NACOE
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ANNUAL SUMMARY REPORT

A35: Identification of Residual Risk for each Element and Development of a Funding Allocation Methodology of Elements (2019–20: Year 3)

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Summary

This report documents the outcomes of Year 3 for the National Asset Centre of Excellence (NACOE) Project A35 *Identification of Residual Risk for each Element and Development of a Funding Allocation Methodology of Elements*.

This year's focus was on finalising the framework for the Pavement Residual Risk Model (PRRM), developed initially in Year 1 and based on an analytical hierarchical process (AHP). The PRRM is made up of five risk dimensions with each dimension built up from risk indicators. There are now 13 risk indicators in total in the model.

A state-wide implementation of the PRRM was carried out in Queensland, with the following requirements:

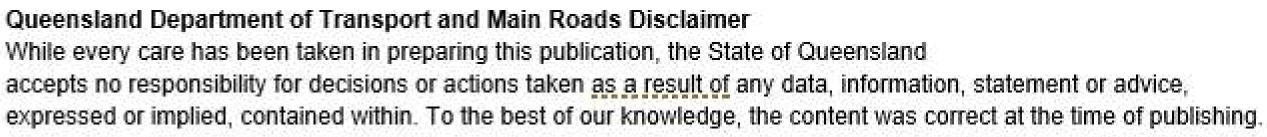
- accessible and reliable data was used to generate each risk indicator to provide a state-wide coverage
- the available data was capable of being categorised into a five-point risk rating system adopted for all risk indicators
- a process was used that had the transparency to demonstrate the influence that each risk indicator had on a risk dimension and, in turn, the collective impact of each risk dimension on the overall pavement residual risk (PRR) score
- there was flexibility in summarising and visualising the PRR score data at road, district and state level
- granularity of the data was available so it could be reduced to 100-m-long segments.

The PRRM framework consists of two components, the calculation database and the visualisation of the results. All PRR score calculations were undertaken and stored in a master file linked to a visualisation tool built for the project. A series of charts and maps are used to visualise the PRR score results at various levels of state-wide, districts and individual road levels.

The PRRM framework provides TMR with flexibility to adjust the weightings of risk indicators and risk dimensions to assess their impact on the PRR score on the network. The following recommendations are made for the operationalisation of the PRRM:

- Review the risk indicators, especially those which currently have a highly significant influence on the PRR score calculation. Further clarification of how the extent of current road closures is defined is needed for the loss of access indicator in the operations risk dimension.
- Review the PRR score's current weightings against the intended functionality of the PRRM, which now has the capacity to easily adjust the weightings and observe their effect on the entire network.
- Use roads with known deficiencies or residual risks to validate and finalise the above PRR score weightings.
- Explore the potential use of the PRRM in planning and programming of maintenance works.

The undertaking of these recommendations could be added to the scope already proposed for 2020–21 in Project A35 provided sufficient resources are available following a reassessment of priorities upon finalisation of this report.



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1 INTRODUCTION

Queensland Department of Transport and Main Roads (TMR) faces a challenge in addressing the funding needs of multiple asset elements and the impacts on them from traffic use and the environment. Asset performance, and therefore needs and risks, are impacted by a combination of factors, with climate-related factors increasing in importance as evident from Queensland's recent floods. Different parts of the network and specific roads and assets, including structures, slopes, drainage, and signs and lines, are impacted differently. In specific cases, the frequency and scale of impacts effect the risks which can differ from case to case. Road pavements and surfacings, which have been subjected to substantial study, also need to be considered at risk, as there is a need to ensure an appropriate distribution of funding across multiple asset programs.

Therefore, TMR's Maintenance, Preservation and Operations (MPO) Steering Committee has identified a need for a more comprehensive and rational basis for assessing and managing risks. The intent is to allow TMR to better manage its portfolio by more rigorous, risk-based planning and programming, and the provision of clearer guidance to inform implementation.

1.1 Objectives

This project aimed to deliver a framework, guidance, and tools to support a comprehensive, risk-based framework to assist in funding allocations to different elements. At this stage in Year 3 of the project, the focus was on developing a quantitative residual risk model for road pavements.

It is envisaged that once the framework for the Pavement Residual Risk Model (PRRM) has been developed, a similar blueprint will be adopted for the development of a residual risk model (RRM) for other asset types.

1.2 Previous Work

Directly related other NACoE projects include:

NACoE Project A4: Accounting for Life-cycle Costing Implications and Network Performance Risks of Rain and Flood Events

The rain and flood events across Queensland between 2010 and 2013 showed that the road network is more vulnerable to damage from such events than desirable, with between 23% and 62% of the state-controlled network closed or with limited access over four summers. With increasingly uncertain climatic factors and stretched infrastructure budgets, efficient optimisation and prioritisation of works is critical to the overall network condition.

Pavement management maintenance and rehabilitation practices needed to be reviewed to decrease exposure to damage in a cost-effective manner. This project analysed the life-cycle costing implications of rain and flood events in Queensland through modelling three strategic options across a series of seven case studies.

The analysis highlighted two critical factors: (i) the uncertainty surrounding future extreme climate and weather events in the face of predicted increased climate risks to Queensland; and (ii) the importance of treating pavements within their target life before the start of accelerated deterioration (Beecroft & Peters 2017).

NACoE Project A5: Incorporating Uncertainty in PMS Modelling

Pavement management systems (PMS) require data that faithfully reflects the properties and other operating aspects of the network. It is well-known that much of this information is uncertain or poorly represented either due to the nature of the data (e.g. environment) or to the aggregation of the data into discrete homogeneous segments. The approach developed by this project expanded the use of existing deterministic models by using the full range distribution of the data instead of a mathematical representation of the data distribution for each independent variable. The approach also used a comprehensive set of historical data to forecast the probability distribution of key dependent variables (Kadar & Sen 2016).

NACoE Project A26: Incorporation of the Pavement Risk Score (PRS) into the Pavement Condition Index (PCI)

Martin and Hore-Lacy (2017) published a NACoE report detailing the *Incorporation of the Pavement Risk Score into the Pavement Condition Index* as part of the NACoE A26 program. The study was aimed at reviewing, calibrating, and incorporating the pavement risk score (PRS) developed by TMR into the pavement condition index (PCI) implemented in TMR's pavement management system (PMS). The PCI was modified by the addition of the traffic speed deflectometer (TSD) maximum deflection, D_0, that improved prediction of the remaining structural life of pavements.

NACoE Project A34: Customer-based Levels of Service in Road Maintenance (ongoing)

In the context of road maintenance, road agencies have identified that there is a pressing need to relate customer-based levels of service (CLoS) for road maintenance to the maintenance intervention measures, the technical-based levels of service (TLoS), for roughness, rutting, cracking, potholes, etc., used by road asset managers. A re-justification of existing levels of service is required to provide a defendable position to TMR in its decision to allocate funds and manage its financial risks, including potential road user impacts, and the extent TLoS are consistent with whole-of-life-cycle costing–based funding priorities.

This project aims to determine the existence of relationships between CLoS and TLoS for an agreed set of road categories that will allow the determination of a customer acceptable level of TLoS.

1.2.1 Year 1

Work commenced on this project in 2017–18 (Year 1), continued in 2018–19 (Year 2) and the current reporting year of 2019–20 (Year 3). The work has required collaboration with several TMR departments during the project.

The framework for the PRRM, based on an analytical hierarchical process (AHP), was developed in Year 1. The AHP method was adapted from RIVA (Risk analysis of key goods and transit axes including seaports), a GIS-based risk analysis tool, used in Germany to account for the risk associated with natural hazards (Klose 2017). In 2014 Auerbach and Herrmann (2014) outlined a risk analysis approach for adapting the road infrastructure to climate change which formed the initial basis for the RIVA work.

Other methodologies (Nicolosi, Augeri & Soccodato 2019) for allocating funding across assets are available. Nicolosi et al. (2019) used a hybrid framework combination of top down/bottom-up multi-objective approaches. Typically, most asset funding allocation approaches struggle to quantify some of the factors influencing the allocations. In addition, the adoption of a risk-focused quantitative approach to allocation of funding needs a substantial database encompassing all the factors contributing to the risk.

Stage 1 involved the development of a general framework and methodology for determining the level of risk by individual asset types associated with different condition states and operating conditions, with risk quantified in terms of likelihood and consequence. This work built on the outcomes of the NACoE project A26 (Martin & Hore-Lacy 2017), which used only the pavement condition index (PCI) component. The tasks carried out included:

- a review of existing asset element management plan approaches, and national and international practice on risk management
- extending the composition and weightings employed in the PCI to reflect the sensitivity of outcomes to changes in key input variables, with the latter defined as a simplified distribution (with boundary conditions) relevant to each variable, and taking account of estimated time-based changes in distribution, e.g. for climate-related variables
- ensuring the estimated level of risk is responsive to different treatment strategies, e.g. where 'full resilience' or 'stitch-in-time' strategies are adopted, or where funding levels are varied, including accounting for different road use (annual average daily traffic (AADT), and percentage heavy vehicle composition (%HV)
- assembling evidence to allow the principles of the above 'risk model' approach to be adapted and applied to two non-pavement asset elements, selected in consultation with TMR

- presenting the proposed prototype model (and supporting illustrations) to the MPO Steering Committee to inform the suitability of the approach and direction for Stage 2.

Three other different residual risk models were investigated, the Intelligent Transport Systems Residual Risk Model (ITSRRM), the Structures Residual Risk Model (SRRM), and the Environmental Residual Risk Model (ERRM). Formulation of the framework for the SRRM and ITSRRM was commenced in consultation with TMR in Year 1.

1.2.2 Year 2

The main element of the Year 2 scope was the development of the indicators used to assess each risk dimension. This involved an in-depth review of the data for indicators which were of a quantitative nature, and an investigation for alternate methodologies to address qualitative indicators.

Year 2 also progressed the framework for the SRRM and ITSRRM; however, most work was concentrated on finalising the PRRM framework and the operationalisation of the PRRM by a trial application on the TMR road network. A sub-network was selected for the trial consisting of the roads which were field rated as part of NACoE Project A26. The agreed indicators were then calculated for a selected sub-network of TMR roads as an early attempt of implementation. The result was presented in both a graphical and spatial format.

1.3 Scope and Contents of this Report

The PRRM framework established in Year 2 was further developed by revising several indicators with consideration of state-wide implementation. This report documents the data source for each indicator, the process used to derive each risk dimension and the outcomes of running the PRRM tool. The tool was purpose-built for the project for visualisation of each component from segment, road, district to state-wide level.

Preliminary work for the development of the residual risk approach applied to the intelligent transport systems (ITS) and structures (bridges and culverts) assets has also been underway concurrently with the residual risk for pavement assets, although this work is not being reported at this stage and will be conducted under Year 4 of this project.

Following this introductory section, the report includes:

- Section 2 **–** which describes the components of the PRRM, including each risk dimension and the risk indicators contributing to them. The data source and how each indicator is categorised into a five-point risk rating category is also described. The relationship between the calculation and the visualisation files that make up the platform of the tool is explained to ensure sustainability for future updates.
- Section 3 **–** which illustrates the state-wide result from running the tool with the current agreed weighting where examples of charts and maps were provided. The result of alternative weightings where all the indicators were set at equal weighting is also provided.
- Section 4 **–** which provides the conclusions and recommendations of Year 3 tasks and outlines the scope of Year 4.

1.4 Year 3 Deliverables

Accompanying this report, ARRB has provided the PRRM visualisation tool in Microsoft Power BI format.

The master calculation file in MS Access and the individual indicator calculation files will be supplied to TMR separate to this report due to the very large file size. The main output within the master file is a table called 3_PRR_Output which is linked to a Microsoft Power BI file called A35_Pavement_Residual_Risk.

2 Pavement Residual Risk Model (PRRM)

2.1 Introduction

This section details the information used as input for the PRRM. This includes the definitions of the risk indicators and risk dimensions, the risk rating categories, and the calculation of pavement residual risk (PRR) score for the TMR road network.

Specifically, this section is structured as follows:

- Access Vulnerability Risk Dimension (Section 2.2)
  - Thornthwaite Moisture Index (TMI) Indicator (Section 1)
  - Annual Rainfall Indicator (Section 2.2.2)
  - Traffic annual average daily traffic (AADT) and percentage heavy vehicles (%HV) Indicators (Section 2.2.3)
  - Terrain Indicator (Section 2.2.4)
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- Stakeholders and Community Risk Dimension (Section 2.3)
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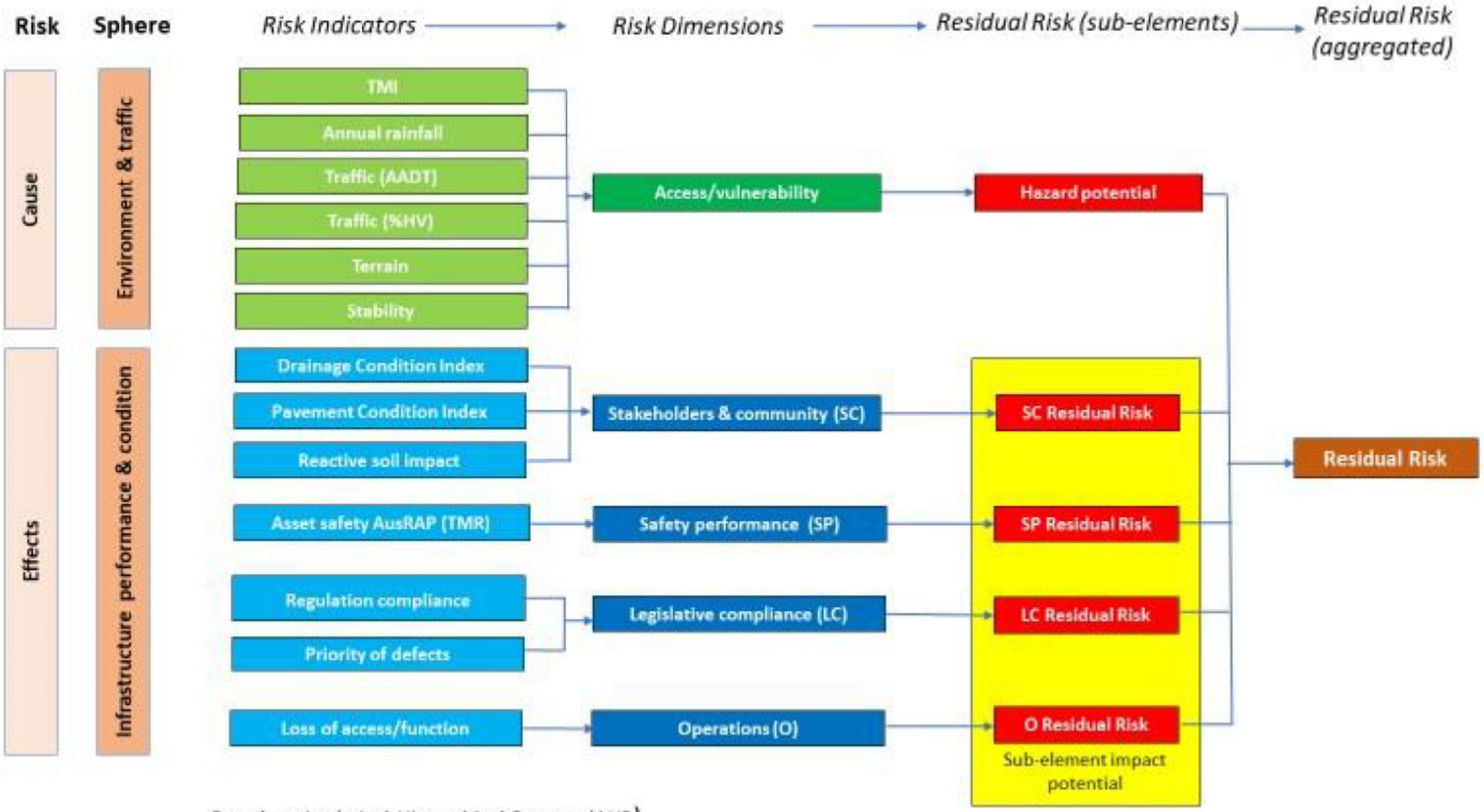
  - Loss of Access Indicator (Section 2.6.1)
- Pavement Residual Risk Estimation (Section 2.7)
  - Calculation of Pavement Residual Risk PRR score (Section 2.7.1)

The PRRM is made up of five risk dimensions with each dimension built up from risk indicator(s). There is a total of 13 contributing risk indicators in the model. A clearly defined framework for the model has been established as illustrated in Figure 2.1.

For a state-wide implementation of the PRRM the following were considered:

- data input to generate each indicator should have a state-wide coverage
- the available data should be able to be processed into a five-point risk rating scoring system adopted for all indicators
- transparency should be provided to see the influence of each indicator on a risk dimension and in turn, the collective impact of each risk dimension on the overall PRR score
- there should be flexibility in summarising and visualising the data at road, district and state level
- there should be granularity of the data to be analysed at 100 m long segments.

Figure 2.1: Pavement residual risk model structure



Based on Analytical Hierarchical Process (AHP)

Most of the above requirements are fulfilled by placing the PRRM framework in a Microsoft Power BI platform. One of the main deliverables of the Year 3 outcome is the purpose-built PRRM tool in Power BI which accompanies this report.

A summary of the PRRM components and source of data used as inputs is provided in Table 2.1. The main database structure is TMR ARMIS inventory data at 100 m long intervals covering the entire TMR road network.

Table 2.1: PRRM components summary

No	Risk dimension	Indicators	Data source	Score rating
1	Access vulnerability	TMI	Bureau of Meteorology (BOM) rainfall & temp	1–5 rating
		Annual rainfall	BOM rainfall	1–5 rating
		Traffic (AADT)	TMR ARMIS AADT	1–5 rating
		Traffic (%HV)	TMR ARMIS HV%	1–5 rating
		Terrain	TMR ARMIS general terrain	1, 3–5 rating
		Slope stability	TMR slope stability database	1–5 rating
2	Stakeholder & community	Drainage condition index	TMR RMPC from NACoE A37	1–5 rating
		Pavement condition index	TMR ARMIS condition	1–5 rating
		Reactive soil impact	TMR ARMIS zone	1–5 rating
3	Safety performance	Asset safety AusRAP	TMR AusRAP vehicle run-off score rating	1–5 rating
4	Legislative compliance	Roughness compliance	TMR_ARMIS_IRI	1–5 rating
		Priority defect	TMR hazardous defect backlog	1, 4–5 rating
5	Operation	Loss of access/function	TMR road closure data	1–5 rating

2.2 Access Vulnerability Risk Dimension

The Access Vulnerability risk dimension refers to the extent to which a road is susceptible to, or unable to cope with, the adverse effects of the environment and traffic. The indicators included in this category are the Thornthwaite (1948) Moisture Index (TMI), annual rainfall, traffic, terrain and slope stability.

Table 2.2 provides a detailed five-point scale risk rating category for each indicator. The influence of each indicator on the access vulnerability risk dimension has been weighted with consideration of the likelihood of its occurrence. For example, the risk of flooding (annual rainfall) is weighted higher than the risk of landslides (slope stability). This weighting approach to the contributing risk dimensions was adopted for estimating each risk dimension that comprises the aggregated residual risk.

Table 2.2: Access vulnerability risk category

	Category/rating					
Indicator	V Low (1)	Low (2)	Fair (3)	High (4)	V High (5)	Weight
TMI	–50 to –25	–24.9 to 0	0.1 to 30	30.1 to 60	60.1 to 100	0.25
Annual rainfall (mm)	< 250	251–500	501–800	801–1 500	> 1 500	0.25
Traffic (AADT)	< 250	251–1 000	1 001–10 000	10 001–15 000	> 15 000	0.05
Traffic (%HV)	< 25	25–100	101–300	301–1 000	> 1 000	0.12
Terrain class	Level	–	Rolling	–	Mountainous	0.16
Slope stability (ARL[1] rating)	Inert	Stable	Mod. stable	Mod. unstable	Very unstable	0.17
	(ARL = 5)	(ARL = 4)	(ARL = 3)	(ARL = 2)	(ARL = 1)	

1. Assessed risk level.

2.2.1 Thornthwaite Moisture Index Indicator

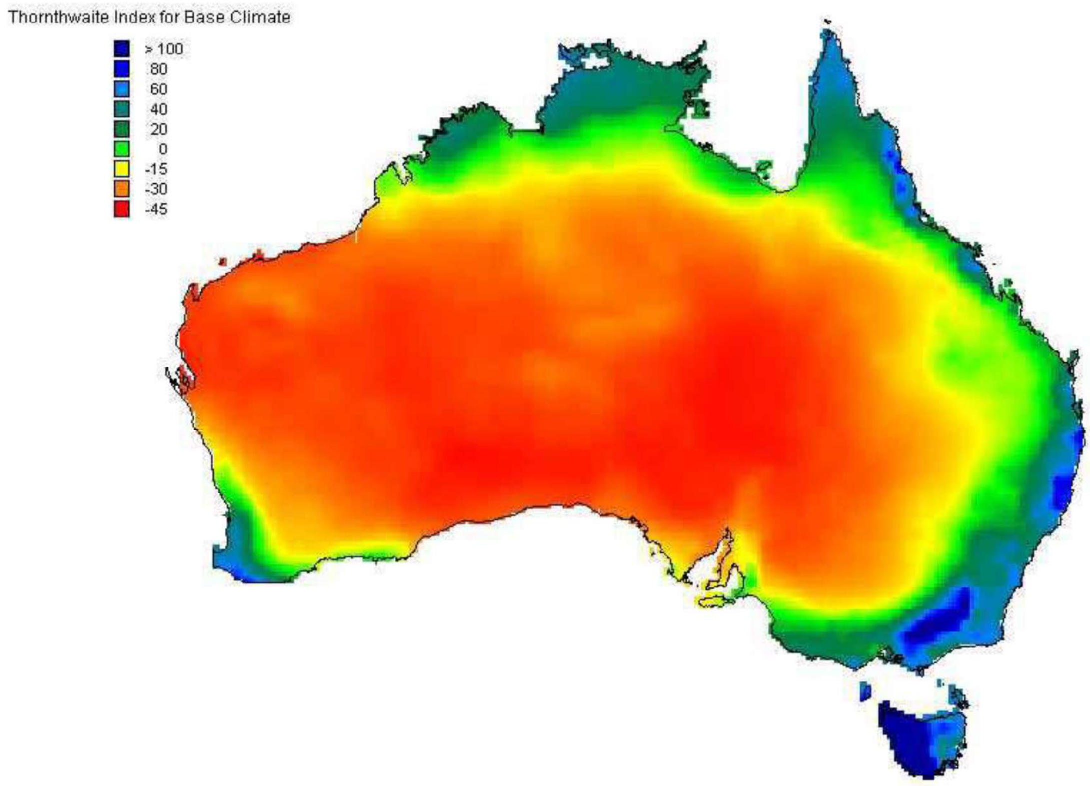
The TMI indicator quantifies the aridity or humidity of the soil and climate of an area. It is calculated by analysing the collective effects of precipitation, evapotranspiration, soil water storage, moisture deficit and run-off (Austroads 2004). TMI can be used to classify various climate types according to the moisture index limits which are outlined in Table 2.3. The distribution of TMI across Australia is shown in Figure 2.2.

Table 2.3: Thornthwaite climate type classification

TMI climate type	TMI
Term	**Range**
Perhumid	> 100
Humid	80 to 100
Humid	60 to 80
Humid	40 to 60
Humid	20 to 40
Moist subhumid	0 to 20
Dry subhumid	−20 to 0
Semi-arid	−40 to −20
Arid	−60 to −40

Source: Thornthwaite (1948; cited in Austroads 2004).

Figure 2.2: Thornthwaite Moisture Index for Australia in 2000



Source: Austroads (2004).

Data for estimating the TMI were sourced from the Australian Bureau of Meteorology (BOM) website for relevant weather stations in Queensland. TMI can represent the impacts of the extreme weather events on the road infrastructure that occurred from 1998 to 2019. These extreme events can affect road access as they cause road closures due to damage and associated repairs. Further, the retention of water in the environment from rainfall, can lead to network disruption due to flooding.

2.2.2 Annual Rainfall Indicator

The annual rainfall indicator is defined as the long-term average annual rainfall, sourced from the BOM, for each 100 m road segment location. The long-term average annual rainfall for each segment was calculated by averaging the annual rainfall of the most recent 30-year period, 1988–2018.

Based on the chainages of the road segments, the nearest town was identified. This town was entered into the BOM's search engine to locate the closest weather station. Relevant towns, and associated weather station characteristics were recorded. Weather stations were selected based on their proximity to the town and the amount of data available. Ideally, weather stations with 30 years of rainfall data were selected.

2.2.3 Traffic AADT and %HV Indicators

The impact of traffic on residual risk was calculated for two separate indicators, the AADT and the %HV using the road. Traffic can affect the operation of the network in terms of potential road congestion as the traffic increases which in turn reduces the accessibility level. Additional traffic can also cause increased wear of the road to reduce its rideabiity.

Traffic data for 2018 were sourced from TMR ARMIS data repository.

2.2.4 Terrain Indicator

The terrain indicator refers to the physical features of the land across which the road traverses. TMR defines terrain in three categories, level, rolling and mountainous. The terrain category associated with each of the road segment locations was provided by TMR. Most roads on a level terrain are less vulnerable to damage or closure, except those subject to flooding in low lying areas. Roads in a mountainous terrain are more likely to be affected by erosion and land subsidence from heavy rainfall. This coupled with the level of slope stability can greatly impact the associated risk.

Terrain data were sourced from TMR ARMIS data repository.

2.2.5 Slope Stability Indicator

The slope stability indicator refers to the stability of the batter and cutting slopes along the road. The batter and cutting slopes are the uniform side slopes of the road batters and cuttings, as distinct from grade, and are expressed as a ratio of the horizontal distance to vertical slope height (Austroads 2015). The stability of the batter and cutting slopes contribute to the structural resilience of the road pavement, including shoulders. The batter and cutting slopes also contribute to the ability of the road to drain by providing a stable base for the table drains to drain run-off from rain and flood events.

Slope stability is measured by TMR with an assessed risk level (ARL). This ARL value is a number from 1 to 5, with 5 being a stable slope, and 1 being an unstable slope. Slope stability is important regarding access, as unstable slopes can cause road closures.

Slope stability data, including the ARL, the slope type, the slope height, the slope angle, location information, and whether the slope has a management plan, were sourced from TMR Engineering and Technology slope stability database, that was made available for the NACoE A37 – Drainage Effectiveness Project.

2.3 Stakeholders and Community Risk Dimension

The stakeholders and community risk dimension is the connection of the pavement's performance and condition to the road users and general community. Pavement performance and condition should be assessed in response to road use and the pavement's interaction with the environment.

Three pavement related indicators were considered: drainage condition index (DCI), pavement condition index (PCI) and soil reactivity.

A summary of indicators and their five-point scale risk rating categories is provided in Table 2.4.

Table 2.4: Stakeholders and community risk category

Indicator	Category/rating					Weight
	V Low (1)	Low (2)	Fair (3)	High (4)	V High (5)	
Drainage condition index (DCI) – Number of RMPC[1]-300 in the last 5 years	V Good	Good	Fair	Poor	V Poor	0.25
	0	1	2	3	> 5	
Pavement condition index (PCI)	V Good	Good	Fair	Poor	V Poor	0.5
	(PCI = 0–1)	(PCI = 1.001–2)	(PCI = 2.001–3)	(PCI = 3.001–4)	(PCI = 4.001–10)	
Reactive soil impact	Non-reactive dry	–	Non-reactive wet	Reactive wet	Reactive dry	0.25

Note: 1. Routine Maintenance Performance Contract.

2.3.1 Drainage Condition Index Indicator

Drainage refers to the natural or artificial means of intercepting and removing surface or sub-surface water from the pavement, usually by gravity (Austroads 2015). The drainage condition index (DCI) indicator in this context is assessed by using the TMR Routine Maintenance Performance Contract (RMPC) data, originally obtained for the NACoE A37 project.

ARRB was provided with multi-year maintenance activity records from the year 2000 to 2017 at one-kilometre intervals across the entire TMR network. In particular, the 300 series of the RMPC activities were of interest since they are related to drainage maintenance. Frequency of maintenance items related to cleaning and repairing surface drainage was derived from the data as illustrated in Figure 2.3.

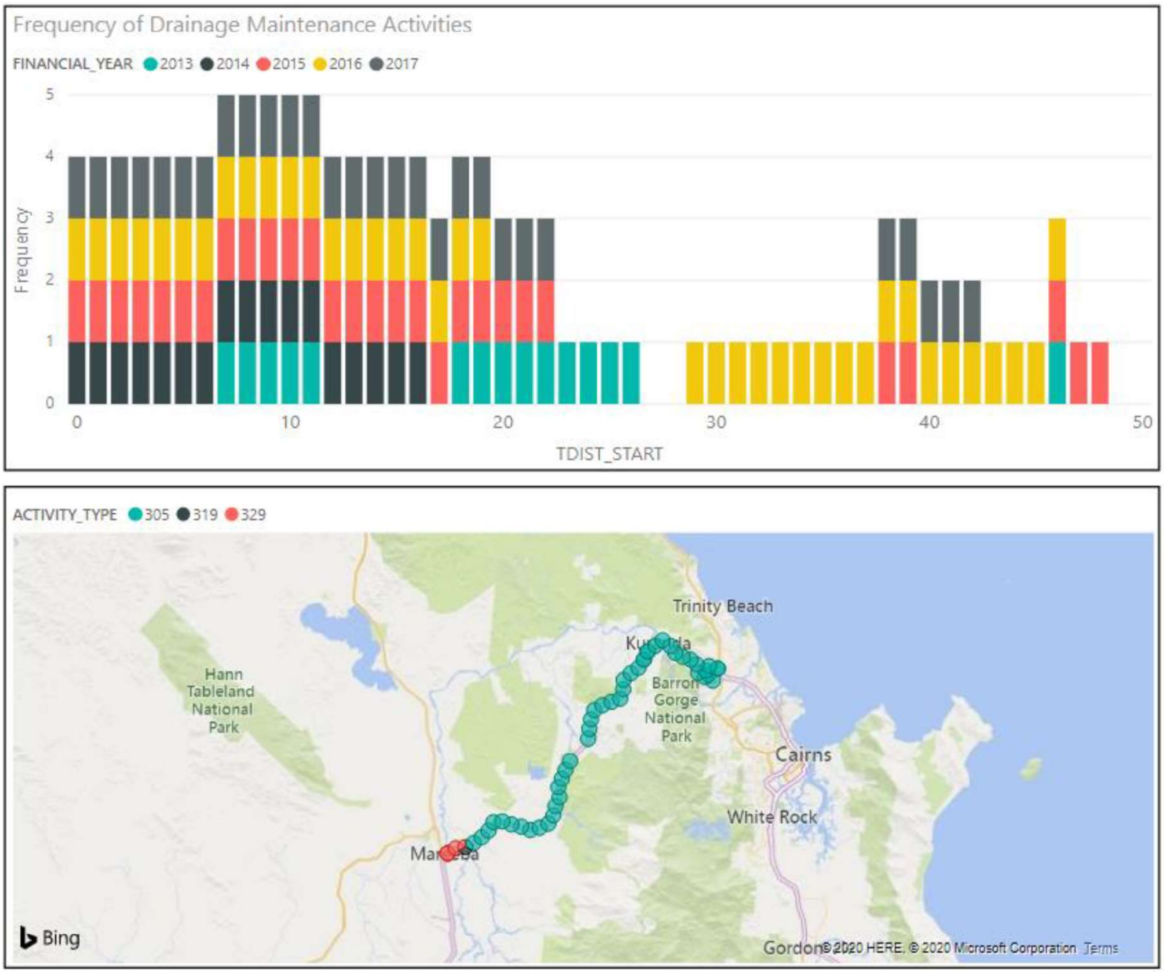
Figure 2.3 shows the number RMPC-300 maintenance activities that meet each DCI rating from 1 to 5.

Only RMPC records spanning five years from 2013 to 2017 were used to coincide with the end of major flood events and the associated reconstruction work including drainage repair done under the Transport Network Reconstruction Program (TNRP).

The example in Figure 2.3 shows a longitudinal profile of drainage maintenance activities on road 32A from Cairns to Mareeba in Far North Queensland. The drainage on the first 20 km of the road was more frequently maintained as it traversed the Great Dividing Range at the start of the road section. This represents a higher risk portion of the road from a drainage perspective.

A high number of annual drainage repairs infers that a significant drainage problem is present, while zero or low numbers of annual drainage repairs implies there are no significant drainage issues. This approach assumes that the road agency responds adequately to rectifying the drainage, although this may not always be the case.

Figure 2.3: Drainage maintenance frequency on road 32A



Source: Bing (2020).

2.3.2 Pavement Condition Index Indicator

The pavement condition index (PCI) indicator is an aggregated index of the individual condition indices (CI), based on the concept of a ‘weighted maximum’, i.e. instead of using an average of the CIs, the maximum (worst) dominates the overall index (COST 2008).

The PCI is calculated by applying Equation 1, as follows:

$$PCI = MAX(w_i \times Index_i) + p\left(\frac{SUM(w_i \times Index_i) - MAX(w_i \times Index_i)}{\sum(w_i) - Avg(w_i)}\right) \qquad 1$$

where

PCI = pavement condition index

w_i = weight for individual condition criteria, including cracking, roughness, rutting and surface age

$Index_i$ = index value for individual condition criteria, including cracking, roughness, rutting and surface age

p = condition factor (the current value is 0.1)

The composition of the PCI used by the project is outlined in Table 2.5.

Table 2.5: Composition of the TMR PCI

Attribute (CI)	Description
Roughness	NAASRA counts per kilometre with separate limits defined by traffic level and speed zone
Rutting	Mean rut depth in millimetre, with separate limits defined by traffic level, climate, and speed zone
Cracking	Area (%) of all cracking
Seal age	Surface seal age in years for different surfacing type
Remaining structural life (RSL)	Estimated remaining structural life in years

Data for roughness, rutting, cracking and seal age were obtained from ARMIS for the 2018–19 financial year survey. The remaining structural life (RSL) CI was calculated based on the notional structural life principal developed by ARRB (Toole & Jameson 2017).

The input to RSL CI is the deflections and curvatures readings as measured from the 2017–18 financial year traffic speed deflectometer (TSD) survey.

Refer to the NACoE A26 final report (Martin & Hore-Lacy 2017) for details on how the PCI was calculated.

2.3.3 Reactive Soil Impact Indicator

The reactive soil impact indicator refers to the effects of the environmental zone through which the road traverses. TMR ARMIS data categorised the entire network in four classifications of a combination of soil reactivity and whether the area is wet or dry. Roads built on non-reactive soil in a dry area possess no risk to pavement integrity. On the other extreme, reactive soil in a dry area is deemed to have the highest risk category considering the highly expansive nature of such soil when saturated. Most of such roads are in the northern and western regions of the state where prolonged dry seasons are often followed by a major flood event, which increases the rate of soil expansion significantly.

2.4 Safety Performance Risk Dimension

There is only one indicator for this risk dimension, the asset safety indicator from TMR's Australian Road Assessment Program (AusRAP). The Australian Automobile Association (AAA 2013) provides a road safety star rating where roads are assigned a score from one (least safe) to five stars (most safe).

However, the AusRAP star rating considers many elements contributing to road safety for the various road users such as pedestrians, bicycles, motorcycles and motor vehicles. For the PRRM, only the TMR measure for the vehicle run-off score rating (VROSC) for crashes was considered as it is the crash type that is likely influenced by level of road maintenance undertaken.

The conversion from AusRAP vehicle run-off score rating to the PRRM indicator risk rating category is provided in Table 2.6.

Table 2.6: Safety performance risk category

Indicator	Category/rating					Weight
	V Low (1)	Low (2)	Fair (3)	High (4)	V High (5)	
AusRAP vehicle run-off score rating (VROSR)	V Good	Good	Fair	Poor	V Poor	1
	VROSR 0–2.5	VROSR 2.5–5	VROSR 5–12.5	VROSR 12.5–22.5	VROSR > 22.5	

2.5 Legislative Compliance Risk Dimension

This risk dimension represents the level of compliance to the regulations outlined by the TMR standards and specifications. This is a risk of the exposure to legal redress, caused by management practices. Two sets of standards were adopted as indicators: the roughness compliance and the priority defects with their risk rating categories shown in Table 2.7, and further information on each is provided in Sections 2.5.1 and 2.5.2, respectively.

Table 2.7: Legislative compliance risk category

Indicator	Category/rating					Weight
	V Low (1)	Low (2)	Fair (3)	High (4)	V High (5)	
Roughness compliance (% above roughness thresholds)	At or below threshold	< 10% above threshold	10–20% above threshold	20–30% above threshold	> 30% above threshold	0.5
Priority of defects	All other segments			Assigned corporate priority of 3 (Safety)	Assigned corporate priority of 1 (Hazard)	0.5

2.5.1 Roughness Compliance Indicator

This indicator provides the level of compliance to TMR roughness intervention levels as defined in Table 2.8. Road segments were categorised by the percentage to which the road is exceeding the roughness threshold for various AADT ranges. Roughness data was sourced from the ARMIS 2018–19 financial year survey.

Table 2.8: TMR roughness intervention limits

AADT range	NAASRA roughness
< 500	130
< 500 and < 1 000	110
>= 1 000 and < 10 000	95
>= 10 000	80

2.5.2 Priority of Defects Indicator

This indicator reflects TMR routine maintenance priorities assigned to each of the defects recorded on a road segment. Although there are six categories of corporate priorities only two categories, the hazard and safety priorities, were used as defined in Table 2.9. ARRB was provided with TMR data from the 2018–19 and 2019–20 financial years.

Table 2.9: TMR corporate priority defects categories

Corporate priority	Description
Priority 1 – Hazard	Defects where the likelihood of harm occurring is greater than a safety defect determined by the hazardous defect identification procedure
Priority 3 – Safety	Defects that are of a safety nature
All other segments	

Source: TMR (2017).

2.6 Operations Risk Dimension

The operations risk dimension refers to the indicators that will affect the asset ability to operate to a normal functional standard. There is only one indicator for this risk dimension, the loss of access indicator.

2.6.1 Loss of Access Indicator

The road closure data supplied by TMR's Infrastructure Management and Delivery division was used to identify segments with a potential loss of access. Table 2.10 provides the loss of access indicator's risk rating categories.

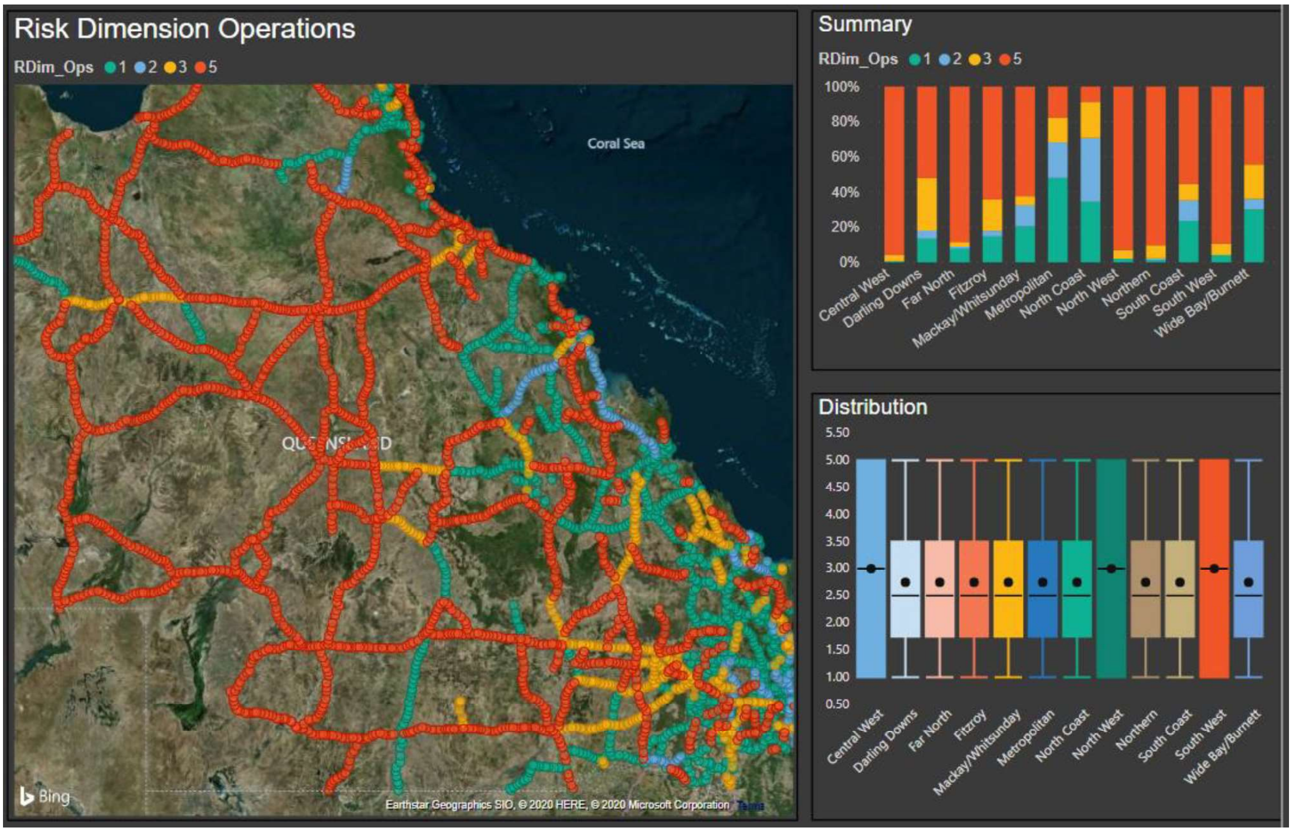
Table 2.10: Rating categories for the indicator that affects operations

Indicator	Category/rating					Weight
	V Low (1)	Low (2)	Fair (3)	High (4)	V High (5)	
Loss of access rating score		2	3		5	1

In the 20178-18 financial year, ARRB was provided with three years of data for flood and hazard events that have occurred. The following were considered when converting the provided data into the risk indicator:

- Events that have been considered to impact the entire link assigned by Road Section ID. This significantly affected state-controlled roads in the western and northern districts where the Road Section ID often represents a far greater length of road compared to those near the coast. This might be the intended effect as roads in districts such as Central West, South West, North West and Northern are often the only route connecting the major towns. The impact of this is demonstrated in Figure 2.4.

Figure 2.4: Operation risk dimension map – effect of assigning loss of access to 'Road Section ID'



Source: Bing (2020).

- A 'Loss of Access' rating system was adopted to incorporate event type, presumed severity, expected duration and the extent of the closure (e.g. full closure, partial closure, delays, restrictions etc.) when assessing the risk. The rating category is provided in Appendix A.
- All events with 'Delay Type Name' listed as 'No Delay Expected' were excluded as this implies no access loss.
- Additional arbitrary rules applied include any road with no qualifying events based on the table was rated a 1 and any road which was rated as 3, but had event occurrences quarterly or more frequently, was upgraded to a rating 5.

2.7 Pavement Residual Risk Estimation

The main deliverable of this project in Year 3 is the Pavement Residual Risk Model (PRRM) framework. It consists of two components, the calculation database, and the visualisation of the estimated PRR scores. This provides TMR with a comprehensive spatial and rational basis for assessing risk.

2.7.1 Calculation of Pavement Residual Risk (PRR) Score

Calculation of the PRR score involves five major risk dimensions with 13 contributing risk indicators as shown in Table 2.11. Each of these risk dimensions is weighted prior to being included in the PRR calculation. The weightings are shown in Table 2.11 and Figure 2.5.

Risk dimension weighting

Safety performance was given the highest weighting, as road fatalities have the greatest social impact. Roads need to be safe for road users to travel on and therefore, this is a high priority in the consideration of residual risk. The remaining risk dimensions are comprised of indicators which are aspects of physical factors affecting the road. These are aspects which can be managed as part of maintenance. Therefore, these risk dimensions were weighted lower.

The potential for hazards for the indicators forming the access and vulnerability risk dimension are the second most critical after safety performance as these determine whether the road is useable. Further, continuity of road use is also greatly impacted by the impact potential of the operations risk dimension of the road. Therefore, these two dimensions were given the second highest weightings.

Table 2.11: PRR weightings for risk dimensions

Risk dimension	Index weight[1]	Indices	Variable name
Access/vulnerability	$w_1 = 0.25$	Hazard potential	AV
Stakeholders and the community	$w_2 = 0.09$	Impact potential	SC
Safety performance	$w_3 = 0.33$	Impact potential	SP
Legislative compliance	$w_4 = 0.08$	Impact potential	LC
Operations	$w_5 = 0.25$	Impact potential	O

1. Weighting is an initial assessment.

The PRR scores are calculated by summing the index weights multiplied by each risk dimension, as shown in Equation 2. Equation 2 can have a minimum score of 1 and a maximum score of 5.

Pavement Residual Risk Calculation

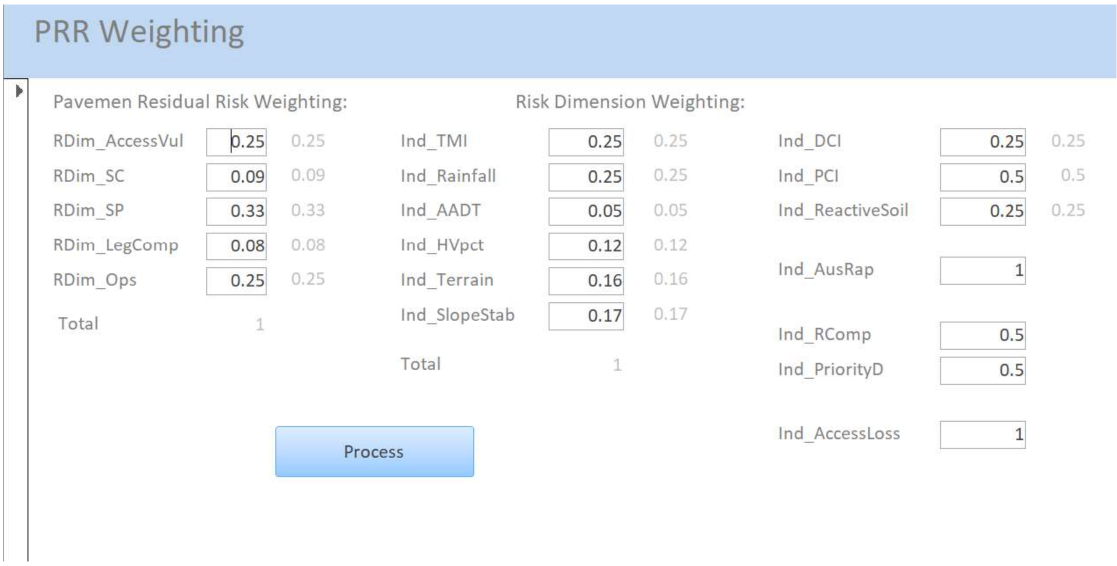
$$Pavement\ Residual\ Risk\ Score = w_1 * \mathrm{AV} + w_2 * \mathrm{SC} + w_3 * \mathrm{SP} + w_4 * \mathrm{LC} + w_5 * \mathrm{O} \qquad 2$$

The risk rating for each indicator was calculated as an independent exercise, each with its own file mostly in MS Access format. The outcome of each individual calculation was then compiled in a master database in MS Access format, called the A35 PRR Master file. This file is the first component of the framework that calculates the PRR score for every 100 m segment covering the entire TMR road network. It also provides a user interface that helps to dynamically change the weightings.

The master file and the individual indicator calculation files will be supplied to TMR separate to this report due to a very large file size. The main output within the master file is a table called 3_PRR_Output. This table is linked to a Microsoft Power BI file called A35_Pavement_Residual_Risk. This is the main outcome of the project which visualises and interrogates the state-wide PRR scores in detail.

Two tiers of weighting are used, the first tier is used when aggregating between the indicators within a risk dimension. The second tier is for aggregation of all the risk dimensions into one PRR score. The current agreed weightings are set as a default for both tiers as shown in Figure 2.5.

Figure 2.5: **PRR agreed current weighting**



PRR Weighting

Pavemen Residual Risk Weighting:

RDim_AccessVul	0.25	0.25
RDim_SC	0.09	0.09
RDim_SP	0.33	0.33
RDim_LegComp	0.08	0.08
RDim_Ops	0.25	0.25
Total		1

Risk Dimension Weighting:

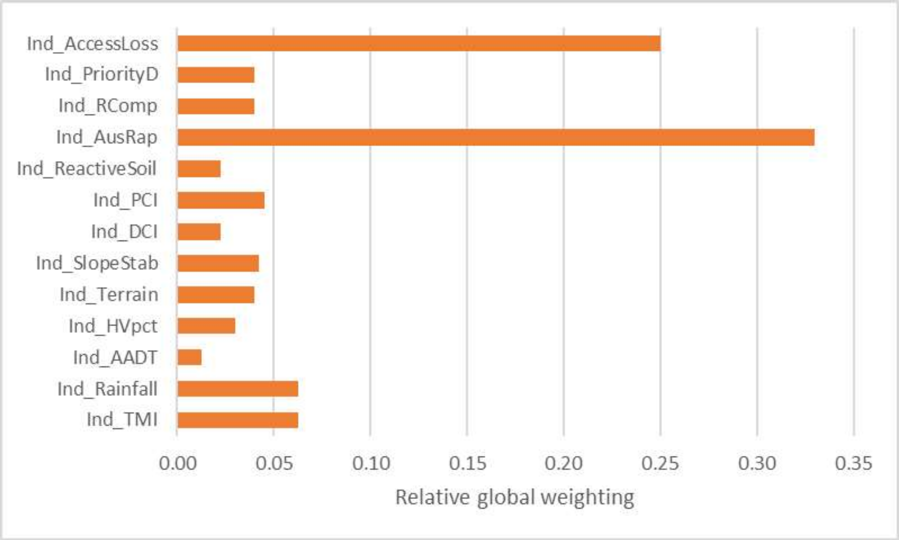
Ind_TMI	0.25	0.25
Ind_Rainfall	0.25	0.25
Ind_AADT	0.05	0.05
Ind_HVpct	0.12	0.12
Ind_Terrain	0.16	0.16
Ind_SlopeStab	0.17	0.17
Total		1

Ind_DCI	0.25	0.25
Ind_PCI	0.5	0.5
Ind_ReactiveSoil	0.25	0.25
Ind_AusRap	1	
Ind_RComp	0.5	
Ind_PriorityD	0.5	
Ind_AccessLoss	1	

Impact of risk dimension weightings on indicators

To illustrate the effect of the above weighting on overall PRR scores, each individual weighting for the indicators was normalised so that the relative contribution of the indicators can be compared to each other as shown in Figure 2.6. The indicators with the greatest influence by a large margin were the AusRAP and loss of access indicators. In the case of the loss of access indicator, this was due to how the extent of a road closure was currently defined with its resultant significant effect on the risk rating of this indicator in some districts. This can be the single most influencing factor in deriving a PRR score.

Figure 2.6: **PRR indicator relative weighting comparison**



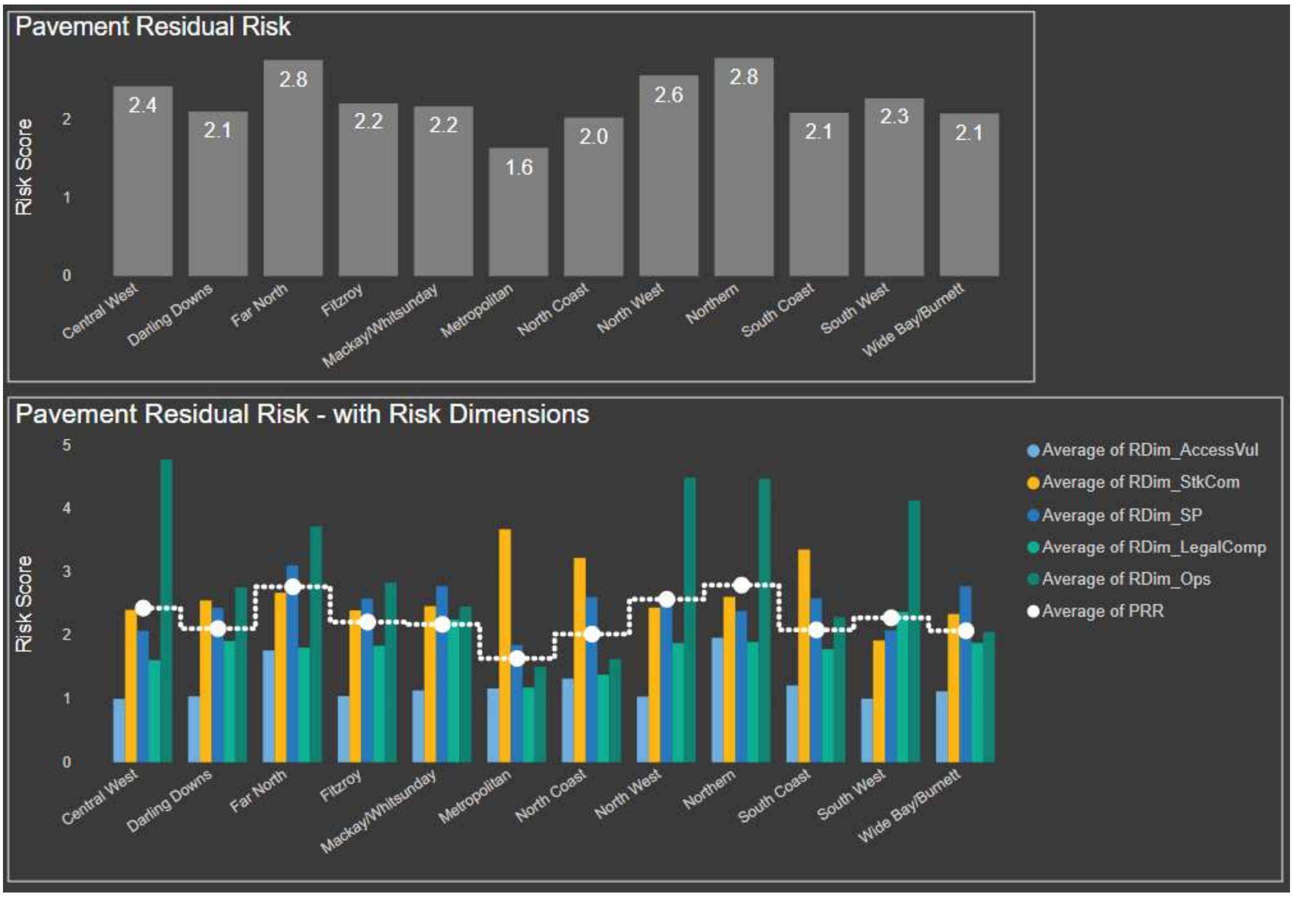
3 State-wide PRRM Implementation Results

The NACoE A35 Pavement Residual Risk Model provides the ability to present and interrogate the PRR data in detail at different levels from a state-wide view, district level and road level down to an individual 100 m long road segment level.

3.1 PRR Score using Current Weightings

The PRR score is a single number value that can be used to assess the level of residual risk at different levels in the road network. An example of the PRR score, using the current risk dimension weightings shown in Figure 2.5, is shown in Figure 3.1 with the average PRR score by district further disaggregated into its risk dimension components.

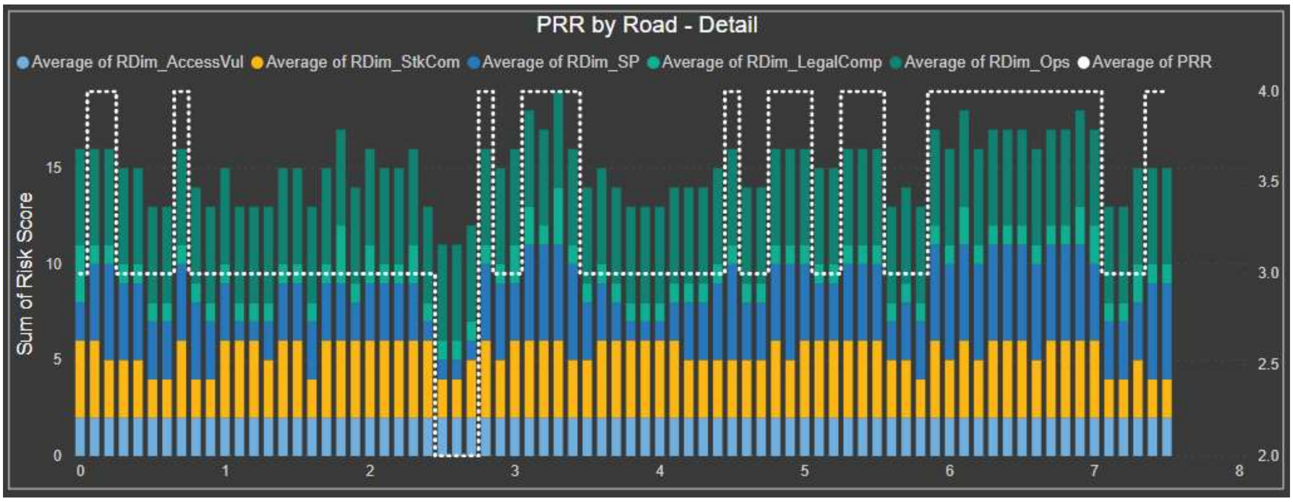
Figure 3.1: PRR score summary at state-wide level



As it stands with the current weighting distribution, the operation risk dimension is a key influencing factor in determining the PRR score in Figure 3.1. The districts with a high average PRR score are those with a high score in the operations risk dimension, as expected, following the consequences for the individual risk indicators shown in Figure 3.1.

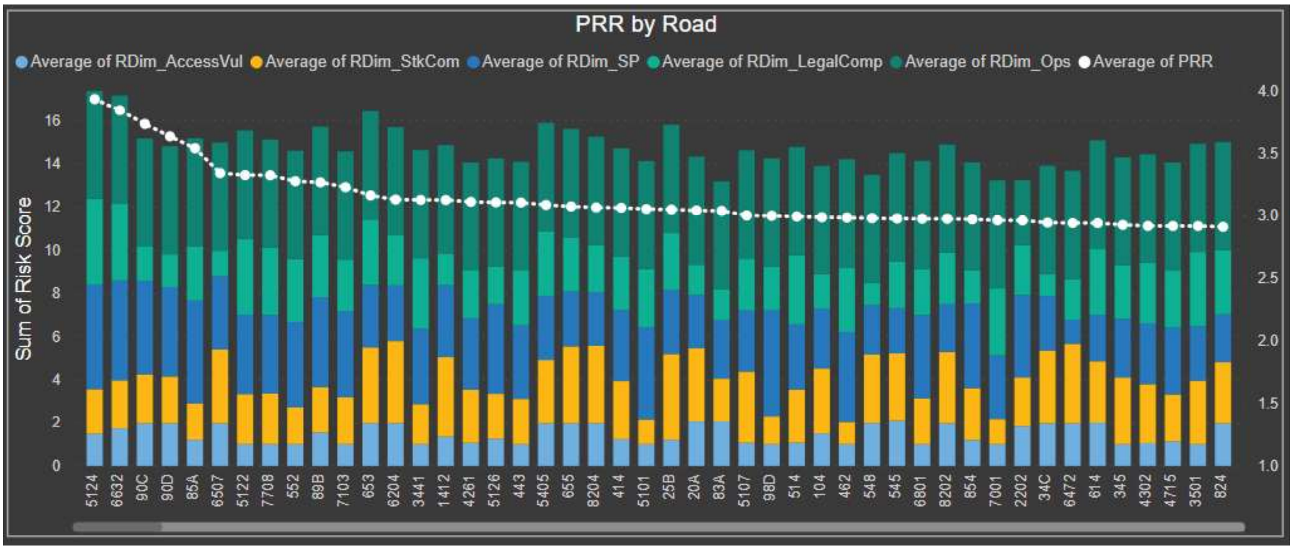
An example of the PRR score at an individual road level is provided in Figure 3.2 for Shipton’s Flat Road (ID 6507). The PRR score, represented by the dotted white line, is calculated for each 100 m segment of the road whilst maintaining transparency by showing the contributing risk dimension. It shows the risk score profile along the road highlighting segments with high and low residual risk.

Figure 3.2: PRR score summary at individual road level – Road ID 6507



The PRR score for each individual road then gets rolled up into a summary which can be viewed state-wide or by district. A state-wide summary of the PRR score of all roads in the network is shown in Figure 3.3, which ranked the roads from high to low PRR score. The St. Lawrence – Croyden Road (ID 5124) in Mackay/Whitsunday district is ranked as the road with the highest pavement residual risk score.

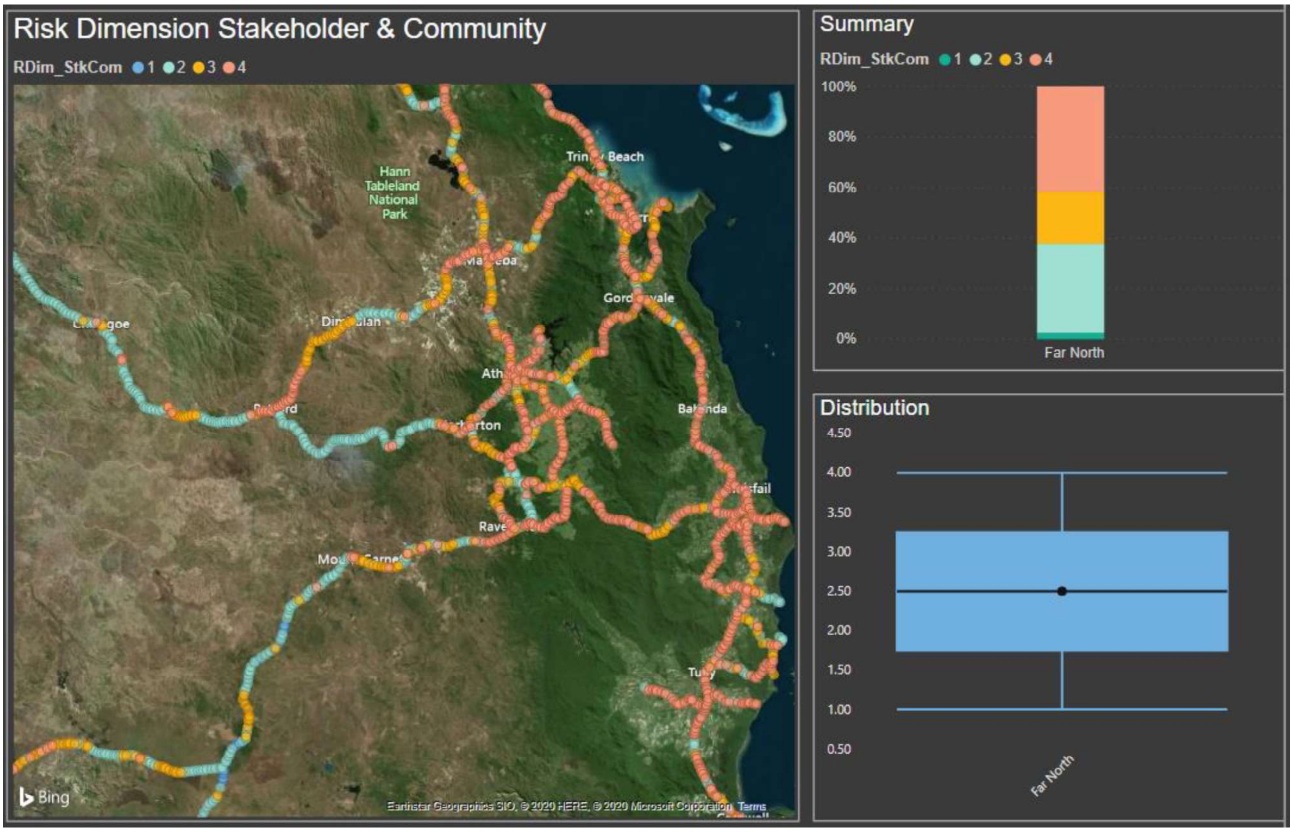
Figure 3.3: PRR score summary by road



In addition to the charts, having the same data presented in a GIS map format is useful in understanding the distribution of the PRR score geographically. An example of this type of map presentation was shown earlier in Figure 2.4 illustrating the state-wide view of the PRR score for the operations risk dimension. A further example of the use of the PRR score is being able to identify and view the roads that traverse the Great Dividing Range. This helps explain the increased risk associated with drainage maintenance. In this case the stakeholder and community risk dimension map of area around Cairns in the Far North district is shown in Figure 3.4. Roads from Cairns to Atherton and the surrounding area have a higher PRR score of 4 because of the drainage condition index indicator. Further inland to the west after the range, the PRR score dropped to 2 or 1.

The PRRM provides six sets of maps for the PRR score and the five risk dimensions. If needed, the flexibility of the Power BI platform would allow for a map to be customised to represent a specified indicator.

Figure 3.4: Far North – stakeholder and community risk dimension map



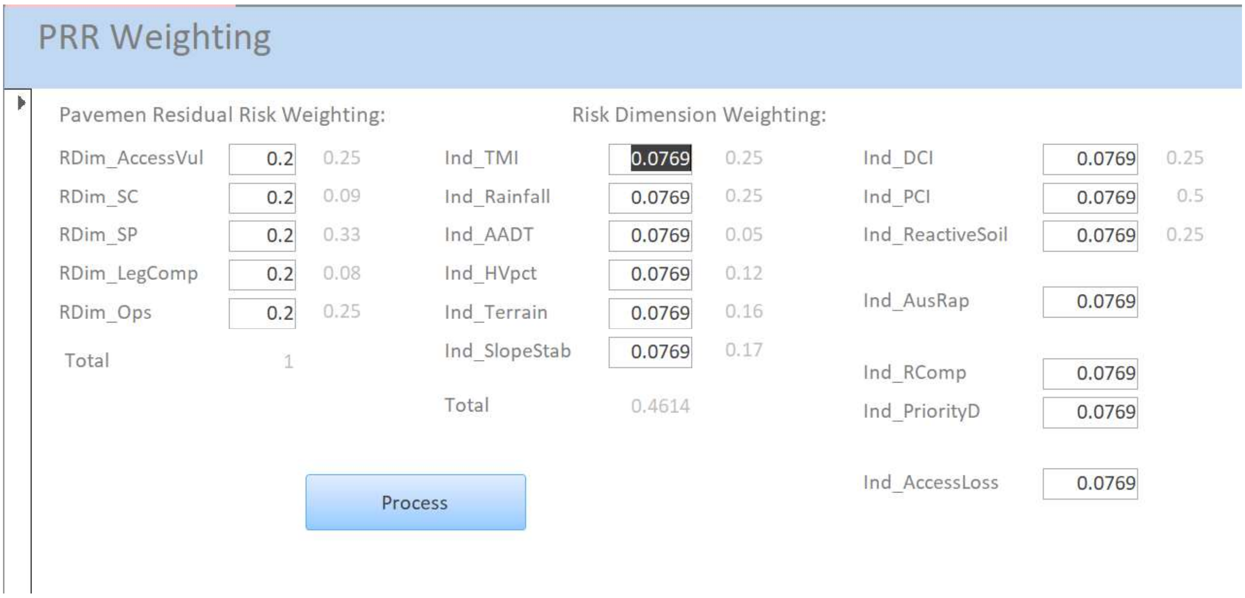
Source: Bing (2020).

3.2 PRR Score using Equal Weightings

The current risk dimension weightings were set early in Year 3 before the visualisation tool was available. The tool allows a better assessment of the impact of adjusting the weightings on the entire TMR network. A user interface is provided to ease the process of adjusting the weightings and seeing the consequences.

If the weightings are to be revisited, a logical starting point would be where all the risk dimensions and indicators are given an equal weighting as shown in Figure 3.5. The resulting PRR score at state-wide level, using a summarised PRR score by district, is provided in Figure 3.6. Compared with the same result for the current weightings, the PRR score trend is similar but the quantum of the score in each district is different. Although the difference may be subtle at this high level, it may be significant at the more granular level of the road segments. TMR can use the PRRM as a tool when discussing high level maintenance budget allocation and for providing granular information as input to the detailed planning and programming of maintenance. At the very least, a validation of the weightings against sites with known residual risks is recommended.

Figure 3.5: PRR equal weighting setup



PRR Weighting

Pavemen Residual Risk Weighting:

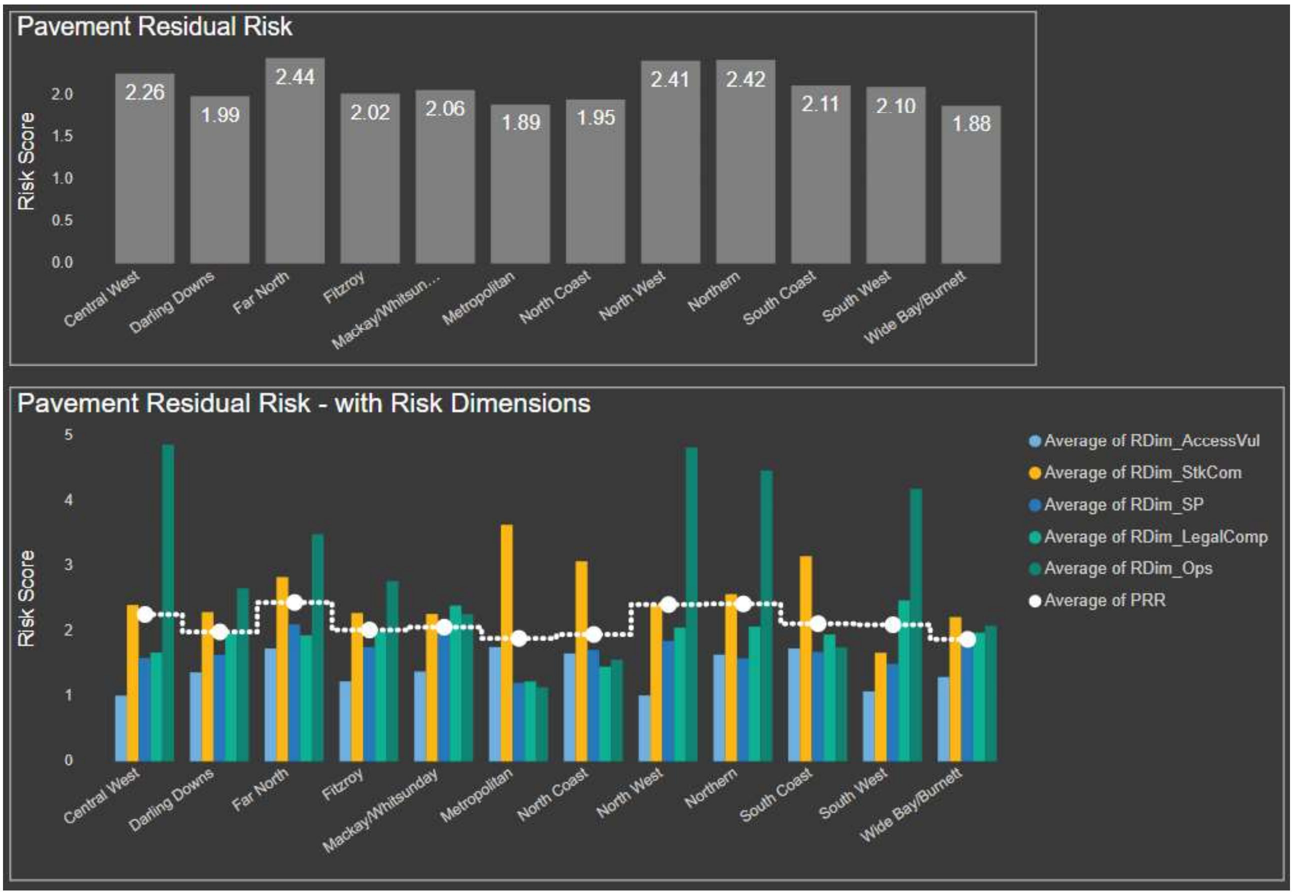
RDim_AccessVul	0.2	0.25
RDim_SC	0.2	0.09
RDim_SP	0.2	0.33
RDim_LegComp	0.2	0.08
RDim_Ops	0.2	0.25
Total		1

Risk Dimension Weighting:

Ind_TMI	0.0769	0.25
Ind_Rainfall	0.0769	0.25
Ind_AADT	0.0769	0.05
Ind_HVpct	0.0769	0.12
Ind_Terrain	0.0769	0.16
Ind_SlopeStab	0.0769	0.17
Total	0.4614	

Ind_DCI	0.0769	0.25
Ind_PCI	0.0769	0.5
Ind_ReactiveSoil	0.0769	0.25
Ind_AusRap	0.0769	
Ind_RComp	0.0769	
Ind_PriorityD	0.0769	
Ind_AccessLoss	0.0769	

Figure 3.6: PRR score summary at state-wide level – equal weighting



4 Conclusions and Recommendations

4.1 Conclusions

The development of the PRRM provides the basis for the development of frameworks for residual risk models (RRM) for other asset types.

The focus of Year 3 was to finalise the PRRM and apply it state-wide. This involved revisiting the earlier PRRM version established in Year 2, reassessing the viability of some risk indicators due to the availability of reliable data to support them for a state-wide representation. The PRRM now has a platform that provides the transparency to trace the contributing risk indicators to the PRR score as well as having different data interrogation and presentation options to assess the residual risk at different levels in the road network.

A summary of the PRRM components and source of data used as inputs is provided in Table 2.1 using the TMR ARMIS inventory data at 100 m long intervals covering the entire network used to structure the main database. Beside ARMIS, data was sourced from other datasets maintained by different TMR divisions and from the Australian BOM website. These data can all be updated and accessed for future maintenance purposes.

When calculating the PRR score, two tiers of weightings were adopted to firstly aggregate the risk indicators within the same risk dimension and secondly, when aggregating the risk dimensions into a PRR score.

The calculation of the PRR score is one of the two main components of the PRRM framework. All calculation of each individual indicator is compiled in one MS Access database called the A35 PRR Master file. The main output within the master file is a table called 3_PRR_Output. This table is linked to a Microsoft Power BI file called A35_Pavement_Residual_Risk tool. This is the second component and the main outcome of the Year 3 project which visualises and interrogates the state-wide PRR scores at different levels in the road network.

4.2 Recommendations Specific to the PRRM

The following recommendations specific to the operationalisation of the PRRM are suggested:

- Review the risk indicators, especially those which currently have a highly significant influence on PRR score calculation. Further clarification of how the extent of current road closures is defined is needed for the loss of access indicator in the operations risk dimension.
- Review the PRR score current weightings against the intended functionality of the PRRM which now has the capacity to easily adjust the weightings and observe their effect on the entire network.
- Use roads with known deficiencies or residual risks to validate and finalise the above PRR score weightings.
- Explore the potential use of the PRRM in planning and programming of maintenance works.

The undertaking of these recommendations could be added to the scope already proposed for 2020–21 in A35.

4.3 Next Steps

It is important for the PRRM framework to be introduced to the MPO Steering Committee where final inputs on accuracy, intended use and appropriateness for adoption for other RRM are expected.

In terms of scope for next year, it is proposed that Year 4 of the project should involve the use of the AHP and the method established this year in developing residual risk framework for intelligent transport systems (ITS) and structural assets, such as bridges and culverts. Some preliminary work in the development of the AHP framework for these assets was undertaken in Years 2 and 3.

The final stages of this project will include a fully documented report and include tools like the PRRM framework and its platform, which will enable TMR to apply the residual risk approach routinely to the TMR road network assets of pavements, ITS and structures.

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Appendix A Loss of Access Rating

Table A.1: Rating categories for the indicator that affects operations

3_Categories						
EVENT_TYPE_NAME	EVENT_SUB_TYPE_NAME	ROAD_IMPACT_TYPE_NAME	Category	Severity	Min_Recurrance	LossAccess_Rating
Flooding	Flash flooding	Closures	FLOOD	MODERATE	3	3
Flooding	Flash flooding	Lanes affected	FLOOD	MINOR	3	2
Flooding	Flash flooding	Lanes blocked	FLOOD	MINOR	3	2
Flooding	Flash flooding	N/A	FLOOD	MINOR	3	2
Flooding	Flash flooding	No blockage	FLOOD	MINOR	3	2
Flooding	Flash flooding	Road restricted	FLOOD	MINOR	3	2
Flooding	Long-term flooding	Closures	FLOOD	MAJOR	1	5
Flooding	Long-term flooding	Lanes affected	FLOOD	MODERATE	1	3
Flooding	Long-term flooding	Lanes blocked	FLOOD	MODERATE	1	3
Flooding	Long-term flooding	N/A	FLOOD	MODERATE	1	3
Flooding	Long-term flooding	No blockage	FLOOD	MODERATE	1	3
Flooding	Long-term flooding	Road restricted	FLOOD	MODERATE	1	3
Hazard	Adverse driving conditions	Closures	FLOOD	MODERATE	3	3
Hazard	Adverse driving conditions	Lanes affected	FLOOD	MINOR	3	2
Hazard	Adverse driving conditions	Lanes blocked	FLOOD	MINOR	3	2
Hazard	Adverse driving conditions	N/A	FLOOD	MINOR	3	2
Hazard	Adverse driving conditions	No blockage	FLOOD	MINOR	3	2
Hazard	Adverse driving conditions	Road restricted	FLOOD	MINOR	3	2
Hazard	Bridge or culvert damaged	Closures	DAMAGE	MODERATE	5	3
Hazard	Bridge or culvert damaged	Lanes affected	DAMAGE	MINOR	5	2
Hazard	Bridge or culvert damaged	Lanes blocked	DAMAGE	MINOR	5	2
Hazard	Fire	Closures	FIRE	MODERATE	3	3
Hazard	Fire	Lanes affected	FIRE	MINOR	3	2
Hazard	Fire	Lanes blocked	FIRE	MINOR	3	2
Hazard	Fire	N/A	FIRE	MINOR	3	2
Hazard	Fire	No blockage	FIRE	MINOR	3	2

3_Categories						
EVENT_TYPE_NAME	EVENT_SUB_TYPE_NAME	ROAD_IMPACT_TYPE_NAME	Category	Severity	Min_Recurrance	LossAccess_Rating
Hazard	Road damage	Closures	DAMAGE	MODERATE	5	3
Hazard	Road damage	Lanes affected	DAMAGE	MINOR	5	2
Hazard	Road damage	Lanes blocked	DAMAGE	MINOR	5	2
Hazard	Road damage	N/A	DAMAGE	MINOR	5	2
Hazard	Road damage	No blockage	DAMAGE	MINOR	5	2
Hazard	Road damage	Road restricted	DAMAGE	MINOR	5	2