity.
2. Actual performance – despite the ability to define pavement structural capacity through structural indices, it is still important to monitor how well a pavement is performing under its given traffic load and environmental conditions. The RI and roughness profiles provide this information adequately.
3. Probability of failure – the physical road attributes such as geometry, the functioning and environmental conditions of the road, traffic loading and strength characteristics have a combined impact on the vulnerability of a road. This vulnerability of the road is commonly translated into a risk/probability of failure as defined in section 4.5.

The first question that comes to mind in defining overall pavement health is, should these three factors be collated into one index or do the individual items carry an important message in themselves. Using the tiered reporting structure recommended in this report (refer to section 3.2), it is recommended that:

- an overall pavement health index is only used at a strategic level, which does not exclude the use of individual measures such as a RI and/or failure risk index
- at a tactical level, all three pavement-related indices (strength, actual performance and risk) should be reported separately.

Given the status of and experience with newly developed pavement indices, it is believed that the development of an overall pavement health index should be undertaken at a later stage. Until then, reporting at a strategic level should be the same as for the tactical level.

5.3 Roughness and smooth travel exposure

The reporting of roughness by the IRI and STE will remain important measures for the NZTA. It should be remembered that both these measures quantify the travel comfort provided by the road surface as experienced by the road user. Road roughness consists of two aspects: a) the road longitudinal profile changes over time (refer to section 4.4) and b) how effectively this longitudinal profile is being absorbed by the vehicle suspension and providing a perceived ride comfort for the user. Both IRI and STE are effective in reporting on the latter, ie ride comfort. The recommended use of roughness indicators is summarised in table 5.1.

Table 5.1 Roughness indicators

Item	Indices	Implementation/future work
Condition monitoring	Wavelength energy levels distribution plots (see section 4.4) IRI – distribution plots	The IRI distribution plots will be used until full confidence is gained in the interpretation of the wavelength energy levels.
Road user costs	IRI – current road user cost models only incorporate IRI	Considerations should be given to updating the IRI/user cost models to reflect modern vehicles and also incorporate the specific cost aspects related to truck ride and associated costs.
User ride comfort	Smooth travel exposure (STE) IRI – distribution plots Truck ride index	Maintain current approach

It is recommended that both the IRI and STE continue to be used in the reporting framework accepting the following:

- Reporting in NAASRA should cease – NAASRA is currently calculated from the IRI and is therefore not a base index.
- IRI should be used in future only in the context of ride quality and not of pavement structural changes over time.

6 New efficiency measures – value-for-money framework

6.1 Introduction

This section proposes a value for money (VfM) framework to help assess the efficiency and effectiveness of the NZTA and territorial local authorities (TLAs) in achieving the stated objectives of the Ministry for Transport, given the funding provided by central government for renewals, maintenance and operation of state highways and local roads. Such a framework will inevitably be comparative, whereby best practice can be highlighted, as indeed can relatively ineffective or inefficient practice. Armed with such information, future funding decisions can, if desired, be based on demonstrated gains in efficiency and effectiveness. In addition, agencies demonstrating best practice can be used as exemplars for underperforming agencies to drive better value for money from the renewals, maintenance and operations funding.

6.1.1 Key definitions

Definitions for efficiency and effectiveness, as used in the research, are provided below. It is important that these are understood before progressing to subsequent sections to avoid confusion in terminology.

- Efficiency is defined as the ability of an organisation to complete a task with the minimum use of resources.
- Effectiveness measures the ability of an organisation to meet its objectives, but does not account for the resources consumed in doing so.

6.2 Proposed generic framework

The framework developed as part of the research was adapted from a generic framework proposed by Ramanathan (1985) specifically for not-for-profit organisations. The NZTA, and indeed TLAs, clearly fit into this category. While the generic framework is general enough to be applicable to a variety of not-for-profit organisations, it naturally requires considerable adaptation to tailor it to the NZTA's requirements. This section presents an adapted version of the generic framework; its specific application to the NZTA's requirements is discussed in section 6.3.

The various levels in the proposed framework are summarised in table 6.1 and elaborated on in the following sub-sections.

Table 6.1 Proposed generic framework

Level	Description
Outcomes (OC)	Desired high-level outcomes, usually set by government, for the services provided by the agency
Outcome indicators (OI)	Represent surrogate measures of the outcomes provided by the agency
Outputs (O)	Represent various measures of activity without regard to whether they lead to successful outcomes
Inputs (I)	Represent non-financial measures of various types of resources consumed by the agency
Costs (C)	Represent the financial value of all resources consumed by an agency in order to provide its services

6.2.1 Outcomes

Outcomes are usually set by the government, and represent the high-level social benefits that an agency provides through the delivery of its services. These benefits are often difficult to quantify and may have several dimensions, resulting in multiple indicators to represent the outcomes. In addition, many parts of an agency contribute to each outcome, thereby making it difficult to quantify the individual contribution from each. External influences can also impact on the outcomes.

6.2.2 Outcome indicators

Outcome indicators provide a convenient, albeit imperfect, substitute for the outcomes for the reasons discussed above. These allow a review of the performance of an agency, or parts of an agency, to be assessed on its own merits. In short, outcome indicators represent surrogate measures of the outcomes provided by the agency.

6.2.3 Outputs

Outputs represent various measures of the volume of activity without regard to whether they lead to successful outcomes. Hence, an increase in output may not necessarily lead to an increase in outcomes, unless they are appropriately targeted. Outputs are generally defined in physical units.

6.2.4 Inputs

Inputs represent non-financial measures of various types of resources consumed by the agency. In theory, increases/decreases in output will result in similar variations in inputs. However, they may not always be strictly proportional, especially where economies of scale are introduced.

6.2.5 Costs

Costs represent the financial value of all resources consumed by an agency in order to provide its services. In theory, increases/decreases in input will result in similar variations in costs. However, they may not always be strictly proportional especially where economies of scale are introduced.

6.3 Proposed NZTA framework

The key challenges in adapting this framework further, to specifically meet the requirements of the NZTA, were in defining the outcomes, outcome indicators, outputs, inputs and costs against which effectiveness and efficiency could be measured. The proposed framework would be demonstrated for the local road network; however, the framework would equally apply to the state highway network, albeit with some minor adjustments.

6.3.1 Outcomes

The *Government policy statement* (GPS) *on land transport funding* (MoT 2009) set out the specific impacts the government expects to be achieved through the use of the National Land Transport Fund. It is proposed that these are adopted as the outcomes for the proposed framework, see table 6.2.

Table 6.2 Impacts the government wishes to achieve

Type of impact/outcome	Impacts/outcomes
Impacts that contribute to economic growth and productivity	Improvements in the provision of infrastructure and services that enhance transport efficiency and lower the cost of transportation
	Better access to markets, employment and areas that contribute to economic growth
	A secure and resilient transport network
Other impacts	Reductions in deaths and serious injuries as a result of road crashes
	More transport choices, particularly for those with limited access to a car where appropriate
	Reductions in adverse environmental effects from land transport
	Contributions to positive health outcomes

While all desired outcomes are presented in table 6.2 for completeness, not all are directly influenced by renewals, maintenance and operations funding. In addition, not all are solely influenced by such funding. Taking ‘Reductions in deaths and serious injuries as a result of road crashes’ as an example, it is clear that renewals, maintenance and operations funding directly influences this outcome through, for example, improvements to skid resistance. However, renewals, maintenance and operations funding is not the sole contributor to reductions in road crashes as policing, licensing and advertising campaigns all have their part to play. Table 6.3 defines the contribution from renewals, maintenance and operations funding for each of the defined outcomes.

Table 6.3 Contribution of renewals, maintenance and operations funding to achieving outcomes

Outcomes	Contribution
Improvements in the provision of infrastructure and services that enhance transport efficiency and lower the cost of transportation.	Directly contributes to lowering the cost of transportation through reductions in surface roughness and, therefore, vehicle operating costs (VOC). Not the sole contributor to this outcome as VOC includes many other elements.
Better access to markets, employment and areas that contribute to economic growth.	Negligible contribution – ignore for the purposes of this research. One of the main contributors to this outcome is new transport infrastructure.
A secure and resilient transport network.	Directly contributes to maintaining a secure and resilient network through improvements to infrastructure health. Not the sole contributor to this outcome, but a significant one.
Reductions in deaths and serious injuries as a result of road crashes.	Road crashes are influenced by three factors: the driver, the vehicle and the environment. Renewals, maintenance and operations directly influence the road condition (including skid resistance), which is one of the environmental factors in crashes. Not the sole contributor to this outcome, but an important one.
More transport choices, particularly for those with limited access to a car where appropriate.	Negligible contribution – ignore for the purposes of this research.
Reductions in adverse environmental effects from land transport.	Indirectly contributes to reductions in adverse environmental effects through reductions in surface roughness, leading to reductions in fuel consumption, and therefore vehicle emissions. Not the sole contributor to this outcome and only a minor contributor. Measures of other adverse environmental impacts such as noise, dust or water quality were not available to this study.
Contributions to positive health outcomes.	Negligible contribution – ignore for the purposes of this research. Although some health benefits will be obtained through reductions in vehicle emissions from the above outcome, any benefits will be captured there.

6.3.2 Outcome indicators

Where outcomes are difficult to quantify, appropriate outcome indicators can be used as surrogates. In determining such outcome indicators, consideration should be taken of whether the activity classes within the agency, in this case covering renewals, maintenance and operations, contribute solely to the measure. In addition, before suggesting new measures to collect, cognisance should be given to the existing data collected by the agencies contained in RAMM. Table 6.4 includes the suggested outcome indicators for each outcome.

Table 6.4 Outcome indicators

Outcomes	Outcome indicators (surrogates)
Improvements in the provision of infrastructure and services that enhance transport efficiency and lower the cost of transportation.	Smooth travel exposure (STE) – a smooth network reduces VOC, thereby lowering the cost of transportation. Average roughness could also be used for this outcome, but STE was considered more appropriate as it relates to vehicle kilometres travelled, and not an average roughness across the network.
A secure and resilient transport network.	Pavement health (SIs, risk to failure and rutting) – condition index, road length overdue for reseal, and STE are all possible candidates to measure the resilience of the road network.
Reductions in deaths and serious injuries as a result of road crashes.	Crash cost – by using the social cost of crashes, rather than the crash rate, the number and severity of the crashes can be combined and normalised.
Reductions in adverse environmental effects from land transport.	STE has been used as the outcome indicator for this outcome, as exposure to smooth travel on the network directly affects fuel consumption and, therefore, emissions.

6.3.3 Outputs

The output measures currently reported to the NZTA by TLAs under renewals, maintenance and operations activity classes are listed below:

- length of road resurfaced
- length of renewal (rehabilitation and reconstruction).

It should be noted that these measures of activity are without regard to whether they lead to successful outcomes, or how much funding has been consumed in producing the outputs. In other words, efficiency and effectiveness are not considered.

6.3.4 Inputs

Typical measures of various types of resources consumed in delivering renewals, maintenance and operations services are listed below.

- labour (skilled and unskilled)
- materials
- plant and equipment.

However, due to the fact that most renewals, maintenance and operations functions are carried out based on unit rates, resulting in very little, if any, use of direct labour, this level has been ignored for the purpose of this research.

6.3.5 Costs

Costs refer to the financial value of all resources consumed by an agency in order to provide its services. The values are the financial costs expended on NZTA subsidised work that TLAs carry out on their road networks. This work is funded (and recorded) within the funding categories set out in the NZTA *Planning, programming and funding manual* (NZTA 2008).

Table 6.5 shows the funding categories applicable to the majority of work carried out by TLAs in New Zealand. Further descriptions of each are included in appendix A, detailing qualifying work for each funding category. Given that the NZTA has a number of outcomes, then ideally the classification and reporting of costs should reflect their purpose, ie if the funding was used to improve safety then an expenditure on safety category should be reported by each agency. However, for the purpose of this research, the current funding categories are used.

Table 6.5 Funding categories

Work category	Code	Description
Maintenance and operations of roads	111	Sealed pavement maintenance
	112	Unsealed pavement maintenance
	113	Routine drainage maintenance
	114	Structures maintenance
	121	Environmental maintenance
	122	Traffic services management
	123	Operational traffic management
	124	Cycle path maintenance
	131	Level crossing warning devices
	141	Emergency reinstatement
	151	Network and asset management
Renewal of roads	211	Unsealed road metalling
	212	Sealed road resurfacing
	213	Drainage renewals
	214	Sealed road pavement rehabilitation
	215	Structures component replacements
	221	Environmental renewals
	222	Traffic services renewals
	231	Associated improvements
	241	Preventative maintenance
Improvement of roads	321	New traffic management facilities
	322	Replacement of bridges and other structures
	323	New roads
	324	Road reconstruction
	325	Seal extension
	332	Property purchase
	333	Advance property purchase
	341	Minor improvements

Not all expenditure by TLAs directly relates to all outcome indicators. The proposed expenditure associated with STE and PII includes expenditure reported in the following categories:

- 111 – Sealed pavement maintenance

- 113 – Routine drainage maintenance
- 151 – Network and asset management
- 212 – Sealed road resurfacing
- 214 – Sealed road pavement rehabilitation
- 324 – Road reconstruction.

Expenditure under these categories has been included as they influence the condition of the sealed road network. Expenditure under unsealed road categories has been excluded, as STE and PII are measures of road condition on sealed roads only. Expenditure from other categories such as traffic services and environmental maintenance has similarly been excluded as they are not deemed to influence STE and PII.

The proposed expenditure associated with the social cost of crashes includes expenditure reported in the following categories:

- 111 – Sealed pavement maintenance
- 112 – Unsealed pavement maintenance
- 113 – Routine drainage maintenance
- 121 – Environmental maintenance
- 122 – Traffic services management
- 123 - Operational traffic management
- 131 – Level crossing warning devices
- 151 – Network and asset management
- 211 – Unsealed road metalling
- 212 – Sealed road resurfacing
- 214 – Sealed road pavement rehabilitation
- 222 – Traffic services renewals
- 231 – Associated improvements
- 321 – New traffic management facilities
- 324 – Road reconstruction
- 325 – Seal extension
- 341 – Minor improvements

Expenditure under the above categories covers work that can have an impact on road safety and decrease the number of crashes. Major capital works, such as new roads and replacement of bridges, have been excluded from this expenditure. Although this work may impact on crash records in the longer term, when comparing annual expenditure with annual crash rates, these large items should not be included as they can skew results. In addition, their effect may not yet be reflected in the indicators.

6.4 Proposed performance controls

The outcome indicators, outputs, inputs and costs represent a hierarchy of performance controls which allow an agency to measure its performance, or the performance of parts of its organisation. To help understand this, the natural linkages among them are included in equation 6.1. Noting that outcomes have been replaced by outcome indicators and inputs are not relevant to this application, this yields just two ratios on the right-hand side.

$$OI/C = OI/O + O/C$$ (Equation 6.1)

The various performance controls are included in table 6.6, along with what they are measuring, and the parts within the agency whose performance is being measured.

Table 6.6 Proposed performance controls for efficiency and effectiveness

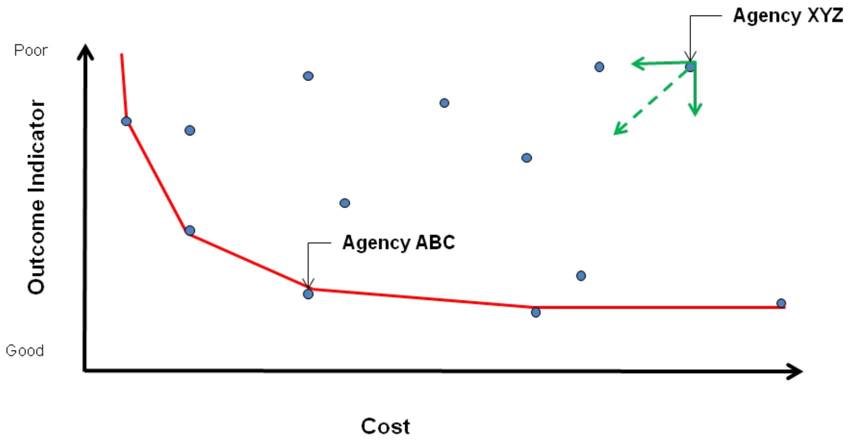
Measure	Description
OI/C	Composite measure of the agency's efficiency and effectiveness in attaining its outcomes. This is a high-level measure for top management.
OI/O	Measure of the agency's quality, success or effectiveness in attaining its outcomes. This measures the effectiveness of decision making by professionals, such as asset managers.
O/C	Traditionally, a composite measure of the ability of the RCA's procurement specialists to acquire resources efficiently and their operations department to utilise those resources efficiently. In this application, it primarily measures the ability of the procurement department to acquire efficient unit rates, but also of their professional services department to direct use of those resources efficiently.
C/O	Reciprocal of the O/C measure, provides standard costs per unit of output.

6.5 Performance improvement

In order to drive improvements in efficiency and effectiveness, the performance controls developed above need to be presented in a format which highlights underperforming agencies and, as an exemplar to these agencies, those demonstrating good practice. Armed with such information, future funding decisions can, if desired, be made based on demonstrated gains in efficiency and effectiveness.

The efficient frontier is proposed as a way of presenting the performance controls developed in section 6.4. Referring to the generic example for OI/C in figure 6.1, the frontier is determined by first plotting the generic outcome indicator, OI, on the ordinate and C, some normalised measure of cost, on the abscissa, with each agency plotted as an individual point on the graph. Those points on the frontier or boundary are then joined up to indicate the efficient frontier. Depending on whether the scale of measurement is increasing or decreasing for the outcome indicator, the frontier will be concave or convex as shown in figures 6.1 and 6.2, respectively.

Figure 6.1 Concave efficient frontier

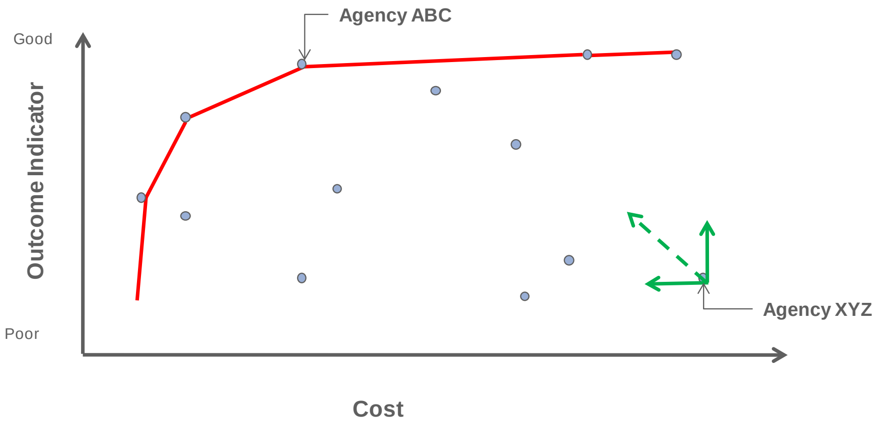


The agencies on the frontier can be considered as demonstrating best current practice. Taking agency ABC in figure 6.1 or figure 6.2 as an example, no other agency with a similar spend has managed to return as high an outcome indicator and, conversely, no other agency with a similar outcome indicator value has managed to achieve it for less cost.

It is equally, if not more important, to identify agencies that are inefficient and/or ineffective. The further an agency is from the frontier the more inefficient they are, all other things being equal. For example, agency XYZ in figure 6.1 or figure 6.2 is the least efficient of those plotted. All other agencies are either returning a higher outcome indicator for the same cost or are achieving the same outcome indicator value but for less cost, or in most cases a combination of both.

Clearly, to improve performance, agency XYZ needs to mirror these other agencies and spend less while maintaining standards, increase standards while spending the same, or possibly a combination of both. Those agencies that exhibit best practice (ie those on the frontier) can be used as an exemplar of how to achieve improvement.

Figure 6.2 Convex efficient frontier



While both examples above relate to the high-level OI/C performance control, similar efficient frontiers can be plotted for OI/O and O/C, thereby providing a tool for comparing, with the intention of improving, asset management decision making and procurement, respectively.

6.6 Network reporting

In order to demonstrate application of the proposed framework, and associated performance controls, network reports have been produced for the local road network. The data for this research was acquired from various sources. Most of the data is publicly available on the NZTA website, and the SmartMovez website (www.smartmovez.co.nz). The funding data from the NZTA website provided information at a summary level. A breakdown of this funding information by funding category was provided directly by the NZTA. All data used was for the 2009/2010 financial year.

6.6.1 Accounting for heterogeneity

When adopting a comparative framework for performance measurement and improvement, buy in from the participating agencies will only be achieved if they feel their individual site characteristics are accounted for in the comparison. Put simply, comparisons need to be made on a like-for-like basis.

A number of the differences in agencies, such as their network length and vehicle kilometres travelled (VKT), can be accounted for through normalisation of the data. In this research it was proposed to normalise the expenditure data by reporting it per million VKT. Similarly, the expenditure could be normalised by network length. Other differences, such as rural/urban split, geological factors and climatic influences, can be more difficult to account for. While sophisticated techniques do exist to adjust the efficiency measures to account for such site characteristics, for the purpose of this research it was proposed to use the NZTA peer groups to account for at least some of the inherent heterogeneity.

The NZTA has developed peer groups for the purpose of comparing road safety performance, as well as condition data, across TLAs (NZTA 2009). The peer groups are detailed below:

- Peer group A – major urban areas with some rural areas on the outskirts (population >97,500 and/or rural crashes less than 30%)
- Peer group B – major urban areas with some rural areas on the outskirts (population 40,000 –97,500 and/or rural crashes less than 35%)
- Peer group C – large provincial towns and hinterland (population 35,000–75,000 and/or rural crashes less than 55%)
- Peer group D – provincial towns and hinterland (population 20,000–75,000 and/or rural crashes greater than 55%)
- Peer group E – small provincial towns, low traffic volumes (population less than 20,000 and/or rural crashes greater than 55%).

6.6.2 Limitations of the data

The information reported on the SmartMovez website (www.smartmovez.co.nz), and held by the NZTA, relates only to the subsidised work carried out by TLAs. Each TLA will carry out a varied amount of non-subsidised road maintenance or improvements work. The value of this work is not available through the data used for this research.

The outcome indicators were selected from the data available. In some instances, the surrogate measures were not the most applicable, but simply the most readily available. For example, STE was selected as the surrogate measure for 'Reductions in adverse environmental effects from land transport' whereas VOC would be a more relevant measure for this outcome.

6.6.3 Reporting efficiency and effectiveness in attaining outcome indicators

This section reports the performance control OI/C, a composite measure of the agency's efficiency and effectiveness in attaining its outcomes. This is a high-level measure for top management and can assist the NZTA in their funding decisions. A sample of efficient frontiers is included below for various peer groups, along with associated commentary. A full set of OI/C plots is included in appendix B.

In general, once the data is presented graphically, an efficient frontier can be established, with those TLAs on the frontier considered as exhibiting best practice. Some clear, relatively poor performing, outliers can also be identified. On the surface, these outliers may be considered poor performers, relative to other TLAs in their peer group; however, further investigation is required to see if there are other influencing factors that may be affecting their performance, such as geological factors or climatic influences.

Figure 6.3 displays, for peer group C, the OI/C plot for STE. The efficient frontier is included as a solid red line. This line represents the best possible outcome for a given cost, thus connecting the highest possible point for each cost. Beyond the limits of the data a 'nominal' efficient frontier is included as a dashed red line, which represents a worst case scenario whereby no further gains are achieved. Therefore no gains are realised for additional costs.

The frontier includes Porirua City, Hastings District and Timaru District; these can be considered the most efficient TLAs, all other things being equal. Given the inherent uncertainty in determining the cost and outcome indicators, Kapiti Coast District is probably close enough to the frontier to be included in an uncertainty 'envelope', and for all intents and purposes is included on the frontier. The appropriate dimensions of such an envelope are yet to be determined. In contrast, Gisborne stands out as the least efficient TLA, reporting one of the worst STE values, while spending by far the most on sealed road expenditure per million VKT.

Figure 6.3 Efficient frontier for STE (peer group C)

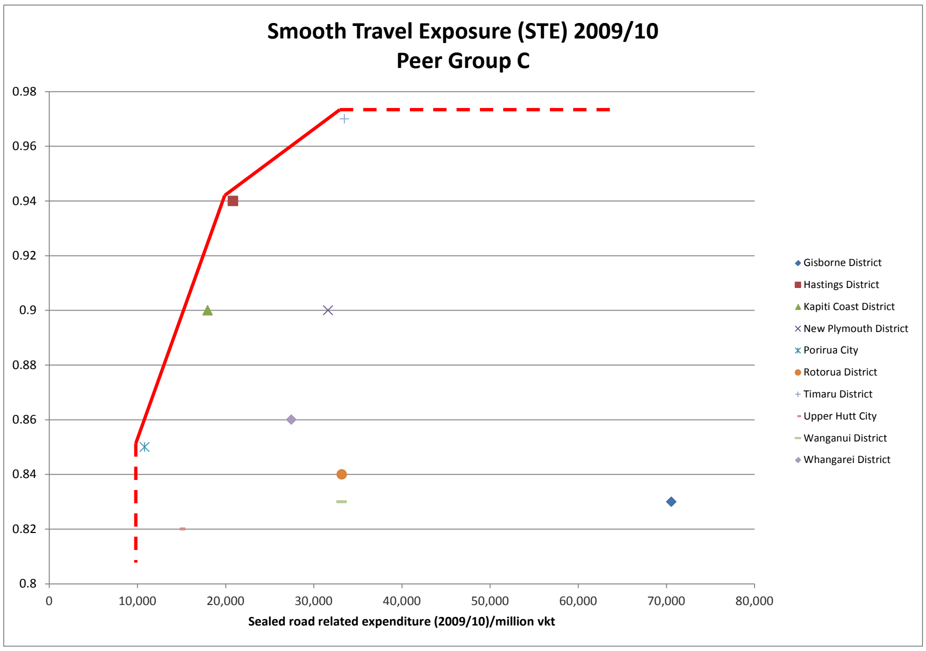


Figure 6.4 displays, for peer group D, the OI/C plot for PII. The frontier includes Selwyn District and Ashburton District; these can be considered the most efficient TLAs, all other things being equal. A number of other TLAs are arguably close enough to the frontier, or within statistical errors, and can therefore be considered as part of the frontier. Thames-Coromandel District, Western Bay of Plenty District and South Taranaki District stand out as the least efficient TLAs.

Figure 6.4 Efficient frontier for PII (peer group D)

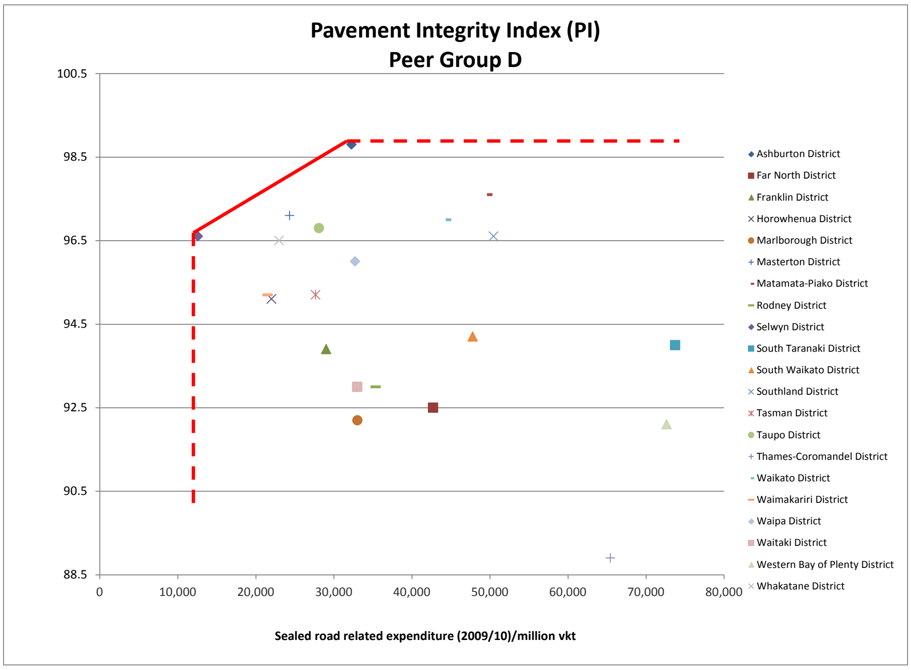
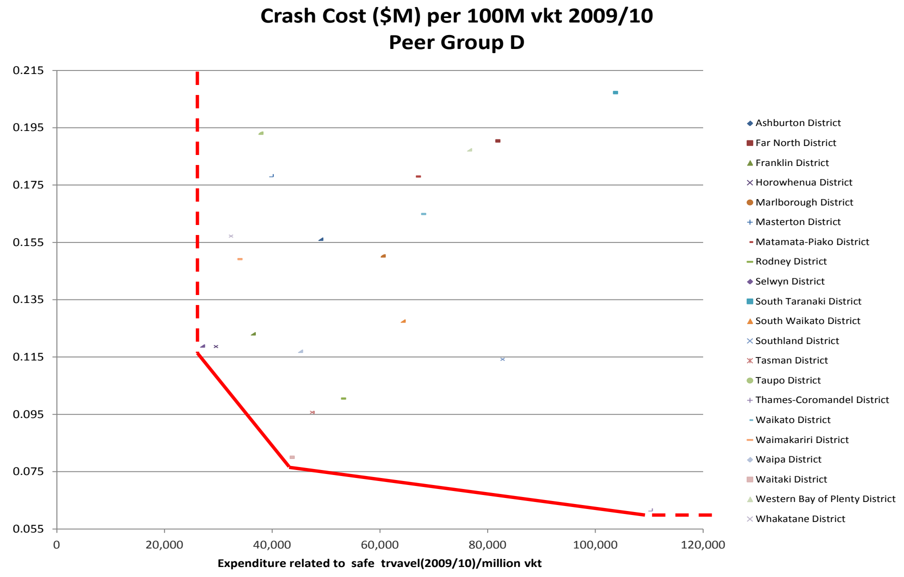


Figure 6.5 displays, for peer group D, the OI/C plot for crash cost. The frontier includes Selwyn District, Thames-Coromandel District and Waitaki District; these can be considered the most efficient TLAs, all other things being equal. A number of other TLAs are close enough to the frontier to be included in an uncertainty ‘envelope’, and for all intents and purposes are included on the frontier. South Taranaki District stands out as the least efficient TLA, reporting the largest crash cost per 100 million VKT, while spending almost the most on expenditure, per million VKT, related to safe travel.

Figure 6.5 Efficient frontier for crash cost (peer group D)



6.6.4 Reporting efficiency in attaining outputs

This section reports the performance control O/C, primarily a measure of the agency’s procurement department to acquire efficient unit rates, but also of their professional services department to direct use of those resources efficiently. Examples of efficient frontiers have been prepared for all peer groups; however, due to inconsistencies in the data provided these have not been included. Work is ongoing to rectify these inconsistencies and the full set of efficient frontiers will be re-plotted in time.

6.7 Discussion and conclusions

A value-for-money (VfM) framework to help assess the efficiency and effectiveness of the NZTA and TLAs in achieving the stated objectives of the MoT, given the renewals, maintenance and operations funding provided from central government, has been proposed. The framework includes the MoT’s desired impacts at the top (outcomes), surrogate measures for these directly below (outcome indicators), measures of output below that and, finally, costs at the bottom. Performance controls OI/C, a composite measure of the agency’s efficiency and effectiveness in attaining its outcomes, and O/C, primarily a measure of the agency’s procurement department to acquire efficient unit rates, were proposed, along with the efficient frontier as a way of presenting the above performance controls.

Network reports have been produced for the local road network in order to demonstrate the application of the VfM framework and associated performance controls. The reports are broken down by TLA, and, in an attempt to account for some of the variability between the TLA networks, are reported in the NZTA peer groups. Performance controls OI/C and O/C were plotted and efficient frontiers determined. TLAs on the frontier can be considered as exhibiting best practice and can be used as an exemplar to other poorer performing agencies. Some relatively poor performing TLAs were also identified.

Other variables, not accounted for in the selection of peer groups, could be responsible for the relatively poor performance of these TLAs and the need to ‘drill-down’ to determine the reasons behind uncharacteristic values before making decisions on funding is highlighted. However, where no such reasons are evident then significant opportunities present themselves for improvement, be they gains in efficiency, effectiveness, or both.

6.8 Proposed future research

Assuming adoption and acceptance of the above method, then in time the agency should consider the natural progression to a more sophisticated method of measuring relative efficiency using a technique called data envelopment analysis (DEA), developed by Charnes et al (1978). Like the method proposed in this research, DEA computes relative efficiency scores for a number of decision making units, in our case RCAs, and plots them on an efficient frontier. The key difference is that it can incorporate a number of different inputs and outputs into the evaluation, as opposed to the single input-output method proposed here. Such a technique becomes extremely valuable where multiple inputs, for example from different parts of the business, contribute to the same outcome. Consequently, should the agency choose to adopt a relative efficiency measure across the business as a whole, then DEA would be an appropriate technique to adopt provided that it is sufficiently tested and calibrated on a network.

7 Development of a new economic measure – vehicle operating cost index

7.1 Introduction

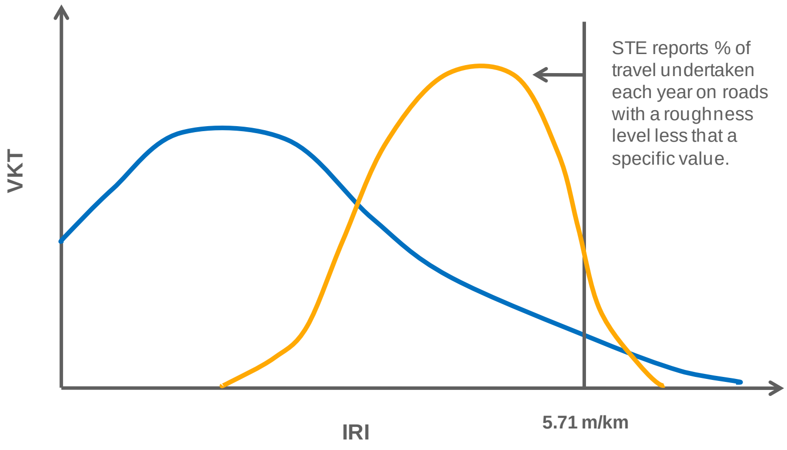
The GPS sets out the specific impacts the government expects to be achieved through the use of the National Land Transport Fund. Under impacts that contribute to economic growth and productivity, 'Improvements in the provision of infrastructure and services that enhance transport efficiency and lower the cost of transportation' is highlighted as a key desired impact that contributes to economic growth and productivity. As noted in chapter 6, renewals, maintenance and operations within the NZTA contribute to 'lowering the cost of transportation' through reductions in pavement roughness, which in turn reduces the vehicle operating costs (VOC) on the network. Consequently, in order to measure performance against this impact in terms of efficiency and effectiveness, there is a need to report on not only road agency costs but also on wider economic costs such as VOC.

7.1.1 Existing economic measures

A review of the existing measures included in the road network condition reporting tool (NZTA 2011b) revealed STE as the only measure currently being considered that includes some indicator of economics in the calculation. STE reports the percentage of VKT each year on roads with a roughness level of less than 5.71 IRI (150 NAASRA counts). STE can therefore be considered as a proxy for VOC.

However, STE was developed to monitor whether roads are providing acceptable travel conditions, not VOC, with the 5.71 IRI cut-off designated as the point above which travel is considered uncomfortable. The choice of the cut-off value varies internationally. In addition, the choice of one value ignores the shape of the distribution, concentrating instead on only those sections with a roughness level less than a set value. Assuming all other variables are equal, the example in figure 7.1 highlights this issue. Although the two distributions result in a similar STE value, the distributions are significantly different. This is particularly significant when the fact that VOC increases with increasing IRI is taken into consideration.

Figure 7.1 Limitations of the STE measure



7.2 New economic measure

In order to overcome some of the limitations of the STE measure, a new economic measure based on VOC is proposed. The new measure is designed to calculate the VOC due to roughness only, the premise being that renewals, maintenance and operations activities contribute to reductions in VOC through reductions in pavement roughness.

The VOC for each network (or sub-network) will be calculated based on the distribution of VKT and roughness throughout that network, thereby removing both the limitation of exception reporting imposed by the STE measure and the need to determine a suitable cut-off value.

7.2.1 VOC index calculation

To enable calculation of the VOC index (VOCI), the data requirements will include the following:

- roughness measured in IRI for each section
- VKT for each section (by vehicle class if available)
- road category for each section (urban, rural strategic, rural other).

The total VOC due to roughness for the network can then be calculated from equation 7.1 as follows:

$$VOCi_{total} = \sum (VOC_{RI} * VKT_{RI}) \qquad \text{(Equation 7.1)}$$

where

VOC_{RI} = additional VOC due to roughness value RI

VKT_{RI} = VKT on road sections with roughness value RI

The additional VOC due to roughness can be sourced from tables A5.12, A5.13 or A5.14 of the *Economic evaluation manual* (NZTA 2010a). These provide additional VOC due to roughness only by vehicle class and/or by road category, which are quoted in cents/km, and are July 2008 values. Alternatively, equation 7.2 below can be used with regression coefficients from table A5.15 in the *Economic evaluation manual*.

$$VOC_{RI} = \min\left(\{a + b * \ln(RI) + c * [\ln(RI)]^2 + d * [\ln(RI)]^3 + e * [\ln(RI)]^4 + f * [\ln(RI)]^5\}, \{g * RI + h\}\right) \qquad \text{(Equation 7.2)}$$

where

VOC_{RI} = additional VOC due to roughness in cents/km

RI = max (2.5, roughness in IRI m/km)

ln = natural logarithm

a, b, c, e, f, g and h are constants

Table 7.1 Additional VOC due to roughness – regression coefficients (NZTA 2008)

Road category	Vehicle class	Regression coefficient							
		a	b	c	d	e	f	g	h
Urban	PC	-24.870	77.057	-86.517	40.422	-5.9464	0	1.4693	6.4171
	LCV	-42.613	129.35	-141.25	64.156	-9.4511	0	1.3664	11.607
	MCV	-19.987	71.074	-91.411	47.557	-7.0566	0	3.0007	12.965
	HCVI	-32.755	112.15	-139.97	71.388	-10.510	0	4.2510	19.534
	HCVII	-20.627	77.632	-108.24	60.487	-8.7532	0	6.5590	13.630
	Bus	-6.1144	33.037	-56.239	34.664	-5.1337	0	4.2313	10.108
Rural	PC	-226.98	846.70	-1224.6	854.94	-287.91	37.983	1.5141	5.8313
	LCV	-370.44	1370.8	-1968.1	1366.6	-459.01	60.422	1.4080	11.062
	MCV	-431.90	1640.9	-2414.8	1712.2	-584.01	77.823	3.0157	12.770
	HCVI	-668.55	2530.7	-3713.6	2628.4	-895.94	119.35	4.2419	19.655
	HCVII	-610.68	2335.4	-3461.4	2469.7	-845.66	113.09	6.5815	13.338
	Bus	-389.20	1502.1	-2242.3	1607.8	-552.26	74.008	4.2594	9.7426
Urban	All	-25.935	80.862	-91.461	43.021	-6.3290	0	1.6381	7.2991
Rural strategic	All	-282.21	1056.6	-1533.9	1074.7	-363.08	48.024	1.8754	7.4853
Rural other	All	-275.08	1029.2	-1493.1	1045.6	-353.07	46.681	1.8108	7.2878

Note that table A5.15 in the *Economic evaluation manual* contains a misprint for the rural, passenger car (PC) regression coefficient 'c'. The value should be '-1224.6' rather than the '-224.6' included in the manual. The values used in this research, included in table 7.1 above, are the same as those in the *Economic evaluation manual* but with the misprint above corrected.

7.2.2 Normalised VOCi

The total VOC due to roughness will obviously be larger for networks with higher traffic volumes. Consequently, normalisation of the index is required to allow comparison between networks and to allow trend analysis over time. To normalise the VOCi calculation, the total VOCi value is divided by the total VKT for each network. This is presented in equation 7.3.

$$VOCi_{perVKT} = VOCi_{total}/VKT_{total} \qquad \text{(Equation 7.3)}$$

where

$VOCi_{total}$ = total VOC due to roughness for the network

VKT_{total} = total VKT on the network

It may also be necessary to baseline the VOC costs to a specific base year, as new vehicle and fuel technology may change the VOC over time. This could be done by using the current VOC calculations as the basis, as the absolute value of VOC is not, in itself, of interest but instead the relative measure of VOC due to differences in pavement roughness is important.

7.3 Network reporting

In order to demonstrate application of the proposed VOCi, network reports have been produced for the state highway network. Examples of these are presented in the following sections using network data from the 2009/10 financial year. The data made available to this study is stored in NZTA's long-term performance measurement data warehouse, an extraction of all RAMM databases since the year 1992 plus annual updates, and is summarised in, or broken down into, 100m lengths. Further information, such as indices, is then calculated within the data warehouse.

7.3.1 State highway network

The data made available to this study for the state highway network was broken down into the regions listed alphabetically below:

- Auckland Alliance
- Bay of Plenty East
- Bay of Plenty West
- Central Waikato
- Coastal Otago
- East Waikato
- East Wanganui
- Gisborne
- Marlborough
- Napier
- Nelson
- Northland
- North Canterbury
- Otago Central
- PSMC 005
- PSMC 006
- Rotorua
- Southland
- South Canterbury
- Tauranga
- Wellington
- West Coast
- West Waikato
- West Wanganui

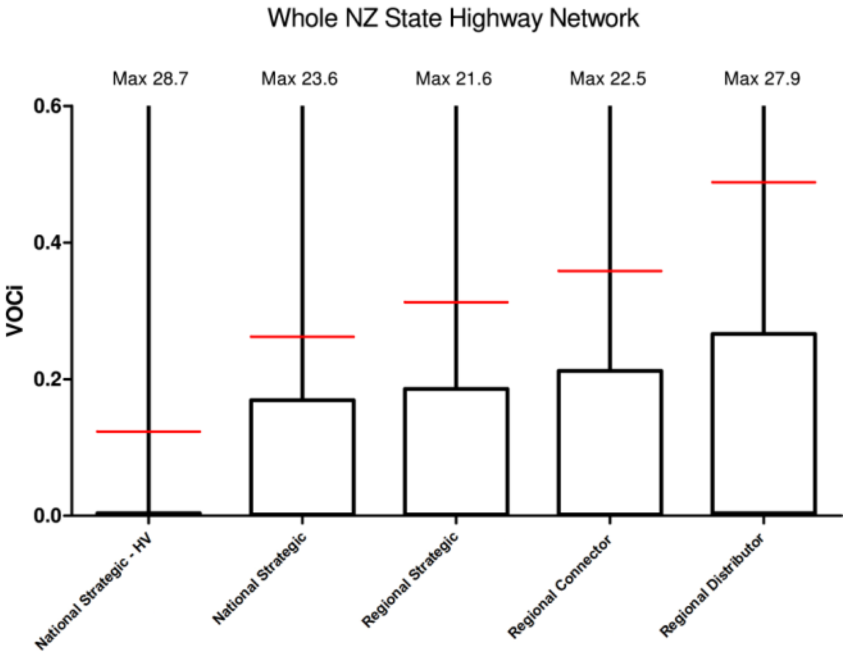
The network was further subdivided according to the new NZTA state highway classification system. The new classification system categorises roads in the state highway network based on their function, where function refers to the road's main purpose, such as moving freight to and from a port, or people between main centres. Such classifications should also provide the basis for defining differing LOS based on the functional importance of the route. The categories are as follows:

- national strategic – high volume
- national strategic
- regional strategic
- regional connector
- regional distributor.

7.3.2 Reporting by state highway classification

Figure 7.2 displays a box plot of the VOCi by state highway classification, for the NZTA state highway network as a whole. A number of conclusions may be drawn from the data, including the highly skewed distributions and the long distribution tails. The minimum, mode and 25%ile of the distributions are all negligible, with the same true for the 75th percentile of the national strategic – high-volume classification.

Figure 7.2 VOCi by state highway classification (nationally)



What is also evident is that as the functional importance of the classification decreases the average VOCi increases (indicated by the horizontal red bar), which is consistent with appropriate stewardship of the asset taking account of the relative functional importance of the route, as reflected in the LOS provided. In addition, the variability in the data increases as the functional importance of the classification decreases, as demonstrated by the increasing 75th percentile. The maximum values and hence tails of the distributions are all extremely high, identifying those sections that account for the maximum VOC per VKT.

Figures 7.3 and 7.4 display the average VOCi for two example regions, by state highway classification. The national averages are also included for comparison, along with VKT for information. The intention here is to demonstrate that the national state highway network trend is not necessarily reflected in all regions. Referring to the figures, it is clear that the national strategic routes do not follow the national trend, and should be maintained to a higher LOS given their classification. Similar figures are available for all regions and are included in appendix C.

Figure 7.3 Average VOCi by state highway classification (Central Waikato)

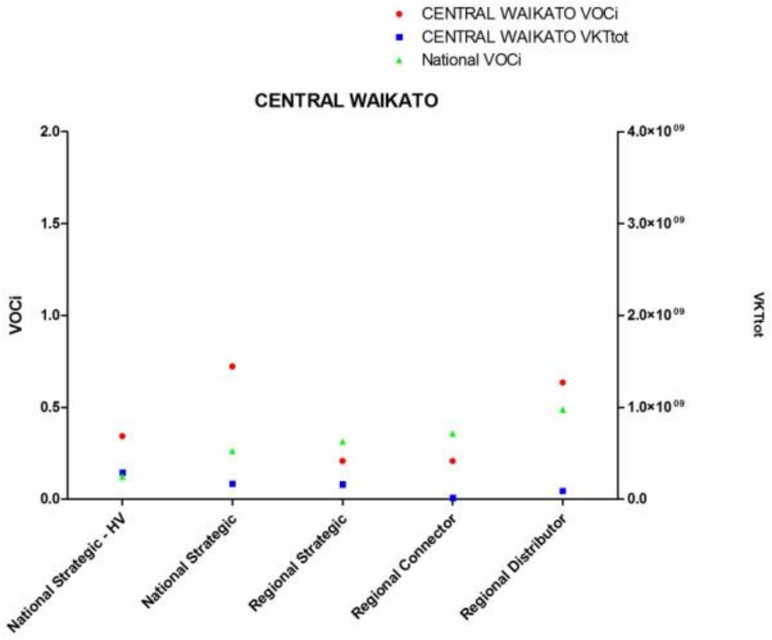
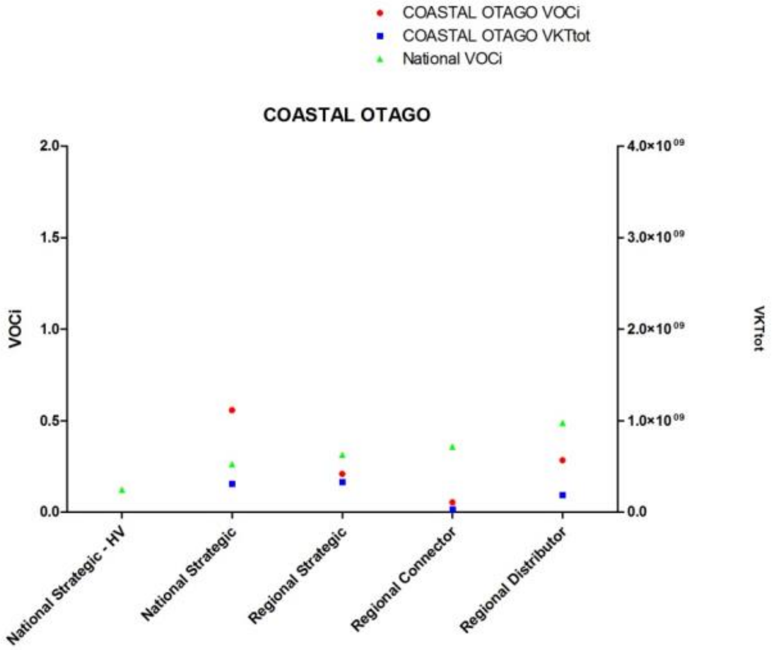


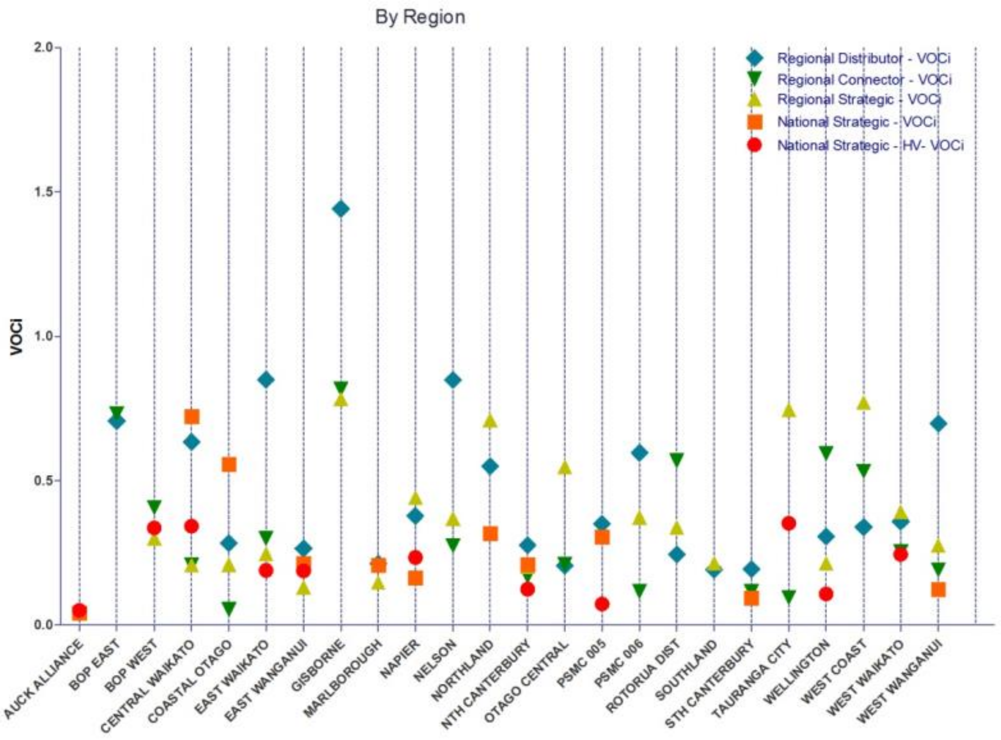
Figure 7.4 Average VOCi by state highway classification (Coastal Otago)



7.3.3 Comparison between regions

Figure 7.5 displays the average VOCi for all regions by state highway classification. This plot allows for a comparison between regions for each classification. It also allows for comparison of average VOCi by classification within a particular region, thereby indicating whether the higher classified routes are being maintained to a higher level and vice versa.

Figure 7.5 Average VOCi by region and state highway classification



Looking across the regions it is evident that a number of the regions do not maintain their national strategic routes at a higher level than their regional routes, using VOCi as an indicator. Comparison between the regions also identifies the Auckland Motorway Alliance, as expected, as the best served region, and, at the other end of the scale, Gisborne as the worst served region, using VOCi as an indicator.

Further plots are provided in the figures below for each classification by region. VKT is also provided for information and the regions are listed in order of increasing VKT. Immediately evident is the increase in variability in the region averages as the classification of the networks decreases.

Figure 7.6 displays the average VOCi by region for national strategic – high-volume routes. Points of note include the significant VKT on the Auckland Alliance network and correspondingly low VOCi. Interestingly, PSMC 005 has a comparably low VOCi but has significantly lower VKT on their network. The form of contract, and incorporated performance measures, almost certainly influence those values.

Figure 7.6 Average VOCi by region (national strategic – high volume)

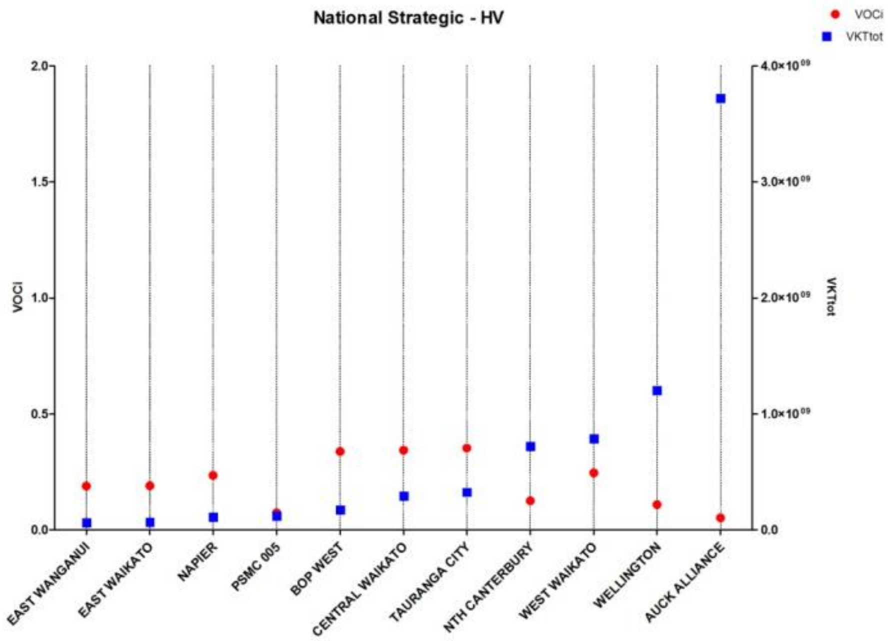


Figure 7.7 displays the average VOCi by region for national strategic routes. Points of note include the relatively high VOCi value for central Waikato and coastal Otago. The VOCi is again very low for the Auckland alliance.

Figure 7.7 Average VOCi by region (national strategic)

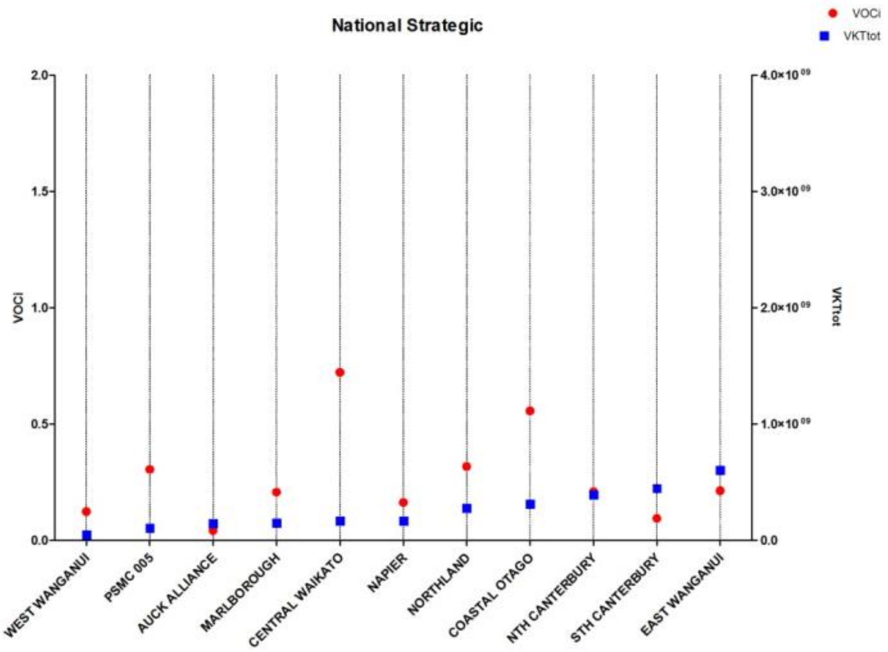


Figure 7.8 displays the average VOCi by region for regional strategic routes.

Figure 7.8 Average VOCi by region (regional strategic)

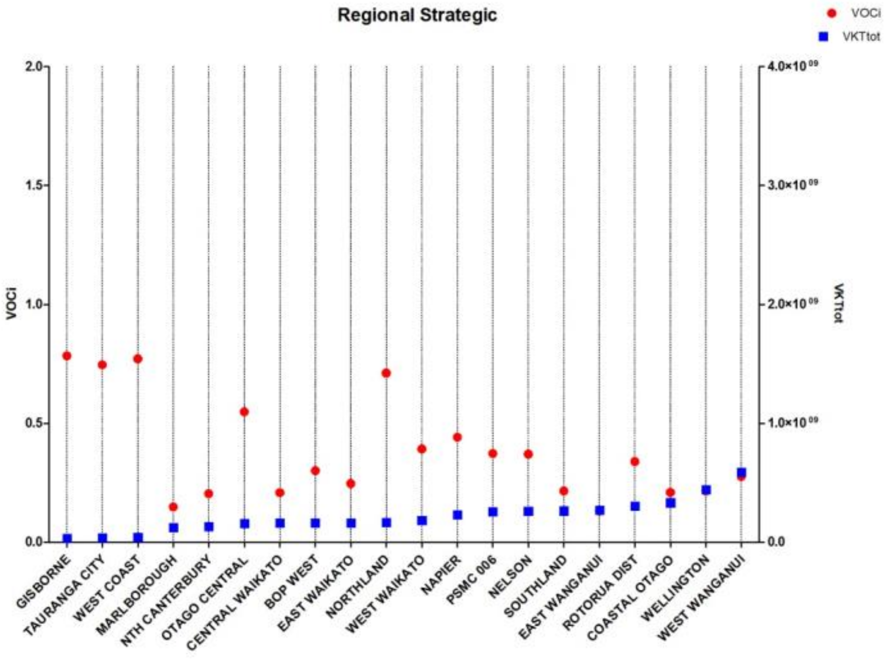


Figure 7.9 displays the average VOCi by region for regional connector routes.

Figure 7.9 Average VOCi by region (regional connector)

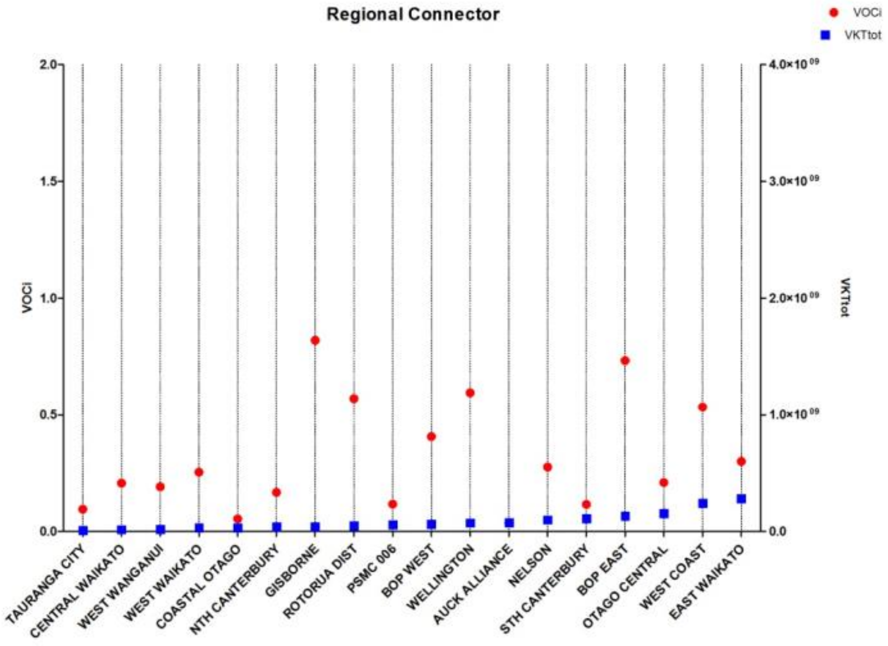
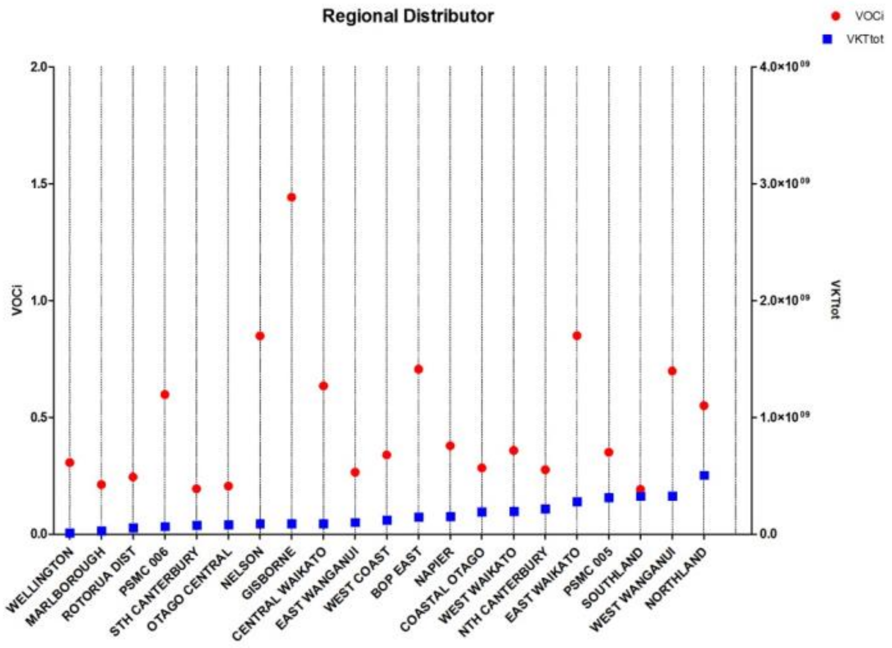


Figure 7.10 displays the average VOCi by region for regional distributor routes. Variability between regions is quite noticeable at this stage with the high VOCi for Gisborne, previously noted in figure 7.5, again evident.

Figure 7.10 Average VOCi by region (regional distributor)



7.4 Discussion and conclusions

Given the MoT's desire to 'enhance transport efficiency and lower the cost of transportation' through the use of the National Land Transport Fund, decisions on renewals, maintenance and operations funding should, ideally, be informed by VOC due to pavement roughness. Other surrogates do exist in the form of IRI and STE; however, neither account for the fact that VOC increases with increasing IRI, and the former ignores the VKT, a significant part of the VOC calculation. The proposed new index, VOCi, addresses both these weaknesses and provides a much more targeted indicator of opportunities to 'lower the cost of transportation' through funding renewals, maintenance and operations.

Network reports have been produced for the state highway network in order to demonstrate the application of the VOCi. These reports are broken down by state highway classification and region. At the national level, the VOCi increases as the functional importance of the classification decreases, as indeed does the variability of the data. This is consistent with appropriate stewardship of the asset, taking account of the relative functional importance of the route, as reflected in the LOS provided. At the regional level, however, the relative functional importance is not always reflected in the VOCi data and variability between regions is, in some case, significant.

However, the data itself cannot provide definitive reasons for the variability between or within regions. For example, a relatively new, or newly rehabilitated, stretch of regional road could skew the network values for VOCi if the road accounts for a significant proportion of the regional classification in question. Such a situation could, for example, result in the average VOCi for the regional classification being lower than the national classifications. Similarly, geological factors, climatic influences and topography could account for higher VOCi values in some regions. Clearly, the VOCi, like any other indicator of its kind, is only part of the information available to decision makers and needs to be presented with sufficient contextual information. It will also not replace the need to ‘drill down’ to determine the reasons behind uncharacteristic values. This is illustrated in the Gisborne region where the challenging topography and resulting geometry are at least in part responsible for the relatively high IRI and resulting VOCi values.

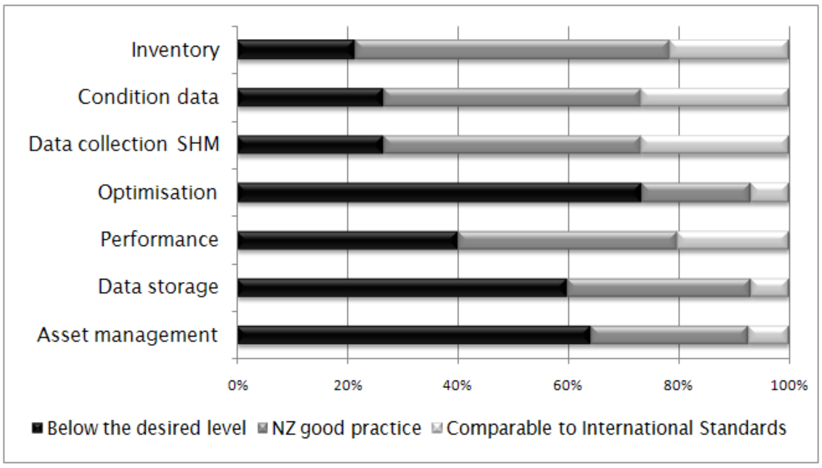
8 Monitoring of bridge structural performance measures

8.1 Status of bridge management in New Zealand

Bridge asset management has become a rapidly developing topic in many countries. One of the obvious reasons for this is that most infrastructure has been constructed following the Second World War, and is up to 70 years old. Given that most bridges were designed for a lifespan of 50 to 100 years, a large portion of this asset base is deteriorating or at least of an age where maintenance has become an important consideration.

Bush et al (2011a; 2011b) surveyed the processes involved with bridge asset management across six state highway areas (67% of questionnaires) and nine local authorities (45% of questionnaires). The main objective of the survey was to establish good practice in New Zealand towards developing a data collection framework. The survey not only questioned practices for data collection, but also investigated the actual use of the data in decision making. Figure 8.1 illustrates the overall outcome from the questionnaire.

Figure 8.1 Status of New Zealand bridge management practices (Bush et al 2011)



Note: SHM – structural health monitoring

Figure 8.1 was developed by assessing the status of each asset management process according to a three-point scale that indicated practice 1) below a desired level, 2) according to New Zealand good practice, or 3) according to international practice. From the figure, it appears that, in general, the data collection on bridges is acceptable. However, due to the type of data collected, little value is realised in the reporting (performance) and decision processes. This ultimately leads to a poor overall execution of asset management.

This project aimed at establishing a framework for the monitoring of bridges in order to better direct funding needs in this area.

8.2 Context for undertaking performance management of bridge structures

It is safe to conclude from the previous section that the asset management processes for bridge structures still have some way to go before a claim can be made that good practice is being followed. At the core of this is the availability of appropriate data. This gap in New Zealand process was addressed as part of three main stream developments including:

- improving practices in relation to structural data collection, especially condition assessment
- setting up a performance monitoring process for structures
- developing a decision support process for structures.

The latter two items cannot be developed prior to putting the data collection process in place. Likewise, the data collection process and requirements needed to be developed in cognisance of the requirements for the performance monitoring and decision processes. The recommended data collection framework is discussed in section 8.3.

8.3 Data collection framework for bridge structures

In a recent NZTA research project, Bush et al (2012) developed a data collection framework for bridge structures in New Zealand. This framework, if adopted, will have a significant impact on the monitoring of structures in New Zealand and, for that reason, it is briefly summarised in this report.

The fundamental principles in developing the framework were as follows:

1. In order to make the appropriate decision on bridges a certain amount of data/information is required. Current processes do not comprehensively provide the required level of information. Good information exists for inventory items and fault detection but not for bridge condition data.
2. Collecting the appropriate level of information on all structures in New Zealand would be unaffordable.
3. Therefore, in order to address points 1 and 2 above, a framework was developed to collect the appropriate level of data on each bridge given its state and importance, ie collect a high level of data where most needed.

The framework proposed by Bush et al (2011) uses a risk and criticality approach in order to a) classify structures and b) apply a pre-defined data collection regime given the resulting classification of the bridge in question. Table 8.1 illustrates the outcome of this system by classifying a few example structures from around the country. Criticality was defined as the network-wide importance of a structure. For example, the Auckland harbour bridge would probably be the most significant bridge in New Zealand given its strategic importance. In contrast, New Zealand has a number of minor structures that ensure access to a limited number of users in remote rural parts of the country. The risk classification considers both the probability of failure of a structure and the direct consequence (replacement cost) should it fail.

Table 8.1 Risk and criticality classification of bridges (Bush et al 2012)

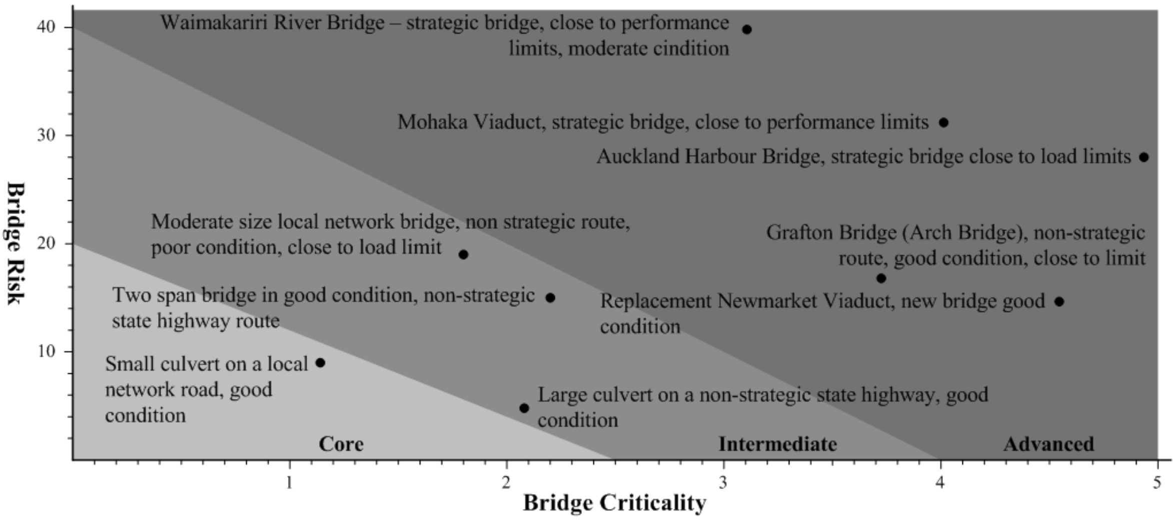


Table 8.1 further shows three zones for the final classification of a bridge according to its associated risk and criticality: core, intermediate and advanced. This classification will put the bridge into a corresponding data collection regime (refer to table 8.2) and as a result of the data collection it will allow a certain level of asset management to be performed (refer to table 8.3). The data collection approach allows for the collection detail, frequency and method to be adjusted according to the classification level of the bridge. Therefore, for higher risk and critical bridges, more advance data collections approaches are being used and data collection is being undertaken more frequently. However on core bridges, just the minimum data is being collected at an infrequent collection interval.

Table 8.2 Data collection regime for bridge structures

Data collection level	Bridge risk and/or criticality band	Risk assessment resolution and reporting	Data collection techniques and frequency
Core	Low	Overall bridge performance risk and criticality	Visual inspections every 3–6 years Limited, usually reactive SHM
Intermediate	Intermediate	Individual element performance risk and criticality	Visual inspections every 2–3 years Some, reactive and proactive SHM
Advanced	High	Individual component performance risk and criticality	Visual inspections every 1–2 years Extensive, mostly proactive SHM

Table 8.3 Classification of bridge data collection levels and asset management levels

Data collection level	Asset management level	
	Core	Advanced
Core	Basic functionality of asset management can be achieved including valuations and prioritisation of annual budget expenditure	Core data may not be sufficient for advanced asset management processes
Intermediate		Advanced asset management processes including network level analysis, forecasting condition/risk and investment level scenario analysis can be achieved using intermediate data
Advanced		Advanced data is utilised for further analyses at a more detail level (eg project detail level) such as diagnostics and more accurate intervention needs and costs

The data collection level reflects its value in terms of how it could be used in the asset management process (refer to table 8.3). If data is collected at a core level, it could be expected that sophisticated forecasting and reporting processes would not be possible. However, it would be possible for structures where this is most needed and appropriate data is collected. In terms of this project, the performance monitoring of bridges should be undertaken on the basis of the proposed framework. In fact, these same principles could also be applied to the collection of pavement data. For example, there are a number of authorities that need to improve the data collection processes on strategic parts of their network. However, this high level of data collection may not be required on the entire network. The following chapter will explore this principle further.

8.4 Monitoring health of bridge structures

8.4.1 Development methodology – linking the bridge performance framework to NZTA strategic outcome areas

The first step towards developing a monitoring process for bridge structures for the NZTA was to link some relevant tactical measures to the NZTA's desired long-term impacts (2011a). These measures are depicted in table 8.4. The table shows there is a strong representation of bridge information contributing towards the NZTA output classes.

Table 8.4 Tactical measures for structures

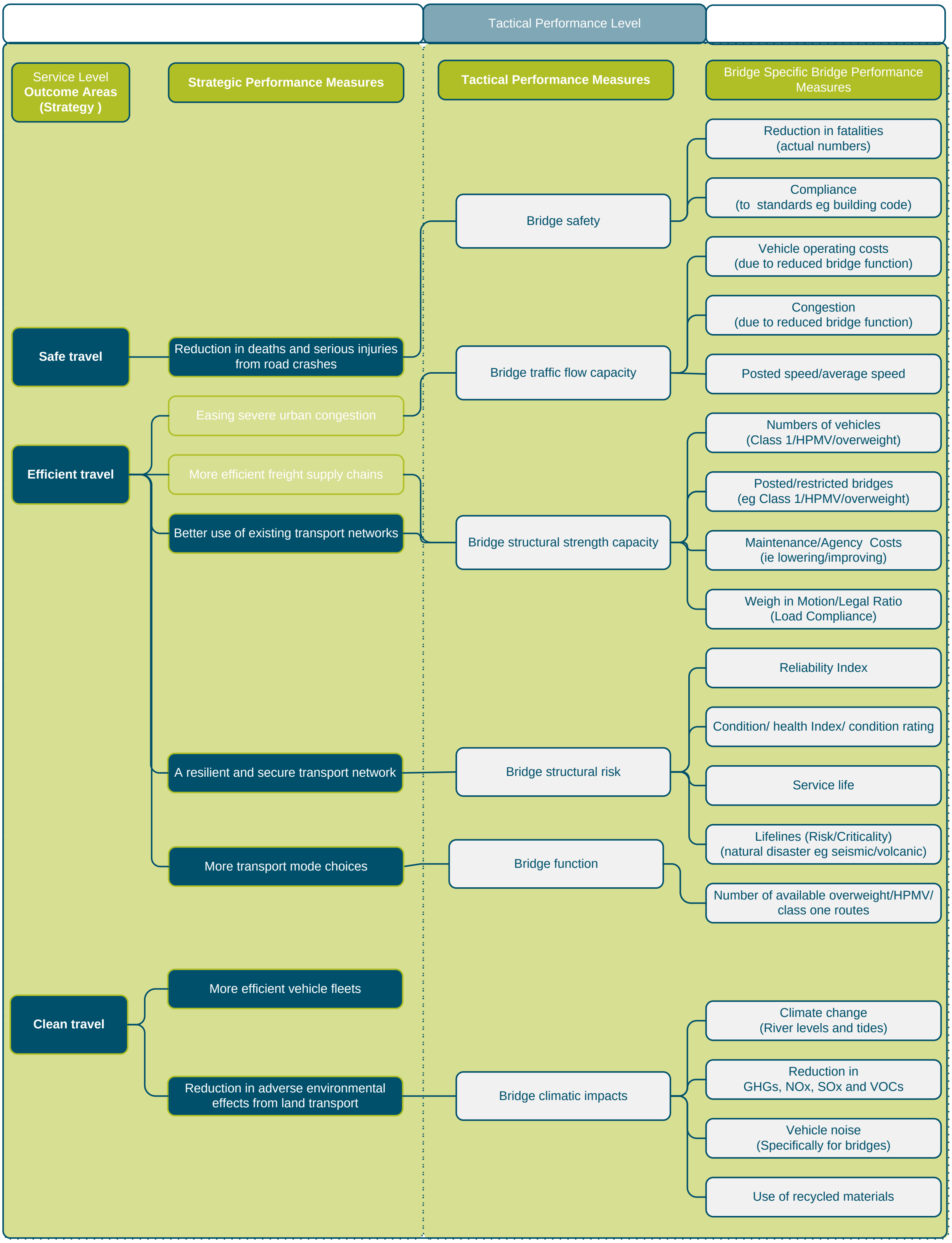
Output class	Desired long-term impacts						
	Better use of existing transport capacity	More efficient freight supply chains	Resilient & secure transport network	Easing of severe urban congestion	Reduction in deaths & serious injuries from road crashes	More transport mode choices	Reduction in adverse environ-mental impacts
Tactical structures measure	Capacity in terms of structural strength	Capacity in terms of structural strength	Structural risk	Capacity in terms of traffic flow	Safety	Bridge function – related to the load it can take (eg pedestrian bridge)	Climatic impacts

The next step was to assign data items/operational performance measures to each of the tactical performance measures. The following section presents the resulting framework from this process. The data collection recommendations are presented in section 10.4.

8.4.2 Recommended framework – linking monitoring needs to data items

Figure 8.2 illustrates the recommended performance framework for bridges and structures in New Zealand. The framework shows that bridge performance could be effectively linked to the NZTA's higher strategic levels.

Figure 8.2 Bridge/structural performance framework



9 Monitoring of traffic services

9.1 Asset coverage

Traffic services assets cover a series of assets defined under the NZTA (2008) *Planning, programming and funding manual*, work category 222: Traffic services renewals. The work category covers the following assets:

- traffic signs, traffic signals and area-wide traffic control systems
- road delineation marker posts
- pavement markings, including bus priority lane and cycleway markings on all non-separated road surfaces and markings for stock crossings
- sight rails
- carriageway lighting, including poles and replacement of lanterns at the end of their economic life with more efficient types
- belisha beacons and lighting at pedestrian crossings
- advanced traffic management systems (ATMS)
- variable message signs (VMS)
- local area traffic management schemes, including speed control devices and threshold treatments
- ramp metering equipment
- surveillance devices and traffic monitoring equipment, such as closed-circuit television systems
- emergency telephones on motorways
- weighing facilities owned by an RCA and/or operated as a weight surveillance facility.

Currently the NZTA receives funding applications for the maintenance (work categories 122 and 123) and renewals (work category 222) for these assets. However there is no current framework for assessing the validity or efficiency of these requests, nor a framework for assessing the performance indicators and levels of service for these assets.

The scope of this research paper has been restricted to those assets which are common to most RCAs or those that hold a significant value. Therefore the assets examined are as follows:

Table 9.1 Assets covered by research topic

RCA assets included	Uncommon specialist RCA assets excluded
Traffic signs	Speed control devices and threshold treatments
Traffic signals	Ramp metering equipment
Marker posts	CCTV systems
Pavement markings	Emergency telephones on motorways
Sight rails	Weighing facilities
Lighting	
ATMS	
VMS	

9.2 Principles of assessment

The process was to develop some performance objectives, and then based on the results, develop appropriate data collection requirements for traffic service assets. The framework also had to link to the NZTA strategic outcome areas.

We propose two steps:

1. Provide the NZTA with guidelines for assessing funding requests:
   a. extent of asset
   b. typical expenditure
   c. compliance issues
2. Develop performance objectives:
   a. condition monitoring
   b. levels of service
   c. managing risk

We have called this a two-step process because the first step will be to get RCAs to collect basic inventory data. Later when the need arises condition data can be collected and used to set performance objectives.

The philosophy behind developing the framework was as follows:

- Traffic services assets typically number many low-value assets, eg signs. It is important not to spend thousands of dollars on asset information and monitoring to save hundreds of dollars in ‘efficiencies’ and ‘good asset management practice’. This issue is explored further by Greenwood and Hansen (2011) who look at the balance between implementing advanced asset management techniques and utilising a more pragmatic approach, depending on the value or criticality of the asset.
- The asset needs to be maintained but not excessively so.
- The purpose of the framework is to give the NZTA guidance in assessing and providing value for money in the maintenance of these assets. The framework does not dictate best practice management for each asset type, but provides a guide to:
  - the minimum standards and asset knowledge the NZTA should expect
  - enable benchmarking value for money between RCAs
  - more advanced asset management measures and KPIs, where appropriate.

We have summarised the recommendations for each asset type as follows:

- Minimum data requirements for the NZTA to support LTP funding applications:
  - This is the minimum information the NZTA should require from the RCA in support of their funding application.
- Moderate data requirements, supported by the NZTA, to support LTP funding application
  - This is the recommended amount of information that would suggest a well-considered and documented funding application.
- NZTA basic benchmarking information to assess funding application:

  - This is the list of information the NZTA needs to assess the funding application and give some guidance on providing value for money.
- Recommended minimum asset management practices:
  - This is the minimum asset management practice the NZTA would find useful for the asset type, for example, simply having an asset inventory with an established process for keeping it up to date.
- Recommended asset management practices:
  - These are the suggested asset management practices the NZTA would find useful to have implemented for a particular asset type. This could be a more active asset management approach to condition assessment and maintenance programming.

9.3 Traffic signs

Traffic signs are an asset category made up of a very high quantity of typically low-value individual assets. They make up a significant portion of the road asset portfolio outside the pavement assets.

Funding subsidy is restricted to signs complying with the *Manual of traffic signs and markings* (MOTSAM) (NZTA 2010b). The only restrictions listed in section 4.30 are tourist information signs or general advertising signs indicating sales outlets adjacent to the road highway.

Criticality: The most critical signs in terms of risk management are signs associated with Stop and Give Way intersections. On rural high-speed networks safety and warning signs perform a similar function and have similar criticality. However, these signs are small and typically of low value.

Signs of secondary importance are signs overhanging carriageways whereby the condition of the supporting structure and fixings needs to be monitored. These provide guidance to improve and aid traffic travelling on the road network. Typically the condition of this supporting infrastructure is covered under the structures maintenance programme where the signs are listed as structures rather than assets.

Value: The most expensive signs are the large gantry or overhead signs. There is also an increasing number of variable message signs. Again these signs are often managed separately from the traffic signage infrastructure as part of the intelligent traffic system assets. They are also covered separately within the framework.

Renewal strategies: Often signs are replaced due to vehicle crash damage or vandalism rather than through lack of performance or condition. The most significant measure for sign performance is reflectivity.

Compliance requirements: Compliance requirements are determined as per MOTSAM.

Annual depreciation for signage varies between 2% and 4% of total road asset depreciation and a similar proportion of operating and renewal expenditure. However, it typically consists of less than 1% of the total value of the road network asset value.

The framework needs to recognise the low individual value of signage assets and the random nature of renewals. This therefore requires a pragmatic and/or targeted approach to their management. A comprehensive framework of inventory management, condition monitoring and complex asset management programming is not justified.

- Minimum data requirements from RCAs to support LTP funding application:
  - approximate quantity of signs on the network

  - approximate quantity of signs being renewed annually on the network
  - approximate maintenance and renewal costs of signs annually on the network
- Moderate data requirements, supported by the NZTA, to support LTP funding application:
  - approximate quantity and type of signs on the network
  - approximate quantity and type of signs being renewed annually on the network
  - typical lifecycle signage information by category
  - asset management plan requirements or LOS requirements relating to signage
- NZTA basic benchmarking information to assess funding application
  - typical signs/km on rural roads, lifecycle and average sign maintenance cost/km
  - typical signs/km on urban roads, lifecycle and average sign maintenance cost/km
  - possible lifecycle breakdown into types, eg fingerboard, regulatory, advisory etc
- Recommended minimum RCA asset management practice
  - inventory of signs with rolling five-year inventory updates
- Recommended RCA asset management practices
  - inventory of signs with rolling five-year inventory updates
  - monitoring of installation and replacement dates to quantify lifecycles
  - condition monitoring/LOS on high-risk/value assets:
    - reflectivity measure on selected critical sign types
    - visual condition assessments 1–5 on selected sign types, eg advance direction signs (ADS)
    - analysis of cause for replacement and lifecycle.

9.4 Traffic signals

Traffic signals are an asset category made up of a high quantity of low-to-moderate value individual assets. They make up a significant portion of the road asset portfolio outside the pavement assets. Items include traffic control equipment including traffic signals, control equipment, SCATs equipment and CCTV monitoring. Also included are associated assets such as electronic speed zone signage, driver feedback signs, red light cameras and pedestrian countdown timer clocks.

Only urban RCAs have significant signal control assets with the larger the city, the higher the number of signals sets. However signals are required to govern high-volume intersections. As city populations increase, the traffic volumes on key routes increase. Therefore larger cities such as Auckland and Wellington will have a much higher number of signalised intersections than smaller cities such as Whangarei or Nelson than the relative populations would suggest. Monitoring of this expenditure category by the NZTA will probably only be necessary for the larger main centres.

Criticality: Criticality of these assets is high as they are used at intersections, governing traffic movements to prevent vehicle conflicts and crashes and to provide efficient movement of vehicles through intersections. As a result, signalised intersections have to allow for some redundancy by requiring multiple signal poles to be visible in the event of any pole not working or having been damaged. However control equipment failure can lead to the entire intersection being inoperable, particularly in the event of power failures. Response times are high and proactive asset maintenance and renewal is important.

Value: The most expensive items are the traffic signal controllers which can be in the order of $20,000 each depending on the complexity of the intersection. The traffic signals themselves have components including poles, signal aspects and cabling and cost less than $3000 for a complete pole and signal set.

Renewal strategies: Maintenance is carried out at regular intervals and assets at the end of their life are renewed. Detector loops are often damaged due to pavement works and utility trenching. Poles are replaced due to damage from vehicles and water ingress. Many poles serve multiple functions, such as lighting or CCTV monitoring. This increases LOS but makes maintenance and renewals more expensive. LED bulbs in the signal aspects are more expensive but are more reliable and energy efficient. Typically age is the main driver of condition. Auckland city uses the age of the controller as a guide to the age of signal sets.

Compliance requirements: Compliance requirements are determined as per the *TMU national traffic signal specification* (IPENZ 2005).

Annual depreciation for signal assets varies between 2% and 4% of total road asset depreciation and a similar proportion of operating and renewal expenditure. However it typically consists of less than 1% of the total value of road network asset value.

The framework needs to recognise the moderate individual value of signal assets and the random nature of renewals. This therefore requires a pragmatic and/or targeted approach to their renewal. RCAs should have either a programmed maintenance regime or at least remote telemetry monitoring of faults so that maintenance response times are as low as possible. A comprehensive framework of inventory management, condition monitoring and complex asset management programming is probably not justified.

- Minimum data requirements from RCAs to support LTP funding application:
  - approximate quantity of signal assets on network
  - approximate maintenance and renewal costs of signal sets annually on the network
- Moderate data requirements, supported by the NZTA, to support LTP funding application:
  - approximate quantity and type of signal assets on network
  - approximate quantity and type of signal assets being renewed annually on network
  - typical lifecycle for signal componentry by category, eg poles, signal aspects, controllers and SCATS loop maintenance
  - AMP requirements or LOS requirements relating to signal assets
- NZTA basic benchmarking information to assess funding application:
  - number of signal controllers, poles, signal aspect, SCATs
  - lifecycle breakdown into components
- Recommended minimum asset management practices:
  - inventory of signals with rolling five-year inventory updates
- Recommended asset management practices supported by the NZTA:
  - maintenance of signal asset inventory

  - monitoring of installation and replacement dates to quantify lifecycles for major components
  - condition monitoring/LOS on high-risk/value assets
  - visual condition assessments 1–5 on signal components
  - analysis of cause for replacement and lifecycle.

9.5 Marker posts

The typical cost for an edge marker post is less than $10. Installation costs per post may be higher but the overall value is low. Selwyn District Council reports 6000 edge marker posts on their rural network. Their details are normally stored in the RAMM database under the traffic facilities table with quantities noted by carriageway section.

It should be noted that the NZTA has ceased requiring storage of marker post assets for the state highway networks in RAMM.

It is recommended that no monitoring be instigated as part of the funding application process for marker post assets.

9.6 Pavement markings

Pavement markings are seldom valued due to their short life, the exception being some of the thermoplastic markings and other specialist road markings. They are inventoried in RAMM but this serves mainly as a basis for providing quantities for road marking contracts. Typically non-thermoplastic markings are not capitalised or valued and are renewed annually under operational expenditure. This renewal can be either on a scheduled basis or a performance basis. Scheduled renewal will typically be either on hierarchy (eg strategic and arterial roads twice a year, others annually) or a volume basis. Performance-based renewal is based around reflectivity.

Some RCAs have no asset record and the supplier holds inventory data for markings through their history on the network. RCAs should hold this data themselves.

Compliance requirements are determined as per MOTSAM:

- Minimum data requirements from RCAs to support LTP funding application:
  - approximate renewal costs of markings annually on network
  - AMP requirements or LOS requirements relating to markings (if any)
- Moderate data requirements supported by the NZTA in funding applications:
  - approximate quantity and type of markings on network
  - renewal strategy, ie performance or schedule basis
  - AMP requirements or LOS requirements relating to markings
- NZTA basic benchmarking information to assess funding application:
  - typical cost/km on rural roads
  - typical cost/km on urban roads
- Recommended minimum asset management practices:

  - schedule based on asset inventory
- Recommended asset management practices:
  - schedule or performance-based specification is fine. Performance based can be beneficial on larger complex networks but has a higher audit/compliance cost associated with it.

9.7 Railings (sight rails and barriers)

For territorial RCAs, sight rails and barriers are not a significant item. Barriers are usually found on high-speed rural roads with moderate to high traffic volumes. In urban areas, they can be found typically as median barriers. The greatest number of barriers and railings occur on the state highway network with the high-volume, high-speed environment justifying these measures on safety grounds.

Replacement is mainly due to crashes. There has been a recent increase in the implementation of barriers on bridge approaches and these assets are valued as a bridge component.

Compliance requirements: Compliance requirements are determined according to the *State highway geometric design manual* (NZTA 2000) and NZTA M23: 2009 Specification for road safety barrier systems.

- Minimum data requirements to the NZTA for funding application:
  - no requirement for provision of data
- Moderate data requirements supported by the NZTA in funding applications for state highway networks:
  - approximate quantity and type of guardrails and barriers on the network
  - renewal strategy, ie as required plus any assessment basis
  - AMP requirements or LOS requirements relating to response times and condition
- NZTA basic benchmarking information to assess funding application:
  - typical cost/m of barrier on rural roads
  - typical cost/m barrier on multilane highways
- Recommended minimum asset management practices:
  - not required
- Recommended asset management practices:
  - monitoring of repair sites to see if a safety issue is causing regular renewals and needs to be addressed.

9.8 Carriageway lighting

Carriageway lighting is an asset category made up of a very high quantity of typically moderate value individual assets. They make up a significant portion of the road asset portfolio outside the pavement assets. Streetlights average around every 50m of urban network and typically have a value of approximately $2500 per pole plus light. Components consist of the lantern, bracket and pole. Pole are often owned by a variety of parties including the RCA as well as utility providers, particularly power companies where the bracket is attached to a power pole. Alongside maintenance and renewal costs is a third factor, power consumption, a significant cost to consider in the management of these assets. Power costs are also subsidised by the NZTA.

Subsidies are not given for amenity lighting including lighting to buildings, property and reserves, under-veranda lighting, festive lighting and any other lighting not directly related to the operation of a road.

A significant issue is non-standard lighting assets, particularly where developers install aesthetically detailed street lighting that does not match other assets making maintenance and renewals inefficient and expensive. Technology is changing also, particularly in lantern design giving more reliable and energy efficient options to be considered.

Criticality: Street lighting provides for improved safety for the movement of pedestrians and vehicles after dark. The individual items have a low criticality but response times need to reflect public safety issues around non-functioning assets.

Value: There is an increasing trend for multifunctional poles which creates capital efficiencies but increased maintenance costs, particularly in the event of crash damage. Undergrounding of power supplies creates the need for new poles where services have utilised power poles. Often ownership of assets is unclear. This is further exacerbated by the charging of power costs over assets the RCAs may not own.

Renewal strategies: These are best described by component:

- Lantern: These are typically undertaken on the basis of replacing lanterns as they fail or by programmed replacement utilising economies of scale to replace lanterns across a scheduled area. This has the advantage of all lanterns in that area having the same installation date and thus the same expected life. Ad hoc maintenance creates lanterns of varying ages although it maximises the life of each lantern.
- Bracket and pole: Ideally poles will be frangible and non-steel poles, particularly fibreglass or concrete poles are a hazard. Non-council owned poles create issues of dependency on external parties. Often these poles are spaced for the needs of the utility provider and are not optimised for lighting requirements. The overhead powerlines often preclude the ability for the RCA to place their own lighting poles should they wish to. Condition assessment of pole condition can be used to programme renewal treatments alongside replacing damaged poles from vehicle crashes as needed.

Compliance requirements: Compliance requirements are determined as per AS/NZS 1158 and RCA lighting policies.

Annual depreciation for signage varies between 1% and 3% of total road asset depreciation and a similar proportion of operating and renewal expenditure. However it typically consists of less than 1% of the total value of road network asset value. However power costs can be in the order of $100 per lantern per year and therefore a significant component also.

The framework needs to recognise the moderate individual value nature of the lighting assets, the random nature of renewals and complexities of the different component types. This therefore requires a pragmatic and/or targeted approach to the management of lighting assets. A comprehensive framework of inventory management, condition monitoring and complex asset management programming can be implemented but needs to be justified.

- Minimum data requirements to the NZTA for funding application:
  - approximate quantity and type of lighting columns on network
  - approximate quantity and type of lighting assets being renewed annually

  - AMP requirements or LOS requirements relating to lighting
- Compliance:
  - AS/NZS 1158
  - RCA lighting policies
- NZTA basic information to assess funding application:
  - number of assets
  - typical lights/km on rural roads and lifecycle
  - typical lights/km on urban roads and lifecycle
  - lifecycle breakdown into components
  - typical costs.
- Recommended asset management practices:
  - monitoring of installation and replacement dates to quantify lifecycles
  - power saving whole-of-life costing of components
  - maintenance activity cost analyses, eg bulk changing vs individual replacements
  - analysis of cause for replacement
  - risk analysis of failure, eg safety issues
  - upgrade for compliance requirements
  - condition assessment, eg poles.

9.9 Advanced traffic management systems

The ATMS funding requirement needs to be investigated on a case-by-case basis. There are no typical ATMS requirements across the general RCA networks from which to compare or benchmark spending. Any individual items, if significant, need to be justified to the NZTA on an individual basis.

9.10 Variable message signage

VMS is becoming more common but the maintenance costs associated with these signs are still too low to warrant a separate detailed funding request within the LTP funding application process for traffic services. They are also not specifically separated out in asset management or activity management plans.

It is recommended improvements focusing on other asset components such as signage, lighting and traffic signals would provide better value at this stage.

10 Appropriate data for monitoring purposes

10.1 Data collection techniques and strategies

Before discussing appropriate data for monitoring purposes it has to be emphasised that:

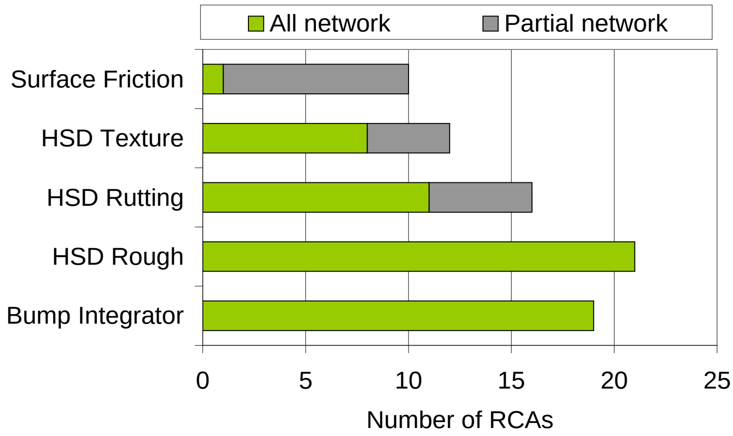
- the data currently being collected on the New Zealand road network limits the success of performance monitoring
- getting the best data on the entire New Zealand network (state highway and local authority networks), would probably not be affordable, or cost efficient given the use of the data.

Therefore, it is safe to assume the industry needs to move towards developing an appropriate data standard that may require more data to be collected on strategic roads, and less or less accurate data on lower order roads. Having a disparate data collection process for different parts of the network is not always practical, and cost differences may suggest moving to a consistent, but less frequent approach for the entire network. There are many ways to address the issue, but having a good understanding of the intended purpose of the data and the data quality is paramount.

10.1.1 Completeness, coverage and sampling

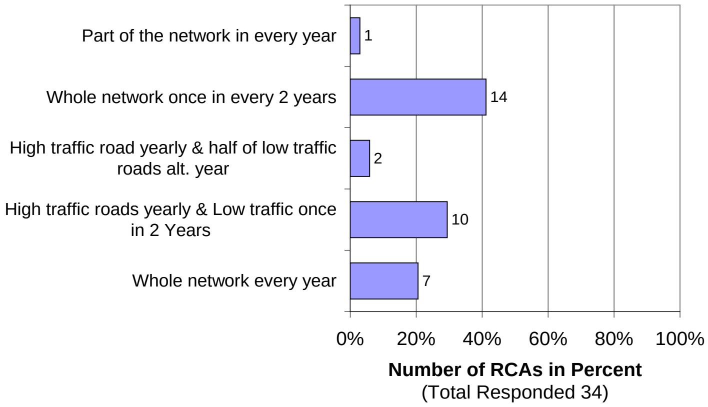
There are three ways in which data collection strategies can vary: completeness, coverage and the sampling regime. Completeness refers to the type of data authorities are collecting. Table 10.1 illustrates the different types of data that are being collected on New Zealand local roads (note that this figure only includes automated collection methods). All 34 authorities surveyed are doing roughness measurements on their entire networks; however, only 16 collect rutting data by means of automated collection methods. Of these, 11 are doing rutting measurements on their entire network. Fewer authorities are doing texture and surface friction data collection.

Table 10.1 Type of data being collected on a sample of New Zealand roads (Pradhan 2009)



Among the 34 authorities surveyed, five different approaches towards network coverage are being used. Of these only seven authorities do full network coverage annually. The rest either do full network coverage every second year or split the network into annual surveys on higher volume roads and partial surveys on the remainder of the network.

Table 10.2 Network coverage of data collection on New Zealand roads (Pradhan 2009)



FWD is the method/instrument used to carry out the sampling of a network, whereas high-speed data is normally completed on a 100% sampling approach. Note that while recording and reporting intervals of devices differ, this aspect is viewed as a precision rather than a sampling issue.

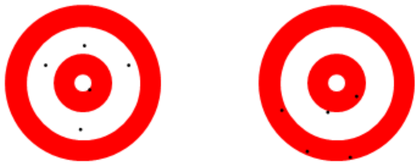
It can be seen from the above that approaches to data collection differ considerably between authorities and this has a significant impact on the condition monitoring process. A more consistent approach is presented in the following sections.

10.1.2 Bias/accuracy and precision

Data collection is prone to two types of errors, namely in relation to accuracy/bias or due to precision. The difference in these two errors is illustrated in figure 10.1. With the type of data collection technologies available, people often associate precision issues with the sophistication of the equipment. In contrast, accuracy and bias are normally a result of calibration or quality control issues. In terms of a performance monitoring process, the most significant concern is precision since imprecise data makes it difficult to analyse in any form. Bias or accuracy can be an issue if peer comparisons are undertaken between authorities where one or both have a bias in the measurements. Similarly, when time-based analyses are undertaken and the bias between years is different, the results will give skewed trends. This is often the case when there is a change in service provider or technology.

Figure 10.1 Bias and precision (Annis 2011)

unbiased, precise biased, precise



unbiased, imprecise biased, imprecise

In terms of performance monitoring, variance in the data impacts on the level of confidence in the resulting values. It would therefore make sense to classify the respective technologies and quality assurance processes to an expected qualitative confidence level. This can then be further developed into a collection framework that takes account of required confidence levels at given road hierarchies.

10.2 Data collection framework – roads

10.2.1 Confidence levels

It is strongly recommended that the performance monitoring process is supplemented with a strong understanding of confidence levels, especially where these differ among peer organisations. Obviously, in situations where doubt exists for comparisons, more notice will be taken of councils that have a higher confidence rating for their information. Pradhan and Deng (2008) suggest a confidence rating framework that has elements that could be used for this project. Some of these include:

- a four-scale rating system, thus preventing the central theorem tendency of the five-point scale (ie everything ends up being a '3') plus it provides more detail than a three-point scale
- the overall rating consists of a combination of factors.

The recommended rating of automated/high-speed data is presented in table 10.3.

Table 10.3 Confidence level rating framework for most common road condition data

Confidence factor	Confidence rating			
	Very low (1)	Low (2)	Medium (3)	High (4)
Equipment sophistication	Visual	Automated – non laser	Automated laser	Automated laser
Calibration standard	No calibration	Internal calibration	Contractual calibration process	Calibrated according to NZTA state highway standards
Quality assurance (QA)	No evidence of QA	Internal QA	Contractual QA, eg loop method	Calibrated according to NZTA state highway standards
Post survey confirmation	None	Compare overall network trends	Consider individual sections and exception reporting	Benchmark with LTPP sites

Note: the overall rating is calculated as the average score from each confidence factor

10.2.2 Collection requirements for road hierarchies

The requirements for each road category's data collection are set out in table 10.4. These should be seen as minimum requirements and can be exceeded where practical.

Table 10.4 Data collection requirements for performance monitoring

Hierarchy		Approximate traffic volume	Data confidence level	Survey frequency	Data items
State highways	Local roads*				
National strategic high volumes			4	Annual	Full HSD
National strategic			4	Annual	Full HSD
Regional connector	‘A’		4	Annual	Full HSD
Regional distributer	‘B’		4	2 years	Full HSD
Regional strategic	‘C’		3	2 years	Full HSD
	‘D’		3	2 years	R&R
	‘E’		3	2 years	Visual

Note* Classification of local roads not available at this point of time

Legend: Full HSD – roughness, rutting, texture, skid, FWD (100% cover)

R&R – roughness, rutting and FWD (20% sample)

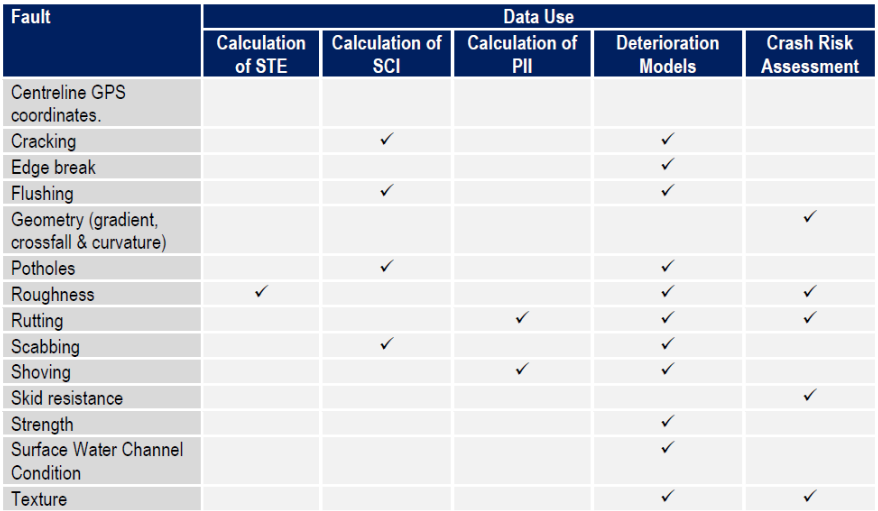
10.3 Data requirements cost implications – case study: Hastings District Council

The requirements defined in table 10.4 may present a significant shift for some authorities in terms of the intensity of data collection. However, without this shift the improvements to the condition monitoring and general asset management processes cannot be realised. In addition, this case study demonstrates that the cost implication could actually be kept to a minimum.

10.3.1 Motivation

Hasting District Council (HDC 2011) realised its historical data collection did not completely satisfy its use and/or needs of the data. Table 10.5 lists the different applications for the respective condition items. In order to address the shortcoming in the data use, a strategy was developed to improve the data collection regime to satisfy the council’s needs as best as possible. Note that the new data collection strategy had to fall within strict data collection costs – initially not exceeding the current data collection costs.

Table 10.5 Use of data items (HDC 2011)



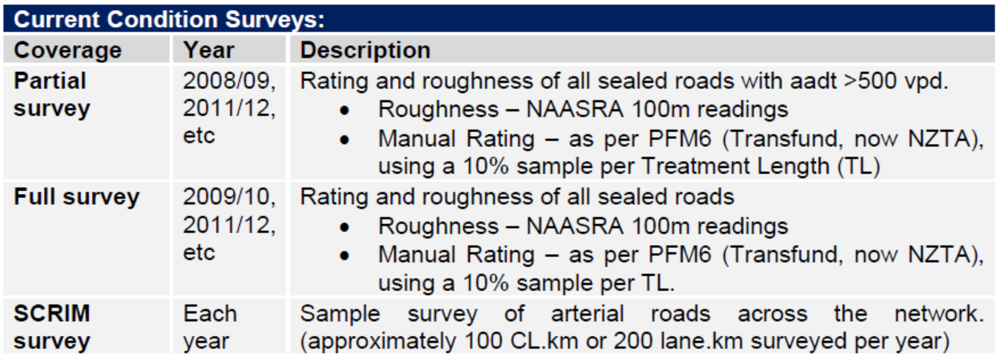
Fault	Data Use				
	Calculation of STE	Calculation of SCI	Calculation of PII	Deterioration Models	Crash Risk Assessment
Centreline GPS coordinates.					
Cracking		✓		✓	
Edge break				✓	
Flushing		✓		✓	
Geometry (gradient, crossfall & curvature)					✓
Potholes		✓		✓	
Roughness	✓			✓	✓
Rutting			✓	✓	✓
Scabbing		✓		✓	
Shoving			✓	✓	
Skid resistance					✓
Strength				✓	
Surface Water Channel Condition				✓	
Texture				✓	✓

Table 10.5 shows that most of the data needs were driven by the deterioration models but other reporting is possible once the data exists. For example, in the crash reduction planning processes additional data items such as rutting, texture and SCRIM become essential.

10.3.2 Newly adopted data collection strategy

The HDC changed its data collection regime from a ‘blanket’ approach to a more strategic approach as illustrated in table 10.6. The table shows the historical data collection approach.

Table 10.6 Data collection strategy (HSD 2011)



Current Condition Surveys:		
Coverage	**Year**	**Description**
Partial survey	2008/09, 2011/12, etc	Rating and roughness of all sealed roads with aadt >500 vpd. • Roughness – NAASRA 100m readings • Manual Rating – as per PFM6 (Transfund, now NZTA), using a 10% sample per Treatment Length (TL)
Full survey	2009/10, 2011/12, etc	Rating and roughness of all sealed roads • Roughness – NAASRA 100m readings • Manual Rating – as per PFM6 (Transfund, now NZTA), using a 10% sample per TL.
SCRIM survey	Each year	Sample survey of arterial roads across the network. (approximately 100 CL.km or 200 lane.km surveyed per year)

This approach has been changed to:

- rural key routes – annual full HSD + rating
- other roads rolling three-yearly full HSD + 10% rating
- urban laser roughness and manual rating
- 10% FWD sampling per year.

Based on feedback from HSD staff, the new data collected has made a significant difference to the robustness of the council’s asset management plan. The council believes that the addition of rutting and FWD, in particular, has made a significant difference in the understanding of network behaviour.

10.3.3 Cost implications

Under the original regime the data collection strategy was valid for a two-year cycle. According to the new approach the strategy has a three-year cycle. The annual average cost of the new three-year cycle has resulted in a net cost increase of 12%. The corresponding cost increase for a two-year cycle with full HSD was 20%. Note that the data collection equates to 1.5% of the entire maintenance programme.

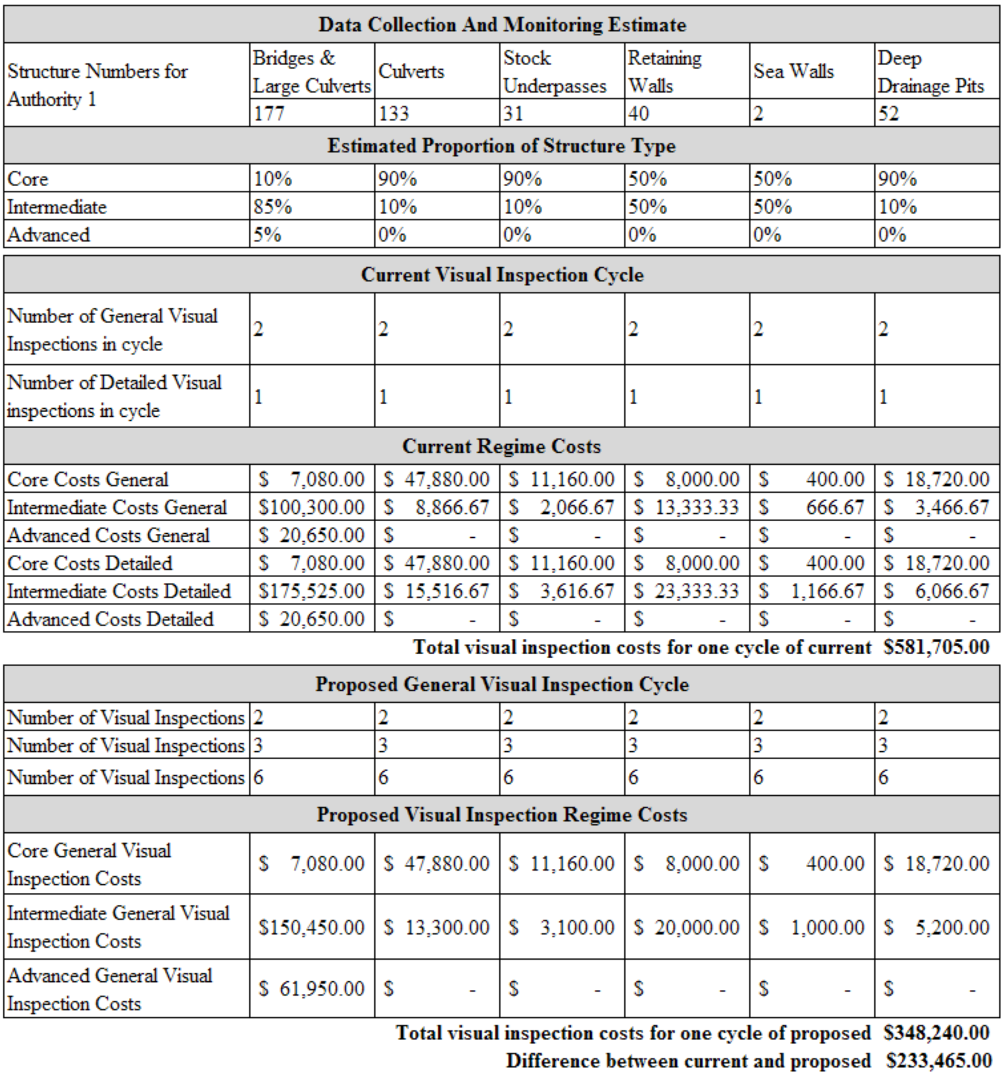
Assuming that the improved data collection process has a conservative 5% efficiency improvement (equating sometimes to only one treatment) for the planning of maintenance work, the improved data collection cost has a BCR of over 30.

10.4 Data availability and systems – bridges

Given the current fragmented approach to the management of bridge data, it is recommended that the NZTA provides data requirements for the annual submission of bridge information. This way, the data items and format are specified, independent of the data management system being used.

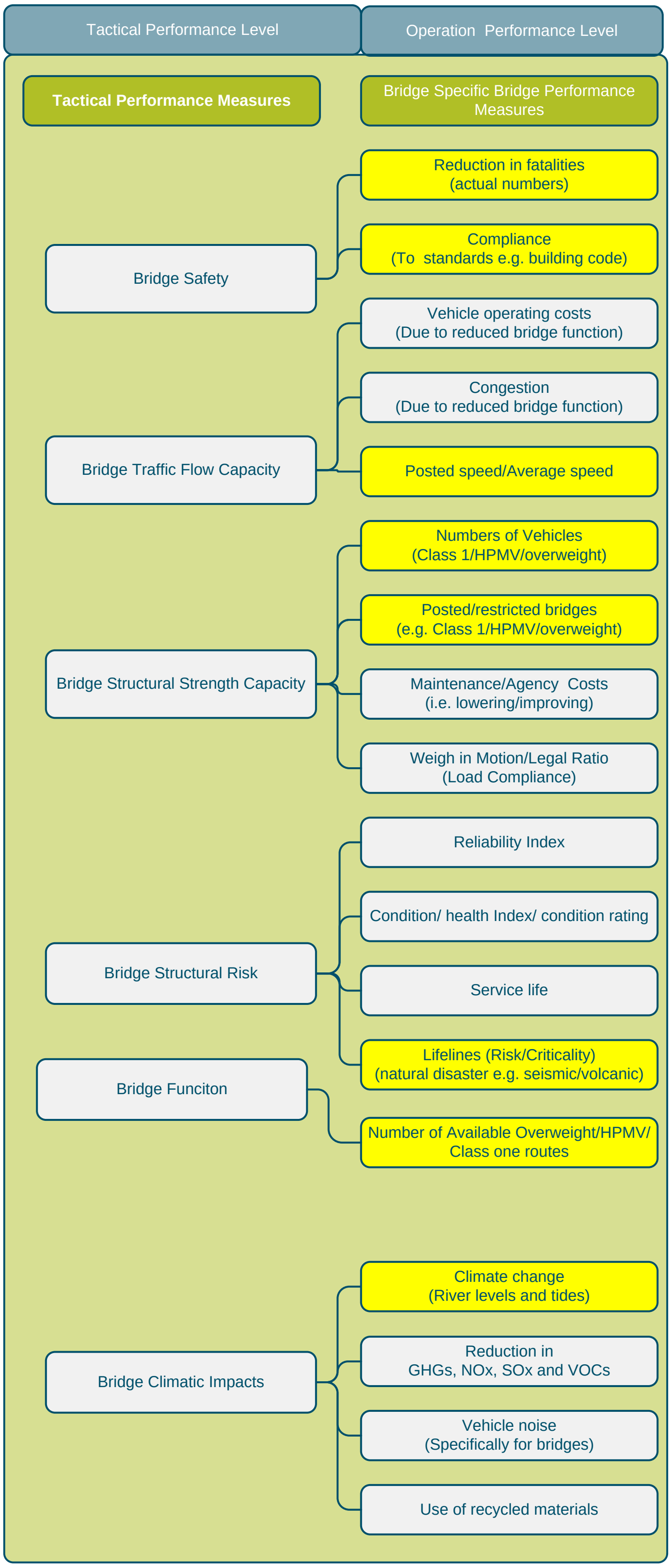
Initially, only the core data items required for a monitoring system would be specified, although this would require the collection of the additional data items within a three-year period. The new data collection regime would possibly have an impact on the cost of data collection. As illustrated in table 10.7, the new data collection framework could easily result in a net saving in data collection cost, which could allow for more non-destructive testing and additional structural health monitoring. Table 10.7 shows that the current cost of traditional data collection would be $581,705, whereas under the proposed data collection regime it would decrease to $384,240.

Table 10.7 Cost implication for bridge data collection strategy (Bush et al 2012)



Data Collection And Monitoring Estimate						
Structure Numbers for Authority 1	Bridges & Large Culverts	Culverts	Stock Underpasses	Retaining Walls	Sea Walls	Deep Drainage Pits
	177	133	31	40	2	52
Estimated Proportion of Structure Type						
Core	10%	90%	90%	50%	50%	90%
Intermediate	85%	10%	10%	50%	50%	10%
Advanced	5%	0%	0%	0%	0%	0%
Current Visual Inspection Cycle						
Number of General Visual Inspections in cycle	2	2	2	2	2	2
Number of Detailed Visual inspections in cycle	1	1	1	1	1	1
Current Regime Costs						
Core Costs General	$ 7,080.00	$ 47,880.00	$ 11,160.00	$ 8,000.00	$ 400.00	$ 18,720.00
Intermediate Costs General	$100,300.00	$ 8,866.67	$ 2,066.67	$ 13,333.33	$ 666.67	$ 3,466.67
Advanced Costs General	$ 20,650.00	$ -	$ -	$ -	$ -	$ -
Core Costs Detailed	$ 7,080.00	$ 47,880.00	$ 11,160.00	$ 8,000.00	$ 400.00	$ 18,720.00
Intermediate Costs Detailed	$175,525.00	$ 15,516.67	$ 3,616.67	$ 23,333.33	$ 1,166.67	$ 6,066.67
Advanced Costs Detailed	$ 20,650.00	$ -	$ -	$ -	$ -	$ -
					Total visual inspection costs for one cycle of current	**$581,705.00**
Proposed General Visual Inspection Cycle						
Number of Visual Inspections	2	2	2	2	2	2
Number of Visual Inspections	3	3	3	3	3	3
Number of Visual Inspections	6	6	6	6	6	6
Proposed Visual Inspection Regime Costs						
Core General Visual Inspection Costs	$ 7,080.00	$ 47,880.00	$ 11,160.00	$ 8,000.00	$ 400.00	$ 18,720.00
Intermediate General Visual Inspection Costs	$150,450.00	$ 13,300.00	$ 3,100.00	$ 20,000.00	$ 1,000.00	$ 5,200.00
Advanced General Visual Inspection Costs	$ 61,950.00	$ -	$ -	$ -	$ -	$ -
					Total visual inspection costs for one cycle of proposed	**$348,240.00**
					Difference between current and proposed	**$233,465.00**

Figure 10.2 Data priority bridges



Note: Shaded items are the priority 1 items (to be collected within a year). All other items should be reported within three years

10.5 Data management aspects

This project was undertaken using the reporting database from the NZTA. Two reasons for using this database were:

- it provided the ability to do data analysis according to a slice in time
- it summarised all the data in 100m reporting intervals. This was tested and believed to be the most practical analysis length for reporting purposes.

The philosophy of this project was the proof of concept of all measures and recommendations from this work within the NZTA database. Once the recommended processes have been adopted, the information can be distributed to authorities along with a process to follow and a definition of tools required that will enable them to do their own reporting.

11 Recommendations and further work

11.1 Overall performance frameworks

11.1.1 Road pavements

The recommended framework for road pavements is presented in figure 11.1.

Figure 11.1 Recommended performance monitoring framework for pavements

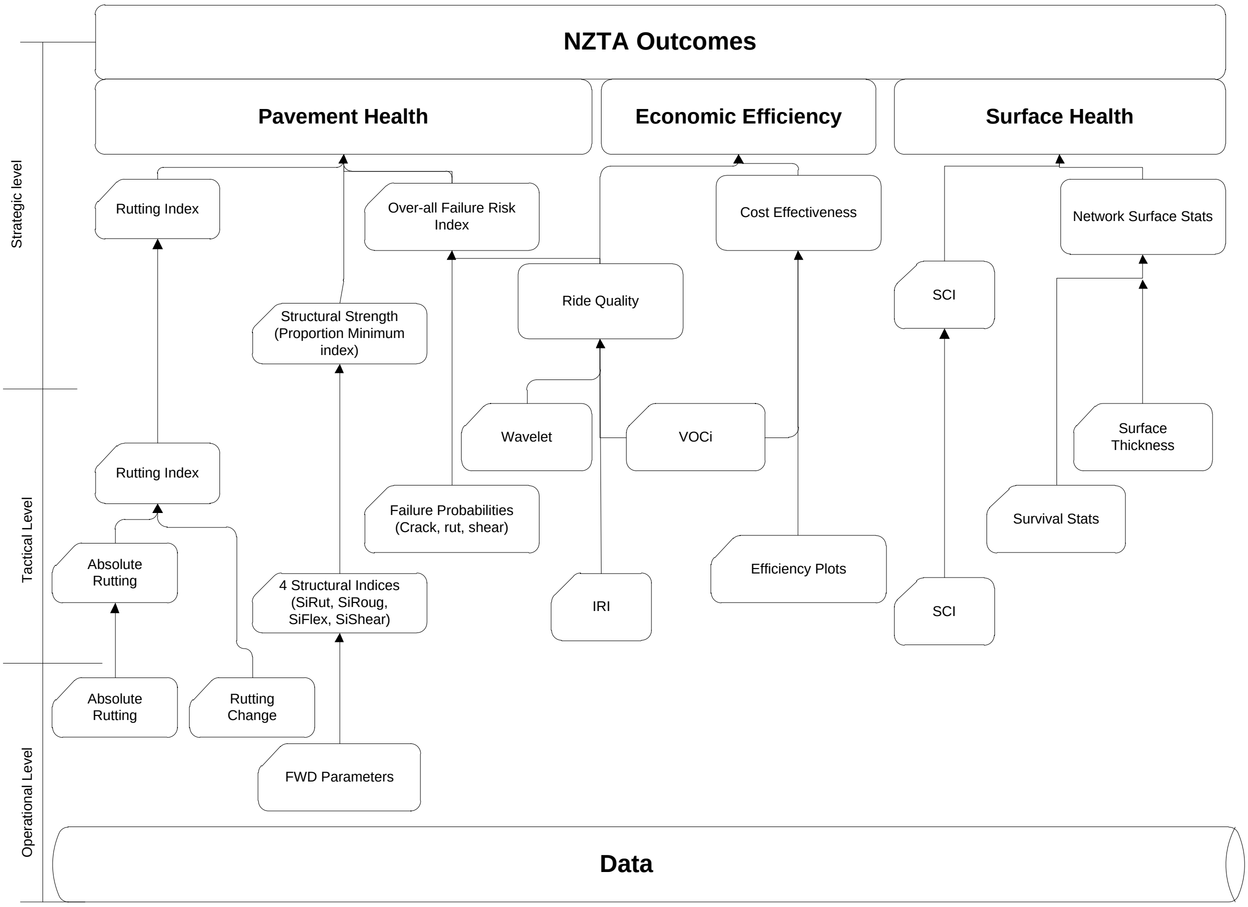


Figure 11.1 shows the framework reporting in the three main areas of:

- pavement health
- surfaces
- economic efficiency.

A three-tier approach, with a target audience for each level, has been recommended as follows:

- high-level/strategic level – politicians/policy/strategy/industry steering groups or governing organisations/funding
- mid-level/tactical level – asset managers/industry steering groups or governing organisations/funding /research
- low level – asset managers/engineers/research/audit.

11.1.2 Structures

The overall framework for bridge structures is presented in figure 8.2. This illustrates the linkage to the NZTA outcome areas and how each tactical measure relates to the respective outcome areas. The main tactical measures for the structures include:

- capacity in terms of structural strength
- structural risk
- capacity in terms of traffic flow
- safety
- bridge function – related to the load it can take (eg pedestrian bridge)
- climatic impacts.

This report has shown how the performance framework was created with strong links to a recommended data collection strategy developed in a NZTA research project (Bush et al 2012). The research demonstrated that data collection on structures was predominantly focused on fault detection and not bridge condition assessment. A risk/criticality approach has been proposed whereby more data is collected on high-risk/criticality bridges. A staged implementation of the performance monitoring process would allow authorities to provide core data immediately and some of the more advanced data progressively as it becomes available.

11.2 A review of performance indices

11.2.1 Review outcome and recommendations

The review of the existing performance measurements resulted in a suite of recommended indices summarised in table 11.1. This report documents the fundamental background to the new indices, whose robustness was demonstrated during the research through testing on full networks or a sample of networks.

Table 11.1 Recommended performance measures for road pavements

Performance area	Performance measure	Notes/recommendation
Pavement structural health	Rutting index (RI)	A combination of the actual rut depth and the change in rut depth during the past three years. Testing of the index revealed that it is sensitive to the network change; however, appropriate weightings for the index need confirmation following intensive use.
	Wavelength	The wavelength spectrum energy levels can be reported in terms of their absolute value and the incremental change over time. Both reporting mechanisms displayed useful result for the understanding of the profile changes. The results also highlighted that roughness changes were different for different speed environments. This needs to be incorporated into future reporting, especially relating to STE.
	Roughness (IRI)	The limitations of the IRI are well understood. However given the significant historical context of the IRI its use should continue. The use of NAASRA should cease.
	Smooth travel exposure (STE)	STE is used for exception reporting and should therefore be supplemented with a distribution plot of IRI. Additional recommendations include: • STE should be reported separately for different speed zones • an STE for trucks should be used on the basis of the truck ride index.

Performance area	Performance measure	Notes/recommendation
	Pavement integrity index (PII)	The PII should be phased out as soon as the other pavement indices are adopted.
	Structural indices (SIs)	Four SIs are recommended. These represent the four main failure modes of New Zealand pavement types including: • SIRut – based on a subgrade failure criteria • SILflex – based on cracking characteristics of the pavement • SIShear –based on the shear properties of upper pavement payers • SIRough –based on the differential deflection longitudinally to the road. The research demonstrated both the robustness of these indices and their value in performance monitoring. Good correlations were established with actual performance and explainable results were obtained on network level. It should be noted though that the SIs are contextual indices as they neither indicate actual performance nor do they take traffic loading into account.
	Failure risk index	A probability of pavement failure was developed for three condition items including rutting, cracking and shear. Pavement strength, physical carriageway and pavement composition plus current condition date are considered for determining the failure index. Positive testing results were obtained from this index. Further work is required to refine the index, especially on urban networks.
Surface health	Surface condition index (SCI)	The current SCI was reviewed on the basis of other research findings (Jooste et al 2009). It was also assessed on the basis of network results. In conclusion, there are no recommended changes to the make-up of the SCI. However, some improvement to the index may result from improvements to the data collection –manual rating system. In addition the SCI should report separately on asphalt and chip sealed roads. Significant cracking exists on asphalt compared with chip seal surfaces and reporting the results together skews the results.
	Survival curves	In order to identify the poor performance of surfaces, the use of survival curves is recommended as a comparative measure between networks. This overcomes the limitation of considering either the distribution of current seal or the past performance of surfaces in isolation.
	Total surface thickness	Top surface reporting is an effective way to monitor the resurfacing practices of councils. Total surface thickness above 40mm may be prone to flushing which warrants the monitoring on a network level. It is recommended to use this index on a tactical level only.
Economic efficiency/ economic measures	Efficiency frontier	Efficiency frontier can be developed for any of the performance measures. By normalising the condition parameter and plotting it against the cost of addressing a particular performance measure, one can plot an efficiency frontier that summarises the gains realised for a given investment level.
	Vehicle operating cost index (VOCi)	The VOCi is a ratio between the vehicle operating cost and the VKT travelled on a network. It is therefore a normalised index that indicates the relative cost of travelling on different networks. Testing of this index has revealed that it is very effective in assessing the efficiency of network investment in terms of reductions in user costs.

11.2.2 Testing and implementation process

The status of the indices listed in table 11.1 varies significantly. The recommended implementation process beyond this research for all indices includes:

- undertaking a full-scale test of all indices for a sample of both state highway and local council networks
- providing index outcomes to the authorities tested in 1 and gaining feedback from the respective asset owners
- on acceptance of the indices, commencing full-scale reporting in parallel with legacy indices and measures
- dropping redundant indices on industry acceptance of new indices.

11.3 Recommendations for data collection

11.3.1 Data collection for road condition

The data requirements for local councils were reviewed and the recommended strategy is presented in chapter 10, tables 10.3 and 10.4. The main recommendation from the review was to consider a hierarchical process for data collection strategies. According to this approach:

1. The more important assets would be monitored more frequently, with a higher level of accuracy.
2. Industry would consider a data collection quality rating system.

11.4 Performance as part of the overall asset management process

The performance framework fulfils important functions for both the NZTA and local authorities. It was believed that outcomes from this research would ultimately lead to more effective benchmarking and trend monitoring from a funding perspective. The real potential of a valuable performance monitoring process would be realised at the individual authority level.

Based on recognised asset management processes, performance monitoring is an essential step in the asset management planning process. Figure 11.1 illustrates a typical asset management process, where the performance monitoring precedes future planning processes. With performance monitoring the asset manager can assess the impact of prior investment levels and maintenance regimes. It also highlights potential symptomatic issues on the network that have to be addressed in future programmes.

Figure 11.1 Asset management cycle (RIMS 2012)

Once the recommended performance framework has been tested and implemented it is recommended that authorities need to adopt it as part of the asset management cycle.

11.5 Further work

It is recommended that the NZTA considers a forum to take ownership of the monitoring process, to capture learning and to execute required changes. Potential bodies may include RCAs and/or the Road Information Management Support Group (RIMS).

Further research work should also consider examining:

- sustainability indices to asset management and whether current maintenance treatments are providing technical and environmental benefits
- whether data frequency can be even less
- rates of changes in rut depth roughness and SIs so that treatments can be better applied or estimated.

Once the operations performance measures have been tested and fully adopted the remaining components of the monitoring framework such as the tactical and strategic measures can be developed.

12 References

Abeysekara, A (2010) *Understanding whole of life cost for New Zealand resurfacing practices in chipseal pavements*. Year 4 research report. Auckland: University of Auckland, Department of Civil and Environmental Engineering.

Annis, C (2011). *Statistical engineering*. Accessed August 2011. www.statisticalengineering.com/index.html -

Brown, D, W Liu and TFP Henning (2010) Identifying pavement deterioration by enhancing the definition of road roughness. *NZ Transport Agency research report 430.* 66pp.

Bush, SJW (2011) A data collection and monitoring strategy for asset management of NZ road bridges. A thesis submitted in complete fulfillment of the requirements for the degree of Master of Engineering. Auckland: University of Auckland.

Bush, S, P Omenzetter, TFP Henning and P McCarten (2011) A bridge data collection and monitoring strategy for use with performance frameworks. *90th Annual Meeting of Transportation Research Board*, Washington DC, 22–26 January 2011.

Bush, S, P Omenzetter, TFP Henning and P McCarten (2012) *Data collection and monitoring strategies for asset management of New Zealand road bridges*. Wellington: NZTA.

Byrne, M and T Parry (2010) A generalized approach to outlier identification in pavement condition data. *In proceedings of the 24th Australian Road Research Board (ARRB) Conference*, Melbourne, Australia. October 2010.

Charnes, A, WW Cooper and E Rhodes (1978) Measuring the efficiency of decision making units. *European Journal of Operational Research 2*, no. 6: 429–444.

Ghasemi, H, J Penrod and JM Hooks (2009) Developing advanced methods of assessing bridge performance. *Public Roads, US Federal Highway Administration (FHWA) 73*, no.3: 2.

Committee for Land Transport (COLTO) (1992) *Pavement management systems: standard visual assessment manual for flexible pavements.* TMH 9. South Africa: Department of Transport.

Committee for Land Transport (COLTO) (1998) *Structural design of flexible pavements for interurban and rural roads.* TRH 4. South Africa: Department of Transport.

Deng, Z and TFP Henning (2013) *Testing of new NZTA condition performance measures.* Wellington: NZTA.

Fawcett, G, TFP Henning, N Pradhan and M Riley (2001) The use of composite indices as resurfacing triggers. *Fifth International Conference on Managing Pavements*, Seattle, Washington.

Fletcher, E and AJ Theron (2011) Performance of open graded porous asphalt in New Zealand. *NZ Transport Agency research report 455.* 66pp.

Greenwood, I and C Hanson (2010) Are we over-managing our assets? *2010 Ingenium Conference*, Wellington.

Hastings District Council (2011) *Pavement condition data rating strategy. Transportation asset management plan*. Hastings: Hastings District Council.

Hendry, M and J Brass (2010) Road performance indicator structure. Internal memorandum to research team. Christchurch: NZTA.

Henning, TFP (2009) *The development of pavement deterioration models on the state highway network of New Zealand*'. PhD thesis, The University of Auckland. Obtainable from http://researchspace.auckland.ac.nz/handle/2292/4236

Henning, TFP, S Muruvan, WA Feng, RC Dunn (2011) The development of a benchmarking tool for monitoring progress towards sustainable transportation in New Zealand. *Transport Policy 18*, no.2: 480–488.

Hussain, J, DJ Wilson, TFP Henning, D Alabaster (2009) Investigating the moisture sensitivity of road pavement materials in New Zealand. *10th NZ Transport Agency and NZIHT Conference – Customer Driven Highways*, Rotorua, 1–3 November 2009.

Institution of Professional Engineers New Zealand (IPENZ) (2005) *National traffic signal specification.* Wellington: National Signals Committee and Signals New Zealand Users Group (SNUG).

Jooste, FJ (2010) Implementation of a rule-based deterioration model for dual carriageway road networks. *In proceedings of the 24th Australian Road Research Board (ARRB) Conference*, Melbourne, Australia 2010.

Jooste, S, TFP Henning, DC Roux and C Thew (2008) A review of composite condition indices used in New Zealand. *NZIHT*, Napier, 12–14 October 2008.

Judd, D and FJ Jooste (2010) Toll road pavement management – planning to execution – case study. *In proceedings of the 24th Australian Road Research Board (ARRB) Conference*, Melbourne, Australia 2010.

Kodippily, S, TFP Henning and J Ingham and P Cenek (2010) Modelling the flushing mechanism of thin flexible surfaced pavements in New Zealand. *2nd ARRB International Sprayed Sealing Conference – Sustaining Sprayed Sealing Practice*, Melbourne, 10–12 October 2010.

Kodippily, S, TFP Henning and JM Ingham (2012) Detecting flushing of thin sprayed seal pavements using pavement management data. *Journal of Transportation Engineering 138,* no.5: 665–673.

Kyle, R (2005). A pavement management strategy response to changing reactive repair costs. *6th International Conference on Managing Pavements*, Brisbane, Australia.

Liu, W, TF Fwa and Z Zhe (2005) Wavelet analysis and interpretation of road roughness. *Journal of Transportation Engineering 131*, no.2.

Ministry of Transport (MoT) (2009) *Government policy statement on land transport funding 2009/10 – 2018/19*. 30pp.

NAMS Group (2006) *International infrastructure management manual.* Wellington: National Asset Management Steering Group.

National Research Council and National Round Table on Sustainable Infrastructure (NRC and NRTSI) (2009) *Model framework for assessment of state, performance, and management of Canada's core public infrastructure.*

New Zealand Transport Agency (NZTA) (2000) *State highway geometric design manual* (draft). Wellington: NZTA.

New Zealand Transport Agency (NZTA) (2008) *Planning, programming and funding manual.* Wellington: NZTA.

New Zealand Transport Agency (NZTA) (2009) *State highway national condition report – 2009*. Wellington: NZTA.

New Zealand Transport Agency (NZTA) (2010a) *Economic evaluation manual – volume 1*. 685pp. Wellington: NZTA.

New Zealand Transport Agency (NZTA) (2010b) *Manual of traffic signs and markings* (MOTSAM). Wellington: NZTA.

New Zealand Transport Agency (NZTA) (2011a) *NZ Transport Agency statement of intent 2011–2014*. Wellington: NZTA.

New Zealand Transport Agency (NZTA) (2011b) *Road network condition reporting tool – road assets reports (wv6.0*). Accessed 28 July 2011. *www.smartmovez.org.nz/references/refs/data/road_network_condition*

Perera, P and M Islam (2010) The applicability of newly developed structural indices for road conditions reporting, monitoring and pavement deterioration modelling. Year 4 research project. Auckland: University of Auckland.

Pradhan, N (2009) Review of pavement condition rating practices. NZTA report, unpublished.

Pradhan, N and Deng, Z (2008). Review process for medium-term road maintenance forward works programme*. NZ Transport Agency and NZIHT 9th Annual Conference.*

Rainsford S and TFP Henning (2004) *Performance condition index (PCI) national investigation.* Special study task 6403. Wellington: RIMS Group.

Ramanathan, KV (1985) A proposed framework for designing management control systems in not-for-profit organisations. *Financial Accountability & Management 1*, no.1: 75–92.

RIMS Group (2012). *Body of knowledge. A compendium of best practice guidelines for NZ road managers*. Wellington: RIMS Group, Ingenium.

Salt, G, TFP Henning, D Stevens and DC Roux (2010) Rationalisation of the structural capacity definition and quantification of roads based on falling weight deflectometer tests. *NZ Transport Agency research report 401*.

Schlotjes, MR (2011) PhD annual review report for the University of Birmingham. Unpublished.

Schlotjes, MR, TFP Henning and JD St George (2009) The risks associated with pavement failures In New Zealand. *2009 NZTA & NZIHT 10th Annual Conference*, Rotorua.

Schlotjes, MR, TFP Henning and MPN Burrow (2011) Improved network understanding – a diagnostic approach to the risk of pavement failure. *Presented at 8th International Conference on Management Pavement Assets*. Santiago, Chile.

Stevens, D, G Salt, TFP Henning and DC Roux (2009) Pavement performance prediction: a comprehensive new approach to defining structural capacity (SNP). *2009 NZTA & NZIHT 10th Annual Conference, Rotorua,* November 2009.

Zimmerman, KA, LM Pierce and J Krstulovich (2010) *Pavement management roadmap*. Washington DC: US Department of Transportation. Federal Highway Administration.

Appendix A: Funding categories and definition of qualifying work

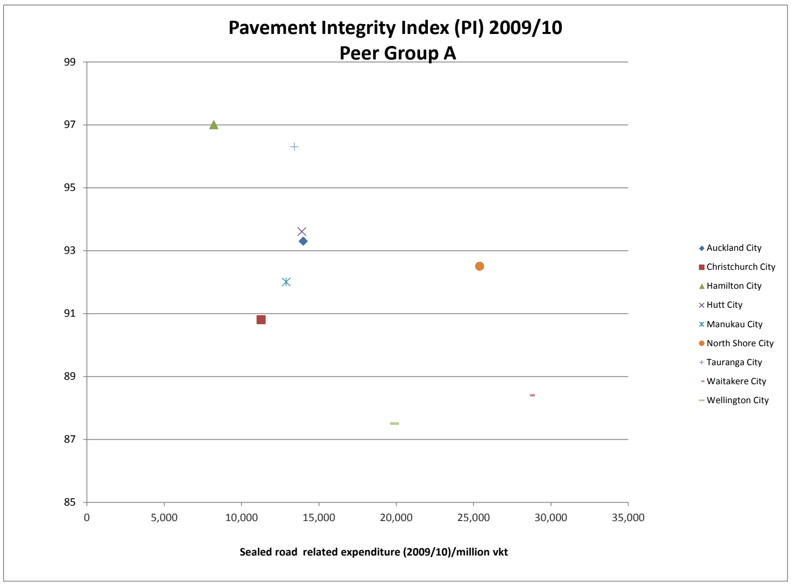
Work category	Description	Definition of qualifying work	STE	PII	Crash cost
Maintenance and operation of roads					
111	Sealed pavement maintenance	Covers the routine care of sealed pavements to maintain structural integrity and serviceability. Includes pavement maintenance patches; shoulder maintenance.	√	√	√
112	Unsealed pavement maintenance	Covers the routine care of unsealed pavements to maintain structural integrity and serviceability. Includes grading, spot metalling and shape restoration.			√
113	Routine drainage maintenance	Covers the routine care of drainage facilities to maintain function. Includes cleaning kerbs, sumps and cesspits; surface water channel and subsoil drain maintenance; stream cleaning to maintain watercourse through culverts.	√	√	√
114	Structures maintenance	Covers routine maintenance and minor repairs to road bridges; retaining structures; guardrails; tunnels and the like.			
121	Environmental maintenance	Covers work in the road reserve to maintain safety, aesthetics and environmental standards. It includes snow/ice clearing; vegetation control; litter collection (rural roads) water quality controls; intersection sweeping; minor slip clean-up; crash debris clean up; and abandoned vehicle removal.			√
122	Traffic services management	Covers maintenance of road furniture, road markings and street lighting.			√
123	Operational traffic management	Covers maintenance and costs associated with traffic signals and traffic management equipment.			√
124	Cycle path maintenance	Covers maintenance and renewal of cycle paths.			
131	Level crossing warning devices	Covers the TLA share of the costs associated with maintenance, renewal an upgrading of railway level crossing warning devices.			√
141	Emergency reinstatement	Covers for restoration of the road and/or road structures following a			

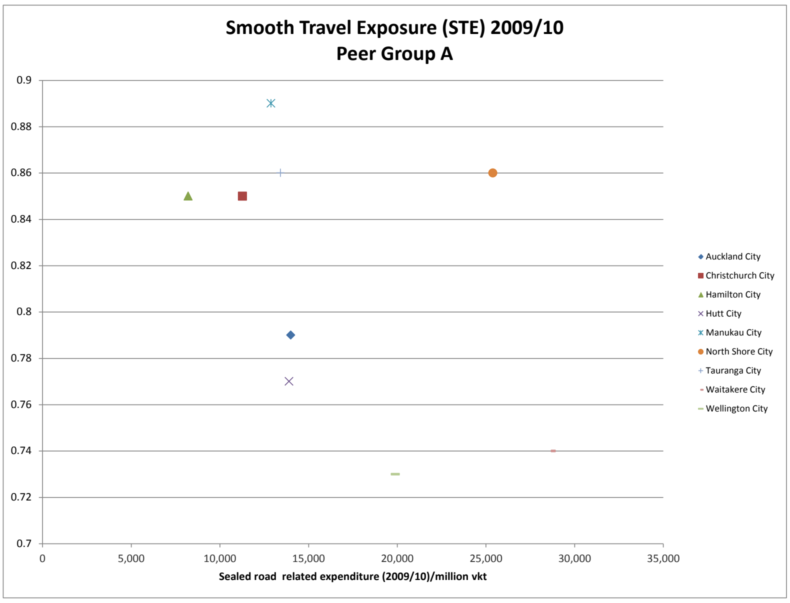
Work category	Description	Definition of qualifying work	STE	PII	Crash cost
		defined, major, short-duration natural event.			
151	Network and asset management	Covers the general management and control of the road network. Includes professional services associated with Renewal and Improvements works, as well as maintenance and operations.	√	√	√
Renewal of roads					
211	Unsealed road metalling	Provides for the planned periodic renewal of pavement layers on unsealed roads.			√
212	Sealed road resurfacing	Provides for the planned periodic resurfacing of sealed roads. Includes chip seal resurfacing and asphalt surfacing not exceeding 40mm. Pre-seal repairs are funding under pavement maintenance.	√	√	√
213	Drainage renewals	Provides for the renewal of drainage facilities, not routine in nature. Includes renewal of culverts and repair and replacement of kerb and channel provided that deterioration is likely to adversely affect the pavement.			
214	Sealed road pavement rehabilitation	Provides for the restoration of strength to pavements. It excludes improvements (covered under 231). Work must be the long-term least – cost option to qualify.	√	√	√
215	Structures component replacements	Provides for the replacement and renewal of deteriorated components on road structures.			
221	Environmental renewals	Provides for the renewal of existing environmental control facilities such as stock effluent disposal facilities, slip catch fences and water quality devices.			
222	Traffic services renewals	Provides for the renewal of existing road furniture, lighting, traffic management equipment and facilities.			√
231	Associated improvements	Provides for minor drainage improvements and seal widening carried out with pavement rehabilitation; widening existing seal (for cost benefits) and installation of minor traffic management equipment.			√
241	Preventative maintenance	Provides for non-routine work required to protect roads and road structures from damage. Includes			

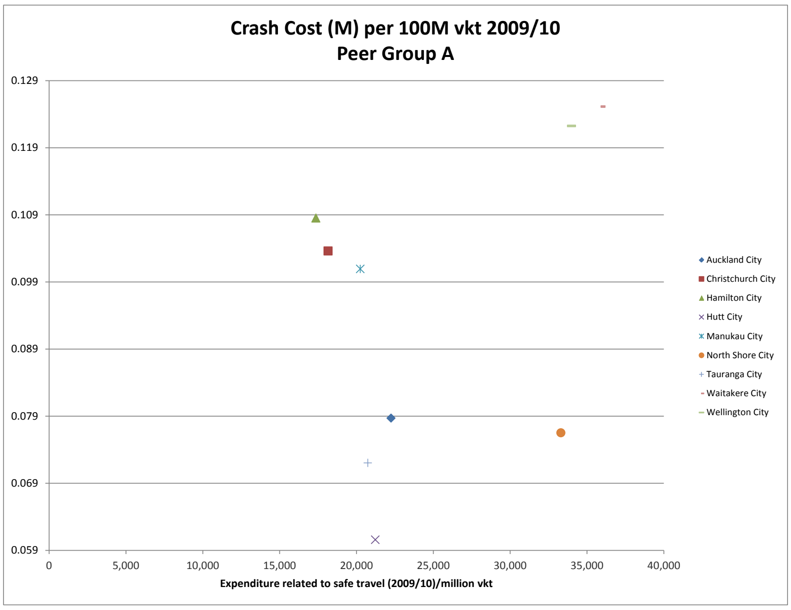
Work category	Description	Definition of qualifying work	STE	PII	Crash cost
		protective planting, draining slips, toe weighting unstable slopes, and the like.			
Improvement of roads					
321	New traffic management facilities	Provides for new facilities that assist with the management of the road network. Includes traffic signals, ramp metering and are-wide traffic control systems,			√
322	Replacement of bridges and other structures	Provides for the upgrade or replacement of existing bridges and road structures. Includes replacement, strengthening and widening.			
323	New roads	Provides for the construction of new roads, includes associated structures.			
324	Road reconstruction	Provides for the reconstruction or upgrade of an existing road.	√	√	√
325	Seal extension	Provides for sealing an existing unsealed road.			√
332	Property purchase	Covers the purchase of land for road purposes.			
333	Advance property purchase	Provides for property acquisition prior to approval of a project.			
341	Minor improvements	Provides funding to carry out low-cost/low-risk improvements, with the value of individual projects being less than $250,000. All projects require approval by NZTA before commencement. Includes intersection improvements, traffic calming, guardrail installation and the like.			√

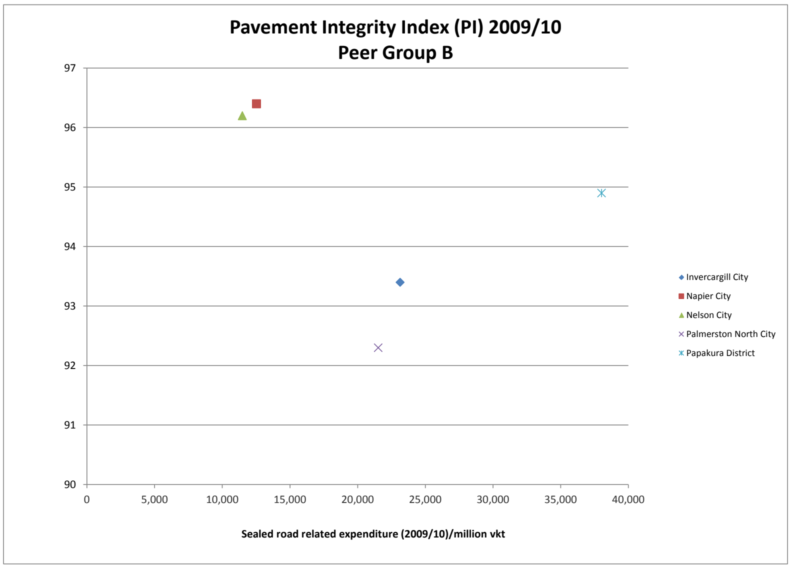
Note: The definitions of qualifying work have been extracted from the NZTA (2008) *Planning, programming and funding manual,* and have been abridged for the purpose of this research. The definitions contained in this table are not exhaustive, and should not be used as a complete reference.

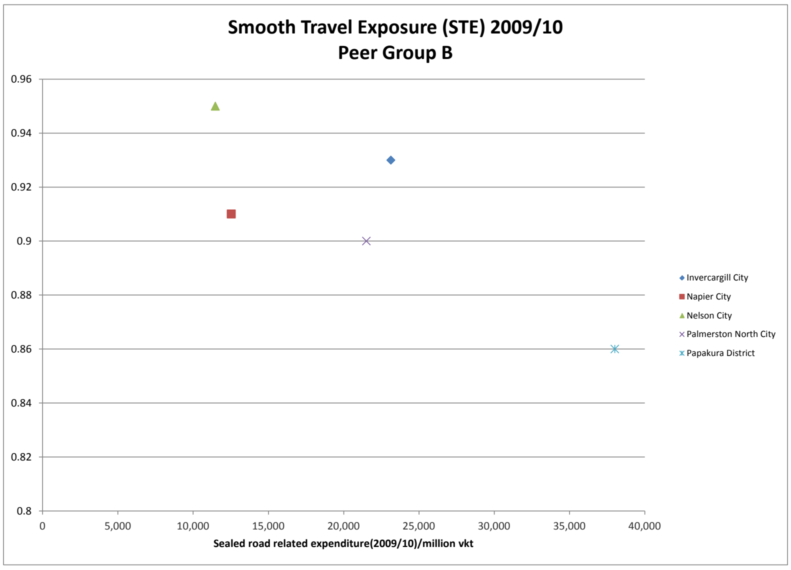
Appendix B: OI/C performance control plots by peer group

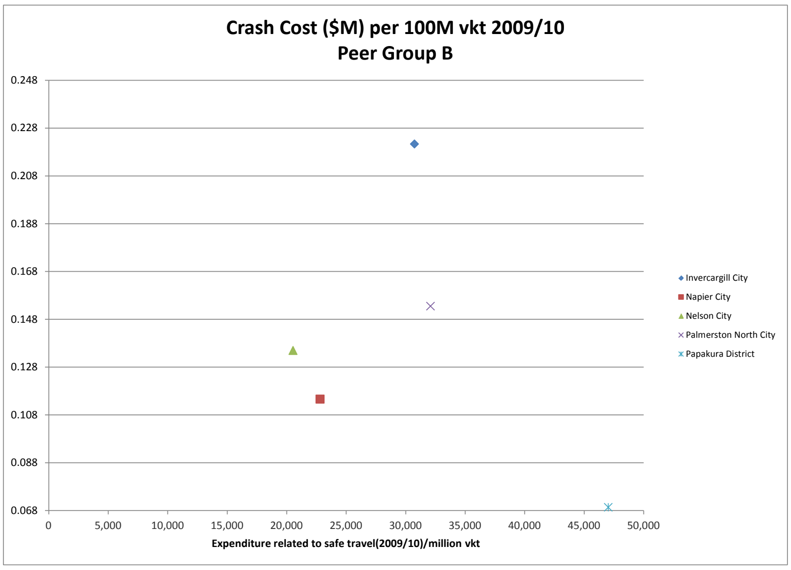


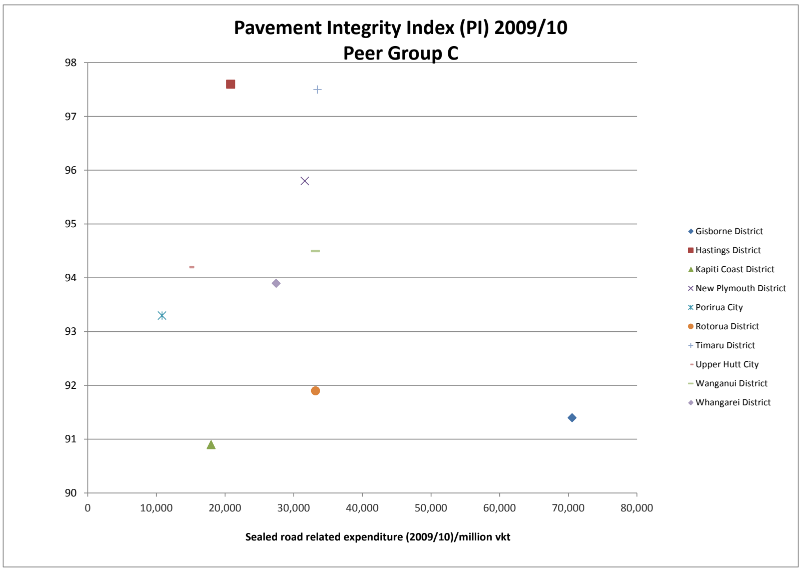


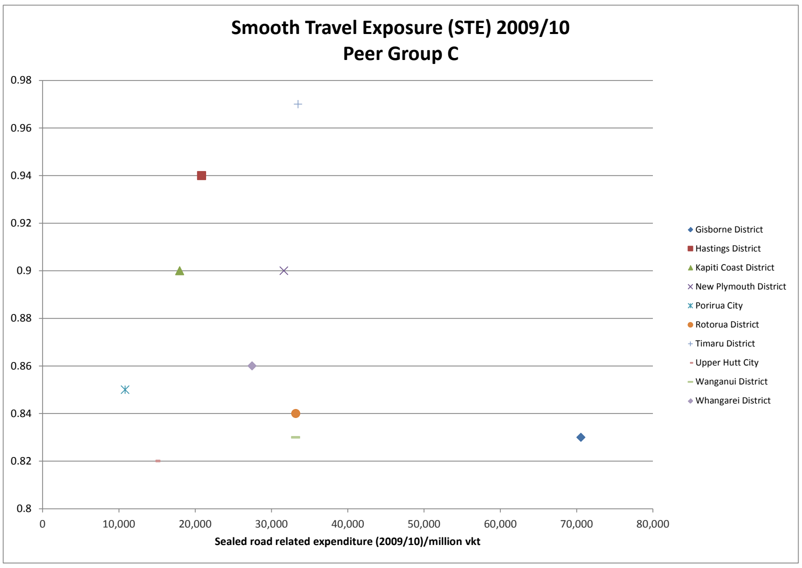

Crash Cost (M) per 100M vkt 2009/10
Peer Group A
0.129
0.119
0.109
0.099
0.089
0.079
0.069
0.059
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Expenditure related to safe travel (2009/10)/million vkt
Auckland City
Christchurch City
Hamilton City
Hutt City
Manukau City
North Shore City
Tauranga City
Waitakere City
Wellington City

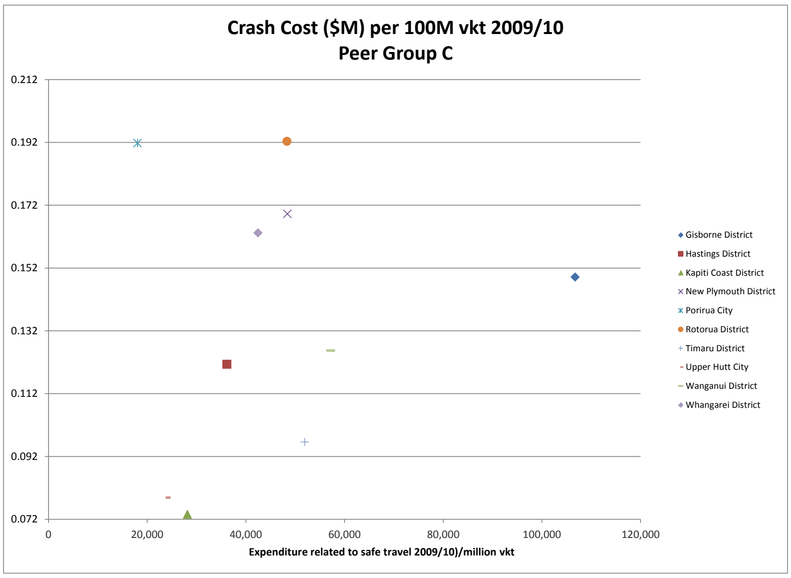

Pavement Integrity Index (PI) 2009/10
Peer Group B
97
96
95
94
93
92
91
90
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Sealed road related expenditure (2009/10)/million vkt
Invercargill City
Napier City
Nelson City
Palmerston North City
Papakura District

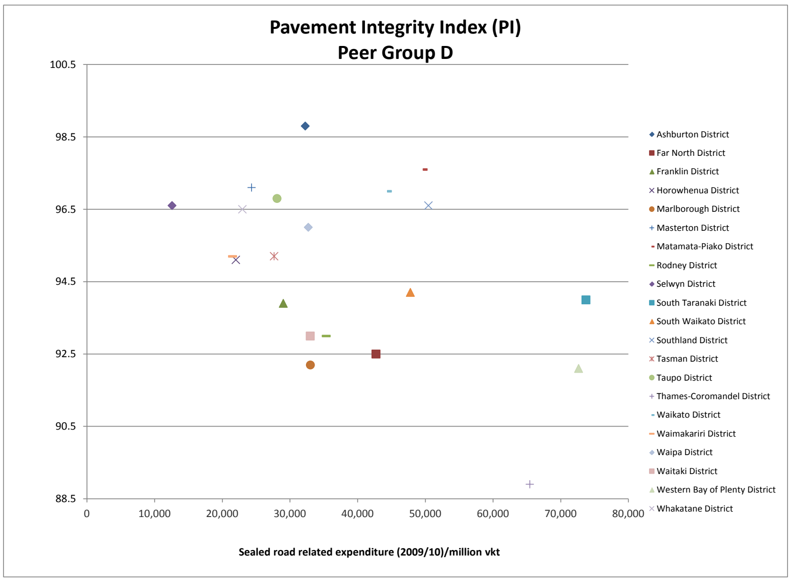

Smooth Travel Exposure (STE) 2009/10
Peer Group B
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
Sealed road related expenditure(2009/10)/million vkt
Invercargill City
Napier City
Nelson City
Palmerston North City
Papakura District

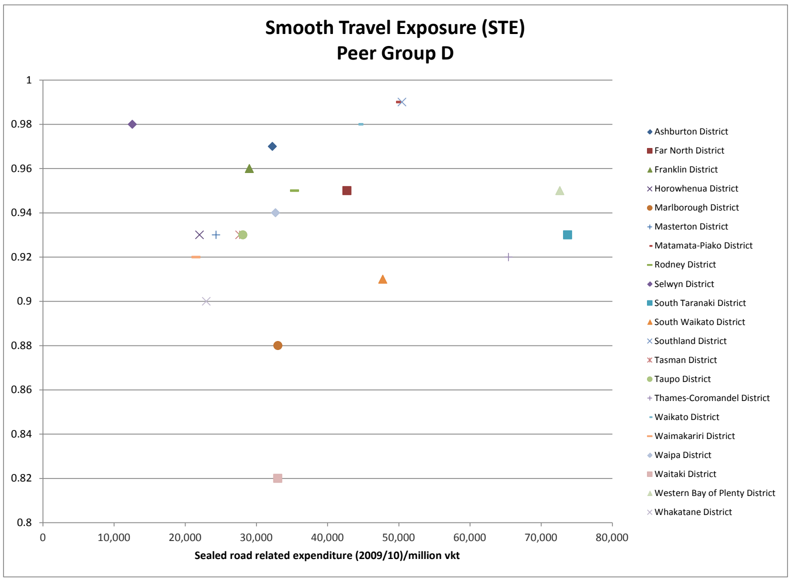

Crash Cost ($M) per 100M vkt 2009/10
Peer Group B
0.248
0.228
0.208
0.188
0.168
0.148
0.128
0.108
0.088
0.068
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
Expenditure related to safe travel(2009/10)/million vkt
Invercargill City
Napier City
Nelson City
Palmerston North City
Papakura District

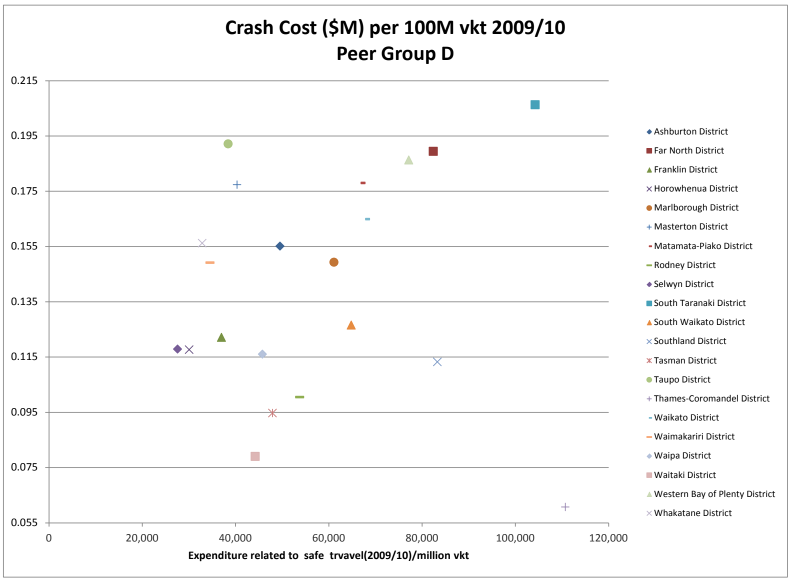

Pavement Integrity Index (PI) 2009/10
Peer Group C
98
97
96
95
94
93
92
91
90
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
Sealed road related expenditure (2009/10)/million vkt
Gisborne District
Hastings District
Kapiti Coast District
New Plymouth District
Porirua City
Rotorua District
Timaru District
Upper Hutt City
Wanganui District
Whangarei District

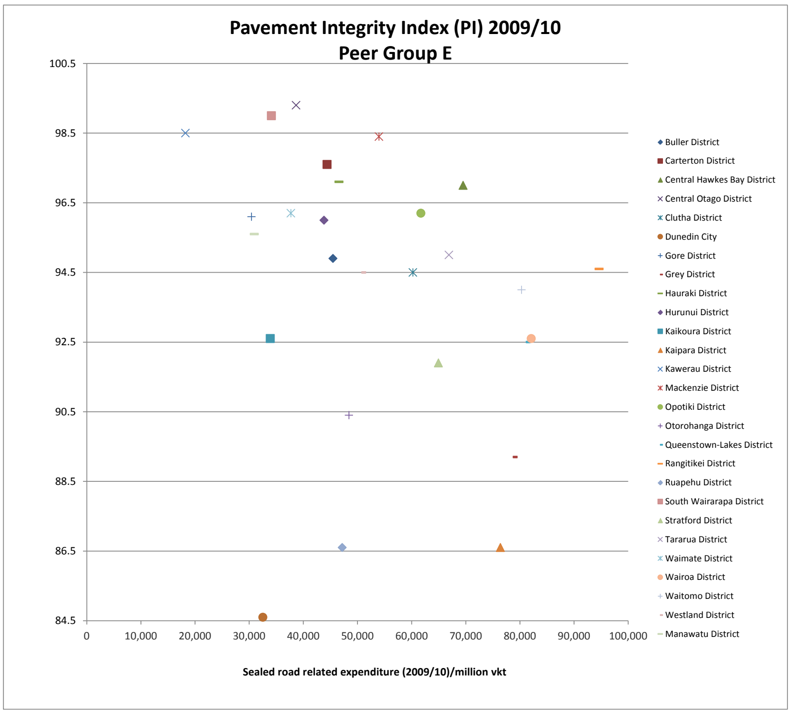

Smooth Travel Exposure (STE) 2009/10
Peer Group C
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
Sealed road related expenditure (2009/10)/million vkt
Gisborne District
Hastings District
Kapiti Coast District
New Plymouth District
Porirua City
Rotorua District
Timaru District
Upper Hutt City
Wanganui District
Whangarei District

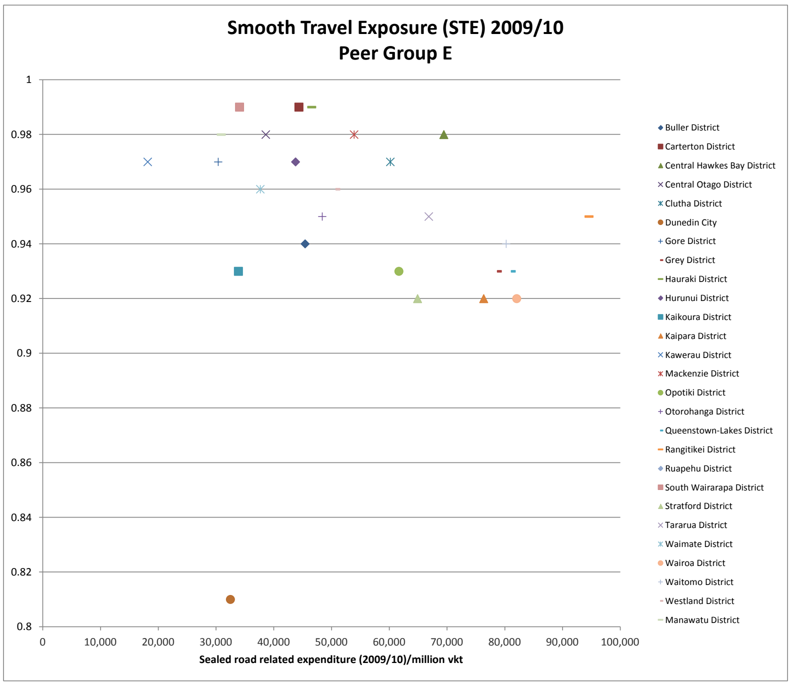

Crash Cost ($M) per 100M vkt 2009/10
Peer Group C
0.212
0.192
0.172
0.152
0.132
0.112
0.092
0.072
0
20,000
40,000
60,000
80,000
100,000
120,000
Expenditure related to safe travel 2009/10)/million vkt
Gisborne District
Hastings District
Kapiti Coast District
New Plymouth District
Porirua City
Rotorua District
Timaru District
Upper Hutt City
Wanganui District
Whangarei District

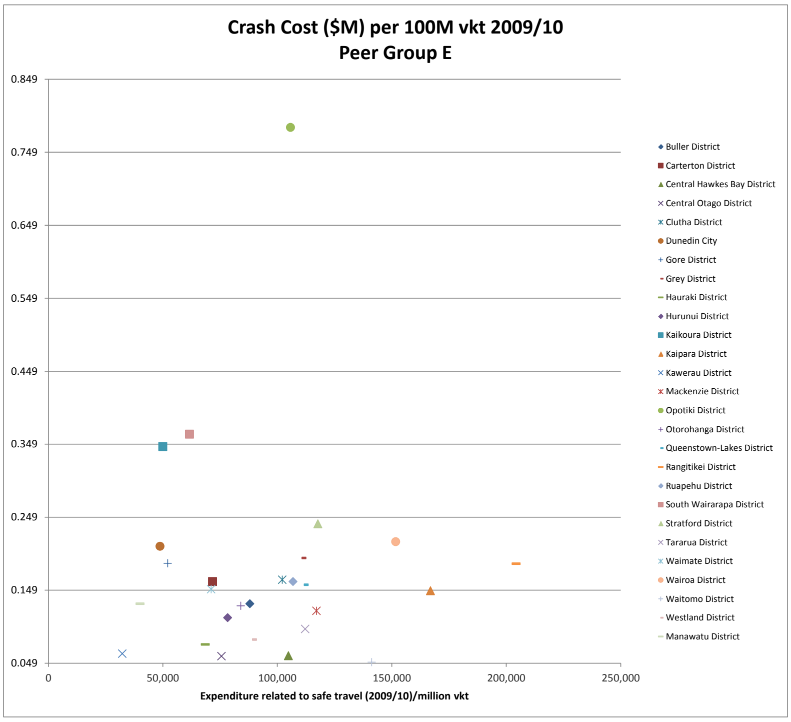

Pavement Integrity Index (PI)
Peer Group D
100.5
98.5
96.5
94.5
92.5
90.5
88.5
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
Sealed road related expenditure (2009/10)/million vkt
Ashburton District
Far North District
Franklin District
Horowhenua District
Marlborough District
Masterton District
Matamata-Piako District
Rodney District
Selwyn District
South Taranaki District
South Waikato District
Southland District
Tasman District
Taupo District
Thames-Coromandel District
Waikato District
Waimakariri District
Waipa District
Waitaki District
Western Bay of Plenty District
Whakatane District


Smooth Travel Exposure (STE)
Peer Group D
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
Sealed road related expenditure (2009/10)/million vkt
Ashburton District
Far North District
Franklin District
Horowhenua District
Marlborough District
Masterton District
Matamata-Piako District
Rodney District
Selwyn District
South Taranaki District
South Waikato District
Southland District
Tasman District
Taupo District
Thames-Coromandel District
Waikato District
Waimakariri District
Waipa District
Waitaki District
Western Bay of Plenty District
Whakatane District

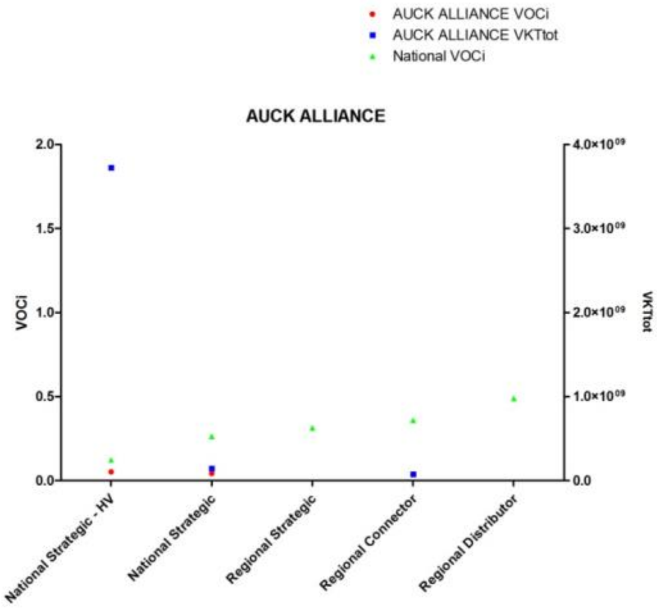

Crash Cost ($M) per 100M vkt 2009/10
Peer Group D
0.215
0.195
0.175
0.155
0.135
0.115
0.095
0.075
0.055
0
20,000
40,000
60,000
80,000
100,000
120,000
Expenditure related to safe trvavel(2009/10)/million vkt
Ashburton District
Far North District
Franklin District
Horowhenua District
Marlborough District
Masterton District
Matamata-Piako District
Rodney District
Selwyn District
South Taranaki District
South Waikato District
Southland District
Tasman District
Taupo District
Thames-Coromandel District
Waikato District
Waimakariri District
Waipa District
Waitaki District
Western Bay of Plenty District
Whakatane District

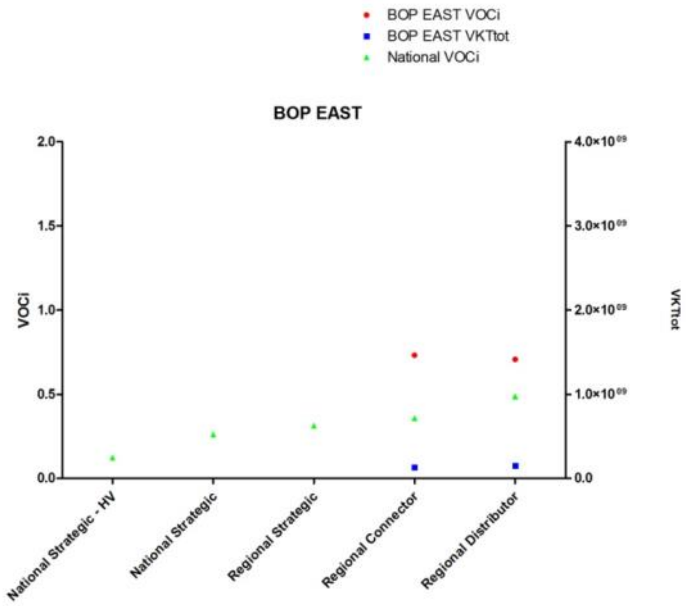

Pavement Integrity Index (PI) 2009/10
Peer Group E
100.5
98.5
96.5
94.5
92.5
90.5
88.5
86.5
84.5
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
Sealed road related expenditure (2009/10)/million vkt
Buller District
Carterton District
Central Hawkes Bay District
Central Otago District
Clutha District
Dunedin City
Gore District
Grey District
Hauraki District
Hurunui District
Kaikoura District
Kaipara District
Kawerau District
Mackenzie District
Opotiki District
Otorohanga District
Queenstown-Lakes District
Rangitikei District
Ruapehu District
South Wairarapa District
Stratford District
Tararua District
Waimate District
Wairoa District
Waitomo District
Westland District
Manawatu District

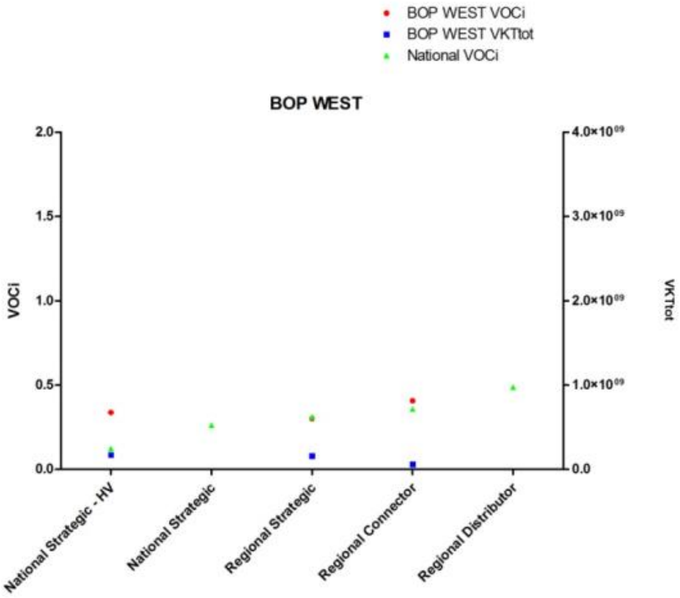

Smooth Travel Exposure (STE) 2009/10
Peer Group E
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
Sealed road related expenditure (2009/10)/million vkt
Buller District
Carterton District
Central Hawkes Bay District
Central Otago District
Clutha District
Dunedin City
Gore District
Grey District
Hauraki District
Hurunui District
Kaikoura District
Kaipara District
Kawerau District
Mackenzie District
Opotiki District
Otorohanga District
Queenstown-Lakes District
Rangitikei District
Ruapehu District
South Wairarapa District
Stratford District
Tararua District
Waimate District
Wairoa District
Waitomo District
Westland District
Manawatu District

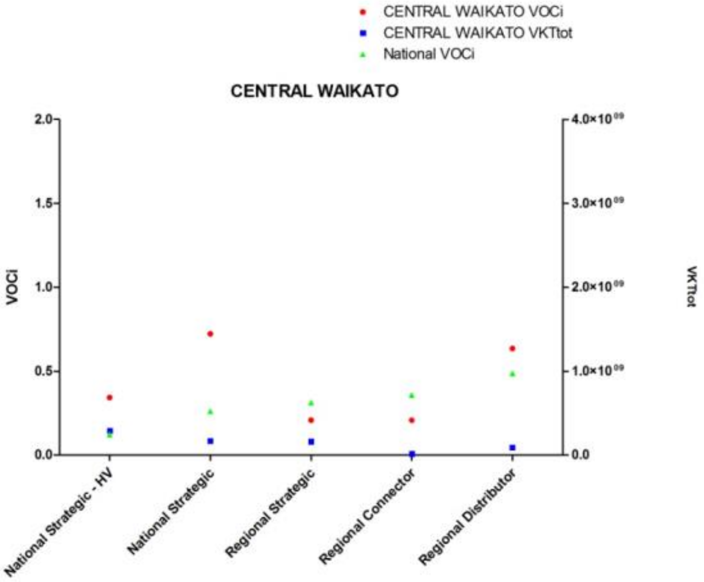

Crash Cost ($M) per 100M vkt 2009/10
Peer Group E
0.849
0.749
0.649
0.549
0.449
0.349
0.249
0.149
0.049
0
50,000
100,000
150,000
200,000
250,000
Expenditure related to safe travel (2009/10)/million vkt
Buller District
Carterton District
Central Hawkes Bay District
Central Otago District
Clutha District
Dunedin City
Gore District
Grey District
Hauraki District
Hurunui District
Kaikoura District
Kaipara District
Kawerau District
Mackenzie District
Opotiki District
Otorohanga District
Queenstown-Lakes District
Rangitikei District
Ruapehu District
South Wairarapa District
Stratford District
Tararua District
Waimate District
Wairoa District
Waitomo District
Westland District
Manawatu District

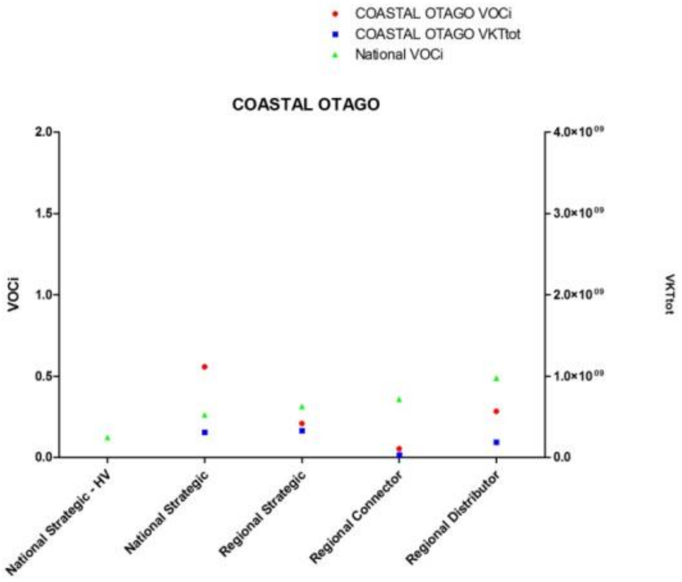
Appendix C: Average VOCi by state highway classification by region

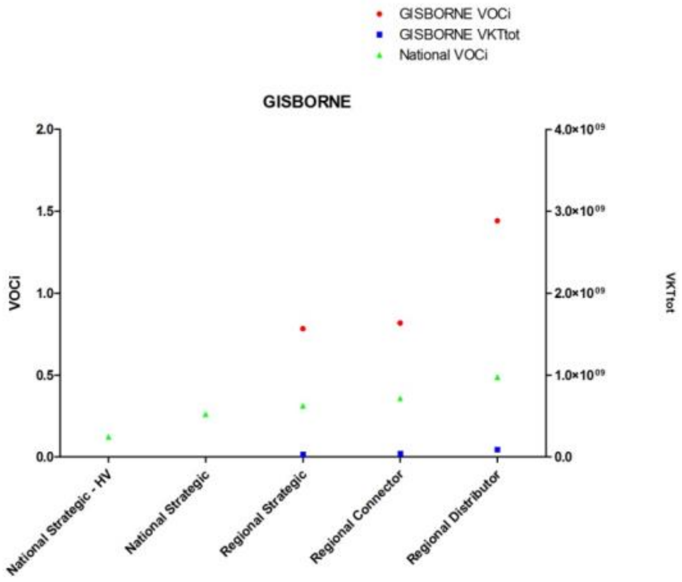


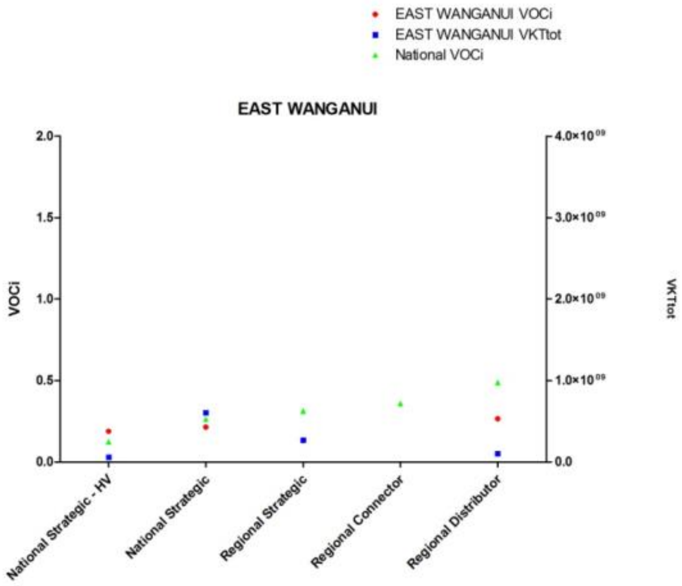


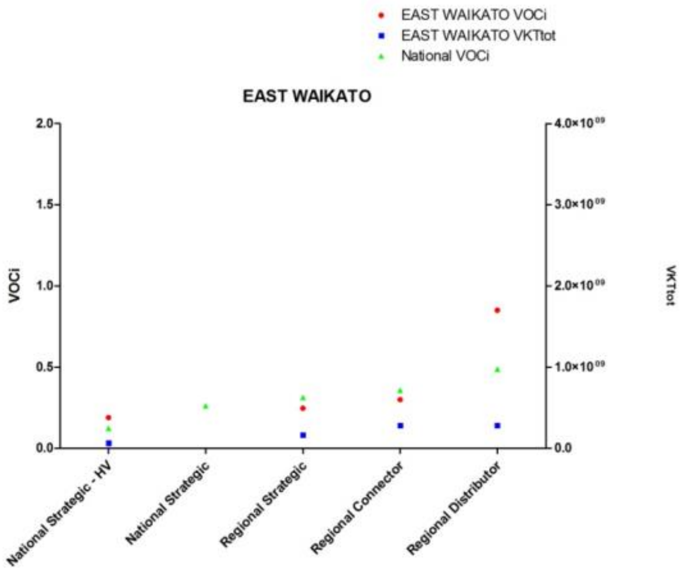


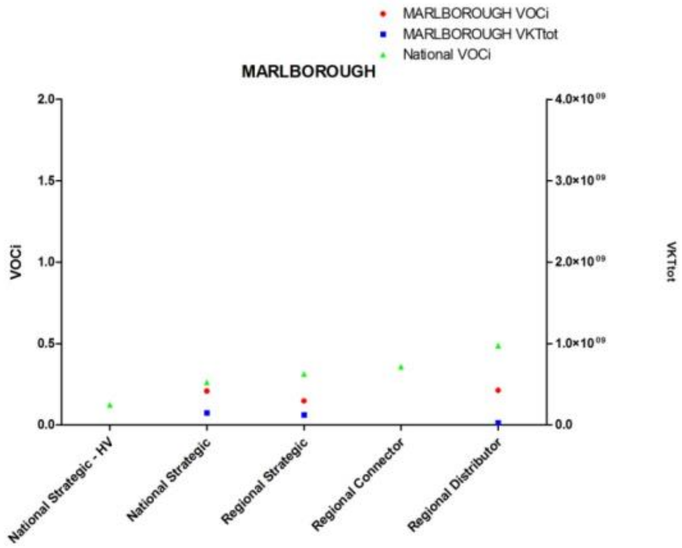


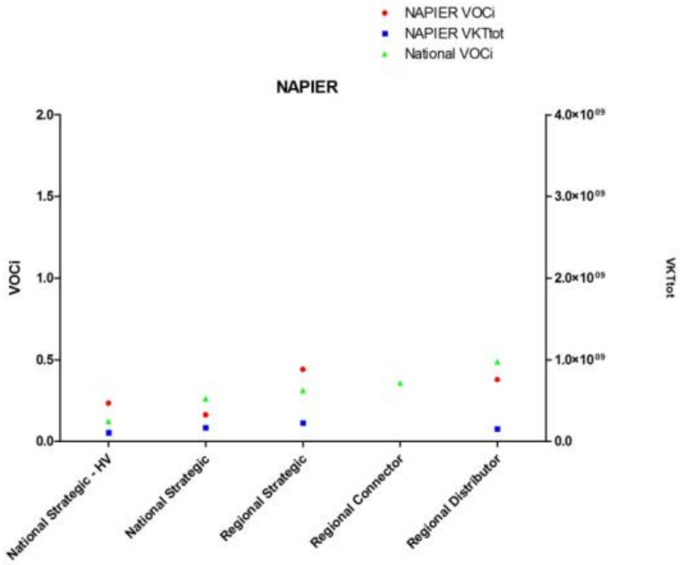

COASTAL OTAGO VOCi
COASTAL OTAGO VKTtot
National VOCi
COASTAL OTAGO
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

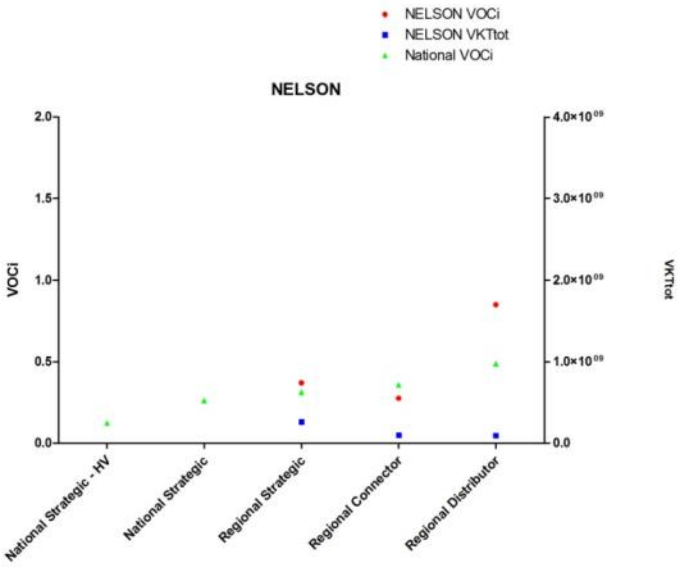

GISBORNE VOCi
GISBORNE VKTtot
National VOCi
GISBORNE
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

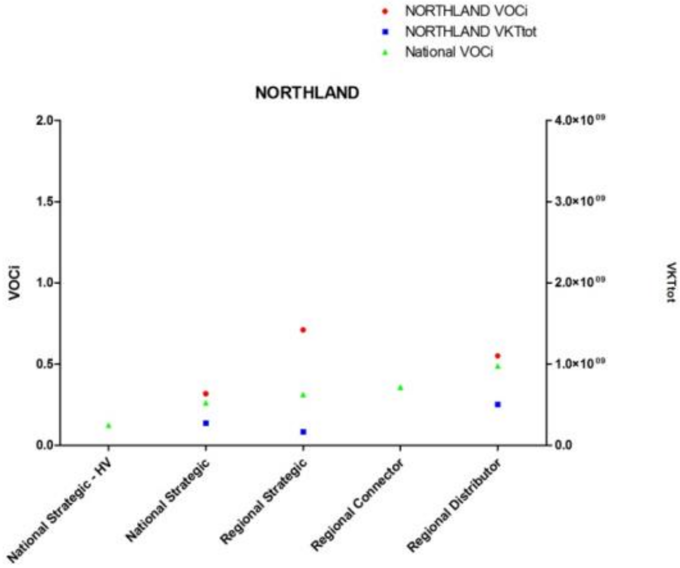

EAST WANGANUI VOCi
EAST WANGANUI VKTtot
National VOCi
EAST WANGANUI
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

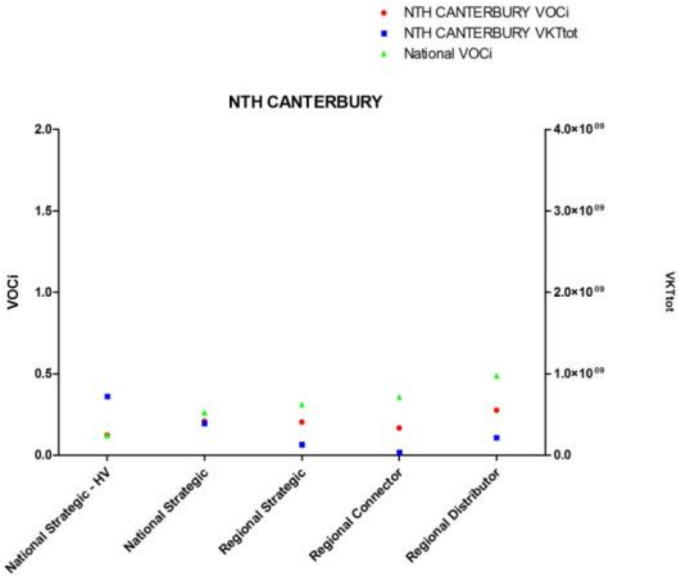

EAST WAIKATO VOCi
EAST WAIKATO VKTtot
National VOCi
EAST WAIKATO
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

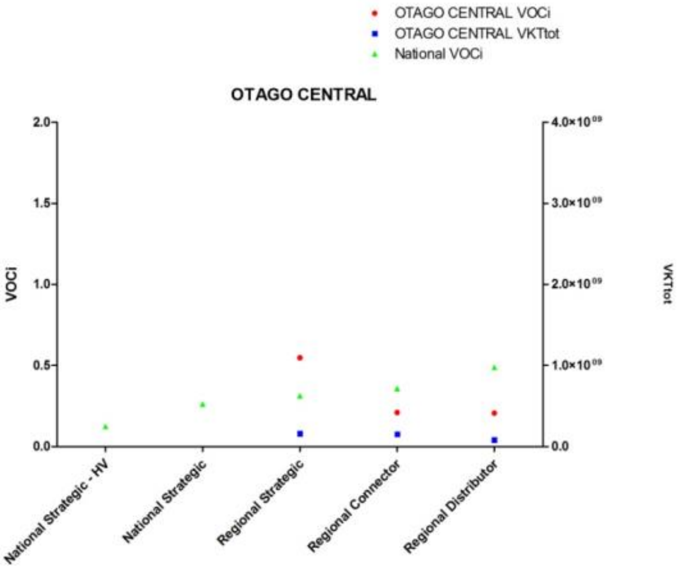

MARLBOROUGH VOCi
MARLBOROUGH VKTtot
National VOCi
MARLBOROUGH
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

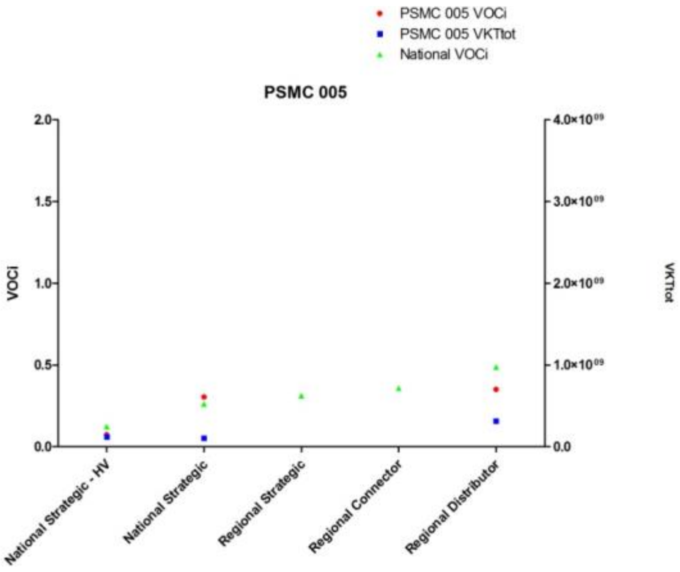

NAPIER VOCi
NAPIER VKTtot
National VOCi
NAPIER
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

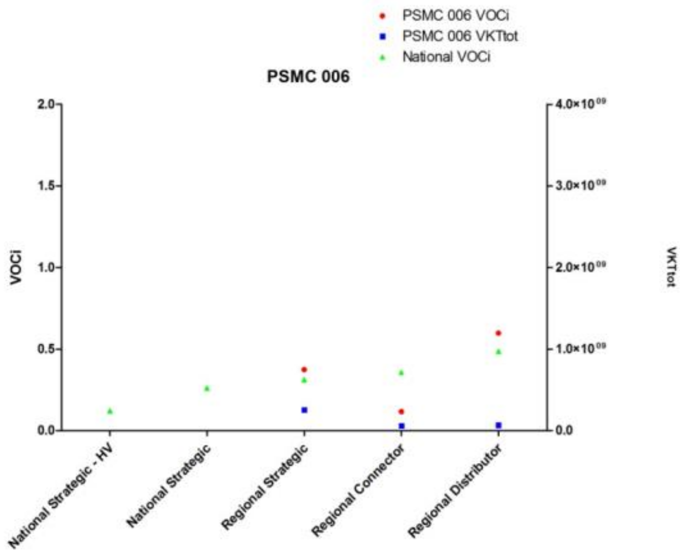

● NELSON VOCi
■ NELSON VKTtot
▲ National VOCi
NELSON
VOCi
2.0
1.5
1.0
0.5
0.0
VKTtot
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

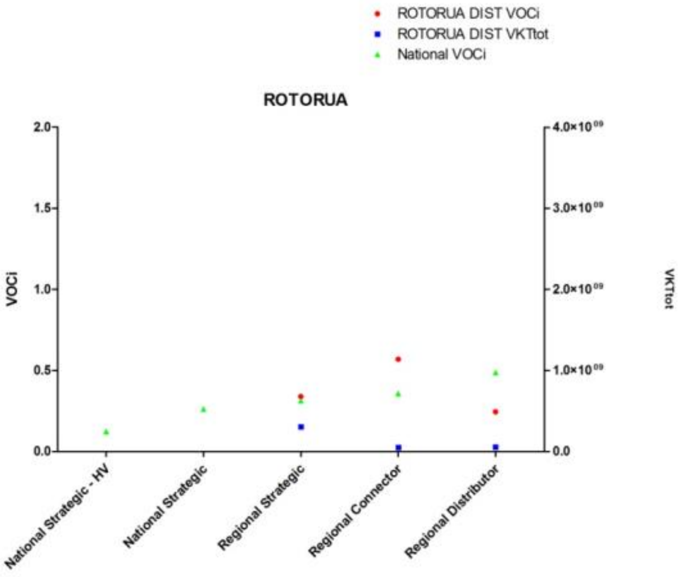

● NORTHLAND VOCi
■ NORTHLAND VKTtot
▲ National VOCi
NORTHLAND
VOCi
2.0
1.5
1.0
0.5
0.0
VKTtot
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

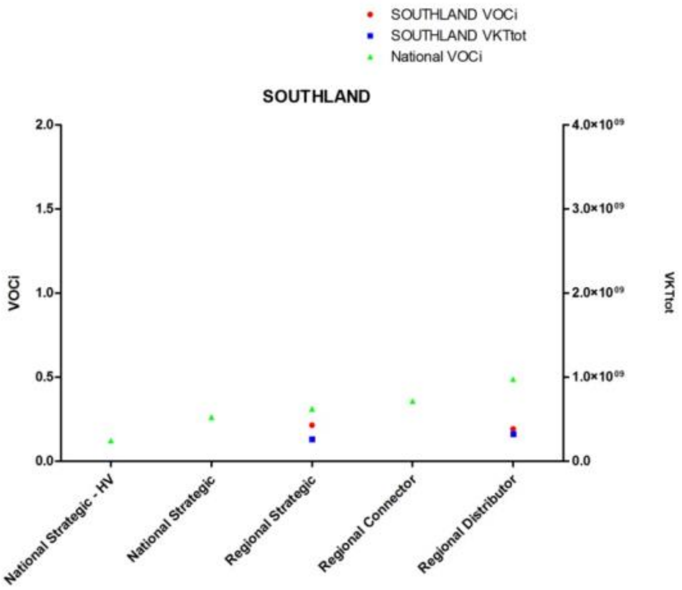

● NTH CANTERBURY VOCi
■ NTH CANTERBURY VKTtot
▲ National VOCi
NTH CANTERBURY
VOCi
2.0
1.5
1.0
0.5
0.0
VKTtot
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

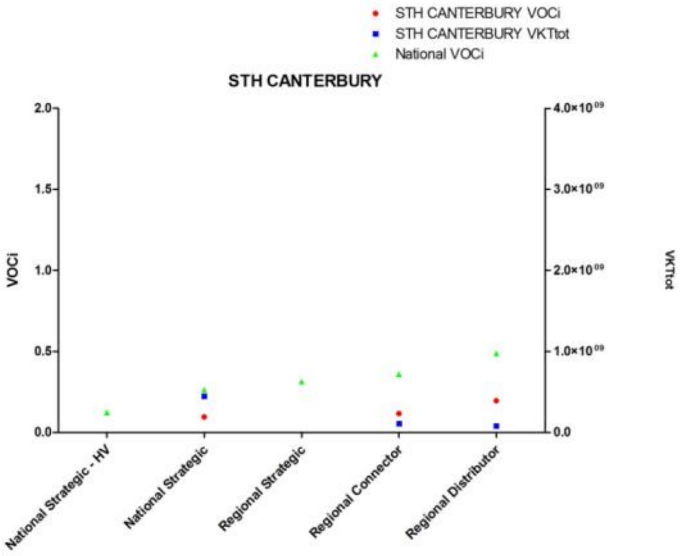

● OTAGO CENTRAL VOCi
■ OTAGO CENTRAL VKTtot
▲ National VOCi
OTAGO CENTRAL
VOCi
2.0
1.5
1.0
0.5
0.0
VKTtot
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

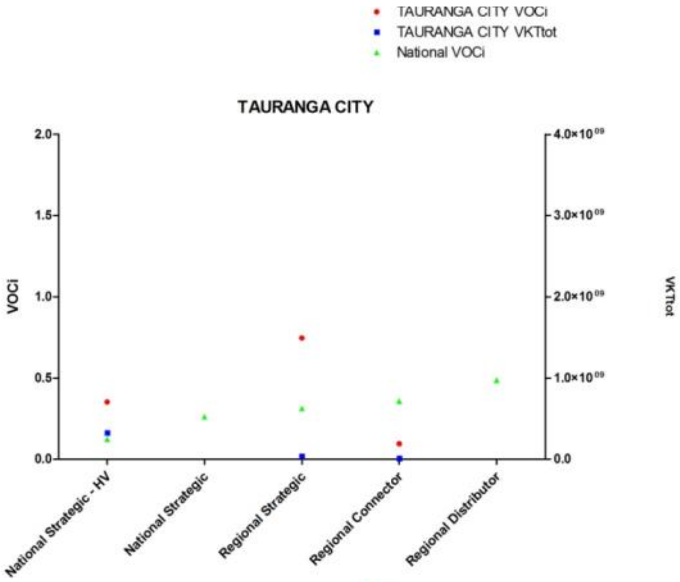

● PSMC 005 VOCi
■ PSMC 005 VKTtot
▲ National VOCi
PSMC 005
VOCi
2.0
1.5
1.0
0.5
0.0
VKTtot
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

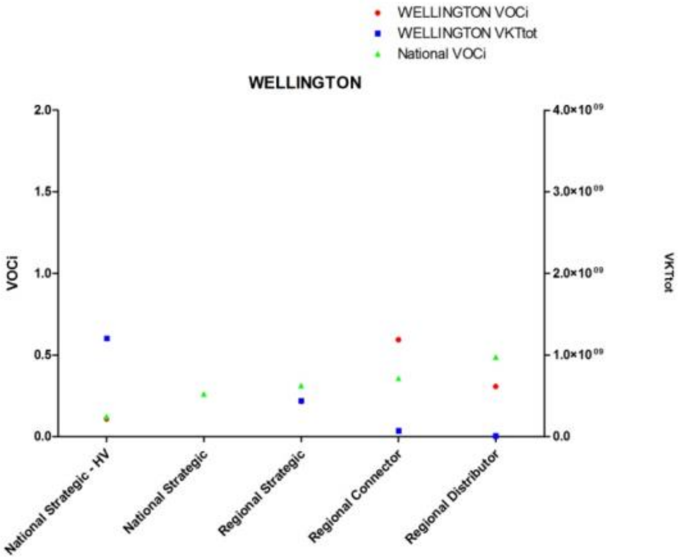

● PSMC 006 VOCi
■ PSMC 006 VKTtot
▲ National VOCi
PSMC 006
VOCi
2.0
1.5
1.0
0.5
0.0
VKTtot
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

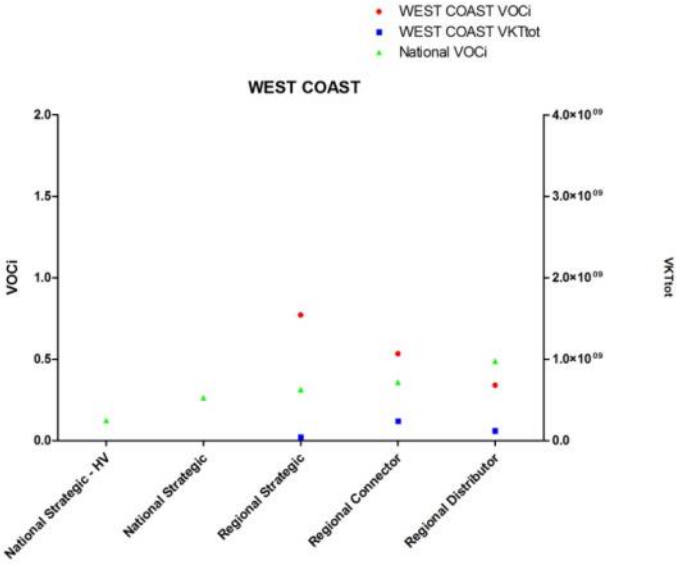

● ROTORUA DIST VOCi
■ ROTORUA DIST VKTtot
▲ National VOCi
ROTORUA
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

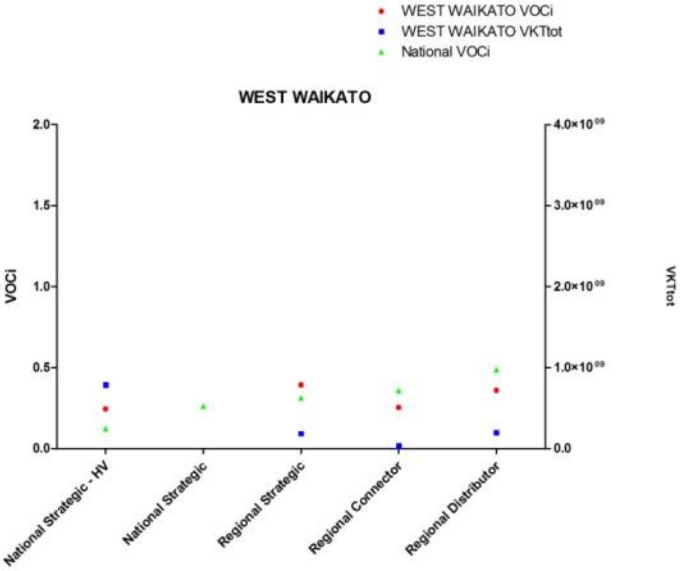

● SOUTHLAND VOCi
■ SOUTHLAND VKTtot
▲ National VOCi
SOUTHLAND
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

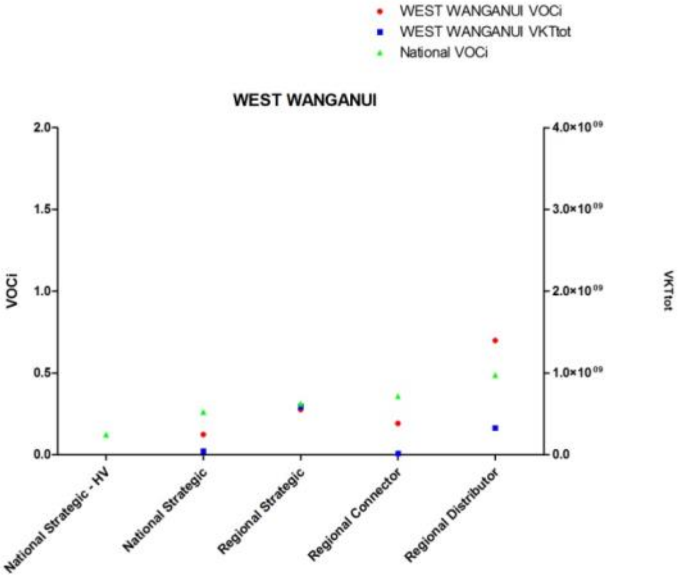

● STH CANTERBURY VOCi
■ STH CANTERBURY VKTtot
▲ National VOCi
STH CANTERBURY
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor


● TAURANGA CITY VOCi
■ TAURANGA CITY VKTtot
▲ National VOCi
TAURANGA CITY
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor


● WELLINGTON VOCi
■ WELLINGTON VKTtot
▲ National VOCi
WELLINGTON
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor


● WEST COAST VOCi
■ WEST COAST VKTtot
▲ National VOCi
WEST COAST
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor


WEST WAIKATO VOCi
WEST WAIKATO VKTtot
National VOCi
WEST WAIKATO
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor


WEST WANGANUI VOCi
WEST WANGANUI VKTtot
National VOCi
WEST WANGANUI
VOCi
VKTtot
2.0
1.5
1.0
0.5
0.0
4.0×10⁰⁹
3.0×10⁰⁹
2.0×10⁰⁹
1.0×10⁰⁹
0.0
National Strategic - HV
National Strategic
Regional Strategic
Regional Connector
Regional Distributor

Appendix D: Glossary

AADT	annual average daily traffic
ARRB	Australian Road Research Board
ATMS	advanced traffic management systems
BVPI	best value performance indicator
CPI	core public infrastructure (Canada)
CVI	core visual inspection
DEA	data envelope analysis
DfT	Department for Transport (UK)
DSO	departmental strategic objectives
FWD	falling weight deflectometer
GPS	Government policy statement
HDC	Hastings District Council
HDM	World Bank Highway Design and Maintenance Model (HDM-III and HDM4)
HSD	high-speed data
IRI	international roughness index
KPI	key performance indicator
LOS	level of service
LTPP	long-term pavement performance
MOTSAM	*Manual of traffic signs and markings*
MPD	mean profile depth
NAASRA	National Association of Australian State Road Authorities
NI	national indicator
NRC	National Research Council (Canada)
NRTSI	National Round Table on Sustainable Infrastructure
NZTA	New Zealand Transport Agency
PII	pavement integrity index
QA	quality assurance
RAMM	Road asset and maintenance management (database)
RCA	road controlling authority
RCI	road condition index
RI	rutting index
RIMS	Road Information Management Support Group
SCANNER	surface condition assessment for the national network of roads
SCI	surface condition index
SFC	sideways force coefficient
SII	surface integrity index
SNP	adjusted structural number
STE	smooth travel exposure
TLA	territorial local authority

UKPMS	UK pavement management system
VfM	value for money
VKT	vehicle kilometres travelled
VOC	vehicle operating costs
VOCi	vehicle operating cost index