Technical Report: Considerations for Sealing Local Government Roads in WA

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About LG TRRIP

The Local Government Road Research and Innovation Program (LG TRRIP) is an initiative between Main Roads Western Australia and the Western Australian Local Government Association.

LG TRRIP has a strategic commitment to the delivery of collaborative research and development that positively contributes to the design, construction and maintenance of safe, sustainable transport infrastructure in Western Australia.

Summary

This report provides the detailed technical basis for the *Practitioners Guideline: Considerations for Sealing Local Government Roads in WA* (O'Connor et al 2023a).

Local government authorities (LGAs) play a vital role in the provision and management of Western Australia's (WA) road assets, being responsible for more than three-quarters of the road network. Furthermore, of the 185,700 km long road network, approximately 69% is unsealed.

Unsealed roads, even though often considered as lower-order roads, play a vital role in WA in terms of:

- providing access to rural communities
- the movement of primary and processed produce to markets
- traffic movements within State forests and defence training areas
- access to forests or fire management on public land
- haulage roads for the mining and timber industries
- recreational, social and tourist pursuits (ARRB 2020).

However, LGAs operate almost invariably under constant funding constraints and, in many cases, experiences a lack of both financial and human resources. It is, therefore, essential for the ongoing viability of the unsealed road network that road agencies are provided with the most appropriate tools and methods to manage their road assets, including the selection of upgrade candidates (ARRB 2020).

A key consideration for LGAs in WA is the impact of vehicle traffic on both sealed and unsealed local roads, and the associated costs of road upkeep and the costs to road users. Increasingly over time, there has been greater utilisation of unsealed local roads by heavier axle loads and axle configurations and light traffic resulting from an increase in traffic related to various sources, including general use through subdivision growth, industry, and local tourism. This has had a direct impact on the condition of the roads and, as a consequence, local government is facing significant increases in costs from road wear.

The Local Government Road Research and Innovation Program (LG TRRIP) is an initiative between Main Roads Western Australia and the Western Australian Local Government Association (WALGA). The outputs of this project are two documents:

- *Technical Report: Considerations for Sealing Local Government Roads in WA*
- *Practitioners Guideline: Considerations for Sealing Local Government Roads in WA*

The aim of these documents is to equip LGAs with the necessary information to make informed decisions about the sealing of unsealed roads within their jurisdiction.

In order to develop the documents, the following was undertaken:

- A literature review to identify previous research, guidelines, and technical documents.
- Subject matter expert discussion to expand on the content of the literature review.
- Stakeholder consultation/request for information with LGAs to identify current practices and future needs.
- Application of a whole-of-life asset management approach: Using the information gathered as part of the literature review, stakeholder consultation and a stakeholder workshop. A comprehensive set of analysis cases, and a selection of example studies were also developed that apply a whole-of-life asset management approach in determining when to seal an unsealed road, or when to leave a road unsealed. The whole-of-life cycle costs account for road maintenance and renewal costs for both the sealed road and unsealed road options, and road user costs, comprising vehicle operating costs, travel time costs, and crash costs.
- Development of the documents, this report and the *Practitioners Guideline* (O'Connor et al 2023a).

This report captures the findings from the research component of this project, and provides additional information for LGAs to reference in support of the application of the *Practitioners Guideline*.

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1 Introduction

1.1 Background

Two documents – a *practitioners guide* and a *technical report* – have been developed by the Australian Road Research Board (ARRB) for the Western Australian Local Government Association (WALGA) with the support of Main Roads Western Australia (MRWA) under the Local Government Transport and Roads Research and Innovation Program (LG TRRIP).

LG TRRIP was established in 2022 by MRWA and WALGA as a research and innovation program dedicated to the needs of the local government road network in Western Australia (WA). The objective of the program is to achieve better implementation of innovative practice by improving the specialist capability of Local Government Authorities (LGAs) through a collaborative program of projects which deliver advanced technology and cost-effective solutions to roads and transport issues for the people of WA.

A key consideration for LGAs in WA is the impact of vehicle traffic on both sealed and unsealed local roads, and the associated costs of road upkeep and the costs to road users. Increasingly over time, there has been greater utilisation of unsealed local roads by heavier axle loads and axle configurations and light traffic resulting from an increase in traffic related to various sources, including general use through subdivision growth, industry, and local tourism. This has had a direct impact on the condition of the roads and, as a consequence, LGAs are facing significant increases in costs from road wear.

Previous local research in this space has focused on the impacts of additional freight tasks on sealed and unsealed roads, with these informed by national and international research findings. These studies resulted in the development of guides to determine the cost of road wear related to heavy vehicle (HV) usage to inform the contribution from operators that LGAs could use to maintain local roads.

However, whilst heavy freight impacts are well documented, there is no specific guidance for LGAs in terms of when an unsealed road should be sealed as a result of increased traffic. In addition, there is a need to consider a wider range of factors which may impact the decision to seal an unsealed road, including:

1. Accounting for all sources of costs, including those which affect road users and crash costs, and other impacts to inform a more wholistic evaluation of upgrade options and their justification.
2. Factors which impact road preservation, and upgrade and renewal costs including:
   a. the condition of the unsealed road network and the causes and effects of deterioration over time, including the performance of the materials used on the unsealed road network
   b. whole-of-life costs associated with the maintenance/preservation of unsealed roads and sealed roads options
   c. upgrade costs, including accounting for existing road geometry and infrastructure provision and required design standards
   d. the impacts of climate and extreme weather events on road infrastructure, and how this can be expected to change over time.
3. Impacts on road users and the levels of service provided accounting for:
   a. vehicle operating costs and travel time costs related to community and industry use
   b. the levels of service sought by road users.
4. Road safety considerations, including the potential changes in crash rates and crash severity as a result of an upgrade, and also the costs of road safety countermeasures.
5. Environmental considerations, some of which also impact design standards and preservation costs, including soil reactivity and stability, erosion and sedimentation, roadside vegetation and impacts on biodiversity and wildlife.

For regional LGAs it is important to consider all of these factors to ensure good planning, including the need to determine all sources of costs and whether the direct infrastructure-related costs should be borne solely by the LGA or whether a user-related charge or development contribution is appropriate.

Given the complexity of the factors to be accounted for in evaluating unsealed roads and the justification for an upgrade, LGAs would benefit from guidance and further research in this area so that timely, planned upgrades of roads can occur in a transparent, fair and well considered manner. This has led to a need for an extension of existing studies to better understand the impacts associated with all the varying factors.

Improving the performance and management of WA's extensive unsealed road network would result in improved safety, ride quality, reduced road use costs and lower whole of life-cycle costs of the network (ARRB 2020).

1.2 Purpose

The purpose of this report is to provide detailed information supporting the development of the *Practitioners guideline* which was developed to equip LGAs with the necessary information to make informed decisions regarding the sealing of unsealed roads within their jurisdiction. The purpose of this report is to provide a comprehensive analysis of the potential benefits and drawbacks of sealing unsealed roads, taking into consideration the whole-of-life cost implications, likely impacts of the traffic generated by new developments, and quantifiable safety benefits. It addresses a range of loading scenarios and application conditions specific to WA.

The aim of the report is to provide transparency and equity in asset investment decision-making and to ensure that appropriate conditions for development approvals and access conditions for freight movements with regard to unsealed road upgrades are adopted. It will also support the appropriate forward planning of road upgrades based on anticipated growth in traffic volumes and their composition. Additionally, it will provide justification for charging users, and the need for upgrades, related to the approval of HV access and concessional loading permit applications.

Overall, these documents will enable LGAs to make well-informed decisions about whether to seal a particular unsealed road or, as part of a screening activity, to identify candidates, and how to proceed in a manner that maximises benefits while minimizing costs and potential negative impacts.

1.3 Structure

A summary of the structure of the two reports is presented in Table 1.1:

- *The Practitioners guideline*, which is similar to the current WALGA guidelines in that it outlines the steps involved in investigating and informing cases for upgrade, including simple illustrated guidance (tables, figures, etc.) to inform the selection of candidate upgrade projects.
- The technical basis for the *Practitioners Guideline* (O'Connor et al 2023a), including:
  - the use of unsealed roads including vehicle types and volumes, the road surface types, maintenance and upgrade costs, rates of deterioration, etc., to enable informed decisions on the sealing of unsealed roads from a whole-of-asset-life cost basis
  - the likely changes and impacts of future traffic, including new developments, on maintenance costs, to inform the whole of life costs and benefits of sealing the road
  - current and future use scenarios (volumes and loading) covering the range of applications, conditions and location-related factors to inform upgrade decisions, with these illustrated in example case studies representative of conditions in Western Australia.

Table 1.1: Document structure

Document	Detail
Practitioners guideline	• User friendly • Practical • Links to the technical report • Provides a summarised framework flowchart of the steps in the assessment • Provides a catalogue of solutions • Provides worked examples
Technical report	• Full report with all background and research for the process and solutions development • Supporting technical information for case studies and worked examples

1.4 Scope

The report supports the development of the guideline *Considerations for sealing local government roads in WA*, which adopts an asset management approach for selecting candidate unsealed roads that warrant an upgrade from a whole-of-life cost basis. It describes the development and application of the methodology, and its application in guiding LGAs on when an unsealed road (or a specific section of road) should be sealed due to increased traffic.

This Guide is limited to the considerations of asset management in unsealed road decision-making. Therefore, this Guide excludes:

- the design of unsealed roads (including pavement design and geometric road design)
- the process for sealing unsealed roads (including mix-design, pavement design, and geometric road design)
- consideration of the various types of seals that could be adopted to seal an unsealed road (i.e., sprayed seal, asphalt, recycled materials such as crumb rubber, etc.)

All guidance provided must be considered in relation to current local government practices, state-based practices, and relevant legislation. Additional limitations for the implementation of the guidance process developed through this project are provided in Section 1.5.

To develop this document, and the subsequent User Guide, the following five key methodology stages were implemented:

1. Literature review, including the identification of previous research, guidelines, and technical documents, including a search using the resources of the Australian Road Research Board (ARRB) MG Lay Library. These resources included the library's comprehensive collection of technical land transport literature and information retrieval specialists with extensive experience in the transport field, as well as access to the collections and expertise of other transport-related libraries throughout Australia and internationally.
2. Subject matter expert opinion: Drawing on the project team's experience and opinions, including in research and practice and the development of similar guides.
3. Stakeholder consultation/request for information comprising:
   a. Consultation with LGAs to identify the current practices and future needs of local government.
   b. Review and discussion of information gathered in the stakeholder consultation and how it will be used in the development of the guide, including technical analysis to inform the development and provision of the catalogue of solutions to be provided in the guide and cases where more first principles-type analysis is likely to be required.
4. Application of a whole-of-life asset management approach: Using the information gathered in the literature review, stakeholder consultation and a stakeholder workshop. A comprehensive set of analysis cases, and a selection of example studies were also developed which apply a whole-of-life asset management approach in determining when to seal an unsealed road, or when to leave a road unsealed.
5. Development of the User Guide.

1.5 Limitations

During this project additional concepts were identified that were outside its scope, which nonetheless may enhance the knowledge and practices associated with the management of unsealed roads and upgrade decisions for capital works. Key areas for further investigation include:

- Further detailed modelling of the long-term performance of known marginal and substandard materials across WA, whilst recognising that recent nationally-published research has improved understanding but also identified gaps.
- A detailed investigation of the projected climate change to be experienced in regional WA and the likely impacts on road infrastructure. This would address the resilience of solutions, with recent examples in the north western parts of WA showing 'low' resilience and requiring substantial reconstruction work following severe events. The risk is that these will continue to occur and possibly increase in severity and frequency.
- Optimal maintenance schedules when: (1) AADT varies significantly seasonally, e.g. grain harvest or tourist seasons; and (2) significant seasonal variations in climate and weather periodically impact level of service, noting this research employed an annual approach which considered the aggregate traffic numbers in a year to represent both normal traffic and seasonal traffic.

2 Fundamentals of Unsealed Road Asset Management

This section provides an overview of unsealed roads and how their asset management is conducted. Asset owners in WA have autonomy to decide when to seal or unseal a road, as long as they comply with relevant legislation that outlines their responsibility for operating the asset. While there is no specific legislation describing how asset owners must maintain unsealed roads, they are responsible for ensuring that the road remains safe and usable for road users.

Understanding the factors that influence unsealed road performance is crucial when considering whether to seal an unsealed road. In order to describe the fundamentals of unsealed road asset management, this section of the report provides the key definitions relevant to this report.

Section 2.1 provides definitions of key terms such as: what is an unsealed and sealed road. Section 2.2 outlines common asset management practices for unsealed roads, such as road asset preservation strategies, road asset investment strategies, and road use management strategies. These practices are used to manage and maintain unsealed roads to provide safe and reliable travel conditions for road users. By understanding the key definitions and common asset management practices for unsealed roads, asset owners and managers can make informed decisions about how best to manage these important assets, including whether to seal a road based on the road's condition and expected usage or leave it unsealed.

2.1 Key Definitions

2.1.1 Unsealed Roads

An unsealed road is a road that has been formed and constructed but is not sealed. Unsealed roads play an important transport role in terms of:

- providing access to rural communities
- the movement of primary produce to markets
- the movement within state forests and defence training areas, including fire management
- access to forests or fire management on public lands
- haulage roads for the mining and timber industries
- recreational, social and tourist pursuits (ARRB 2020).

Rural roads in poor condition can result in isolated communities, increased fuel consumption, damaged vehicles, an increased risk of crashes, and an increase in the cost of goods and services (Moore 2000; cited in ARRB 2020).

In terms of construction type, the unsealed road network is made up of unformed and formed earth and in situ surface materials and formed and gravelled roads, as illustrated in Table 2.1. This guide is primarily intended for formed and gravelled roads (ARRB 2020).

Table 2.1: Unsealed road types

Unformed road	Formed road	Formed and gravelled road
		
These are non-engineered roads that consist of a track that is cleared of vegetation. They are often not all-weather roads and carry very low traffic volumes. These roads may provide access to an individual rural property or be used for administration purposes in forest areas or by emergency vehicles, e.g. in fighting fires. These roads are seldom maintained and may only be suited for four wheel drive vehicles.	These roads are desirably designed to appropriate geometric standards and adequate drainage is provided. They are earth roads comprised of local materials sourced from the road reservation. Generally, no imported gravel is used. Periodic maintenance of these roads should be carried out.	These roads are designed to appropriate geometric standards with adequate drainage provided. A layer of imported granular material, compacted to the required thickness, should be provided to support the estimated traffic loads. Maintenance is carried out on a regular basis.

Source: ARRB (2020).

This report is focused on gravel roads, and the upgrading of gravel roads to sealed roads. This is because, generally, an unformed road will be transitioned to a formed road, and a formed road will be transitioned to a gravel road, prior to sealing being considered.

2.1.2 Sealed Roads

Sealed local roads have a pavement structure which, in many instances, has evolved over time rather than having been designed and upgraded according to systematic procedures. In general, the main pavement structure is a flexible pavement consisting of unbound layers with a sprayed seal or asphalt surface (ARRB 2020).

The surface of a sealed road involves using bitumen (in a sprayed seal), concrete or asphalt to:

- provide a safe, economical and durable all-weather surface
- protect lower layers of a pavement from moisture ingress
- provide a dust-free surface
- extend the life of the pavement
- reduce vehicle operating and maintenance costs (ARRB 2020).

The whole of life benefits of sealed roads compared to unsealed roads include:

- lower transport (construction, maintenance and vehicle operating) costs
- increased social benefits (more reliable access to schools, clinics, etc.)
- reduced adverse environmental impacts and health and safety problems.

2.2 Road Network Asset Management Practices

2.2.1 Asset Strategies for Managing the Road Network

Asset management strategies are important because they provide an asset owner, local council or road agency with a structured decision-making framework to guide actions, and to demonstrate and articulate infrastructure goals in providing outcomes for the community (ARRB 2020).

Asset management strategies provide the following core outcomes:

- an integrated approach to the management of the capacity, condition and use of assets
- a consistent approach across all elements of the network and by all geographic parts of the organisation
- transparency and auditable accountability to the community, with road system performance standards driven by community objectives and achieved through the efficient and effective management of community road assets (ARRB 2020).

When developing asset strategies for managing a road network, there are three main asset management strategies which can be developed, which all sit within an overall road network management strategy (RNMS) as illustrated in Figure 2.1.

Figure 2.1: Key road asset management strategies

Source: ARRB 2020.

A core component in developing an asset management strategy for unsealed road is the setting of Levels of Service (LoS). LoS represents road standards and qualities that the asset owner agrees to provide to users. They are key drivers critical to good asset management practice and the basis upon which recommendations, conclusions, decisions, and budgets should be based.

There are two categories of LoS: technical-based levels of service (TLoS), and customer-based levels of service (CLoS).

- Customer LoS (CLoS) focusses on how customers experience services. They tend to be outcomes that customers understand. These include safety, ride comfort, the availability of direction signage and the accessibility and reliability of travel (ARRB 2020). CLoS is described in further detail in Section 4.8, in the context of community expectations.
- Technical LoS (TLoS) relates to the service the physical asset provides, measured in objective technical terms. It is linked to the CLoS, but expressed using technical language, such as average travel speed, crashes per hundred thousand of kilometres travelled, and roughness (rideability) levels (ARRB 2020). TLoS is described further in Section 4.1, in relation to the use of these factors to determine unsealed road condition.

Measuring and meeting LoS performance commences with the characteristics of the services that are 'valued' by customers and ends with the delivery of those actions through the use of TLoS measures as illustrated in Figure 2.2. Information on identifying LoS and intervention levels for various condition parameters is provided in Section 2.3 and 4.1.

Figure 2.2: Aligning CLoS and TLoS with what customers value

2.2.2 Road Asset Preservation Strategies

A road asset preservation strategy (RAPS) identifies and prioritises what asset maintenance and renewal activities are required to achieve and sustain the asset condition and performance standards. It recognises both measured and forecast patterns of deterioration of asset condition, the effects of various treatment strategies on the life-cycle costs of the asset and the effect of asset condition on road user costs, ride quality, and safety. RAPS provides the strategic framework for managing the condition and performance of the road network. It enables the development of sustainable maintenance and restoration programs to achieve and maintain the asset condition and performance objectives and target TLoS standards (ARRB 2020). In addition, guidance can be included for under what conditions upgrades from unsealed to sealed roads may be undertaken.

The key elements in formulating a RAPS, as detailed in ARRB (2020) are:

- Conduct inventory and condition data collection, and update documentation for road lanes and shoulders.
- Review the minimum CLoS acceptable road conditions for ride quality (roughness), safety (rut depth, pothole depth and frequency, wearing surface stability) and the accessibility and reliability of travel data identified through community consultation.
- Analyse road condition trends over time (patterns of deterioration and improvement). Strategy level analysis is undertaken by predicting the common performance of broad groups of similar roads under similar operating conditions, e.g. rural and rural remote pavements according to road classification.
- Develop 5- and 10-year expected performance and condition predictions for each road group.
- Analyse the effect of different generic routine and periodic maintenance treatments and different intervention levels on road asset condition, road user costs and whole of life-cycle costs. Alternative scenarios for annual budget requirements also need review.
- Identify the optimum condition intervention level to achieve and sustain acceptable target CLoS conditions at minimum life-cycle cost.
- Assess current and projected maintenance treatment needs and costs, recognising the current life-cycle stage of each road, predictions of deterioration, and treatment effectiveness under assumed traffic demand growth scenarios.

- Prioritise projected maintenance needs in terms of the impact on road user safety, exposure and costs (strategic route importance, traffic volume), road serviceability and life-cycle costs.
- Review forward funding scenarios (local, state, and federal government program sources) and potential private sector contributions.
- Document proposed target road network conditions, treatment regimes, and budget requirements for each road.

2.2.3 Road Asset Investment Strategies

A road asset investment strategy (RAIS) outlines the priorities for investment in meeting the needs of road system capacity. A RAIS identifies and prioritises those capital investments that will progressively achieve the target network configuration and capacity, recognising forecast patterns of road use demand and funding availability.

The RAIS also provides the framework for the progressive development and evaluation of road system improvements to achieve the performance objectives and target standards developed in the over-arching RNMS. It is used for the guidance of planners, project designers and the developers of road investment proposals.

The key elements in formulating a RAIS are as follows:

- Review the RNMS to identify priority locations of current poor road system performance and social and environmental impacts with respect to current CLoS.
- Review the RNMS for future travel demand and road system performance predictions for at least 5- and 10-year scenarios based on traffic growth assessments.
- Examine the identified performance deficiencies and project concepts which would provide potential cost-effective short-term (< 5 years) and medium-term (5 to 10 years) performance considering network connectivity and relevant RUMS.
- Develop a planning concept, including the scope, design standards, and estimated costs of such proposed works.
- Evaluate the benefits and impacts of proposed works, including indicative marginal benefit/cost ratios (MBCR). Evaluate the effectiveness of the implementation of individual projects; the implementation of groupings of suitable compatible projects is also required.
- Review scenarios for the phased implementation of the RAIS, recognising priorities for progressively achieving road network performance targets and forward funding scenarios (local, state, and federal government program sources) and potential private sector contributions.
- Recognise that capital investments in new roads, and the increased capacity road assets through the implementation of the RAIS, have long-term maintenance implications, so they need to be integrated into the RAPS. The predictions of asset growth in the RAIS are an important input to the RAPS.
- Review and refine the strategy with stakeholder consultation.

2.2.4 Road Use Management Strategies

A road use management strategy (RUMS) provides a strategic framework to manage the use of the road system. Examples include vehicle registration criteria, mass and dimension limits, operational requirements, the licensing of drivers and operators, traffic management, and road space allocation. Such operational management strategies are complementary to the RAIS and the RAPS (ARRB 2020).

The road system cannot respond to unconstrained use. Strategies to manage use are commonly included in a RUMS as separate focused strategies for particular road user groups (e.g. freight strategy, port access strategy, timber cartage strategy, grain haulage, etc.).

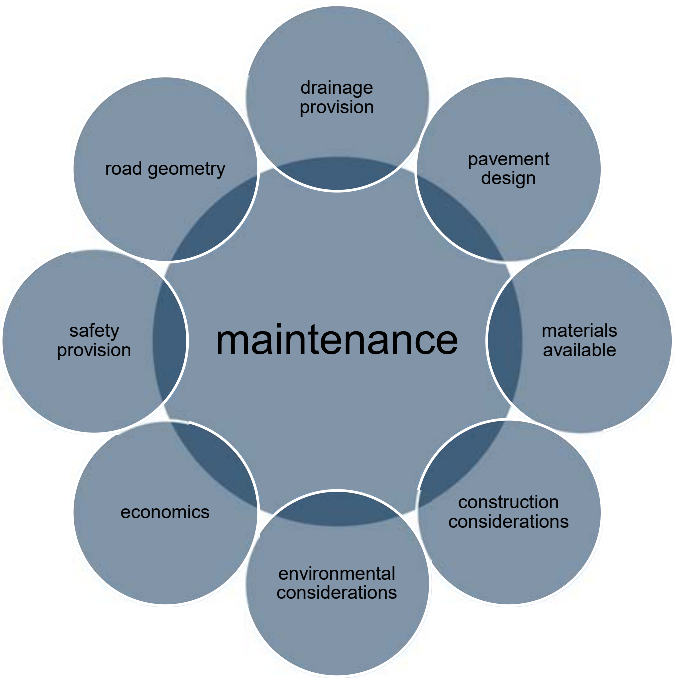
A typical RUMS may include:

- designated routes for oversize vehicles
- speed management strategies
- seasonal variation in traffic (e.g. grain harvesting)
- no, or limited, road use during rainfall and post rainfall conditions until the road is deemed trafficable
- level of service/intervention level requirements (ARRB 2020).

2.3 Maintenance Standards and Intervention Levels

Unsealed road deterioration cannot be prevented, but good maintenance practices should aim to slow down the rate of deterioration by ensuring that the key elements listed in Figure 2.3 are adequately managed.

Figure 2.3: Key elements of road maintenance practices



Source: ARRB (2020).

Maintenance can be defined as those activities that are intended to maintain the serviceability of a road due to the deterioration caused by traffic and climate. However, as many of these roads were developed from horse and cart tracks, maintaining them to their original condition is not always possible due to the lack of engineering updates to suit modern vehicles. Instead, maintenance works programs should make use of some of the funding available for more substantial works to correct significant design and construction deficiencies that will, over time, reduce future maintenance demands.

The main objectives of maintaining unsealed roads are to meet community expectations by:

- providing a smooth riding surface
- providing a well shaped and sufficiently impermeable surface which shed water and protects lower layers from the infiltration of moisture
- minimising safety hazards to vehicular traffic.

2.3.1 Reactive and Proactive Maintenance

Maintenance can vary from on-demand (reactive) maintenance to correct immediate defects, to preventative (proactive) maintenance to reduce the occurrence or frequency of defects in the future. On-demand maintenance is usually carried in response to unforeseen events such as floods or to manage impacts on road safety or serviceability. Preventive maintenance, on the other hand, involves routine or periodic maintenance scheduled or planned in advance to eliminate or reduce the occurrence and severity of defects.

For unsealed roads, preventive maintenance is:

- primarily concerned with maintaining adequate ride quality and repairing the drainage system
- involves regular grading of the pavement surface to remove corrugations, potholes, rutting and loose material
- often associated with major reshaping of the road and resheeting operations.

A combination of reactive and proactive maintenance is required throughout the life of a road to ensure the optimal service lives of the pavement. It also contributes to reduced vehicle operating costs and travel time costs, increased safety for road users, and potential cost savings for the owner/managing agency.

Failure to adopt a comprehensive approach to maintenance may lead to higher costs to road users and the road agency; if defects remain uncorrected then more severe pavement deterioration and costly repairs will b required.

2.3.2 Intervention Levels

The severity and frequency of defects such as corrugations, potholes, rutting and loss of crossfall, coupled with service levels and available resources, should be considered in setting the maintenance requirements for the road network. These include:

- Intervention thresholds, which depend on the category of the road section and available funding. Threshold levels should be determined using local criteria based on the number or severity of defects and/or safe speeds of travel over a road section.
- Intervention (maintenance) threshold levels are set to trigger when maintenance operations should be carried out. Values for these thresholds will vary between climatic regions, traffic levels, and overall quality standards.

A road agency should determine the relevant threshold or intervention level(s) for any defect. Intervention thresholds can be classified as:

- Warning/urgent threshold – the level indicating a need to monitor the condition of the road with a view to determining an appropriate remedial treatment.
- Optimum threshold – the level at which maintenance activities will minimise total costs.
- Public acceptability threshold – the minimum level that is compatible with road user demands; this may change over time, as community perceptions change.

The last two thresholds will vary from road to road and with traffic.

Appropriate intervention thresholds should consider:

- the importance of a particular road section; for example, a major road carrying large numbers of heavy, high-speed vehicles will have different intervention thresholds compared to a low-volume unformed track
- local conditions pertaining to the particular section of road
- safety risks
- community expectations and whole-of-life costs
- current practices and local resources.

Various threshold values have been cited in publications. However, these should only be used as a guide to assist a road agency to develop its criteria for triggering maintenance activities.

Table 2.2 presents intervention levels, based on visual assessment. Road agencies can use this as a guide for the development of criteria based on local needs.

Table 2.2: Guide to intervention levels for unsealed roads

Defect	Level to intervene	Extent	AADT	Urgent maintenance required	Typical action
Windrows, channels, corrugations, soft slippery areas, coarse surface texture, loose material, roughness	Safe travelling speed of less than 85% of environmental speed	20% of road	Any	Safe travelling speed of less than 70% of environmental speed	Grade or resheet
Loss of pavement/running surface[1]	Remaining depth of 50 mm	> 20% of sub-length	Any	Depth of cover remaining of 0 mm over > 10% of sub-section length	Resheet
Wheel ruts, shoving and potholes[2]	Depth of 75 mm	Any	Any	Defect depth of 150 mm	Grade/repair
Coarse texture/ride quality[3]	IRI > 9.8 (AADT < 100) IRI > 7.6 (AADT > 100) or safe travelling speed of less than 60% of environmental speed	> 50%	See Column 2	IRI > 9.8 (AADT < 100) IRI > 7.6 (AADT > 100) or safe travelling speed of less than 50% of environmental speed	Heavy grading and reshaping
Insufficient crossfall	Crossfall of 4% or less	Any	Any	Crossfall of 2% or less	Grade
Excessive crossfall	Crossfall of 6% or steeper	> 20% of sub-length	Any	Crossfall of 8% or steeper	Grade
Insufficient formation height above natural surface	In rolling country – natural ground level In flat terrain – 100 mm In flood plain areas – 0 mm	> 20% of sub-length	Any	Water ponds, and formation is lower than natural ground (level measured at the shoulder point)	Heavy grade and import fill
Insufficient formation width	Width of 8 m	> 20% of sub-length	Any	Width of 6.5 m or 8 m when visibility is restricted	Formation widening or realignment

Note: Environmental speed for a road is based on elements of the road and traffic environment that collectively influence a road user's determination of the appropriate travel speed.

Source: Adapted from Department of Transport, Queensland (1992) with revisions and additional criteria based on the following: TRL (2003); VicRoads (2014); cited in Austroads (2020a).

A road agency has a duty to inspect, maintain and repair public roads for which it is responsible. This requires that inspection and response times be set for the various road classes based on available resources, budget cycles and weather events.

An example of inspection frequency and response time codes for unsealed roads when the intervention levels are exceeded is given in Table 3.3. In many cases there may be more work generated by the inspections and response times set. In such cases a maintenance prioritisation procedure should be established to ensure that high-risk sites are dealt with first.

Table 2.3: Inspection and response frequencies codes when intervention levels are exceeded

Road type	Inspection frequency	Response time(1)
Main (Class 4A)	Three months	Within one week to one month of notification or inspection
Minor (Class 4B)	Twice per year	Within one week to three months of notification or inspection
Access (Class 4C)	Once per year	Within one month to six months of notification or inspection
Track (Class 4D)	Two years	Within twelve months of notification or inspection

1. Short response times recommended where the hazard poses an immediate safety risk or is likely to impact road operation or require road closure. The higher response time relates to hazards which pose a lower risk.

Source: Department of Environment, Land, Water and Planning (2019) with revisions and additional criteria based on VicRoads (2014) and typical Local Government practices, cited in ARRB (2020a)

2.4 The Benefits of Sealing Unsealed Roads

This Guide aims to provide a practical guidance on when to seal an unsealed road.

Queensland Department of Transport of Main Roads (TMR) (2015) describe the general benefits associated with sealing an unsealed road. They include, but are not limited to:

- Improved access, amenity and safety for all road users.
- A reduction in road user costs including both outlay when purchasing vehicles and maintenance costs.
- A reduction in agency costs relating to maintenance and rehabilitation items.
- Improved environmental outcomes from dust reduction and the preservation of scarce unbound granular pavement materials and water, resulting in better environmental outcomes (externalities).
- Improved conditions for vehicles carrying livestock, with better outcomes for livestock (for example, reduced damage to livestock through bruising and/or suffocation from dust) resulting in stock losses and the associated productivity losses.
- Reduced delays during wet weather conditions.
- Increased tourism uptake (particularly for tourists without four wheel drive vehicles).
- Increased freight competition/efficiency resulting from reduced risk of damage freight, vehicles and trailers.
- Improved social connectivity as road users are more willing to travel for social functions when the route is sealed.
- Reduced travel times.
- Reduced driver fatigue.
- Improved network flood resilience and associated reduced flood damage.
- Reduced freight costs.

Similarly, Henning, Kadar & Thew (2006) describe the benefits of sealing an unsealed road as follows:

- Productive gains on adjoining agricultural properties.
- Ameliorating driver and passenger discomfort (improving ride quality).
- Reducing the adverse effects on adjoining residential properties.
- Reduced vehicle operating costs.
- Travel time savings due to higher speed.

However, these benefits come at a significant cost, as the construction and maintenance costs are significantly higher compared to unsealed roads. In addition, providing an all-weather sealed surface usually requires:

- adequate geometric design standards

- sufficient drainage
- the availability of technologies, materials and skill (Henning et al. 2005).

The asset management of sealed roads is not covered by the Guide. However, extensive guidance can be found in documents such as the ARRB Best Practice Guide to Sealed Roads.

3 Unsealed Roads in Western Australia

3.1 Funding Context

State Road Funds Agreement

Through the State Road Funds to Local Government Agreement 2018/19 to 2022/23 (Government of Western Australia 2018), local government is allocated a portion of funding from State roads sources for:

- direct grants, e.g. routine maintenance
- road project grants, e.g. specific high-priority projects
- state black spots, e.g. improving road safety in high-risk crash zones.

Whilst this guideline is supported by, and targeted to, projects funded through the State Roads Agreement, it is envisaged that this guide will be suitable for use for all local government decision-making in asset management, presentation, maintenance and capital works.

In addition, this guideline may also be utilised to guide unsealed roads asset management practices generally, i.e. for works not conducted under this agreement. This includes the asset valuation process & Grants Commission, and the impact of preservation models on these processes. This is a complex model, but it is a consideration.

Commonwealth and Other State Funding Programs

LGAs may be able to access funding through the Regional Economic Development grants (Department of Primary Industries and Regional Development (DPIRD) 2023a), subject to meeting the regional priorities (for their region) and grant submission requirements provided by the Department.

LGAs may also be able to access funding through the Growing Regions Program managed through the Department of Infrastructure, Transport, Regional Development, Communications and the Arts (DITRDCA). This Australian government agency program 'provides grants of between $500,000 and $15 million to local government entities for capital works projects that deliver community and economic infrastructure projects across regional and rural Australia (DITRDCA 2023).

The guide can provide a method for identifying suitable road sections for upgrading from unsealed to sealed. When aligned to the grants program objectives, these can form part of submissions for the above grant programs.

Local Government Revenue

Funds provided through the State Road Funds to Local Government can cover 100% of funding (via direct grants and Australian black spot program grants), or up to two-thirds (66%) of funding via other funding sources.

LGAs will need to fund the balance that is not covered by the agreement. it will also need to fund any projects and works that do not meet the grant funding program requirements. For some LGAs, the balance of funding they must provide towards their road construction projects can be over 50% of the expense.

Heavy Vehicle Operators

The *User guide estimating the incremental cost impact on sealed local roads from additional freight tasks* (WALGA & ARRB 2015) provides a method for determining the cost impacts arising from heavy vehicle (HV) movements on sealed roads. The relevance to this guideline is that once a road is sealed, there is a method for LGAs to charge fees for HV operators to use the road. Once a road is sealed, to apply fees LGAs will need to:

- ensure the fees are approved through Council and recorded in its fees and charges register - this may require consultation with industry to define the method of applying the fees
- for restricted access vehicles, confirm each operator is accredited to operate heavy vehicles by MRWA – this can be done by accessing the MRWA website and searching for 'HVs accreditation and auditing'.
- determine the nature of the freight function for each operator and see if it meets the requirements of the WALGA & ARRB (2015) user guide
- arrange a method of reporting vehicle freight tasks with the operator, and charge fees as appropriate.

As this process of recording freight tasks, checking and invoicing can require significant administrative effort, LGAs should ensure that the benefit from charging incremental costs exceeds the cost of administration, both for them and the operator.

Developments and Development Contributions

As provided by the Planning and Development Act 2005 (refer Section 3.2.3), LGAs may be able to seek contributions from developers or require developers to upgrade all or part of a road or roads.

It is recommended that LGAs develop long-term plans to upgrade unsealed roads so that as development is proposed, they can demonstrate the need for the roads to be upgraded, thus enabling contributions or construction by developers.

3.2 Legislative Framework and WA Guidelines

This report has been prepared in general accordance with the processes and requirements outlined in current legislation, industry standards and best practice guidelines as set out in:

- WA:
  - *Land Administration Act 1997*
  - *Local Government Act 1995*
  - *Local Government (Uniform Local Provisions) Regulations 1996*
  - *Main Roads Act 1930*
  - *Planning and Development Act 2005*
  - *Public Works Act 1902*
  - *Work Health and Safety Act 2020 (WHS Act)*
  - *Work Health and Safety (General) Regulations 2022 (WHS Regulations)*

Please refer to the Western Australian Legislation website for copies of the relevant legislation, available for free via https://www.legislation.wa.gov.au/.

3.2.1 Work Health and Safety Legislation

The Work Health and Safety Act 2020 (WHS Act) applies whenever work is undertaken. It extends from the workers and contractors doing the work, to other persons who may be put at risk from the work underway. In the context of maintaining and upgrading unsealed roads, the responsibilities may include: road surveying and site visits, site construction activities, maintenance activities, and traffic management of the sites.

The consideration is what is the change in risk arising from sealing an unsealed road that would not otherwise be present. The WHS legislation in WA includes:

- Work Health and Safety Act 2020 (WHS Act)
- Work Health and Safety (General) Regulations 2022 (WHS Regulations)

- codes of practice and guidance notes.

In respect of the WHS Act, LGAs will need to ensure the assets are adequately managed as the asset wears and ages, to limit exposure for staff and public when maintenance is required.

3.2.2 Legislation for the Management of Local Roads

Under the *Land Administration Act 1997*, clause 55 (2):

> Subject to the Main Roads Act 1930 and the Public Works Act 1902, the local government within the district of which a road is situated has the care, control and management of the road.

For clarification the term ‘road’ is defined in the Land Administration Act, and this does not include private roads. The Act does not further elaborate the meaning of ‘care, control and management’.

Note the *Local Government (Uniform Local Provisions) Regulations 1996* also defines a ‘Government road’ as being a road declared by an order of Council under the Public Works Act 1902.

The Main Roads Act 1930 clause 24 (5) defines a ‘secondary road’ as being the responsibility of local government:

> The local government of a district in which a secondary road or any part of a secondary road is situated shall be responsible for maintaining such secondary road or part; (continues).

As provided by the Main Roads Act, in the event that the local government fails to maintain a road, the Commissioner of Main Roads may direct for work to be undertaken.

All roads that are declared ‘highways’ or ‘main roads’ are under the responsibility of Main Roads WA as defined in the Road Responsibility Policy (Main Roads Western Australia 2022), which is issued as procedural advice to the Main Roads Act 1930. Local governments are delegated responsibility for local roads as provided by section 2.1.2 of the Road Responsibility Policy, which states:

> All other public roads in WA (with the exception of the previously mentioned access roads to remote communities and roads in National Parks etc.) are the responsibility of local government, and are managed by incorporated municipal councils across the State.

Main Roads WA also retains responsibility for traffic signs and devices on LGA’s roads and certain types of bridges.

The conclusion from the legislation is that, when a road is not a main road or highway, and where it has not been identified by Main Roads WA as a road under their management and control, then the road is a local road, also referred to as a secondary road. The LGA is responsible for the care, control and management of local roads (not including private roads).

The legislation does not specify minimum care and management standards. LGAs should refer to the Main Roads WA Codes of Practice and industry standards to determine the appropriate level of maintenance and management of roads in their jurisdiction.

MRWA has developed the following operational procedures to define the extent of responsibilities between MRWA and LGAs:

- Operational Procedure 112: Operational boundaries and asset responsibilities – Metropolitan Region (Main Roads WA 2020)
  - This document provides principles and practical guidance for determining how the responsibility for maintaining the different parts or elements of highways and main roads is to be allocated between the Commissioner of Main Roads (hereafter referred to as Main Roads) and Local Government. The

  document also provides guidance in respect of some parts of local government roads potentially involving Main Roads (e.g. signs and intersections with highways and main roads).

- Operational Procedure 113: Maintenance responsibility within town sites (Main Roads WA 2022)
  - This document provides guidance to both Main Roads and local government, in terms of the allocation of responsibility of each authority in regard to maintenance of state and local roads, including intersections, roads, and road reserves within town sites or built-up areas.

3.2.3 Planning and Development

Under the *Planning and Development Act 2005 (WA)*, people and businesses developing land are required to seek approval from the Western Australian Planning Commission (WAPC). Depending on the scale of development, the application may be referred by the WAPC either to the appropriate LGAs for assessment and decision, through a Development Assessment Panel, or through other regulatory mechanisms.

In the context of unsealed roads, and considering whether they can be upgraded to sealed roads as part of a development, the LGAs can:

- develop a strategy for the upgrading of unsealed roads
- ensure the intention to upgrade unsealed roads is communicated to its statutory planning and strategic land use planning teams
- where appropriate, seek a Transport Impact Assessment from the developer during the application process
- assess the development and its impact to the road network in the context of the strategy.

The necessity for a strategy (for the upgrading of unsealed roads) is to ensure that a condition of approval for a development can be enforced. In the absence of a strategy, the LGAs may find it difficult to apply conditions of approval for a development. It may also find it difficult to defend against a developer who does not agree with the condition and who has challenged the requirement through the State Administrative Tribunal.

A strategy for the upgrading of a road or roads may include:

- current and forecast traffic volumes and types
- other traffic and community factors that support the need for an upgrade
- forecast of when a traffic volume will trigger the need for the unsealed road to be upgraded in accordance with this guideline
- concepts of the required road upgrade, with indicative pavement and surface features
- identification of changes in land ownership needed for the road
- forecast timeframes and costs.

As the planning for road upgrades is typically undertaken by the asset infrastructure teams within LGAs, it is necessary for the team to communicate across the organisation so that the LGAs can take advantage of opportunities through the land use development processes.

Completed in accordance with the *Transport impact assessment guidelines* (Western Australian Planning Commission (WAPC) 2016), a Transport Impact Assessment (TIA) identifies the traffic types and volumes that are generated from a development, and in turn how this impacts the local road network. Local government can use this information to determine if the impact is significant enough to warrant an upgrade to the local road.

If it is determined that the impact is significant, the LGAs can seek to have the developer upgrade the road, or contribute towards the cost of upgrading the road, as part of the development approval.

As part of the development approval, the LGAs can use the *Model subdivision conditions schedule* (WAPC 2022) code T5:

> Satisfactory arrangements being made with the local government for the full/ partial [INSERT VALUE HERE] cost of upgrading and/or construction of [INSERT VALUE ROAD(S)] in the locations as shown on the plan dated [INSERT] (attached) to a standard of [INSERT VALUE]. (Local Government).

It should be noted that a single development would rarely trigger the requirement to upgrade an entire road. LGAs should not create false expectations in this regard.

3.3 The Road Network

The length of road network in WA is 185,654 km, with only 31% of this network sealed. A breakdown of the road network kilometres is provided in Table 3.1.

Table 3.1: Road classifications

Road classification (as at 30 June 2018)	Unsealed (km)	Total (km)	Sealed (%)
National land transport routes	0	5,120	100
Highways	108	5,902	98
Main roads	776	7,507	90
Local roads regularly maintained	88,311	127,765	31
Local roads not regularly maintained	970	1,027	6
Roads managed by Department of Parks and Wildlife (DPaW)	37,975	38,333	1
Total WA road network	128,140	185,654	31

Source: Main Roads Western Australia (2018).

Of this 185,654 km, information on 152,404 km exists within the Main Roads WA Open Data Database, where 132,612 km (87%) are defined as local roads and 19,762 km (13%)are defined as state roads (MRWA 2018).

In MRWA *Asset management documentation* (MRWA 2021), roads are referred to by hierarchy. This hierarchy, and the number of kilometres of the overall road network which exists in each of these categories, are defined in Table 3.2.

Table 3.2: Kilometres of road network according to road hierarchy

Road hierarchy	Sum of road length (km)	Description
Access road	93,100	Roads managed by local government that: prioritize amenity, safety, and aesthetics, provide access to abutting properties, and are bicycle and pedestrian friendly.
District Distributor A	1,248	Urban roads managed by local government that carry traffic between industrial, commercial, and residential areas. They generally connect to Primary Distributors and are likely to be truck routes. They provide limited access to adjoining property.
District Distributor B	569	Similar to District Distributor A roads, these are also urban roads managed by local government that connect to Primary Distributors, but with reduced capacity due to flow restrictions from access and roadside parking alongside adjoining property.
Local distributor	25,634	Urban and rural roads managed by local government that carry traffic within a cell and link District Distributors or Regional Distributors at the boundary to access roads while discouraging through traffic, accommodating buses but discouraging trucks.
Primary distributor	19,790	Major regional and inter-regional roads managed by Main Roads WA. They carry large volumes of fast-moving traffic and serve as strategic freight routes and state roads.
Regional distributor	12,063	Rural roads managed by local government that link significant destinations. They are designed for the efficient movement of people and goods within and beyond regional areas.
Grand total	152,404	

Source: MRWA (2021).

3.4 Localities

Localities in WA are defined as metropolitan, regional, remote or very remote. The length of the local road network in each of these localities, and the pavement type, is defined in Table 3.3.

Table 3.3: Kilometres of road network according to locality and pavement type

MRWA region	Locality	Asphalt seal	Sprayed seal	Gravel	Formed	Unformed	Total
Gascoyne	Remote WA	12	534	1,644	1,805	236	4,232
Goldfields-Esperance	Very remote WA	202	1,416	7,407	3,730	4,414	17,169
Great Southern	Remote WA	199	2,961	7,420	1,569	335	12,483
Kimberley	Very remote WA	10	530	1,837	977	1,019	4,373
Metropolitan	Metropolitan WA	10,698	3,370	200	50	22	14,339
Mid-West	Regional WA	171	3,084	8,291	4,304	1,166	17,016
Pilbara	Very remote WA	233	532	2,521	1,339	1,196	5,821
South-West	Regional WA	1,324	4,843	3,712	646	153	10,680
Wheatbelt North	Regional WA	89	6,619	12,858	3,709	644	23,918
Wheatbelt South	Regional WA	23	3,914	10,101	2,660	336	17,036
Grand total		12,960	27,804	55,991	20,789	9523	127067
Percentage of total length		10.2%	21.9%	44.1%	16.36%	7.5%	100%

Source: WALGA (2023).

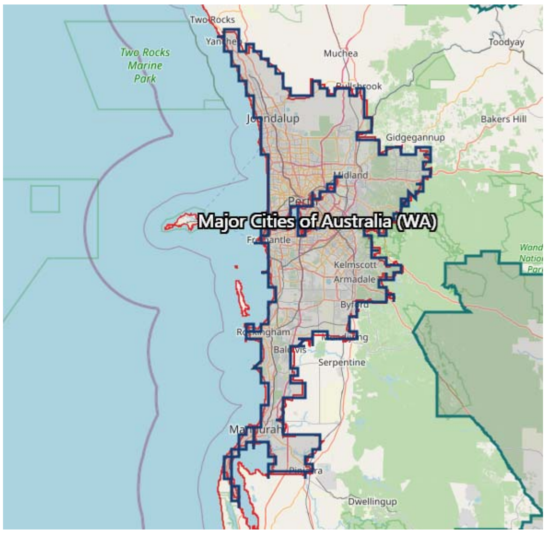
Metropolitan WA

Metropolitan WA is positioned to the southwest and primarily includes the greater Perth region as shown in Figure 3.1 and Figure 3.2. In accordance with the MRWA Operational Procedure 112 – Operational boundaries and asset responsibilities (Main Roads Western Australia 2020a), the following LGAs areas are listed as Metropolitan Local Government: City of Armadale, Town of Bassendean, City of Bayswater, City of Belmont, Town of Cambridge, City of Canning, Town of Claremont, City of Cockburn, Town of Cottesloe, Town of East Fremantle, City of Fremantle, City of Gosnells, City of Joondalup, Shire of Kalamunda, Town of Kwinana, City of Melville, Town of Mosman Park, Shire of Mundaring, City of Nedlands, Shire of Peppermint Grove, City of Perth, City of Rockingham, Shire of Serpentine-Jarrahdale, City of South Perth, City of Stirling, City of Subiaco, City of Swan, Town of Victoria Park and Town of Vincent or City of Wanneroo.

Figure 3.1: Metropolitan WA (greater state)

Source: Australian Bureau of Statistics (2022).

Figure 3.2: Metropolitan WA



Source: Australian Bureau of Statistics (2022).

Note: These maps on the Australian Bureau of Statistics site do not exactly match the definition of regional LGAs from the Department of Local Government, Sport and Cultural Industries. For example the City of Mandurah (appearing at the southern end of the figure) is identified as regional by the department.

Regional WA

Regional WA is positioned to the southwest in an inner regional area and an outer regional area surrounding the greater Perth region as shown in Figure 3.3 and Figure 3.4.

Figure 3.3: Inner regional WA

Source: Australian Bureau of Statistics (2022).

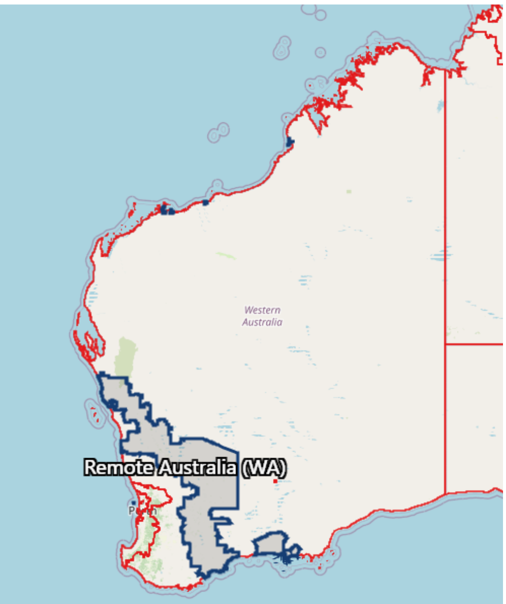
Figure 3.4: Outer regional WA

Source: Australian Bureau of Statistics (2022).

Remote WA

A large portion of regional WA is positioned to the southwest surrounding the regional areas, with small isolated regional zones along the northwest coastline. A map of this nominated area is shown in Figure 3.5.

Figure 3.5: Remote WA

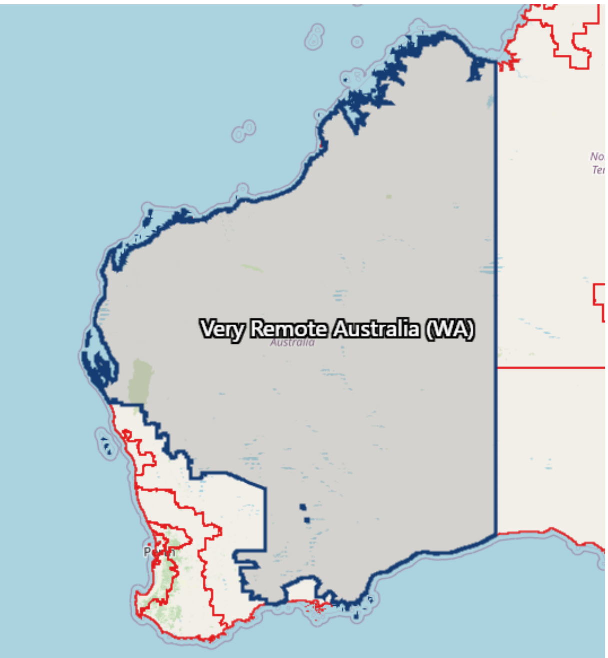


Source: Australian Bureau of Statistics (2022).

Very Remote WA

The majority of WA (by area) is considered very remote. It generally includes all areas outside of the states southwest as shown in Figure 3.6.

Figure 3.6: Very remote WA



Source: Australian Bureau of Statistics (2022).

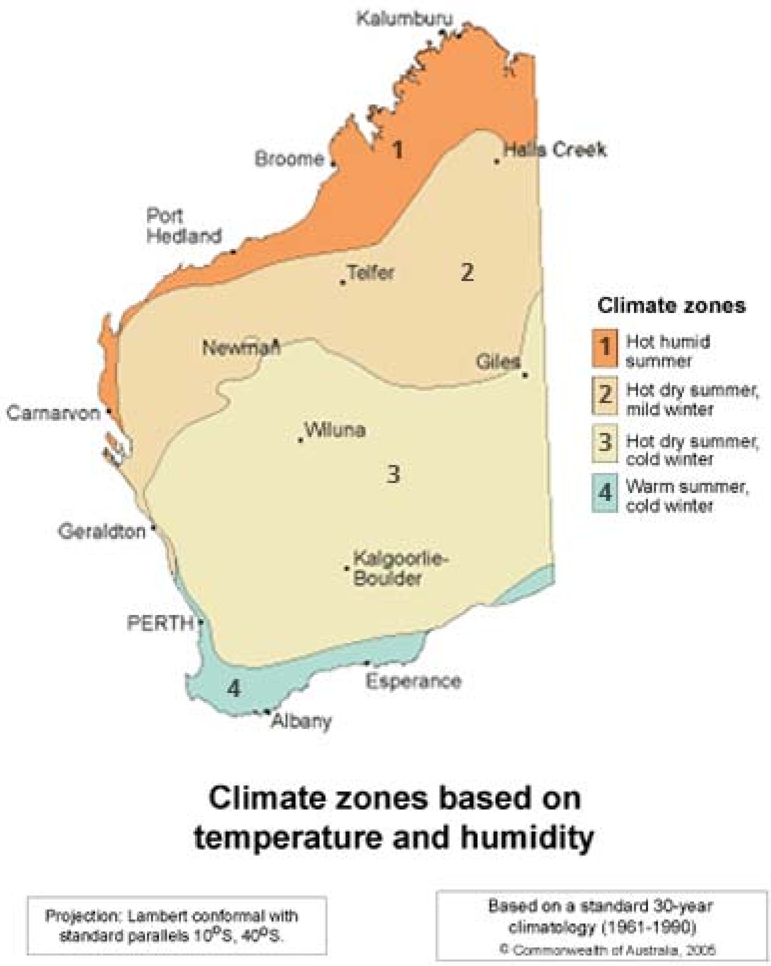
3.5 Climate Zones

The establishment of consistent climate zones throughout the WA region offers several advantages, including the ability to locate Bureau of Meteorology (BoM) sites that provide comprehensive data for a full year. This data includes key climate parameters such as maximum temperature, minimum temperature, and mean rainfall. The Climate Zones are:

- Climate Zone 1 Hot humid summer
- Climate Zone 2 Hot dry summer, mild winter
- Climate Zone 3 Hot dry summer, cold winter
- Climate Zone 4 Warm summer, cold winter.

These climate zones represent distinct climatic characteristics experienced within the WA. They provide a framework for understanding the variations in temperature and precipitation patterns across different areas. How these influenced the case studies are detailed in Appendix A. A visual representation of the condition areas is shown in in Figure 3.7.

Figure 3.7: Climate zones



Source: Bureau of Meteorology – Climate classification maps.' Available at http://www.bom.gov.au/climate/maps/averages/climate-classification/ [Verified 29/06/2023].

4 Key Factors in Decision-Making

The structure of this section is based on the key factors of decision-making which were used to develop the material in the *Practitioners Guideline*. The topics covered include:

- Road condition
  - Historical condition: the cause and effects of deterioration of the unsealed road network over time and the prediction of future condition.
  - Current condition: how to assess the condition of the unsealed road network including the cause and effects of current deterioration; deterioration (RD) modelling, and works effects (WE) modelling, and how this can be used in the management of the unsealed road network.
- Materials
  - Performance of unsealed road materials.
- Traffic
  - Assessing current and future traffic levels and their composition on the unsealed road network.
- Environmental considerations
  - Soil reactivity and stability, erosion and sedimentation
  - Roadside vegetation, biodiversity and wildlife protection.
- Climate
  - Climate and weather conditions, and the impact which climate can have on unsealed road asset management.
  - Understanding how climate and weather conditions will change over time, and the impact which climate change will have on unsealed road asset management.
- Whole-of-life costs
  - Cost/economics of unsealed roads maintenance/preservation, and when it may be more economical to seal a road
  - How to undertake an economic evaluation, and the optimisation of road preservation and upgrade options.
- Road safety
  - Potential trade-offs in road safety with increased speed.
  - See also the *Technical Report: Low-Cost Road Safety Improvements for Rural Local Government Roads in WA (Mak & Tang, 2023)*.
- Community expectations
  - Public pressure/road user complaints
  - Customer-based Leves of Service in road maintenance.

To identify relevant research, a search was conducted using:

- Previous studies in this area with a local government focus, including studies specific to WA and those specifically supported or commissioned by WALGA:
  - *Technical basis for estimation of the cost of road wear on unsealed local government roads in Western Australia* (WALGA & ARRB 2019)
  - *Technical basis for estimating the incremental cost impact on sealed roads from additional freight tasks* (WALGA & ARRB 2015)
  - Australian LGA Subscription: ARRB Local Road deterioration study
  - *Investigating key performance measures and predictions on unsealed roads: road deterioration and works effects models (Austroads 2015a)*

  - *Appropriate use of marginal and non-standard materials in road construction and maintenance* (Austroads 2018)
  - *Sustainable roads through fit-for-purpose use of available materials: technical basis* (Austroads 2020a)
  - *Sustainable roads through fit-for-purpose use of available materials: evaluation tool and user guide* (Austroads 2020b)
  - *Prolonging the life of road assets under increasing demand a framework and tools for informing the development and justification of asset preservation and renewal* (Austroads 2021).
- Used specifically in this literature search were the Australian Transport Index (ATRI) and Transportation Research Information Documentation (TRID) databases. The use of these databases ensured wide coverage of quality research material within the subject area from national and international sources.

4.1 Road Condition

This section of the report details the cause and effects of deterioration on unsealed roads (Section 4.1.1), how to classify the deterioration of unsealed roads (Section 4.1.2), how to assess the current condition of unsealed roads (Section 4.1.3), and the life-cycle performance and maintenance effects on unsealed roads (Section 4.1.4).

4.1.1 Cause and Effects of the Deterioration of Unsealed Roads

Studies in Australia, e.g. the Local Roads Deterioration Study (Martin, Choummanivong & Toole 2013), and elsewhere (Paterson 1987, Paige-Green 1987, Toole et al. 2001, Morosiuk et al 2009 and ARRB Group 2009), provide an insight into the factors which affect the performance and costs of providing and maintaining unsealed roads. Those considered of significance to this study are:

- current condition and suitability for carrying significant additional loads, e.g. surface condition, shape and structural adequacy
- surface materials quality/specification, and the availability of different materials
- vehicle types, level of loading and duration of additional loading, and typical base traffic
- maintenance strategies, including the type(s) and frequency of regular maintenance and surface replacement (or regravelling)
- future performance in response to these factors and climate and terrain, operating speeds, etc.

The outcomes of these factors can be influenced by deliberate choices, although there will be cost implications, whereas others are location- and operating conditions-specific. The determination of the relevant maintenance and preservation costs needs to be based on data and assumptions relevant to a specific project case, and the characteristics of the specific roads and the treatment options chosen.

4.1.2 Classification and Deterioration of Unsealed Roads

Road Condition: Summary/Outcome

Dry weather can cause wear and abrasion to road surfaces, leading to loose material, ruts, and concave shapes. Additionally, loss of surfacing material by dust and movement of loose material can cause corrugations and ravelling, resulting in increased roughness and material loss.

Environmental factors such as wet weather and traffic can cause erosion, wear and abrasion on road surfaces, leading to rutting, material loss, potholing, and roughness. These factors can result in increased deterioration of the road, affecting its shape and structural integrity.

Wet weather can increase the risk of shear failure and deformation in the upper pavement when the surfacing layer is weak. The road may become impassable even after the passage of a few HVs. Performance can vary depending on road geometry and vehicle mass, with increased rut depths, poor traction, and trafficability in the wet all issues to be considered.

When roadbed material is weak, wet weather influence over-stressing of the subgrade or roadbed, requiring protection and limitation of deformation to acceptable levels. Locations with poor drainage and weak soils may experience accelerated deterioration. The road is also likely to develop severe rutting or permanent deformation in the wheelpaths.

A distinction is normally made between engineered unsealed roads, and non-engineered unsealed roads and tracks (Toole et al 2001). Each may have gravel or earth surfaces which influences both the level of service and the deterioration of the road. Engineered roads have controlled alignment, formation width, cross-section profile and drainage, whereas tracks are essentially trafficked ways along natural contours with or without the removal of topsoil. Unsealed roads incorporated in a classified road network are usually engineered or partly engineered, whilst tracks are usually not classified. The distinction between earth and gravel roads is usually based on whether an imported material has been used in the running surface. Therefore, it is possible for perfectly acceptable engineered earth roads to exist alongside gravel roads.

Earth roads are also characterised by seasonal performance, where the presence of moisture can affect trafficability. They are also weak in the presence of water and susceptible to failure, leading to severe rutting under load. Gravel roads generally have few trafficability problems except where the cover thickness (which provides protection to the subgrade) is inadequate, or where they have deteriorated badly, e.g. if potholes and ruts are extensive and severe. Seasonal performance differences may exist, with moisture from rainfall aiding dust suppression and enhancing soil binding properties, whereas excessive rainfall can lead to erosion and rutting.

There are three fundamental mechanisms of deterioration of the surface of an unsealed road (Austroads 2018):

- wear and abrasion of the surface material under traffic
- deformation of the surface and roadbed material under the stresses induced by traffic loading and moisture condition
- erosion of the surface by traffic, water and wind.

Consequently, the modes of deterioration differ in dry weather and wet weather, and also depend on the strength of the surfacing and roadbed material, which are most critical in wet weather. The modes and the approaches for modelling can be placed in four categories as described below (Visser 1981):

- dry weather deterioration
- wet weather deterioration of pavements
- wet weather deterioration with weak surfacing layer

- wet weather deterioration with weak roadbed material.

The most prominent deterioration mechanisms and modes of distress for each category are summarised in Table 4.1. Whereas a focus is often given to the selection of suitable wearing course materials and addressing routine (scheduled) and periodic maintenance requirements, consideration of structural adequacy is necessary, particularly where heavy traffic loads already exist or through additional loading. A variety of sources of evidence and procedures for determining structural adequacy exist, including the US Army Corps of Engineers (Webster & Alford 1978, Giroud & Noiray 1981, TRL (Powell et al 1984) and ARRB Group (2020), with the latter incorporating simple design charts for cover thickness.

Table 4.1: Description of unsealed road performance categories

Category	Deterioration mechanisms	Modes of distress
Dry weather deterioration	• Wear and abrasion of the surface generates loose material and develops ruts and a concave shape. • Loss of the surfacing material by whip off and dust. • Movement of loose material into corrugations under traffic action. • Ravelling of the surface, in cases where there is insufficient cohesion in the material to keep the surface intact.	• Increased roughness and material loss, the rates of deterioration being primarily a function of the properties of the surfacing material and its moisture condition.
Wet weather deterioration of adequate pavements	• Environmental and traffic influences on surface erosion. • Wear and abrasion of the surface by traffic causing rutting and loss of surfacing material. • Formation of potholes under traffic action, accentuated and accelerated by the presence of free water on the surface and the passage of vehicles.	• Increased deterioration (multiple modes including rutting, material loss, loss of shape, potholing and roughness) resulting from erosion, wear and abrasion, and traffic action.
Wet weather deterioration with weak surfacing layer	• Increased risk of shear failure and deformation occurring in the upper pavement • Potential for soft and slushy surface conditions in wet conditions, with increased risk of the road becoming impassable after the passage of even a few HVs. • Performance expected to vary depending on road geometry, particularly gradient, and the weight and number of vehicles.	• Similar to above, but with increased rut depths and poor traction and trafficability in the wet
Wet weather deterioration with weak roadbed material	• High likelihood of over-stressing of the subgrade or roadbed, promoting need to protect the roadbed and limit the level of deformation developing under traffic to acceptable levels. Accelerated deterioration in locations of poor surface and subsurface drainage and weak soils.	• Similar to above, but with likelihood of severe deterioration in the form of rutting, or permanent deformation in the wheelpaths.

Source: Visser (1981).

4.1.3 Assessing Current Road Condition

Assessing Current Road Condition: Summary/Outcome:

Refer to the WALGA (2016) *Road visual condition assessment manual* when surveying road conditions.

Unsealed roads with potholes, rutting, corrugations, dust, coarse texture, and poor shape have increased safety risks and higher vehicle operating costs due to poor ride quality and damage. Inadequate compaction, poor grading practices, insufficient pavement depth, lack of maintenance, and variable quality of pavement materials cause these issues.

The shape of an unsealed road is crucial to prevent water damage and ensure safe driving conditions. Poor shape caused by factors such as inadequate maintenance, poor drainage, and insufficient pavement depth can result in an increase vehicle operating costs and create safety hazards such as rutting and loss of steering.

Inadequate material depth can lead to severe rutting, creating a trafficability problem and increasing vehicle operating costs. Poor surface drainage, inadequate material strength, and lack of maintenance can also increase the risk.

Unsealed roads are vulnerable to damage caused by environmental factors and traffic, with wet weather often exacerbating the problem. Factors such as weak surfacing or roadbed material, poor drainage, and inadequate cohesion in the surfacing material can lead to deterioration and reduced road performance. Given these challenges, it is essential to assess the condition of unsealed roads regularly to identify areas in need of maintenance and repair, reduce risks to road users, and ensure the road's longevity.

Defects are usually the result of interactions between pavement materials, traffic, climatic conditions and construction methods. When assessing defects and the necessary actions to repair the road, it is the level or quality of service that is critical in determining the maintenance effort required.

A summary of common defects associated with unsealed roads is presented in Table 4.2.

Classification of defects into ‘surface’ and ‘structural’ provides a basis upon which the causes and remedies can be analysed, and to distinguish between superficial and deep-seated issues. Surface defects, which are confined to the upper pavement layers, primarily impact on the safety and comfort of road users. Structural defects are caused through over-stressing the pavement and/or the subgrade which can result in deformation of the pavement.

Generally, surface defects can be attributed to a variety of factors including traffic, climatic conditions, inappropriate maintenance, a lack of availability of suitable material, inappropriate grading, poor compaction or any combination of these factors.

Structural defects are generally characterised by deep rutting and require investigation into the causes. Causes can be a lack of drainage, poor compaction and the use of inappropriate or insufficient material to carry the axle loads.

Table 4.2: Defects on unsealed roads

Defect	Issue	Causes
	Unsealed surface extent	
Potholes [2]	• Increased roughness and poor ride quality. • Increased safety risk. • Increased vehicle operating costs. • Damage to vehicles (when potholes is 250–1500 mm diameter and > 50–75 mm depth).	• Ponding of water due to inadequate crossfall (bridge approaches, alignment changes, superelevation etc). • Excessive weakening of pavement by moisture. • Inadequate compaction. • Variable quality of pavement materials.

Defect	Issue	Causes
		
Localised rutting [2] 	• Retain water that can cause pavement damage. • Safety hazard due to loose material between ruts and loss of steering. • Increased vehicle operating costs.	• Dry season rutting caused by non-cohesive materials displaced sideways. • Wet season rutting caused by inadequate wet strength. • Insufficient pavement depth. • Poor surface drainage. • Poor material grading. • Lack of maintenance. • Vehicle tracking. • Traffic compaction of pavement or subgrade.
Corrugations [2] 	• Increased roughness and poor ride quality. • Increased safety risk. • Increased vehicle operating costs.	• Inadequate quality material for prevailing climatic conditions. • Loose surface material combined with dynamic traffic impacts. • Absence of tight surface combined with high proportions of coarse sandy materials. • Poor grading practices (inappropriate operating speed or damaged blades).
Dust extent [2] 	• Increased nuisance posed to local residents • Increased safety risk	• Ponding in top layer • Inadequate thickness
Coarse texture [1] 	• Increased roughness and poor ride quality. • Increased vehicle operating costs.	• Attrition or erosion of fines from coarse pavement materials. • Exposure of rocky subgrade. • Use of oversize basecourse materials.

Source: ARRB (2020).

Image source: (1) Local Government and Municipal (LGAM) knowledge base (n.d.); (2) WALGA (2016) *Road visual condition assessment manual.*

Note: Refer to WALGA (2016) *Road visual condition assessment manual* for details of the methods used to measure these defects.

4.1.4 Life Cycle Performance and Maintenance Effects

Life cycle performance and maintenance effects: Summary/Outcome

Optimum grading techniques can maintain the correct level of service on unsealed roads by increasing the frequency and quality of maintenance operations.

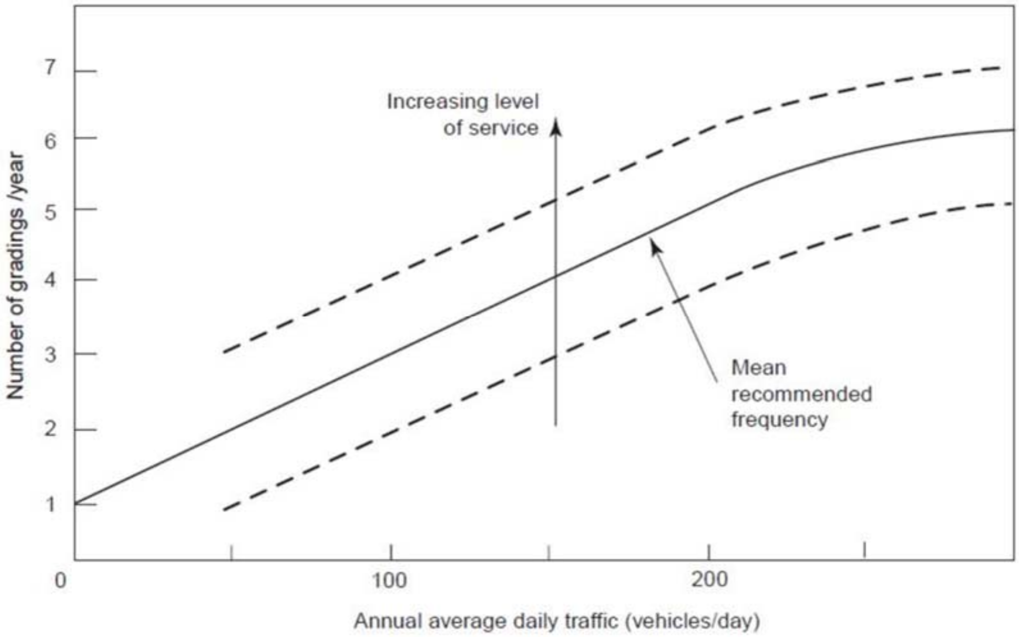
Different maintenance techniques have varying effectiveness, such as full reprocessing (grading and compaction) or heavy grading being more effective than light grading.

A four-phase model has been developed to understand the life-cycle performance of unsealed roads and maintenance effects.

Using this model, a family of optimum maintenance frequency relationships can be produced, which are chosen by identifying the frequency of each operation that minimizes total transport costs or maximizes net present value for each traffic level.

The relationship between road frequency and level of service is based on economic optimisation. As indicated in Figure 4.1, increasing the frequency of maintenance operations improves the level of service. In areas with higher rainfall, an increased frequency of operations is usually required to maintain the road's camber and remove ruts. In contrast, lower rainfall areas may require maintenance operations to be concentrated in the wetter parts of the year to minimise damage to the road surface, or for operations to involve the addition of water.

Figure 4.1: Example optimum grading relationship for heavy grading



Source: TRL (1987).

It is worth noting that the effectiveness of different maintenance techniques can vary, with some treatments being more effective than others. For example, full reprocessing involves reshaping the surface, accompanied by watering and compaction, to produce a smooth, well-knit surface. Heavy grading allows some reworking in the presence of natural moisture and limited traffic compaction, while light grading only respreads loose material across the roadway with almost no change in the shape of the underlying surface. As a result, the material will be displaced quickly, and surface conditions deteriorate rapidly to pre-works levels.

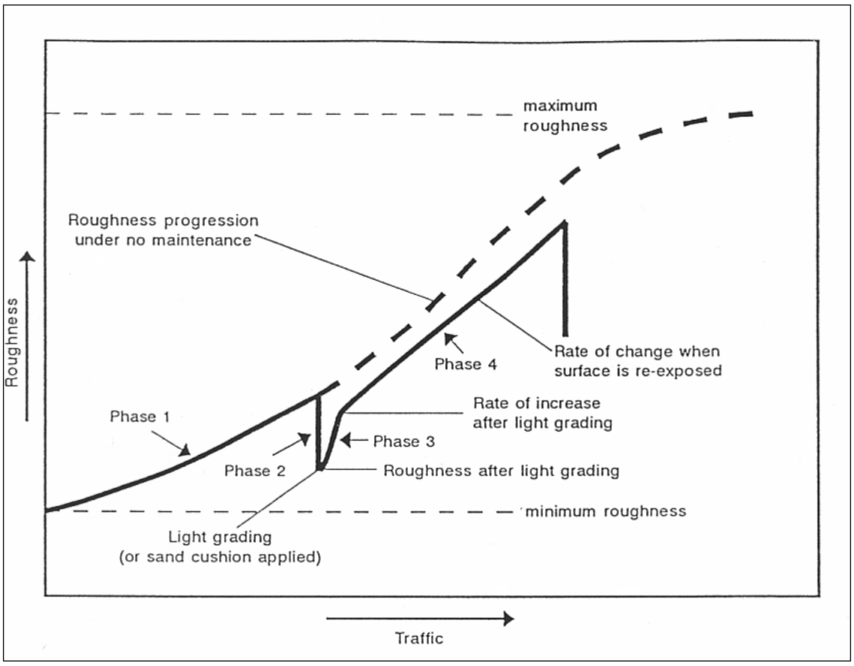
There is a need to distinguish between treatments if the life-cycle performance of unsealed roads and maintenance effects is to be better understood. Surface roughness on unsealed roads varies in both longitudinal and transverse profiles: it changes over time and responds to maintenance in a cyclic manner. In other words, the deterioration cycle involves short-term changes in surface condition which are then restored by maintenance, and the cycle of deterioration then recommences.

The observed trends and response to maintenance and construction activities have led to the development of a four-phase model for the progression of roughness for unsealed roads. This model describes the rate of wear of the original surface before any maintenance is applied (Morosiuk & Toole 1997):

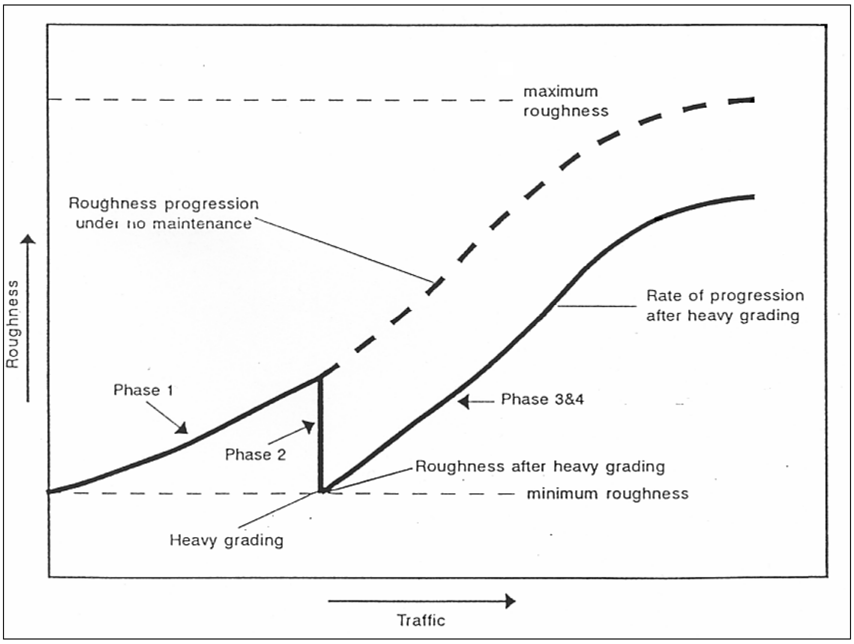
- Phase 1 – the rate of wear of the original surface before any maintenance is applied
- Phase 2 – the change in roughness as a result of maintenance
- Phase 3 – the rate of wear, or removal of the uncompacted or loosely compacted upper surface layer immediately after maintenance
- Phase 4 – the longer-term rate of wear of the surface once any loose or poorly compacted material is removed.

The model forms a convenient framework for describing the application of current unsealed road roughness progression models in determining life cycle behaviour and, thereafter, optimum maintenance frequencies Figure 4.2a) represents light grading (or blading) in the absence of water, whereas Figure 4.2b) represents heavy grading or full reprocessing. The costs of these operations differ considerably, and this needs to be reflected in any life-cycle cost analysis. At a practical level, location factors may mean that techniques which are feasible are limited due to the lack of water sources, and due to low or unpredictable rainfall.

Figure 4.2: Illustration of the 4-phase roughness progression model for unsealed roads



(a) Effect of light grading



(b) Effect of heavy grading or full reprocessing

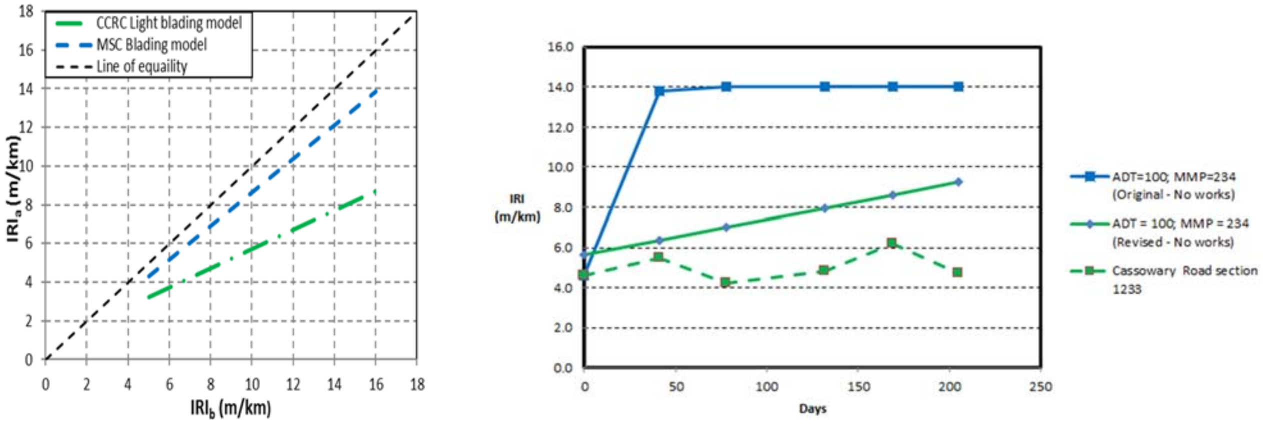
Using this four-phase model, the various levels of improvement that occur as a result of specific operations and subsequent rates of progression can be correctly represented. It allows a family of optimum maintenance frequency relationships to be generated that relate to specific operations such as light grading, heavy grading, and reprocessing. The optimum frequency is chosen by identifying the frequency of each operation that minimizes total transport costs or maximizes net present value for each traffic level. Assumptions are made on various parameters, including traffic composition, costs, climate, etc.

Observed performance in Australia has been utilised to develop a similar relationship drawing on the results of both the original Local Road Deterioration Study (LRDS) and the follow-on maintenance studies (Martin et al. 2013; Austroads 2018). This enabled the effectiveness of maintenance treatments to be determined and employed in producing an optimum grading relationship for both 'typical' works practices, and what is termed 'good' practice where moisture and compaction is employed (Austroads 2020a). The steps in developing the relationship included the following:

- Firstly, demonstrate the effectiveness of grading operations in terms of reducing roughness, which can vary considerably. This is illustrated in Figure 4.3(a) for two examples, one of which shows little change in roughness after grading, whereas the other (CCRC) shows a considerable change.
- Secondly, the trend of roughness increase post-grading (or reconstruction) can differ significantly. This is illustrated in Figure 4.3(b) with the upper trend based on the original LRDS model and the lower trend based on the revised model resulting from the follow-on studies which were aimed at gaining a better understanding of actual practices. Whilst the former was based on multiple sites with little knowledge of the original quality of construction and effectiveness of the maintenance treatments, the latter represents deterioration under a controlled maintenance regime which, from the available evidence, is shown to be highly effective at maintaining a relatively low long-term trend in roughness progression. The lowest trend represents the effect of cyclic grading with water and compaction applied.
- Thirdly, undertake a life cycle analysis which applies the two models and investigates the effect of varying technique and its frequency applied to different traffic levels (50 – 500 veh/day) to determine the minimum total transport cost option for each. This is illustrated in Figure 4.4, with the lowest point of each curve representing the optimum for the associated traffic level.
- Fourthly, present the results as a simple relationship with the optimum frequency plotted against AADT producing a similar relationship to that in Figure 4.5, but for the two techniques evaluated. Also plotted on is the frequency employed by a LGA with reasonably close agreement with that derived by analysis.

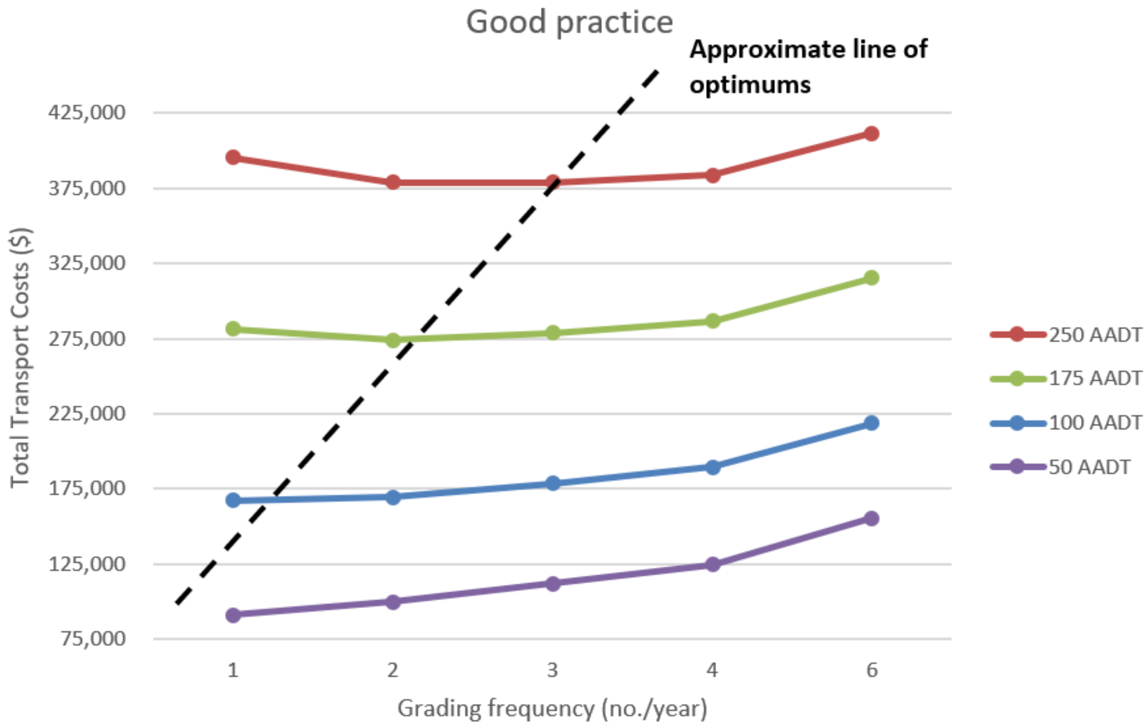
Figure 4.3: Impact of quality and type of grading on performance

(a) Effectiveness of grading (Green = Good) (b) Deterioration trend (Green = Good)



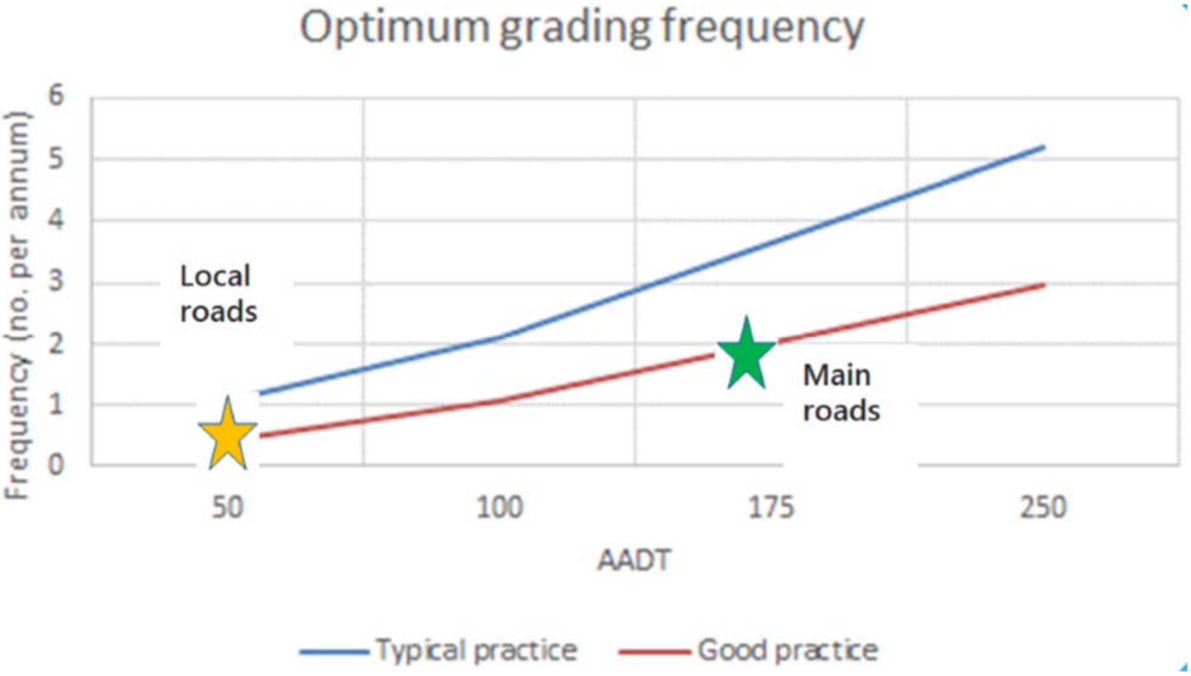
Source: Austroads (2018a).

Figure 4.4: Determination of optimum grading frequency: good practice



Source: Austroads (2018a).

Figure 4.5: Comparison of outcomes for the optimised frequency of grading



Source: Austroads (2018a).

4.2 Materials

Materials Summary/Outcome

The choice of gravel material for unsealed roads is a compromise between high plasticity to minimize gravel loss in dry seasons and low plasticity to prevent rutting and deformation in wet conditions.

Specifications require a mechanically stable grading with a higher fines content for binding action to occur.

HV loads applied to unsealed roads can cause ravels, corrugations, slippery surfaces, and material erosion.

Finding the 'sweet spot', such as the 'Good' range found in the Port Macquarie case study reported in Austroads (2020a), can lead to optimal material choice and minimize the negative effects of HV loads.

This section of the report discusses the impact of materials and construction quality on the long-term performance and deterioration of unsealed roads, and how these factors may influence the decision to seal such roads. When selecting materials for unsealed road pavements, factors such as availability, material properties, cost, and environmental considerations are considered. Proper material selection is crucial for achieving optimal performance of unsealed roads.

Experience in the field has informed the identification of desirable material properties and criteria for selecting gravel wearing course materials. The following characteristics are important for achieving satisfactory performance:

- The surfacing material should contain enough binder in the form of fine-grained material to prevent the surface from becoming loose and dusty during dry periods, resist material movement, reduce gravel loss, and prevent the formation of corrugations. However, if the fines content is too high, the bearing capacity of the road will be substantially reduced in wet conditions, leading to excessive deformation and a slippery surface.
- The material should not contain a large quantity of coarse particles that may become exposed through trafficking and lead to high surface roughness or pose a traffic hazard. Large particles may also hinder efficient reshaping of the road surface and increase the risk of pothole formation if they are dislodged by traffic or grading operations. Moreover, they may prevent even transmission of compaction forces through the layer, resulting in low densities and a greater likelihood of potholing.

The selection of an appropriate range of plasticity for road construction is dependent on the climate conditions of the region. The criteria for selecting the range of plasticity can vary, as illustrated Table 4.3.

Table 4.3: Recommended plasticity characteristics for gravel wearing courses

Climate	Liquid limit not to exceed (%) [1]	Plasticity Index (%) [1]	Linear Shrinkage (%)
Moist throughout the year	35	4 – 9	2 – 5
Seasonally wet	45	6 – 20	3 – 10
Predominantly dry	55	15 – 30	8 – 15

1. Higher limits may be acceptable for some laterites or concretionary gravels that have structure that is not easily broken down by traffic. Lower limits may be appropriate for some other gravels that are easily broken down by traffic. Any variation from these limits should be based on carefully collated local experience.

Source: Adapted from Toole et al (2001).

In addition to the above-mentioned factors, the choice of the gravel surfacing material is also critical in ensuring the longevity and performance of unsealed roads. Studies have shown that the selection of a suitable gravel material involves a compromise between high plasticity to minimize gravel loss during dry conditions and low plasticity to prevent rutting and deformation in wet conditions (Morosiuk & Toole 1997). Specifications for gravel materials typically prioritize these properties along with a mechanically stable grading that includes a higher fines content to provide binding action (Paige-Green 1987).

In an example case for an Australian LGA (Austroads 2020a), the gravels used for unsealed roads were typically a compromise between high plasticity to minimize gravel loss in dry conditions and low plasticity to prevent rutting and deformation in wet conditions. However, some roads in hilly areas tend to rut and become slippery in wet conditions due to the properties of the gravels used. Both Figure 4.6 and Figure 4.7, illustrates the properties of typical gravel surfacing materials and shows a desirable material of "good" performance under HVs (shaded in green in Figure 4.6). Material properties have been weakly represented in road deterioration models, and other factors such as rainfall have been shown to have both beneficial and detrimental effects.

Figure 4.6: Performance assessment of typical gravel surfacings in an Australian LGA

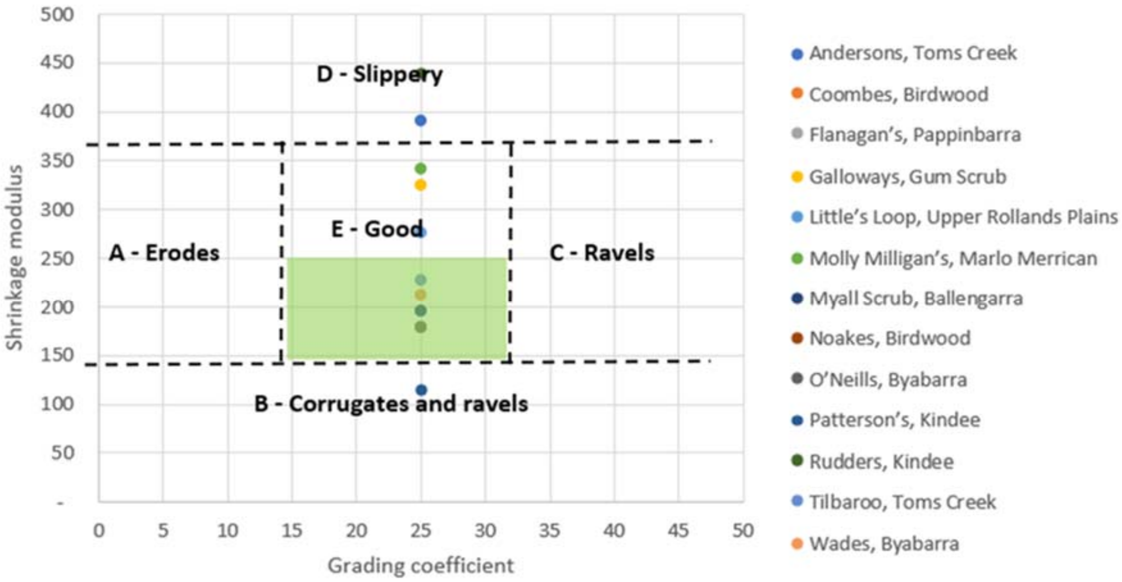
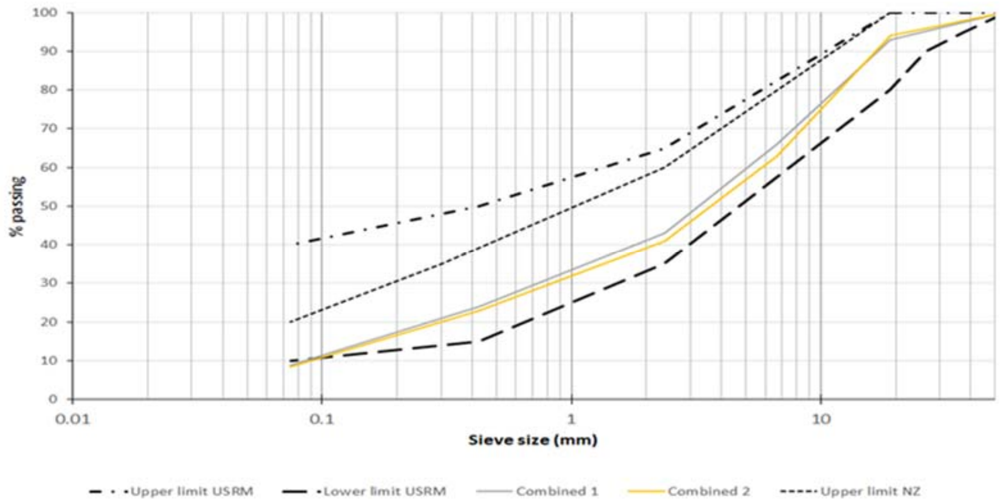


Figure 4.7: The optimal material combined gradings for recycled concrete from a single source



4.3 Traffic

Traffic: Summary/Outcome

Vehicle use is a major contributor to road deterioration, particularly for unsealed roads.

Increased traffic on unsealed roads leads to increased maintenance costs, which may result in the decision to seal the road.

The deterioration rates for unsealed roads vary based on factors such as gravel material, climate, and geometry.

HV axle loading has not been isolated as a specific parameter in most studies.

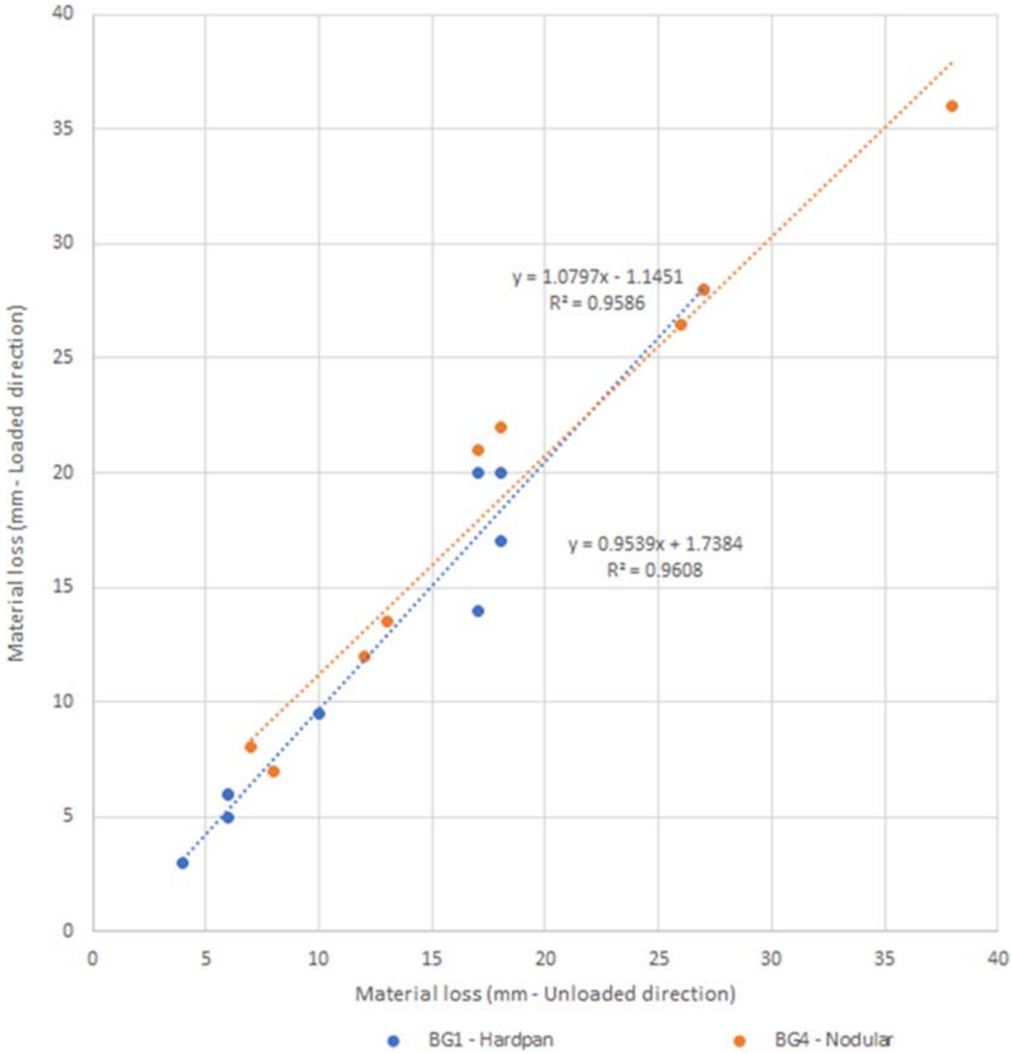
Heavy axles may contribute to wear through greater tractive forces, while unloaded axles also damage roads through bouncing and surface wear. Based on the evidence provided, it is recommended to use the number of axle pairs to represent HVs when estimating traffic loading-based cost attribution parameters for unsealed roads. This approach has been found to provide more accurate cost attribution compared to other approaches such as assigning light vehicle unit (LVU) factors or using PCU factors.

Vehicle use of roads is the highest contributor to the deterioration of roads. In the case of unsealed roads, as vehicle traffic increases, the cost of maintenance will also increase. This may lead to the decision to seal an unsealed road. This section of the report describes how traffic impacts on the performance and subsequent deterioration of unsealed roads.

There are limited research results relevant to estimating traffic loading-based cost attribution parameters based on traffic for unsealed roads: there are conflicting findings ranging from no attributable costs to separate attributable costs for both light and HV usage. The deterioration rates for unsealed roads are also known to vary markedly with factors such as the properties of the gravelling material, climate (rainfall and rainfall intensity) and geometry, as explained earlier. This contributes to the large variation in research findings. Furthermore, most studies have been conducted on public roads with low proportions of HVs; therefore, observations are limited with axle loading having not been isolated as a specific parameter.

Drawing on an example from southern Africa (Toole 1987), where directional differences in HV daily ESAs varied by a factor of up to 4, the material loss (Figure 4.8) was found to be almost identical for both the loaded and unloaded directions on two sections of road subject to low maintenance and monitored over a 12-month period where traffic was reasonably well separated by travelling direction. Ride quality values were also similar. The reasoning given for the absence of any clear effect of level of loading was that heavy axles may contribute to wear through the application of greater tractive forces and possible dynamic loading, while unloaded axles also damage unsealed roads as the axles tend to lose contact with the road surface and effectively bounce more than loaded axles, leading to surface wear/damage.

Figure 4.8: Comparison of material loss for two directions on an unsealed calcrete surfaced road



Source: Toole (1987).

Note: Calcrete, also called Hardpan, calcium-rich duricrust, is a hardened layer in or on a soil. It is formed on calcareous materials as a result of climatic fluctuations in arid and semiarid regions.

In a review of cost attribution for Australia, Martin and McLean (2005) reported that the South African gravel road maintenance cost relationship (Paige-Green 1987) occupies the middle ground within the range of research findings and is approximately equivalent to using passenger car unit (PCU), and therefore PCU-km, as the allocation parameter for unsealed road maintenance costs.

Such an approach was applied in a study of the marginal cost (MC) of road wear for unsealed roads in Queensland, with LVU factors of 1, 2 and 5 applied to HVs. It was shown that the assignment of an LVU factor to represent HVs increases the MC in direct proportion to the factor chosen. For example, adopting an LVU of 3 for a 6-axle articulated truck, in proportion to the number of axles, would increase the MC values by a factor of three. An alternative would be to employ a PCU factor, in which case the multiplication factor could be as high as 5 for the same vehicle, or much higher for multi-combination vehicles.

Based on this evidence an approach whereby the number of axle pairs are used to represent HVs is recommended.

4.4 Environmental Considerations

Various environmental factors can have a significant impact on unsealed road performance. Based on the presence of these factors, consideration may be made towards investment in upgrades of an unsealed road to a sealed road. This section of the report focuses on some of these factors broadly (Section 4.4.1), as well as the impact of moisture in more detail (Section 4.4.2). In addition, this section also details the impact which soil erosion and sediment control (Section 4.4.3) and the availability of natural resources will have on road surface selection (Section 4.4.4). Lastly, this section of the report details the impacts which geology and topography, in conjunction with climate, will have on unsealed road selection and performance (Section 4.4.5).

Environmental Considerations: Summary/Outcome

Unsealed roads can affect different elements of the environment including waterways, the air, land and its biodiversity.

The presence of moisture on unsealed roads can cause several problems, including reduced traction, increased maintenance costs, and accelerated road deterioration. However, proper cross fall and drainage techniques, such as constructing table drains, can help to effectively manage and remediate the issue of moisture on unsealed roads.

As road surfaces erode due to traffic and the environment, they need to be replaced. The replacement of gravel is both a financial and an environmental burden.

4.4.1 Environmental Impacts

Unsealed roads can affect different elements of the environment including waterways, the air, land and its biodiversity. For example:

- Local roads may be used to transport many different types of hazardous material such as fertilisers, pesticides or fuel, which can threaten water supplies and natural waterways if spills occur as a result of road accidents.
- Air pollution from unsealed roads will be caused by vehicle and dust emissions.
- Degradation of the landscape surrounding the road can occur due to soil contamination by chemicals used during road use and maintenance activities, soil compaction by vehicles and machinery and by soil loss due to erosion from bare or disturbed areas of soil.

Table 4.4 provides a summary of the additional potential negative environmental impacts which an unsealed road may have on the surrounding environment. Although extensive, this list is not exhaustive, and does not cover all environmental impacts. Where these negative environmental impacts are occurring due to the presence of an unsealed road, consideration may be given to upgrade works in sealing the unsealed road.

Table 4.4: Potential environmental impacts of unsealed roads

Environmental impacts	Considerations
Erosion and sedimentation	• Erosion of material from the road surface, table drains and batters, with the possibility of material removal and concentrated damage (gullies, channels, etc.). • From an ecological perspective, sediment is the most significant of all road run-off pollutants. Unsealed roads can generate large amounts of sediment which can cause serious environmental damage to waterways. • Where a road is poorly located and/or the surrounding drainage system is poorly designed, an unrestricted flow can yield up to 15 t of sediment per km per year from a 10 m wide unsealed pavement. • Potential impacts of sediment include burying aquatic vegetation which leads to reduced water depths, smothering and killing of fish eggs/aquatic larvae, turbidity which reduces light and interferes with the respiration and feeding of aquatic animals/plant, and transmission of other pollutants such as heavy metals.
Local air impacts	• Unsealed roads can negatively impact the quality of air through dust and vehicle emissions. • Dust can impair visibility and safety for motorists, pose a health hazard and smother roadside vegetation.
Land degradation	• Vehicle traffic and maintenance activities along unsealed roads can damage soils and displace previously intact parts of the landscape. • Soil can become contaminated, compacted or eroded following road construction, usage and maintenance. • Weed spread caused by vehicles or maintenance activities. • Roads can modify catchment hydrology leading to increased erosion or increased recharge to ground water, as well changing local ground water and surface water flow. • Local water-tables may be affected causing increased salinity of wetlands and streams.
Biodiversity	• Road corridors can have both positive and negative impacts on wildlife and native vegetation. • Road corridors can remove/reduce habitat, act as a barrier to wildlife movement and result in significant roadkill. • Road corridors can present difficulties for fish movement at culverts and road crossings. • High sedimentation of waterways can kill aquatic species. • Road corridors can facilitate the introduction of exotic flora and fauna due to soil and habitat disturbances.
Resource use and greenhouse gas emissions	• Unsealed road construction and maintenance activities utilises natural resources and energy. • Carbon dioxide (CO2) emission are generated at an approximate rate of 2.7 kg CO2/litre diesel fuel used during construction and maintenance activities. • The growing scarcity of natural materials (including water) in some areas can increase the total cost of pavement construction and maintenance. • Using alternative materials, such as recycled and marginal (non-standards) materials can assist in making unsealed roads more sustainable. • Choosing materials with the lowest life-cycle costs are becoming increasingly important.

Source: ARRB (2020).

4.4.2 Moisture

As described in Section 4.2, the performance of unsealed roads is known to be critically dependent on the properties of materials used, and the quality and effectiveness of the construction (or resheeting) phase and the maintenance and operations phase. However, critical factors in addition to the selection of materials include how the material is placed, with the moisture content during mixing, spreading and compaction playing a major role in achieving compacted density and mobilising soil cohesion (ARRB 2020).

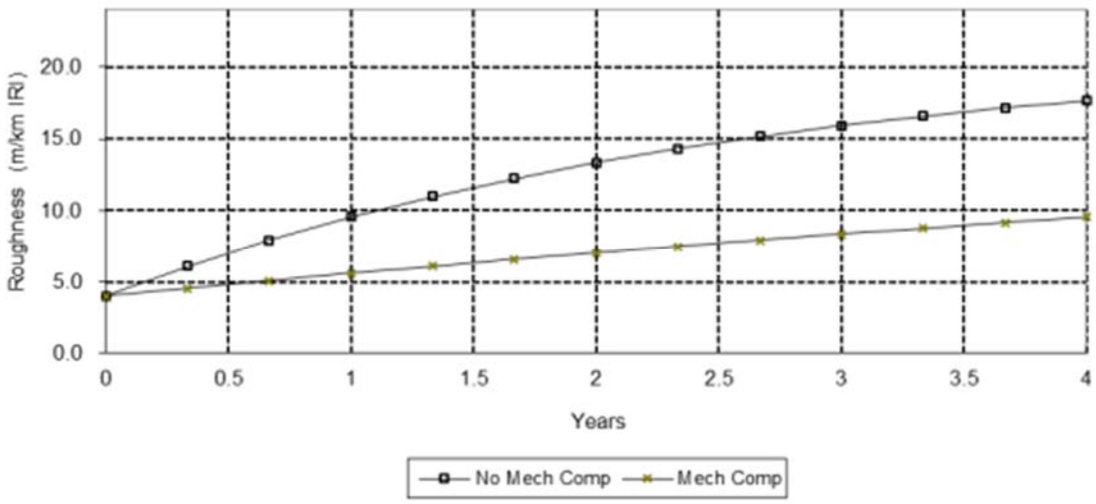
Excessive moisture in pavement materials is one of the most important factors affecting performance, as the stiffness/strength of unbound materials, and subgrade performance, typically inversely correlates with the moisture content. Moisture sensitivity of nonstandard and marginal materials makes moisture entry more impactful on the performance of low volume roads than vehicle load associated stresses.

Based on this finding, Queensland Department of Transport and Main Roads (TMR 2015) *Sealing of unsealed roads with low traffic* recommends the following considerations when sealing an unsealed pavement and developing the sealed solution:

- Drainage assessment should follow the relevant drainage guidance for the jurisdiction, considering both small- and large-scale flows.
- The collection of data regarding water flow through various tools such as Lidar surveys, local authority records, and history is critical for effective drainage.
- The increased intensity of rain on small catchments can impact channel size, location, volume, and flow over time. These changes accelerate during peak flood periods.
- Identification of the type and condition of existing and required drainage, including surface drainage, drainage channels, table drains, side drains, mitre or turn out drains, relief drains, and cut off/interceptor drains.
- The identification of culverts and other structures including adequacy of outlet, width, condition, structural strength, erosion, response to flooding, settlement, scouring, capacity/level of immunity.
- Unbound granular pavement materials should only be used in applications where the degree of saturation can be maintained below about 70% when trafficked. Moisture contents above this level may result in significant loss of strength and accelerated pavement deterioration.
- Adequate crossfall for drainage is critical.
- Additional drainage for sheet flow and/or acceptance of the afflux effects may be required for an increase in the height of the road's surface.
- Well-constructed and maintained shoulders impact a pavement's moisture content as they provide lateral structural support, restrict water movements under the road, and carry water away from the pavement.
- Open table drains in cuttings are preferred, and if table drains are necessary, aim for regular diversion drains to reduce the need for them.

Studies have shown that significantly different rates of deterioration have been observed depending on the process used to place the material and the moisture content during mixing, spreading and compaction. For example, not achieving compaction close to the defined optimum moisture content for a material can lead to accelerated deterioration as illustrated in SectionFigure 4.9 (Austroads 2020a).

Figure 4.9: Effect of mechanical compaction on road deterioration



Source: Toole et al. (2001; cited in Austroads 2020a).

4.4.3 Soil Erosion and Sediment Control

Soil erosion occurs when soil particles are dislodged and transported by the action of water and/or wind. Sediment is the material produced by erosion. Long-term erosion and sedimentation from unsealed roads is inevitable. However, effective management can minimise erosion and sedimentation and in turn reduce the overall financial cost of maintenance, potential public safety risks and environmental impacts (NSW Office of Environment & Heritage 2012).

Methods for effectively managing soil erosion and sediment control, include:

- Conduct regular inspections to check that the road formation is performing adequately.
- Ensure that drainage is working and the road and discharge areas are stable.
- Inspect sediment and erosion control structures during and after heavy rainfall and minimise traffic where possible.
- Maintain effective erosion and sediment control measures.
- Ensure road usage is commensurate with road design.
- Minimise the area of soil disturbed and exposed to erosion when conducting maintenance operations.
- Stabilise and rehabilitate disturbed soil as soon as possible.
- Consider sealing an unsealed road where oil erosion and sediment control are an ongoing issue.

4.4.4 Availability of Natural Resources

One of the most critical – and largely unappreciated - properties of unsealed roads is the use and depletion of natural resources. As road surfaces erode due to traffic and the environment, they need to be replaced. The replacement of road surfaces is particularly critical for gravel roads that require better quality or engineered material. The gravel layer typically erodes within 5-10 years and needs complete replacement. The replacement of gravel is both a financial and an environmental burden. If the eroded gravel is not replenished, the full investment can be lost within 3-7 years' time. In the future the pressure on the environment will become increasingly important during the surfacing decision process (Henning et al. 2006).

4.4.5 Climate, Geology and Topography

The prevailing climate, geology and topography of an area, can be some of the most significant factors in unsealed road materials selection, design, construction, maintenance, and consideration for capital works and upgrades (Henning et al. 2005). This section of the report highlights why and how these elements should be considered by LGAs, and how these elements may impact upon decision making.

Henning et al. (2005) provide some examples of adverse combinations of these factors of climate, geology and gradient condition for unsealed roads:

- very wet climatic conditions in combination with clayey materials
- dry conditions in combination with sandy material which causes high dust generation and loose sand
- steep gradients combined with wet weather
- periodic flooding combined with unsealed surface.

Factors which needs to be considered, include:

- Topography
  - Roads should be located, where possible, to follow the natural contours and maintain the road at a manageable grade.
  - The design of road locations should avoid steep hill slopes which will require large amounts of cut and fill in the construction process. Cut and fill areas have higher landslip and erosion risks than natural land surfaces.

- Roads can significantly alter the natural drainage pattern of the area, particularly on low-lying land or where drainage is essentially uncoordinated or allows sheet flows across vast areas. This can lead to increased flow in designated drainage channels, which may become prone to erosion and bank instability.
- Siting roads along ridges is sometimes desirable to minimise earthworks and drainage problems (ARRB 2020).

- Geology & Soil Type
  - Relevant information about the area's soils, geology and land capability should be gathered during planning of the route and used as a guide to identifying potential problem areas.
  - Road building should be avoided on soil types prone to landslips, particularly if they are on steep hills. The native vegetation is sometimes a good indicator of these soils because vegetation growing on an angle or the occurrence of benches may indicate prior landslips which should be investigated before the area is approved as a new road location.
  - Road construction on erosion prone soils will increase the impact on the environment and increase construction costs through the need to install permanent erosion control measures.
  - Road construction sites should be assessed for the potential existence of acid sulphate soils (ASS) prior to works commencing. Lands typically subject to ASS are low-lying swampy areas. If these areas cannot be avoided, mitigation of the effects of ASS should be addressed in the environmental review and implemented through the environmental management plan (EMP) (ARRB 2020).

4.5 Climate Change & Extreme Weather Events

This section of the report expands on Section 4.1, by discussing the impacts which the prevailing climatic conditions (Section 4.5.1), extreme weather events (Section 4.5.2) and a changing climate (Section 4.5.3) may have on the unsealed road network, and how sealing of unsealed roads may be beneficial in these circumstances.

Climate Change & Extreme Weather Events: Summary/Outcome

Assuming normal (i.e. typical for the given area) weather patterns, the surface type and material should ensure a reasonable service level in terms of accessibility. Where an unsealed road is not providing adequate access in normal climate conditions, consideration should be given to upgrading this road initially to an all-weather, durable unsealed surface. Consideration could also be given to upgrading to a sealed surface.

When considering the risks to the road network, there are two main aspects through which climate change impacts the road network:

- road infrastructure – for example, pavements and structures impacted by flooding or cyclones, leading to possible severe damage, loss of function, or accelerated deterioration
- road use – for example, temporary loss or reduced quality of access, with increased journey times on preferred routes or from diversions. Operating conditions are also likely to be less safe with reduced vehicle control during adverse weather conditions and where overtopping occurs.

4.5.1 Consideration of the Prevailing Climate

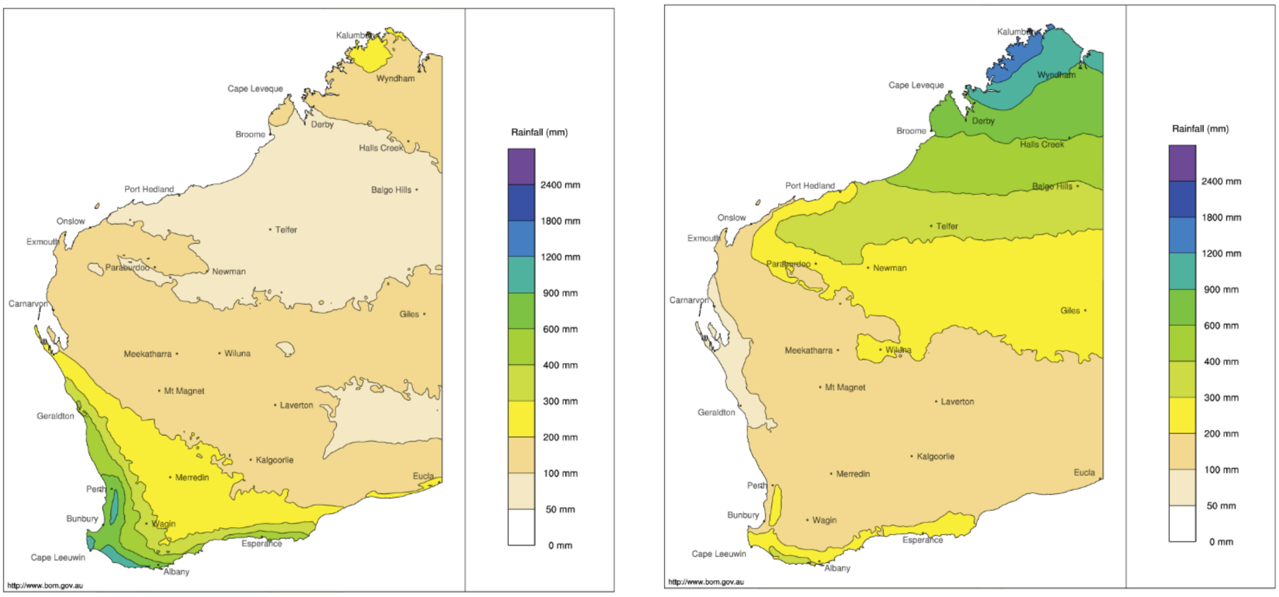
When undertaking decision-making in unsealed roads planning, design, construction, maintenance, operations, and upgrades, consideration must be given to the prevailing climate of the region. Asset managers can use climate trend data, together with data on likely causes and effects, to model projected conditions and plan for the changes (DPIRD 2023b).

The northern and southern parts of WA have contrasting climates (the north is tropical, with summer rainfall), while the south has a Mediterranean climate. The prevailing climate in WA is classified by the Encyclopaedia Britannica (2023) as follows:

- Anticyclones
  - A major determinant of the weather is the movement of an anticyclone that produces winds in an east-west direction across the continent for about half the year. In winter this system moves to the north and is responsible for clear skies, sunny days, and easterly winds in the tropics.
  - To the south of the anticyclonic system, westerly winds and a procession of cold fronts bring cool, cloudy weather and rain and westerly gales along the southern coast.
  - The anticyclonic belt has moved so far south by the summer that its axis is off the southern coast. Easterly winds prevail over most of the state, but in the far north a depression develops, bringing westerly monsoon (wet-dry) wind patterns to the coastal districts northeast of Onslow and to parts of the Kimberley.
- Tropical cyclones
  - Several tropical cyclones (known elsewhere as hurricanes or typhoons) develop offshore during the northern wet season, which lasts from about December to March. They move inland between Broome and Onslow, although occasionally have travelled south of Perth before curving inland.
  - Tropical cyclones can be highly destructive, but they are also beneficial, bringing widespread rain to otherwise parched inland areas.
- Precipitation
  - The highest annual precipitation occurs in the extreme north, on the Mitchell Plateau in the Kimberley, and in the extreme southwest, between Pemberton and Walpole in the karri country. In both locations mean annual rainfall is more than 1,400 mm.
  - Precipitation decreases south and north from both locations and with increasing distance inland from the coast. The driest areas receive less than 200 mm annually, and possibly less than 150 mm)
- Temperature
  - The hottest months are November in the Kimberley, December a little farther south, and January/February in the rest of the state.
  - July is the coldest month.
  - Wyndham is the most consistently hot place, with a mean maximum monthly temperature of about 35.6 °C throughout the year.
  - Marble Bar has the highest seasonal mean maximum monthly temperatures in Australia, registering near 38 °C from November through March.
  - In winter, temperatures may fall below freezing over most of the inland part of the state south of the Tropic of Capricorn; on occasion, the temperature has dropped to about −6 °C in the southwestern part of the state.
  - Frosts may be widespread over the southern part of the state and occasionally extend into the tropical zone but are not generally troublesome. These are most frequent in July and August.
  - Snow is rare, and only in southern areas, especially in the Stirling Range, does it occasionally lie on the ground for a few hours.

Figure 4.10 provides a summary of the average rainfall, for the 30-year climatology, across the April to November (a), and the October to April (b), periods. As can be seen from Figure 4.10, there is significant variation across the state. Therefore, it is important that LGAs are aware of their rainfall conditions, and plan for unsealed road maintenance accordingly. Whilst most analysis types for maintenance planning employ annual average value of climate related parameters, such as rainfall, based on trends; the variation shown between (a) and (b) show that examination of reported daily or seasonal data, rather than annual data, can show considerable variation in the reported metrics, and thus, maintenance needs.

Figure 4.10: Average rainfall – 30-year climatology (1981 to 2010)

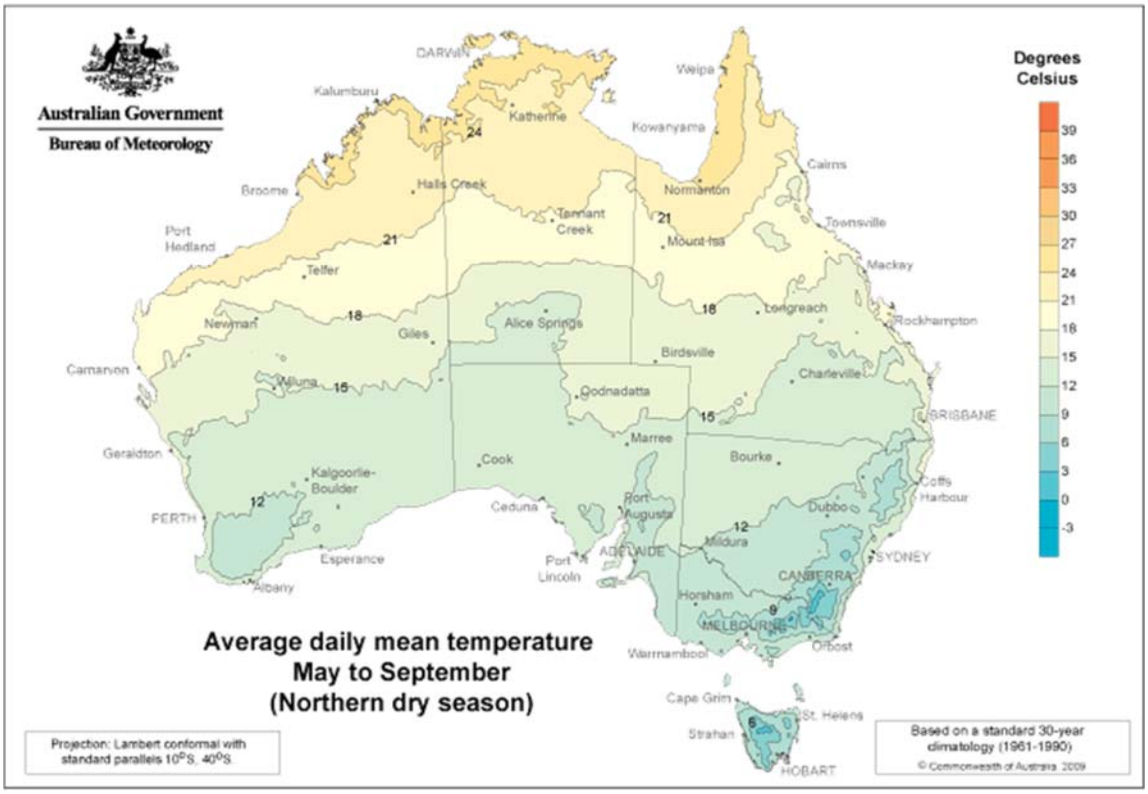


(a) April to November (b) October to April

Source: Bureau of Meteorology (2020).

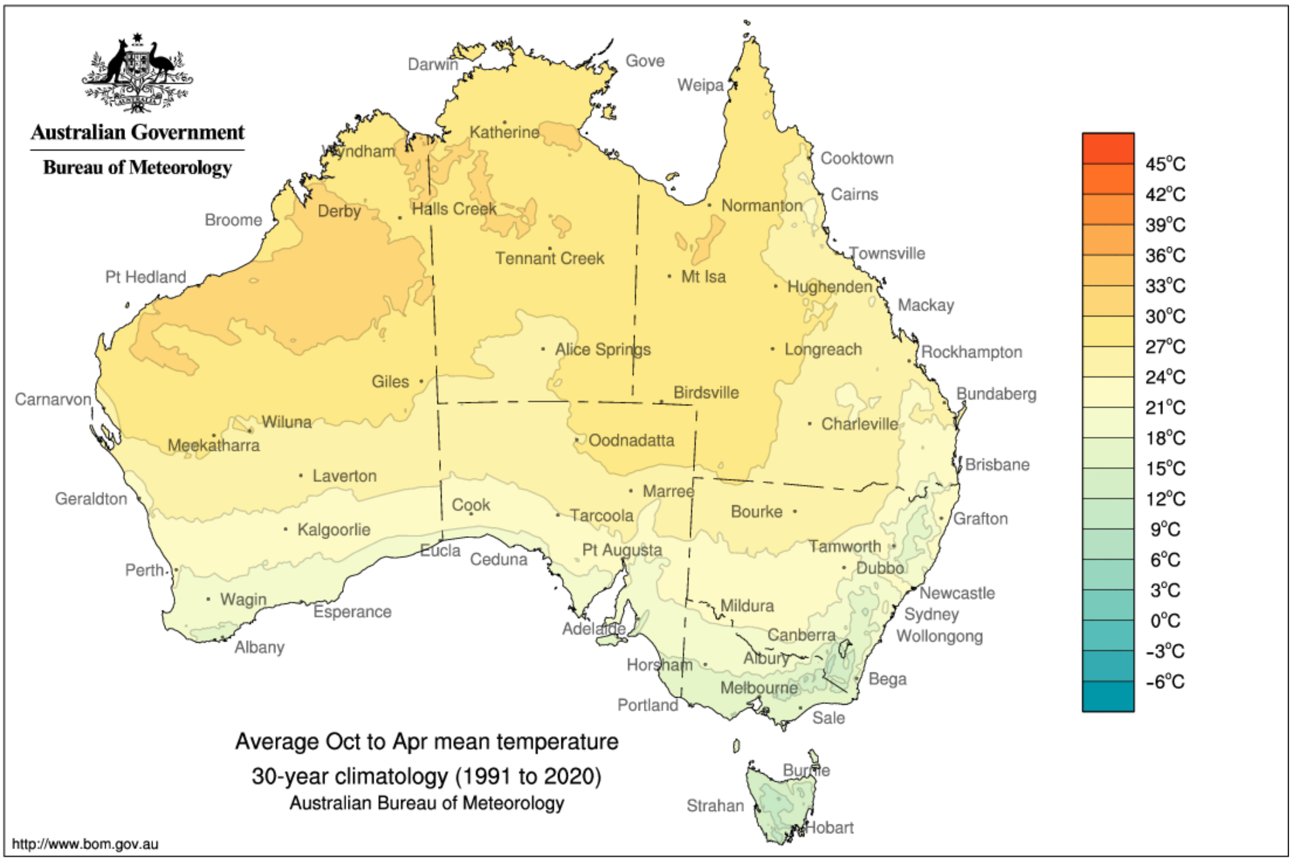
Figure 4.11 provides a summary of the average daily mean temperature for the May to September, and Figure 4.12 provides a summary of the October to April data. There is significant variation across the state, and in varying temperate cycles. Therefore, consideration must be given to the appropriateness of the prevailing temperature conditions in the region, and for the period of the year, when works are to be undertaken.

Figure 4.11: Average daily mean temperature – northern dry season – 30-year climatology (1961 to 1990)



Source: Bureau of Meteorology (2009).

Figure 4.12: Average daily mean temperature – northern wet season- 30-year climatology (1991-2020)



© Commonwealth of Australia 2021, Australian Bureau of Meteorology ID code: AnalyserRen Issued: 18/02/2021

Source: Bureau of Meteorology (2021).

4.5.2 Regional Climate, Natural Hazards and Extreme Weather Events

Assuming normal (i.e. typical for the given area) weather patterns, the surface type and material should ensure a reasonable service level in terms of accessibility (Henning et al. 2005). Where an unsealed road is not providing adequate access in normal climate conditions, consideration should be given to upgrading this road to a sealed surface.

Regardless of the surface type, effective drainage provisions are vital in ensuring the performance of the road under wet conditions. It is often the interaction of water, within and adjacent to the road pavement/surface that has an overarching impact on road performance (Henning et al. 2005). The impact of moisture on unsealed roads is described in further detail in Section 4.4.2.

However, there would be instances where natural hazards, extreme weather, and disastrous climatic events (e.g. cyclones) may occur. These events have the potential to damage and/or disrupt the operation of road infrastructure with unacceptable associated social, environmental and economic consequences (Hall et al. 2022).

In WA, two key natural hazards of concern are tropical cyclones and bushfires. Tropical cyclones are responsible for most of the extreme rainfall events across north-west WA and generate up to 30% of the total annual rainfall near the Pilbara coast. Tropical cyclones make a valuable contribution to rainfall in the north-west, and inter-annual and spatial variability strongly affects the reliability of this rainfall as a source for water supplies. Over the last 40 years, the frequency of tropical cyclones has not changed significantly in WA, but there is some evidence that the frequency of the most intense cyclones has increased (DPIRD 2023b).

Fire danger has increased across Australia over the last 40 years in response to drier and hotter conditions. The relative importance of weather and fuel varies in determining the risk of fire. Fires are not limited by the amount of fuel or the weather during the dry season in northern savannas. In south-west forest areas, fire risk is strongly determined by weather conditions and fuel moisture content.

Between 1973 and 2010, annualised fire weather danger (defined by the Bureau of Meteorology) showed a non-significant, increasing trend at Port Hedland, Carnarvon, Meekatharra, Geraldton, Albany and Esperance, and a statistically significant increase at Perth, Kalgoorlie and Broome. On a seasonal basis, fire weather danger increased more in winter and spring, compared to summer and autumn. The frequency of extreme fires also increased, with significant increases at Perth, Kalgoorlie and Broome (DPIRD 2023b).

4.5.3 Consideration of Climate Change and Vulnerability

Unsealed road networks need to be safe, efficient, cost effective, and resilient to climate shocks (Bland Shire Council 2022). WA's climate has changed over the last century, particularly over the last 50 years. Average temperature has risen about 1 °C. Rainfall has increased over the north and interior, declined along the west coast, and declined by about 20% over the lower south-west. Fire risk has increased across the state (DPIRD 2023b). The latest Intergovernmental Panel on Climate Change (IPCC) report (2021; cited in Hall et al., 2022) reported a large temperature increase over land (1.59 °C increase from 2011–2020) due to human drivers. Hot extremes (including heatwaves) have become more frequent and more intense as well as the frequency and intensity of heavy precipitation events and other extreme climatic and weather events, with human-induced climate change as the main driver. Furthermore, the mean sea level has risen faster since 1900 than over any preceding century in at least the last 3,000 years.

When considering the risks to the road network, there are two main ways that climate change impacts the road network:

- road infrastructure – for example, pavements and structures impacted by flooding or cyclones, leading to possible severe damage, loss of function, or accelerated deterioration
- road use – for example, temporary loss or reduced quality of access, with increased journey times on preferred routes or from diversions. Operating conditions are also likely to be less safe with reduced vehicle control during adverse weather conditions and where overtopping occurs (Hall et al. 2022).

These factors have the potential to greatly impact the condition of road infrastructure across the region and the forecasted changes in these factors must be continually considered in decision making for asset maintenance, upgrade and renewal programs (Hall et al. 2022). Further, climate change is exacerbating the already significant LGA time and resources devoted to road maintenance, particularly during droughts as water is a critical component of roadworks (Bland Shire Council 2022).

For unsealed roads, with droughts becoming more intense and frequent, availability of water becomes a major constraint to road maintenance. For example, without the optimum moisture content for compaction, the lifespan of the unsealed roads reduces due to excessive loss of fines and the poor binding of material causing degradation (Bland Shire Council 2022).

Network vulnerability assessment, as defined by Taylor (2017, cited in Hall et al., 2022) provides a methodology for finding component weakness in the transportation network that render the network vulnerable to the consequences of failure or degradation. The concept of vulnerability can be applied to individual assets or to the networks which consist of a number of assets (Hall et al. 2022).

Vulnerability is defined as the degree to which a system is susceptible or unable to cope with, adverse effects of climate change, including climate variability and extremes (PIARC 2015; cited in Hall et al. 2022). When considering vulnerability, there are three main concepts often referred to:

- Exposure: a function of the character, magnitude and rate of climate change and variation to which a system is exposed
- Sensitivity: the degree to which something is affected, either adversely or beneficially, by climate related stimuli

- Adaptive capacity: refers to the system's ability to cope with and adapt to existing climatic variability and future changes (Taylor 2020, cited in Hall et al., 2022).

4.6 Whole-of-life Costs

Whole of Life Costs: Summary/Outcome

Maintenance and sealing decisions must account for expected costs and benefits across the asset's service life.

Upgrade and maintenance costs are offset by (generally) lower road user costs (cost savings), the greater the agency investment.

Management decisions should target the 'Goldilocks point' where lowest total transport costs (TTC) are achieved.

Modelling and estimates for specific regions and roads is important as management and road user costs vary substantially due to traffic volumes, climate and weather, materials and remoteness, geology and topography, and more.

The rules of thumb, as described in ARRB (2020) on when to seal an unsealed road, subject to a follow-up economic analysis, are as follows:

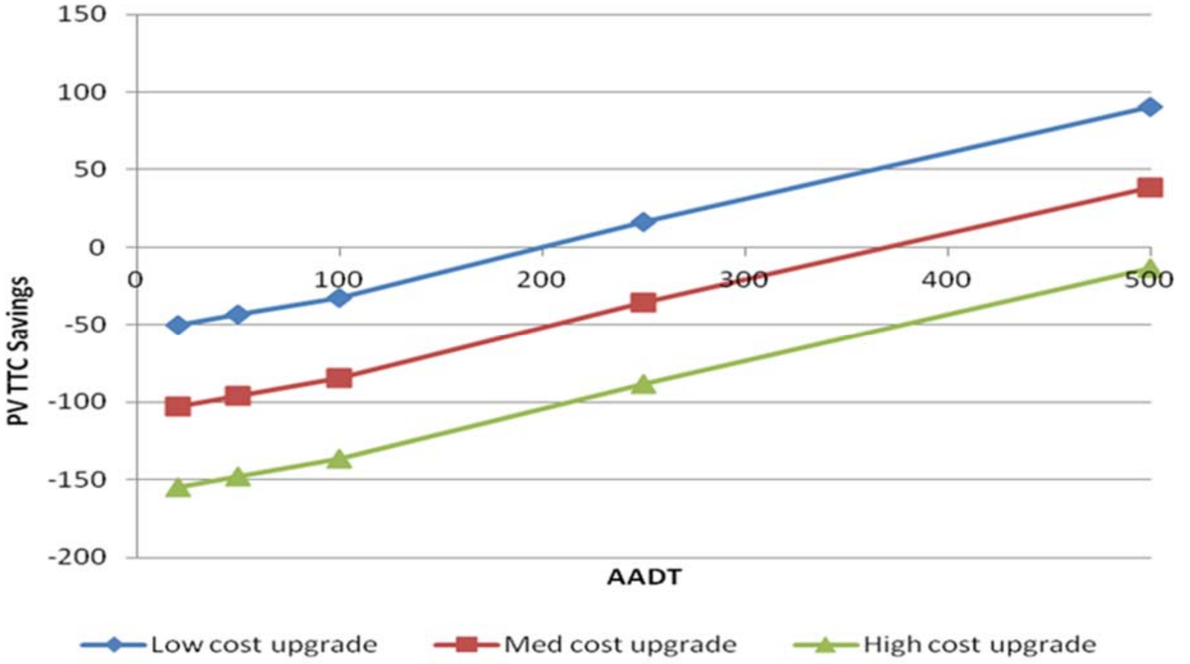
- If traffic volumes are less than 100 vehicles per day (veh/day), it is unlikely that sealing can be justified unless resheeting the existing unsealed road is extremely costly due to scarcity of suitable locally-available gravels.
- If traffic volumes are 100 to 250 veh/day, then the decision to seal an existing road will be highly dependent upon the outcome of a properly conducted economic analysis.
- If traffic volumes are greater than 250 veh/day, then sealing the existing road is highly likely to be justified based on a properly conducted economic analysis.

Based on a specific study from northern Queensland (ARRB Group 2011), Figure 4.13, shows the net present value (NPV) of total transport costs (TTC) by level of AADT and varying levels of upgrade cost. In this example, a breakeven level of traffic for upgrade is approximately 200 veh/day if improvement costs are low; however, the breakeven veh/day is at significantly higher traffic levels when costs are high. It is important, therefore, that economic assessments should be tailored to local conditions, and as demonstrated for this example, a major factor dominating the economic viability of upgrading to seal is the improvement cost required. In a further example from the same study, the breakeven volume shifted significantly when diverted traffic was introduced, as shown in Source: ARRB Group (2011).

Figure 4.14.

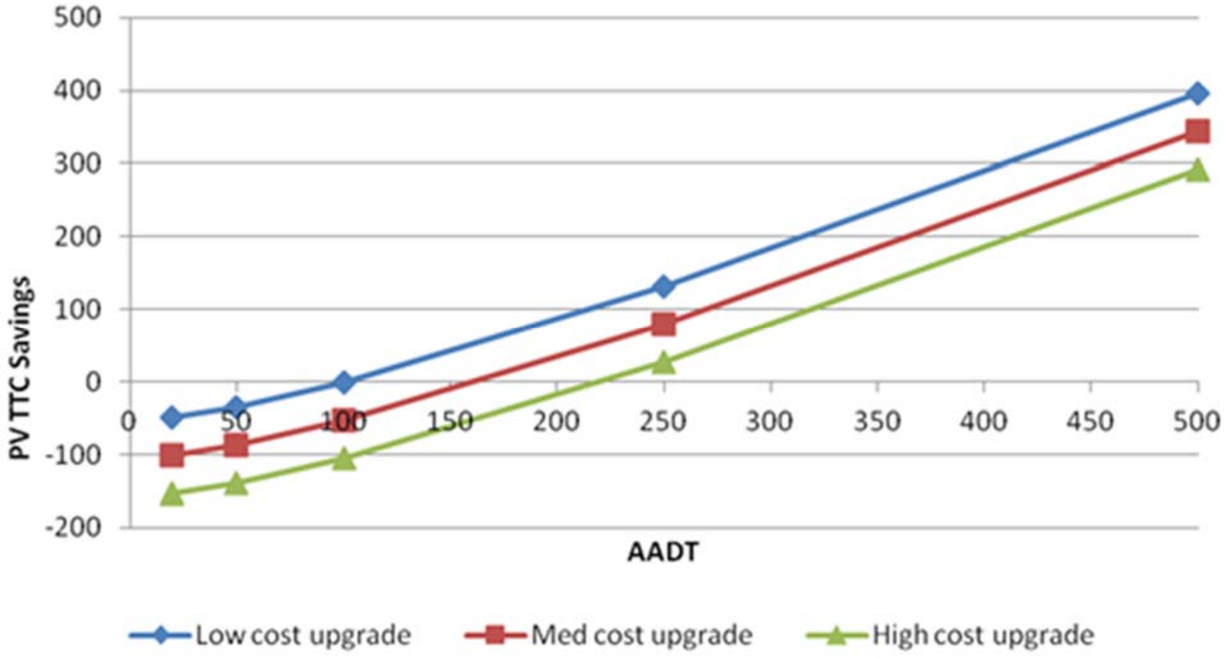
As discussed throughout this report, there are many other factors which should be considered when undertaking unsealed roads asset management decision making. Each of these contributes to the whole-of-life costs of the unsealed roads. The whole-of-life cost of an unsealed road refers to the costs which are incurred at every phase of the roads' operating life. These phases are: planning and design, construction, routine & periodic maintenance, operation & use, renewal / upgrade / capital works, and decommissioning.

Figure 4.13: Net present value of total transport costs against AADT, by level of upgrade cost (no diverted traffic) assumed)



Source: ARRB Group (2011).

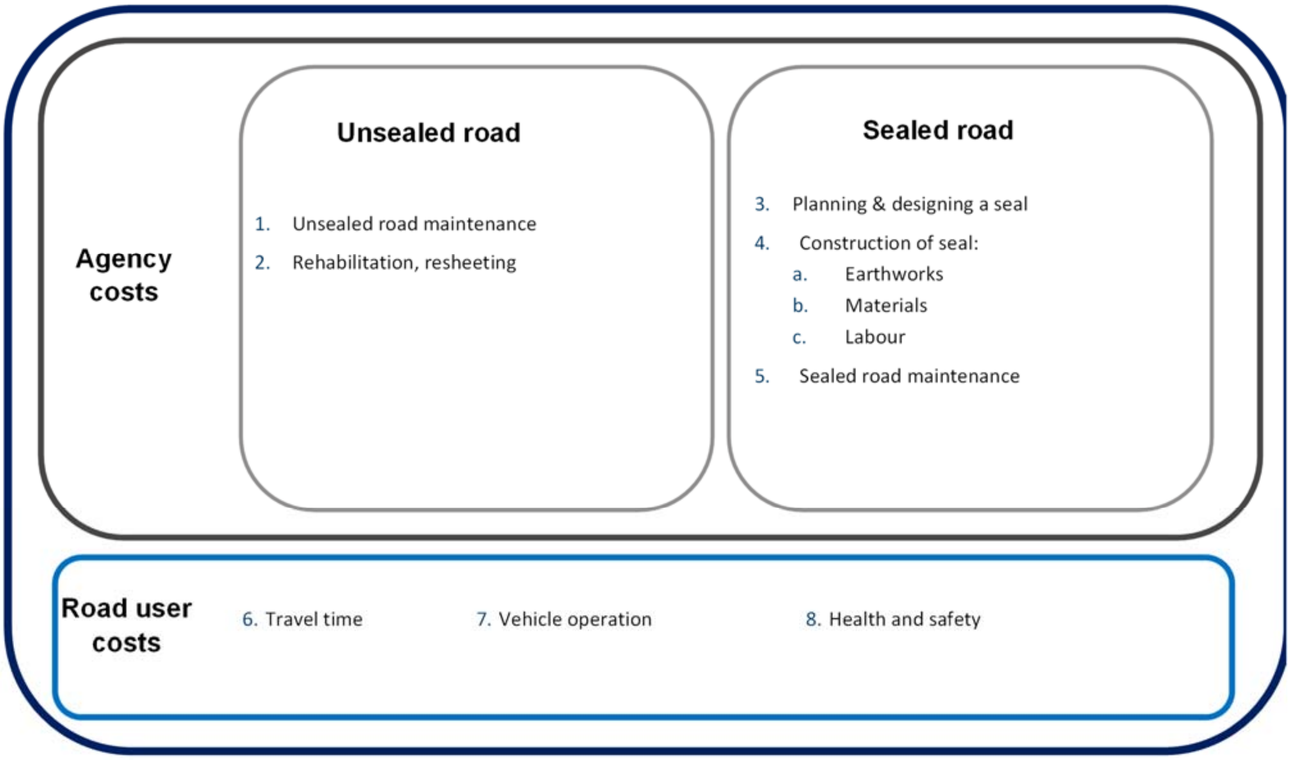
Figure 4.14: Net present value of total transport costs against AADT, by level of upgrade cost (with diverted traffic)



Source: ARRB. Group (2011).

The costs incurred in each of these phases and the lifetime maintenance and renewal schedule depends upon the numerous factors listed throughout Section 4, particularly traffic, weather, and design and materials choices. Furthermore, economic analysis requires an assessment of the costs incurred by stakeholders other than solely the road agency, in particular road users, though pollution and environmental impacts, noise, and other social and economic effects must also be included. The condition of a road and its provided level of service imposes costs on road users due to travel time, fuel consumption, vehicle maintenance, etc., as well as crashes that lead to health costs and property damage. These are intimately linked to road design, maintenance, and renewal and upgrade decisions. Figure 4.15 summarises the different costs and cost attribution across the lifespan of an unsealed or sealed road that have to be assessed when deciding to seal a road or not. This section continues to further discuss costs related to maintenance, renewal, upgrades and capital works (Section 4.6.1), while safety and crash impacts are further detailed in Section 4.7.

Figure 4.15: Whole-of-life costs of unsealed or sealed roads



Economic analyses of road networks, individual road assets, or projects follow the general principles of Robinson, Danielson & Snaith (1998) which address the full suite of topics relevant to road maintenance and asset management. Economic analysis techniques also form the foundation of Australian guidelines on cost-benefit analysis (CBA), including the *National guidelines on transport system management* (Australian Transport Council (ATC) 2006) and the *Australian transport assessment and planning (ATAP) guidelines*, which are currently at different stages of development (DIRD 2023b). Many decision support tools, such as HDM-4 (Kerali, Odoki & Stannard 2006), and pavement management tools use similar principles. These generate models that predict the life-cycle performance of road sections and the costs of vehicle operations under defined circumstances.

For an analysis of maintenance needs, various alternatives (treatment strategies) are applied to produce a series of different life cycle trends, and therefore cost streams of road agency costs (RAC) and vehicle operating costs (VOC). Impacts on travel time and crash costs can also be estimated to produce total road user costs (RUC), and all summed to estimate Total Transport Costs (TTC). Exogenous costs may also be added and incorporated in the final analysis. In this way the total costs of maintaining an unsealed road versus sealing it can be compared over an asset's lifetime, and this can be regularly updated and refreshed as expected circumstances (traffic, weather, etc.) change. Models must be calibrated to represent local conditions, and the characteristics and operating conditions of vehicle fleets. Significant studies have been performed in Australia to adapt the published models, and to build alternatives, with the main sources published by Austroads (2010a, 2010b, 2010c, 2016, 2023), and ARRB (Martin et al. 2013).

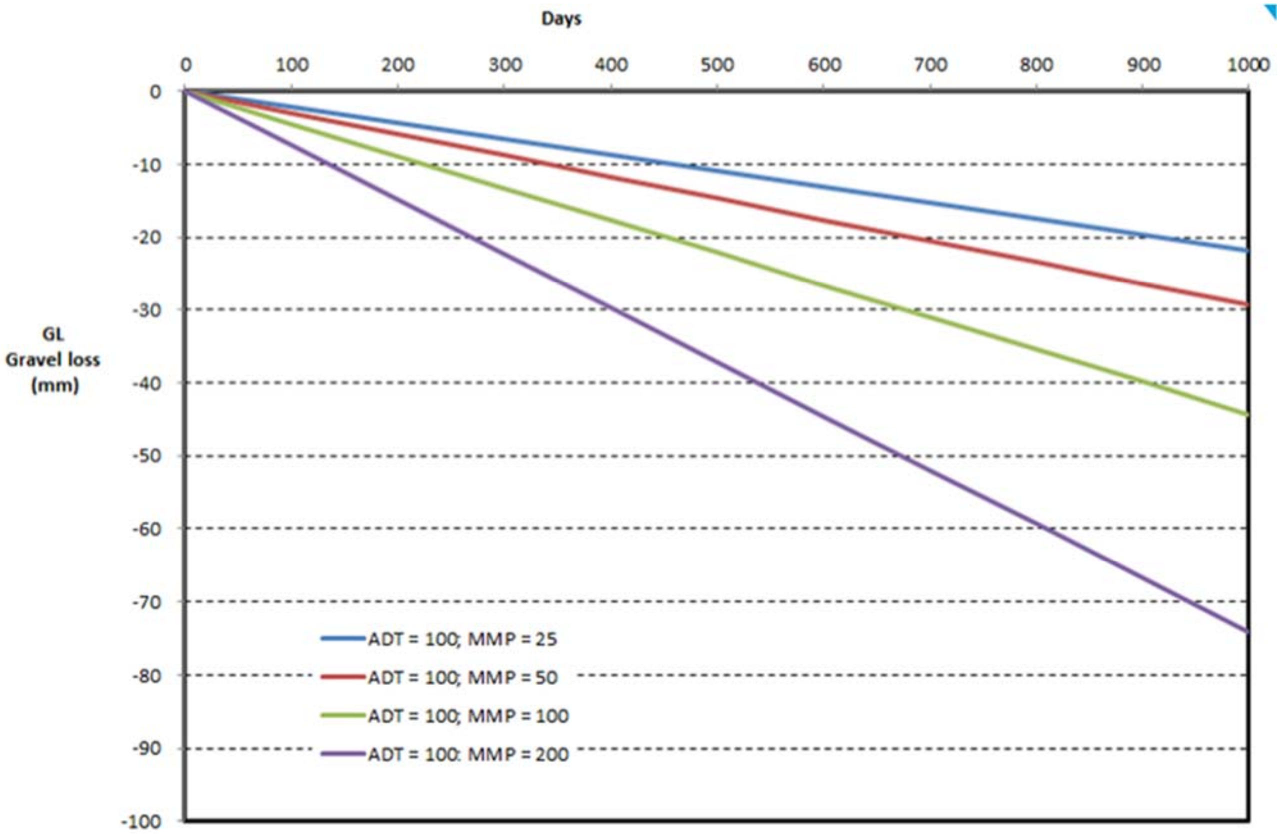
4.6.1 Determining Maintenance and Renewal/Upgrade/Capital Works Cost

Whilst recognising each may be treated under different budget categories, the costs of maintenance and renewal, and upgrade costs, are a significant input into the decision to seal an unsealed road. All need to be considered in terms of whether it is more beneficial to seal or not. They represent the following Road Agency Costs (RAC) in an economic analysis and can influence the decision:

- Optimum maintenance regimes aim to manage roads to either minimise costs to the agency in meeting a desirable service level or minimise total transport costs including impacts on road users. The latter approach is more wholistic and can be employed to justify standards, including intervention levels and upgrades.

- Up to 60% of the total road agency maintenance costs of unsealed roads can be the ongoing replacement of gravel. This will, however, vary depending on the availability and quality of materials, the remoteness of the site, the traffic use of the road, and climate. Figure 4.16 compares the variation in gravel loss by level of precipitation.
- Upgrade costs can vary by a factor of four or more depending on a variety of factors, including the cross-section and geometry, terrain, climate and soil factors, the overall structural adequacy of the existing unsealed road and the design standards sought to carry the anticipated traffic. The corresponding economic-breakeven traffic volume for sealing therefore varies in response to such factors, as demonstrated in Figure 4.13 (ARRB Group 2011 and ARRB 2020).
- After sealing, maintenance also remains critical to the performance of low volume roads, which are often constructed from marginal or non-standard pavement materials, making them more water sensitive. They still require timely resealing and maintenance, including that of ancillary assets such as shoulders, drains, culverts etc, and safety provisions. The inability to appropriately maintain these roads will result in accelerated pavement deterioration (TMR 2015) and render the road less safe.

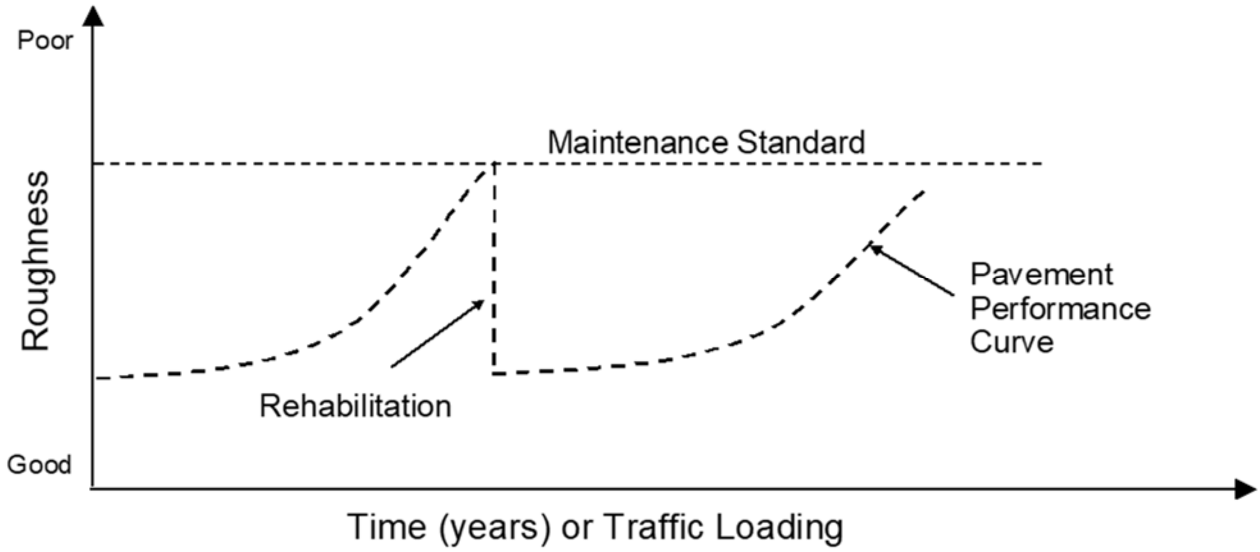
Figure 4.16: Gravel loss over time by precipitation level



Source: This study based on Martin et al (2013).

The overall long-term condition of road pavements, whether unsealed or sealed, directly depends on the maintenance or improvement standards applied to the road. Figure 4.17 illustrates the predicted trend in pavement performance represented by the riding quality that is often measured in terms of the international roughness index (IRI). When a maintenance standard is defined, it imposes a limit to the level of deterioration that a pavement is permitted to attain. Consequently, in addition to the capital costs of road construction, the total costs that are incurred by road agencies will depend on the standards of maintenance and renewal applied to road networks over a specified time period.

Figure 4.17: Concept of life-cycle analysis



Source: Kerali, Odoki & Stannard 2006.

4.6.2 Road User Costs

The impacts of the road condition, as well as the road design standards, on road users and the broader society are measured in terms of road user costs (RUC), and other social and environmental effects. Road user costs comprise:

- vehicle operating costs (VOC) (fuel, tyres, oil, spare parts, vehicle depreciation, utilisation, etc.)
- costs of travel time – for both passengers and cargo, due to road condition and traffic congestion
- costs to the economy of road accidents (i.e. loss of life, injury to road users, including medical system costs and lost productivity and income, and damage to vehicles and other roadside objects).

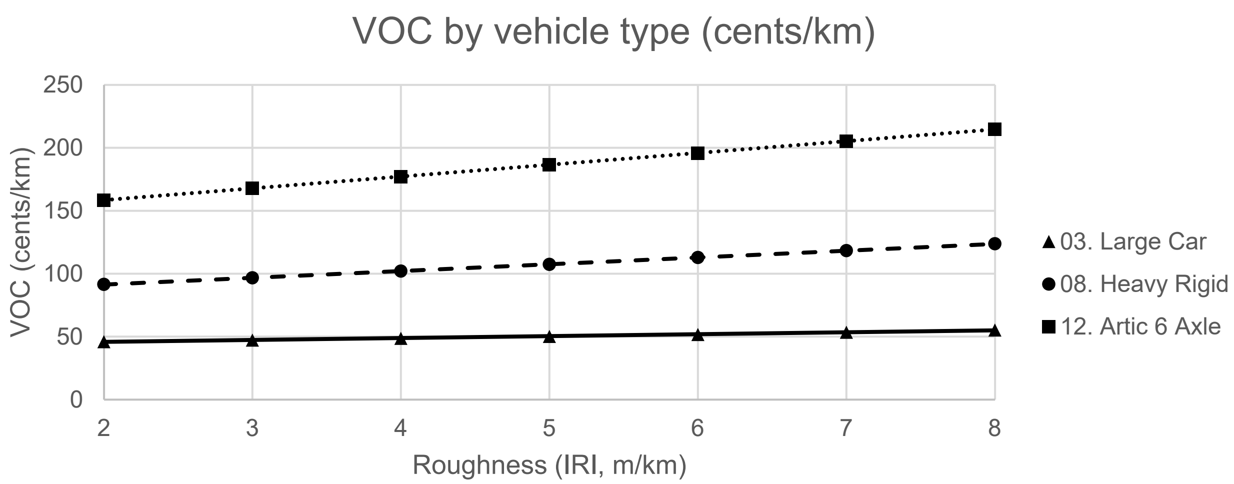
VOC and RUC are key components in whole of life cycle costing (WOLCC). By adopting a long-term view of the road system, comprehensive WOLCC promotes consideration of total costs including construction, maintenance, and operational expenditure, and all of the variables involved in the evaluation such as user costs (delays, travel time and vehicle operating costs), crash costs and associated maintenance and rehabilitation costs, agency capital costs and routine life cycle maintenance costs.

VOC can be estimated for Australian conditions for various scenarios and treatment alternatives, with published models available from the *Australian Transport Assessment and Planning (ATAP) guideline PV2* (Transport and Infrastructure Council 2016). These are responsive to travel speed (typically assumed to be close to the speed limit for asset preservation and upgrade studies), road roughness, and gross vehicle mass for each vehicle type, as well as geometry, for which typical representative values may be employed, or values specific to a road section. Studies which extend these for unsealed roads have also been undertaken both in Australia and elsewhere and a review of the basis of these VOCs is now provided.

One Canadian study involved a review of the costs of trucks operating on unsealed versus sealed roads (Transport Canada & Logistics Solution Builders 2005). In summary, they found that truck repair costs were 20% higher on unsealed roads compared to sealed roads, and tyre costs to be about 70% higher compared to sealed roads. Fuel costs were found overall to be similar. Driver time costs were 8-12% higher due to the lower driving speeds on unsealed roads, all else equal. Applying this study's factors to the Australian VOC model (Transport and Infrastructure Council 2016) indicated an approximately 5-12% increase in unsealed road user costs compared to sealed roads under similar conditions.

Based on a review of the current ATAP models for sealed roads, the significance of changes in road roughness on VOC is illustrated in Figure 4.18, with the nomenclature used reflecting ATAP PV2 classifications (Transport and Infrastructure Council 2016). It can be seen that the VOC increases by approximately 7% and 12% for a passenger car and truck respectively for each increment of IRI. These figures can be used as inputs, along with road agency costs and travel time-related costs, into decisions on whether or not to seal a road. What is required, however, is similar estimates for unsealed roads to inform a full economic analysis.

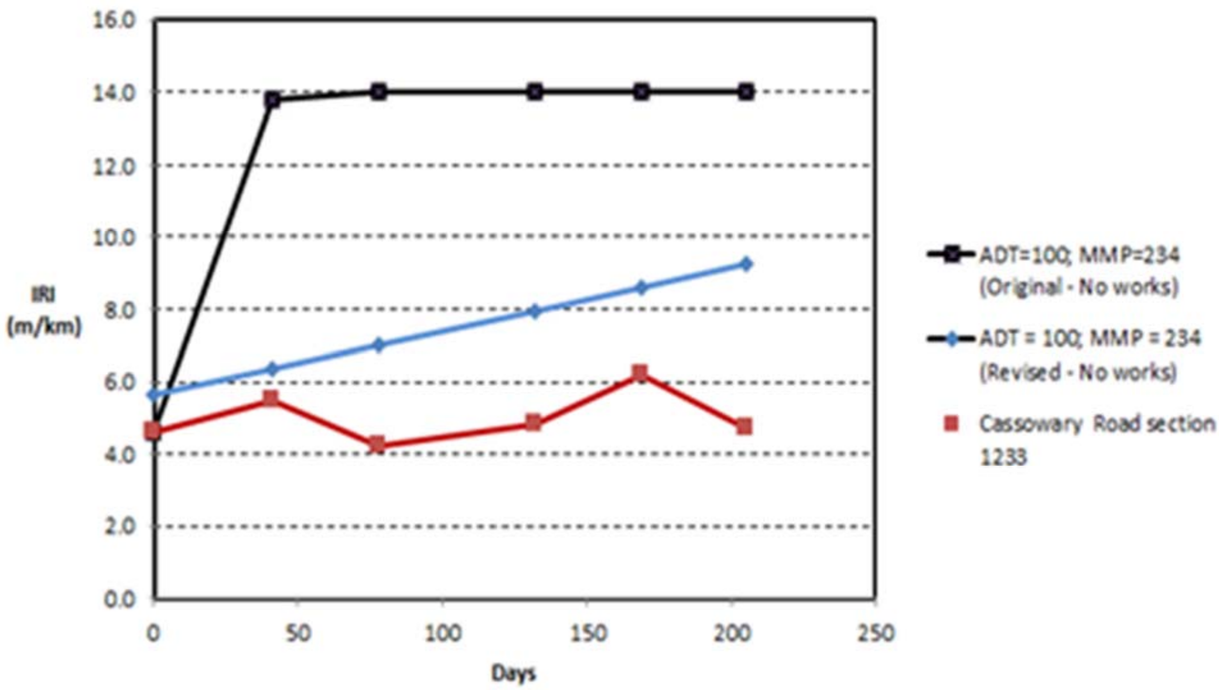
Figure 4.18: Effect of road condition on vehicle operating costs for flat, low curvature conditions



Source: This study based on Transport Infrastructure Council (2016).

While precise data on unsealed roads is often lacking, the results of road deterioration studies in Australia suggest that relatively high roughness values are the norm. This is illustrated in Figure 4.19 where the roughness trend from the original Australia-wide local roads deterioration study (LRDS) models (Martin et al 2013) is compared to a revised model based on the analysis of good practice examples, and to the trend observed on the Cassowary Coast where good practice was applied in materials selection and maintenance (Austroads 2018). The results suggest roughness levels could significantly differ depending on location, although values closer to the upper values are more typical of normal practice.

Figure 4.19: Comparison of deterioration trends for a good practice example and model predictions from the original LRDS study with and without works effects



Source: Austroads (2018).

In summary, the review suggests that, for unsealed roads:

- VOC (ex-capital and crew costs) are likely to be of the order of 20% higher than sealed roads for the same roughness level.
- Where impassability is an issue, for example on earth roads under wet conditions, VOC could be up to 200% higher, particularly where a combination of poor surface condition and impassability exists, with the value dependent on vehicle type and surface material type.
- Average roughness levels are typically high on unsealed roads, as evident from the deterioration trend derived from national studies. This would suggest roughness value of around 10 – 14 m/km IRI as being more likely than the much lower roughness levels achieved where good practice is adopted. This requires consideration in developing the general regression equations and in applying them.

The further incorporation of social and environmental effects, including the impacts of accidents, vehicle emissions, energy consumption and traffic noise during road use (and construction and maintenance), and other welfare benefits to the population served by the roads, is important. Although social and environmental effects can sometimes be difficult to quantify in monetary terms, they can be incorporated within economic analyses if quantified externally, based on economic valuation studies. For example, the ATAP Guidelines (PV5) provide guidance on the parameter values for environmental impacts (DIRD 2023); Austroads has published a guide to valuing environmental and other externalities in Australian road infrastructure projects (Austroads 2003), with a more recent update of unit values to use (Austroads, 2014); and Infrastructure Australia (2021) provides a guide to economic appraisal. It is also in the process of developing a national guide to greenhouse gas emissions valuation (IA 2023). NSW and the ACT have already published values for carbon emissions (the 'social cost of carbon') to use in state and territory policy, planning and evaluation (NSW Treasury 2023a and 2023b; Hutley 2021).

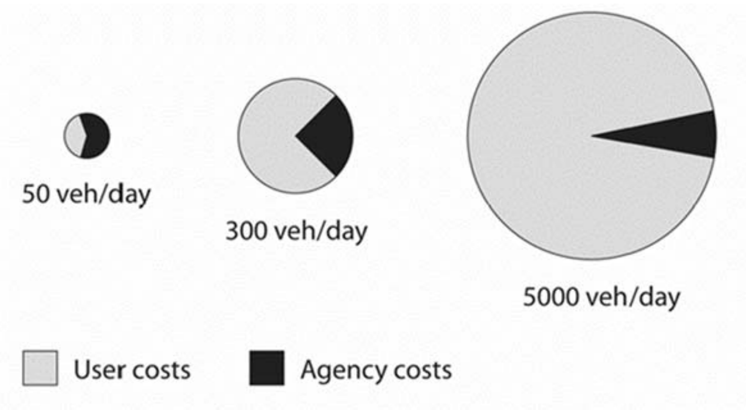
4.6.3 Whole-of-Life-Cycle Costs (WOLCC)

The principle of WOLCC analysis is incorporated into economics-based decision making to ensure road improvement and preservation decisions, and road use management strategies, are made in the knowledge of the long-term cost implications. Most road agencies employ a combination of historical practice, simple rules and the more sophisticated WOLCC methods because no single approach can be guaranteed to produce an 100% accurate outcome in every scenario.

Justifying investment on an economic basis involves investigating the trade-off between road agency and road user costs, with a need to appreciate the proportion of total costs contributed by each (

Figure 4.20). For low traffic roads, the challenge is agency costs dominate TTC and savings in road user costs associated with a higher level of service may not be sufficient to offset the additional costs of provision or maintenance. For higher traffic roads, user costs dominate; therefore, savings are also likely to be available to justify agency costs. Understanding the components of user costs in greater detail provides a basis for decision making as they are key components of the benefits of investment. This is especially the case for lower volume roads, including upgrading considerations for unsealed roads.

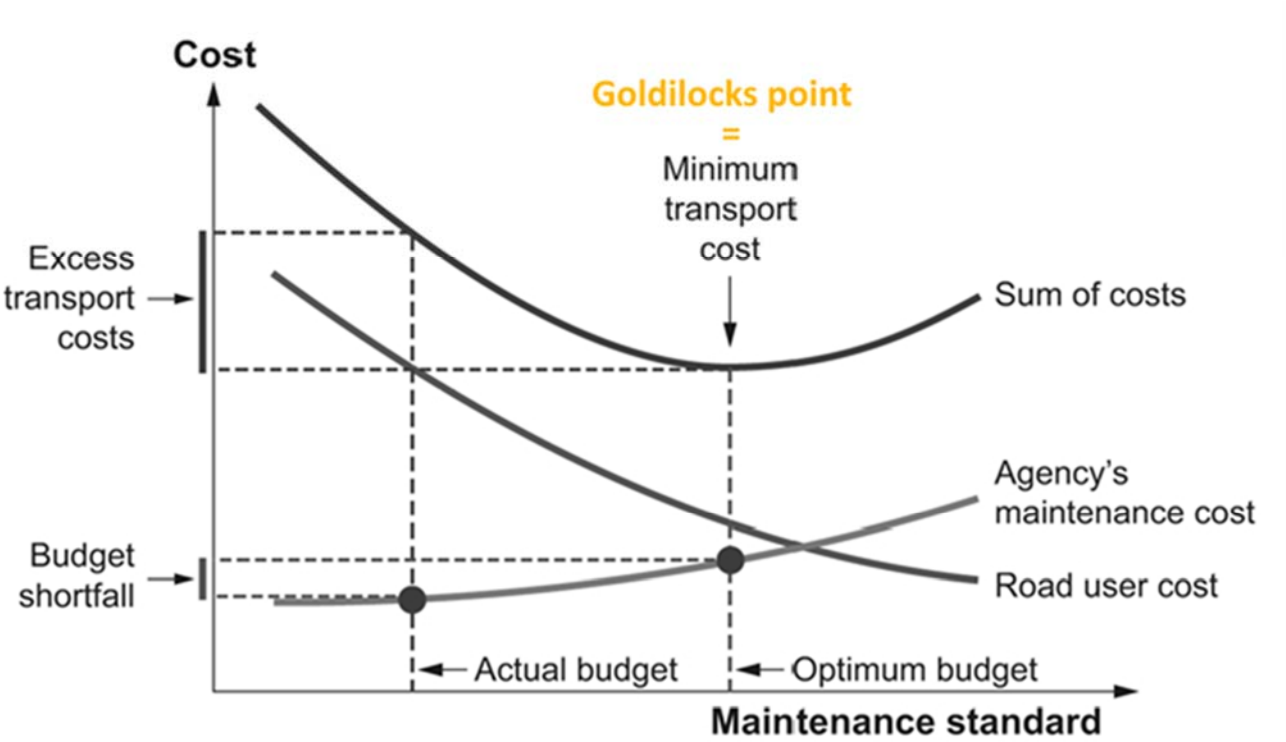
Figure 4.20: Typical split between road user and road agency costs versus AADT



Source: Austroads 2009, 'Typical split between road user and road agency costs versus AADT', p.36.

The WOLCC approach enables asset managers to determine the points at which it is relatively more beneficial to upgrade and seal a road. The target for maintenance standards and upgrade decisions should be the 'Goldilocks point', where total lifetime asset costs are minimised, as demonstrated in Figure 4.21. Sealing an unsealed road reduces the road agency's ongoing maintenance costs, allows all-weather access and reduces the dust from trafficking for safety reasons. It furthermore reduces VOC and RUC through decreasing roughness and travel time and may increase road safety (ARRB 2020). These benefits should offset expected lifetime costs for construction and maintenance to road agencies in support of an upgrade decision.

Figure 4.21: Relationship between maintenance standards and transport costs



Source: SATCC (2003; cited in Austroads 2009).

The economic analysis should consider the following direct agency costs, in addition to road user cost savings and other benefits such road safety (adapted from ARRB 2020):

- the long-term maintenance costs of the existing unsealed road
- the costs of upgrading the road including accounting for
  - the existing traffic levels (AADT and % HVs) and expected future traffic growth

  - the additional costs of realignment, lane width and surface drainage upgrade, if required the expected long-term costs of maintaining a sealed road replacement, having confirmed, or otherwise, that the existing alignment (horizontal and vertical) and lane widths are adequate for future traffic
- the long-term maintenance costs of the sealed road.

A comparison of road maintenance and upgrade project options, including whether or not to seal the road surface, must sum the expected costs and benefits (savings) in each year across the asset's service life, and discount these to present values, as per standard CBA guidance. Then decisions can be made transparently based on the greatest whole-of-life net present value (NPV), or total transport cost savings, or, particularly under restricted budgets, the marginal benefit-cost ratio (MBCR) (ARRB 2020; DIRD, 2023c).

4.7 Road Safety

This section of the report briefly details the road safety considerations when sealing an unsealed road. This includes an overview of the safe system (Section 4.7.1) the increased crash risk associated with unsealed roads (Section 4.7.2), the safety considerations associated with increasing speeds once a road is sealed (Section 4.7.3), and a methodology for estimating crash costs which can be used for whole-of-life assessments of capital works (Section 4.7.4).

Road Safety: Summary/Outcome

Incorporation of the Safe System Approach into Unsealed Road Asset Management Practices.

While the number of crashes on an unsealed road network is often lower in comparison to that of sealed roads, the probability of having a crash on an unsealed road is at least double that of a sealed road.

When sealing an unsealed road, the road type and the road roughness will be improved. Therefore, when a road is sealed the traffic along that road will travel at higher speeds. In fact, on sealed roads, the travel speed can be nearly twice as much as that of unsealed roads.

Along an unsealed road, due to lower speeds, roadside hazards are less of a concern. Along a sealed road, where roadside hazards exist, consideration would need to be given to the removal of these hazards, or the installation of barriers to protect drivers from them.

4.7.1 Consideration of the Safe System

The Safe System is a targeted approach that ultimately aims to eliminate fatal and serious injury on the road. It recognises that motorists inevitably make errors in judgment that may lead to a crash and it is understood that there are limits to the force that the human body can withstand (without causing death or serious injury) in a crash. These limitations are directly linked to the type of crash and the speed of the impact. The Safe System approach aims to support development of a transport system better able to accommodate human error and road user vulnerability. A key strategy in achieving Safe System objectives is through road network improvements (such as sealing unsealed roads), and speed management (Austroads 2013).

Implementing the Safe System approach into unsealed roads asset management practices, and examining the Safe System approach when determining capital works and upgrades for unsealed roads, should be considered.

4.7.2 Unsealed Road Crash Risk

While the number of crashes on an unsealed road network is often lower than sealed roads, the probability of having a crash on an unsealed road is at least double than on a sealed road (Willett 1992; cited in ARRB 2020). There are several varied factors which contribute to the incident and severity of crashes on unsealed roads. These include:

- poor road surface conditions (loose materials, slippery when wet, dust emissions)

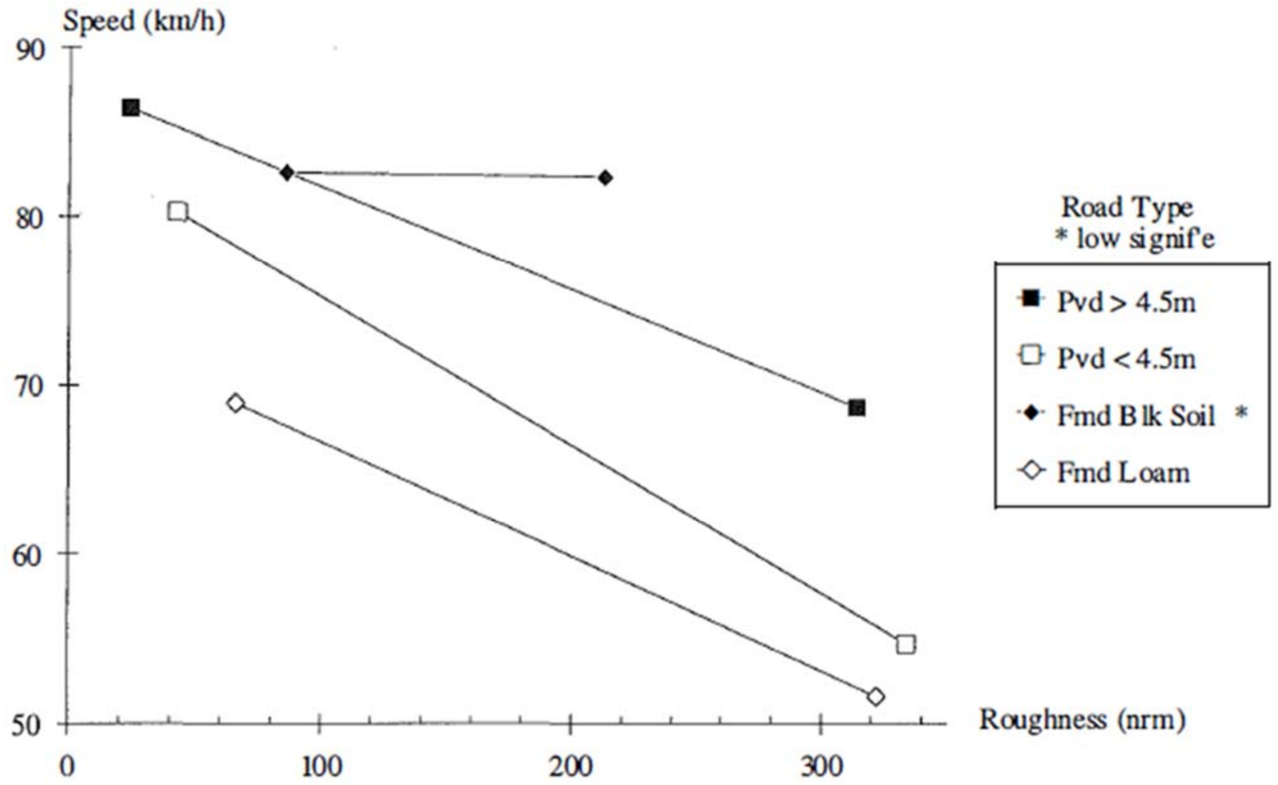
- poor geometric standards (tight curves, restricted sight distance, poor signage and delineation, poor vertical and horizontal coordination, roadside hazards)
- inconsistencies in the road conditions that can surprise an unsuspecting driver (e.g. sudden dip or an isolated sharp curve on an almost straight road)
- low traffic volumes which can encourage higher travel speeds
- traffic composition which may include a high proportion of HVs
- driver behaviour (excessive speed, lower levels of restraint use, failing to keep left)
- collisions with native animals
- driver impairment (alcohol, fatigue)
- driver inexperience
- low levels of enforcement
- longer emergency service response times due to rural and remote location of crashes.

4.7.3 Speed & Safety Considerations

When deciding to seal an unsealed road, consideration must be given to not only the safety benefits, but also the potential costs. There are four key reasons why drivers may increase their speeds on roads: road type, vehicle class, road roughness and width (Botterill & Thorsen 1995). After sealing an unsealed road, the road type and the road roughness will be improved. Therefore, when a road is sealed the traffic along that road will travel at higher speeds. (Henning et al. 2006) reported that, on sealed roads, the travel speed can be nearly twice as much as that of unsealed roads, typically 90-110 km/h as opposed to 40-60 km/h. This is depicted in Figure 4.22, which shows the predicted spot speeds of vehicles, based on roughness and road surface type, calculated using observed roughness ranges for each road type. As can be seen from Figure 4.22, vehicles on low-roughness paved surfaces travel at substantially higher speeds than vehicles travelling on high-roughness formed loam surfaces (Botterill & Thorsen 1995).

Therefore, the speed at which crashes occur, and the risk of causalities, significantly increases. The higher speed demands higher design standards, including consideration of sight distance, alignment, lane width, surface friction, and superelevation. In many cases additional costs are incurred, including rebuilding drainage and widening bridges and other structures (Henning et al. 2005).

Figure 4.22: Predicted spot speeds by roughness and road type



Source: Botterill & Thorsen (1995).

Notes: Estimated as day-time cases.

In addition, roadside hazards are less of a concern along an unsealed road, due to the lower speeds. Along a sealed road, on the other hand, consideration would need to be given to the removal of these hazards, or the installation of barriers to protect drivers from these hazards. This would lead to increase construction and ongoing maintenance costs.

4.7.4 Estimating Crash Costs

This section of the report details the methodology and equations which can be employed to estimate the number and severity of crashes, and crash costs on an unsealed road network. They can be compared between unsealed and sealed road types, in order to assist with decision-making in upgrades and capital works.

The process to be used for calculations is as follows (Austroads 2021):

1. Conversion of International Roughness Index (IRI) to roughness measured using a NAASRA Roughness Meter (NRM), using Equation 1:

$$NRM = (26.49 * IRI) – 1.27 \qquad 1$$

2. Calculation of million vehicle-kilometres travelled (MVKT) per annum, based on the Annual Average Daily Traffic (AADT) and an assumed growth rate of 2% per year for the period of 2020 to 2034, using Equation 2:

$$MVKT(initial) = (AADT(initial) * 365 * Length) / 100000000 \qquad 2$$

$$MVKT\_p.a. = MVKT(initial)*1.02$$

3. Calculation of roughness-based crashes per annum using Table 5.6 from Austroads (2013) and Equation 3:

Injury Crashes_p.a. = Value from Table 5.6 in Austroads (2013) as sum of fatal and personal injury * MVKT_p.a. 3

Table 5.6: Estimation of mid-block crash rates based on the Model Road State concept

MRS based concept

The concept of the Model Road State (MRS) described in Austroads (2001) can be used to help determine the crash risk of a road and the effect of adding certain safety treatments. It employs the following equation to determine an estimated crash rate.

ACR = KMRS * KHA * ABCR

where:

ACR = predicted casualty crash rate (per 100 million VKT)

ABCR = base crash rate (25 casualty crashes per 100 million VKT for a rural road with 7 m seal and a speed zone of 90 km/h or less)

KMRS = model road state factor for no curves

KHA = modification factor for horizontal alignment

MRS-based crash rates for a selection of road configurations.

Model Road State	No. of crashes by severity type (crashes per 100 million vehicle km travelled)			
	Fatal	Personal injury	Damage only	All
MRS04 – Gravel > 4.5 m	1.75	33.25	91.00	126.00
MRS05 – Sealed <= 4.5 m	1.50	28.50	74.00	104.00
MRS08 – Undivided 5.81–6.4 m	1.63	30.88	54.50	87.00
MRS09 – Undivided 6.41–7.0 m	1.25	23.75	45.00	70.00
MRS10 – Undivided 7.01–7.6 m	1.13	21.38	35.50	58.00
MRS11 – Undivided 7.61–8.2 m	1.06	20.19	30.75	52.00
MRS12 – Undivided 8.21–8.8 m	1.00	19.00	29.00	49.00
MRS17 – Undivided >= 13.7 m four lane	1.06	20.19	33.75	55.00
MRS18 – Divided two lane per c/w <= 7.6 m	0.60	19.40	32.00	52.00
MRS24 – Freeway two lane per c/w <= 9.4 m	0.40	5.35	14.25	20.00

Other considerations

For general application, the MRS based system also requires the split between fatal and serious injuries to be determined, and therefore a typical fatal and serious index needs to be considered. It also requires separation of personal injury crashes into serious and minor. Typically, the ratio between each severity of crash is approximately 10, but more specific values have been determined from more recent research (Austroads 2010a).

Source: Adapted from Austroads (2001).

4. Calculation of Killed and Serious Injury (KSI) Crashes Index, using Equation 4. This is based on Austroads (2013):

For Undivided Sealed Roads = 0.0034 * Speed Limit – 0.0949 4

5. For undivided unsealed roads – apply an average speed based on the table below, typically < 80 km/h. The risk is that low volume, 6 m wide sealed roads with vehicles travelling at 100 km/h will have worse outcomes once speed FSI is applied.

Table 5.3: Comparison of spot speeds on unsealed roads.

Road †		Cars		Trucks		Artics	
Standard	Rgh/Wid	Orig'l	New range	Orig'l	New range	Orig'l	New range
Formed Loam	198/3.8	51.0	60.7 (0.7) [413]	41.4	54.6 (1.7) [51]	38.3	59.6 (2.5)* [9]
Formed Black Soil	149/4.6	51.0	84.7 (0.4) [1231]	41.4	75.0 (0.8) [186]	38.3	64.9 (1.5) [63]
Paved <4.5m	170/3.4	40.6	70.1 (0.4) [2480]	32.1	66.1 (0.9) [297]	30.7	70.3 (1.5) [47]
Paved >4.5m	119/6.8	40.6	81.4 (0.1) [17814]	32.1	75.5 (0.3) [2562]	30.7	77.1 (0.7) [509]

† General terrain is Type 1 (level or flat)
Rgh Mean road roughness in nrm
Wid Mean road width in m
Spot speeds in km/h

* Small sample size
( ) SE of spot speed
[ ] Numbers of vehicles in sample

Source: Botterill & Thoresen (1995).

6. Calculation of Killed and Serious Injury (KSI) Crashes, per annum using Equation 5 based on Austroads (2021):

$$KSICrashes = KSI * Crashes\_p.a. \quad (5)$$

7. Calculation of crash costs for non-KSI crashes, per annum for the period of 2020 to 2034, using Equation 6 (Austroads 2021):

$$Non\text{-}KSI\ CrashCosts\_p.a. = Crashes\_p.a. * (1 - KSI) * 72{,}804 \quad (6)$$

8. Calculation of crash costs for KSI crashes, per annum using Equation 7:

$$KSI\ crash\ costs\ p.a. = KSI\ crashes\ p.a. * 810{,}759 \quad (7)$$

9. Calculation of the Present Value for non-KSI crashes, using the built in Excel-based function for Net Present Value.
10. Calculation of the Present Value for KSI crashes using the Excel-based function.

4.8 Community Expectations

Another key reason why LGAs might consider sealing an unsealed road is to meet community expectations, including increasing public pressure. This public pressure may be based on a variety of reasons such as the route being seen as a key throughfare for the community to access the goods and services they require, the road may have consistent maintenance issues leading to customer complaints, the road may have seen increasing traffic due to additional tourism, etc.

This section of the report details the social impacts of unsealed roads (Section 4.8.1), how public pressures and road user complaints received by the local council could be used in the decision-making process for capital works (Section 4.8.2), and how customer-based levels of service in road maintenance could be implemented to foresee community expectations for the route options (Section 4.8.3).

Community Expectations: Summary/Outcome

Public pressure may be based on a variety of reasons such as the route being seen as a key throughfare for the community to access the goods and services they require, the road may have consistent maintenance issues leading to customer complaints, the road may have seen increasing traffic due to additional tourism, etc.

Improvements or upgrades to the unsealed road network, particularly in regional areas, has a significant impact on the social well-being of the community.

Customer complaints can be used to identify locations for routine, periodic and emergency maintenance and inspections. Complaints could be entered into a complaints tracker in order to identify areas and issues that are repeatedly being reported, which can assist in improving ongoing maintenance schedules and actions.

Community expectations can be measured using 'Customer-based Levels of Service' (CLOS).

4.8.1 Social Impacts

Improvements or upgrades to the unsealed road network, particularly in regional areas, have a significant impact on the social well-being of the community. This is less visible in more developed areas, as alternative well-functioning or high-value assets and infrastructure will have been in place for a long time. In general, the key social benefit which will arise from the upgrading of an unsealed road to a sealed road is better accessibility, and increased mobility of the community. Other benefits include: decreased dust pollution, increased use by non-motorised road-users, and improved amenity of community spaces (Henning et al. 2005).

Factors which will influence the community's satisfaction with an unsealed road network may include road characteristics such as road shoulders and edges, road and lane width, smoothness of road surface (road roughness), and the absence of dangerous curves (alignment). The major contributing factors to road user satisfaction on regional road network are summarised in Table 4.5.

Table 4.5: Summary of major factors contributing to road user satisfaction

Contributing Factor	Contribution to Satisfaction (%)
Road types (freeways, country roads)	13.4
Road characteristics (road/lane width, smoothness, shoulders and edges, etc)	12.8
Road features (signage, rest stops, lighting)	10.0
Social (needs of isolated, low income families)	10.2
Traffic management (minimising delays, overtaking lanes)	10.2
Communication (community information and consultation)	9.8
Customer service (counter and telephone service)	8.1
Safety (vehicle road worthiness, driver competence)	8
Non-motorised users (cyclists, pedestrians)	7

4.8.2 Public Pressure and Road User Complaints

Main Roads WA provides an online portal for road users to report road faults on its website: (https://www.wa.gov.au/service/building-utilities-and-essential-services/transport-network-maintenance/report-road-fault). This system asks the road user to input the date, a description of the issue, the location of the issue, and contact information. Similarly, the majority of LGAs in WA have an online form for reporting issues relating to Council-owned infrastructure.

This information can be used by road managers to identify locations for routine, periodic and emergency maintenance and inspections. This could include complaints about fallen trees, vegetation encroachment on roads, potholes, surface deterioration, etc. These complaints can be used to promote urgent action or plan maintenance activities more frequently or sooner than the planned scheduling. Complaints could be entered into a 'complaints tracker' in order to identify areas and issues that are repeatedly being reported as this can assist in improving ongoing maintenance schedules and actions.

4.8.3 Customer-based Levels of Service in Road Maintenance

Road agencies commonly manage the road network using Technical Levels of Service (TLOS). TLOS is defined as referring to the technical intervention requirements for road maintenance, and the standards to which road managers maintain their roads. These standards can be national, such as the Australian Risk Assessment Program (AusRAP) or statistically based and defined by the road agencies. Information on the TLOS commonly used for unsealed roads is provided in Section 2, 2.3, and 4.1.3. However, research has shown that TLOS does not adequately consider the opinions of the community in regard to expected Level of Service to be provided by a road.

Community expectations can be measured using 'Customer-based Levels of Service' (CLOS). CLOS has been defined in the literature as the service level for a road which is required or demanded by customers. There are two main categories of customers: freight transport customers, and non-freight transport customers. In order to assess the CLOS, five indicator categories have been developed which are defined in Table 4.6 (O'Connor & Martin 2020).

Table 4.6: Indicators for customer-based levels of service in road maintenance

Category	Definition
Safety	The methods and measures in place to prevent road users from being killed or seriously injured. Road users include pedestrians, cyclists, motorists, vehicle passengers, horse-riders and passengers aboard road-based public transport (e.g., buses and trams).
Reliability	The ability of a road or road network to perform its intended function without any malfunctions, assuming the road is used within the conditions in which it was designed for (Austroads 2015b). Reliability is directly related to road capacity. Road capacity is referred to by Austroads (2015) as the maximum number of vehicles or pedestrians that can pass

Category	Definition
	over a given section of a lane, road or footpath in one direction (or in both directions for a two-lane or three-lane road) during a given time period under prevailing road and traffic conditions. It is the maximum rate of flow that is expected to occur.
Condition	The condition of an asset is based on a combination of specific characteristics which are used to assess functionality. Examples include rutting, cracking, surface texture, pavement strength (deflection), skid resistance, edge break, edge drop off, local defects, and patching. Issues tend to be reported 'bins' or a distress rating (e.g. good, fair, poor, bad), or on a continuous numerical scale (e.g. IRI, rut depth, crack width, percentage area patched).
Accessibility	Refers to mobility pathways, allowing for the continuity of useable routes between key locations of travel. This means that the road is always open for the use of customers. If the road is unavailable, there is an alternative route available, with an acceptable travel time.
Rideability	Reliability is directly related to the roughness of the road surface.

Source: O'Connor & Martin (2020).

Measuring Customer-based Levels of Service

Each of the defined categories of CLOS (safety, reliability, condition, accessibility and rideability) can be measured and/or assessed by LGAs or road agencies to determine community expectations. This can be done in a variety of ways; for example, and as discussed in Section 4.8.2, using community-based surveys, or pre-calculated equations from the literature, or by undertaking data collection through a complaints tracker or customer relationship management (CRM) system (see Section 4.8.1).

Measuring Rideability

Rideability is the key concern for unsealed roads. Martin (2005) noted the relationship between the CLOS rating with TLOS for rideability, in terms of measuring road roughness. Previous studies conducted from 1998 to 2004 were reviewed. Data related to 128 road samples and 2,679 observations by 17 panels was used to produce 17 relationships between CLoS ratings and TLoS. These relationships were in the form of a roughness rating (CLoS) versus the measured roughness (TLoS).

The relationship developed for the estimate of Acceptable Level of Roughness for a given road type is as follows:

$$y= k1 \times R(t)m+k2y= k1 \times R(t)m+k2 \quad (8)$$

where

y	=	the panel's (community) perception (value) of road roughness at time, t
$R(t)_m$	=	the measured road roughness, IRI (m/km), at time, t
k_1	=	the calibration factor for roughness
k_2	=	the calibration factor for effects other than roughness (lane width, edge condition, surface condition, etc.).

5 Whole-of-life Asset Approach

A whole-of-life asset approach encourages road asset managers to consider all lifetime costs and benefits of road construction, maintenance, rehabilitation and upgrade decisions, to all relevant stakeholders, rather than being limited solely to upfront road agency costs. This approach covers comparative assessments of the continuation (and potentially optimisation) of managing an unsealed road and alternative options for sealing the road to low and high standards. Such assessment follows a decision framework covering aspects of existing and forecast condition and use. Particularly, the following considerations are important:

1. existing road condition
2. initial and forecast traffic levels
3. climate and weather
4. environment and geology
5. WOLCC.

The WOLCC analysis incorporates all of the other aspects. Presented here is a WOLCC model that provides estimates for a range WA-tailored climate, environmental and cost conditions.

5.1 Whole-of-Life Cycle Costs

WOLCC assessments require an economic evaluation of the costs and benefits (converted into comparable units – generally, monetary) of the available alternative road management and upgrade options across the asset's lifetime. It therefore should be tailored to local conditions and costs, and each road's expected AADT. ARRB's Pavement Life Cycle Cost Demonstration Tool (PLCCDT) has been designed to do WOLCC assessments tailored to WA conditions and costs. WOLCC assessments are provided at a number of particular points of AADT, proportion of HVs, climate, cost factors, and maintenance standards. Interpolation between these points can be undertaken for more specific localised estimates.

Decisions regarding whether to seal an unsealed road require an assessment of the trade-off between road agency costs for upgrades and maintenance, and road user and safety costs for different types of road and use. The present assessment considers environmental, air, land, water and noise pollution costs and social and community benefits. These can be added based on state and national guidelines, as described in Section 0. Unsealed roads generally have a relatively low AADT, and this can make the agency costs significant in proportion to road user costs, as described in Section 4.6.3. Compared to existing road maintenance practices, optimising road agencies' processes for maintaining and resurfacing unsealed roads can provide significant benefits in terms of agency cost savings, lower road user costs, and greater safety.

As a simplified tool for practical use, ARRB's PLCCDT model estimates upfront and ongoing road agency costs (RAC) for different scenarios as well as the expected road user costs (RUC) and crash injury and fatality costs for the base case of optimising the current unsealed road, plus a low-cost and a higher-cost (higher quality/performance) seal upgrade. Finally, the cost and impacts of installing additional road safety features to the sealed roads are considered. The model then demonstrates which alternative achieves the lowest total transport costs (TTC), as described in Section 4.6.3, getting closest to the potential 'Goldilocks Point'. The RUC estimations specifically comprise VOC and the value of travel time.

The model estimates the TTC for 160 different cases, covering a combination of climate zones, AADT and HV proportion, for the given road types, a given unsealed grading quality and the level of resheeting material compliance, as shown in Table 5.1.

Table 5.1: WOLCC model road categories

Variable	Levels
Climate zones	(1) hot, humid summer, seasonally wet; (2) warm, humid summer, seasonally wet;

Variable	Levels
	(3) hot, dry summer, mild winter, predominantly dry; (4) hot, dry summer, cold winter, seasonally wet.
Initial AADT	50, 100, 175, 250, 500
Proportion of HV traffic (HV%)	5%, 15%, 25%, 50%
Construction and maintenance costs	Typical, high
Maintenance practice quality and materials compliance	Typical, good
road type	Unsealed, base sealed upgrade, alternative sealed upgrade

The road agency costs for road upgrades are set equal for each road type, i.e. one cost for each of optimised unsealed road, low-cost basic sealed road upgrade, and high-cost alternative sealed road upgrade. These are then given two cost levels – typical cost scenarios and high-cost scenarios. The typical cost scenarios are representative of locations near metropolitan regions or areas with good quality local resources, while high-cost areas are generally rural or remote locations with fewer local road sealing component producers available. These costs have been calculated based on historical data and the stakeholder consultations. Maintenance costs additionally depend on the climatic zone and traffic levels. In particular, the rate of gravel loss and ride quality deterioration, and resulting required grading frequency depends on the climate, AADT, and level of compliance. This also provides the average annual roughness, which feeds into road user costs and crash rates. Users of this guide can select the cost levels, climatic conditions, etc. that most closely match their situation, and/or interpolate between different specified scenarios.

VOC and travel time are both based on the road's roughness and associated estimated driving speed, which stems from official ATAP guideline values (Transport and Infrastructure Council 2016). Crash cost estimations are slightly more involved, relying on numerous factors adapted from Austroads (2013). For unsealed roads, one crash rate is used, viz. 35 casualty crashes per 100 million vehicle-km travelled (VKT). The crash rate for sealed roads, however, is directly based on the average road roughness with the proportion of fatal and serious injury dependent on driving speed. It has been assumed that driving speeds are 100 km/h 80 km/h on sealed roads and unsealed roads respectively. From this crash rate, the number of 'fatal or seriously injured' (FSI) crashes per year are calculated. The ATAP Guidelines provide the economic cost of these FSI crashes, and non-FSI crashes.

Finally, the model includes the costs and benefits of adding supporting safety features to sealed roads, adapted from Austroads (2013). A 30% reduction in crash likelihood due to features such as delineation and road signs was specifically implemented.

On this basis, the model estimates the economic costs for the use and maintenance of an unsealed road, and use, construction and maintenance of typical high-cost sealed roads for each of the 4 climate zones, 5 AADT levels, and 4 HV proportions. In each case, the model provides the RAC, the VOC, and travel time costs, and sums this to show total RUC and TTC. The model further incrementally adds crash costs and safety features to show 'TTC including crash costs', and 'TTC including crash costs and safety features'. Applying the decision criteria of selecting the lowest cost option, the model clearly shows which option has the lowest TTC for each climate-traffic-HV-cost level scenario.

5.2 Development of a Catalogue of Solutions

The outcome of the analysis was used to develop a catalogue of solutions which are presented in various formats, including:

- A set of decision matrices (tabular output) which allow selection of the final sealing choice considering two criteria:
  - Test Criterion 1 – where the selected option delivers the lowest total lifetime cost in each circumstance, representing costs to government and costs to road users, and crash costs.
  - Test criterion 2 – where a preferred option is selected based on a Marginal Benefit-Cost Ratio (MBCR) test, as a measure of the return on investment, where a non-negative MBCR value of less

than 1 is judged 'not viable', a value of between 1 and 2 is judged marginal, and a value greater than 2 is judged viable and is therefore a strong candidate.

- An example has been provided for regional distributor roads with good practice having applied Test Criterion 1 (Table 5.2) and Test Criterion 2 (Table 5.3). All other road categories and practices are detailed in the *Practitioners Guideline*.
- A set of indicative break-even traffic levels (tabular and chart outputs).
  - An example has been provided for regional distributor roads with good practice (Figure 5.1). All other road categories and practices are detailed in the *Practitioners Guideline*.

Table 5.2 demonstrates optimum choices in a decision matrix for roads with typical (lower) and high construction and maintenance costs, including crash costs and safety features. The decisions are that an upgrade to a sealed road is 'not viable' (red) from a TTC-perspective, a 'base upgrade' (orange) has the lowest lifetime TTC, or an 'alternative upgrade' (green) has the lowest lifetime TTC.

Table 5.2: Test criterion 1: Optimum sealing strategy – full decision matrix for regional distributors with good practice

			HV (%)			
			5	15	25	50
Climate Zone 1	Typical Costs	AADT_50	Not Viable	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_100	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_175	Base Upgrade	Base Upgrade	Base Upgrade	Alt Upgrade
		AADT_250	Base Upgrade	Base Upgrade	Alt Upgrade	Alt Upgrade
		AADT_500	Alt Upgrade	Alt Upgrade	Alt Upgrade	Alt Upgrade
	High Costs		5	15	25	50
		AADT_50	Not Viable	Not Viable	Base Upgrade	Base Upgrade
		AADT_100	Not Viable	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_175	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_250	Base Upgrade	Base Upgrade	Base Upgrade	Alt Upgrade
		AADT_500	Alt Upgrade	Alt Upgrade	Alt Upgrade	Alt Upgrade
Climate Zone 2	Typical Costs		5	15	25	50
		AADT_50	Not Viable	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_100	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_175	Base Upgrade	Base Upgrade	Base Upgrade	Alt Upgrade
		AADT_250	Alt Upgrade	Alt Upgrade	Alt Upgrade	Alt Upgrade
		AADT_500	Alt Upgrade	Alt Upgrade	Alt Upgrade	Alt Upgrade
	High Costs		5	15	25	50
		AADT_50	Not Viable	Not Viable	Base Upgrade	Base Upgrade
		AADT_100	Not Viable	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_175	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_250	Base Upgrade	Base Upgrade	Base Upgrade	Alt Upgrade
		AADT_500	Alt Upgrade	Alt Upgrade	Alt Upgrade	Alt Upgrade
Clim ate	Typi cal		5	15	25	50

		AADT_50	Not Viable	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_100	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_175	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_250	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_500	Base Upgrade	Base Upgrade	Alt Upgrade	Alt Upgrade
	High Costs		5	15	25	50
		AADT_50	Not Viable	Not Viable	Base Upgrade	Base Upgrade
		AADT_100	Not Viable	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_175	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_250	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_500	Base Upgrade	Base Upgrade	Base Upgrade	Alt Upgrade
Climate Zone 4	Typical Costs		5	15	25	50
		AADT_50	Not Viable	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_100	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_175	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_250	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_500	Base Upgrade	Alt Upgrade	Alt Upgrade	Alt Upgrade
	High Costs		5	15	25	50
		AADT_50	Not Viable	Not Viable	Not Viable	Base Upgrade
		AADT_100	Not Viable	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_175	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_250	Base Upgrade	Base Upgrade	Base Upgrade	Base Upgrade
		AADT_500	Base Upgrade	Base Upgrade	Base Upgrade	Alt Upgrade

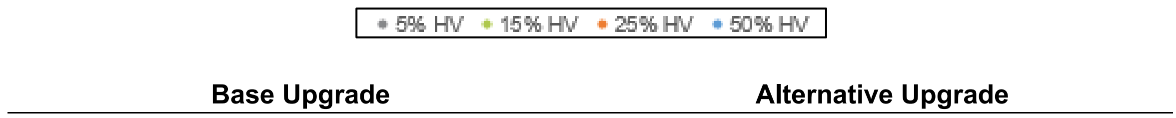
Table 5.3: Test criterion 2: Sealing strategy viability matrix / good practice / regional distributor

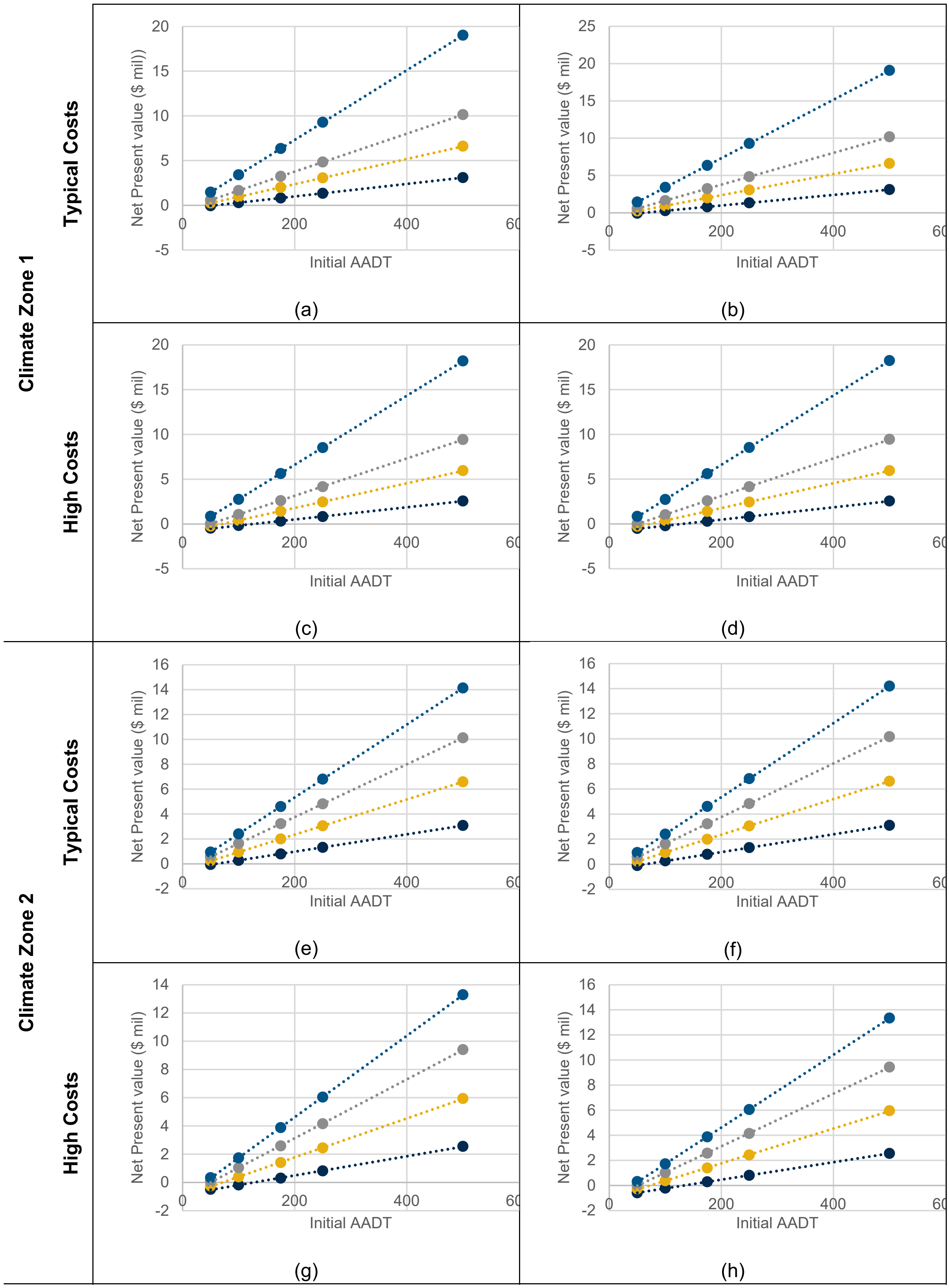
		Seal + base maintenance "Base Upgrade"					Seal + preventative maintenance "Alternative Upgrade"				
			HV (%)					HV (%)			
Climate Zone 1	Typical Costs		5	15	25	50		5	15	25	50
		AADT_50	Not Viable	Marginal	Viable	Viable	AADT_50	Not Viable	Marginal	Viable	Viable
		AADT_100	Marginal	Viable	Viable	Viable	AADT_100	Marginal	Viable	Viable	Viable
		AADT_175	Viable	Viable	Viable	Viable	AADT_175	Viable	Viable	Viable	Viable
		AADT_250	Viable	Viable	Viable	Viable	AADT_250	Viable	Viable	Viable	Viable
		AADT_500	Viable	Viable	Viable	Viable	AADT_500	Viable	Viable	Viable	Viable
	High Costs		5	15	25	50		5	15	25	50
		AADT_50	Not Viable	Not Viable	Marginal	Marginal	AADT_50	Not Viable	Not Viable	Marginal	Marginal
		AADT_100	Not Viable	Marginal	Marginal	Viable	AADT_100	Not Viable	Marginal	Marginal	Viable
		AADT_175	Marginal	Viable	Viable	Viable	AADT_175	Marginal	Viable	Viable	Viable
		AADT_250	Marginal	Viable	Viable	Viable	AADT_250	Marginal	Viable	Viable	Viable
		AADT_500	Viable	Viable	Viable	Viable	AADT_500	Viable	Viable	Viable	Viable
Climate Zone 2	Typical Costs		5	15	25	50		5	15	25	50
		AADT_50	Not Viable	Marginal	Viable	Viable	AADT_50	Not Viable	Marginal	Viable	Viable

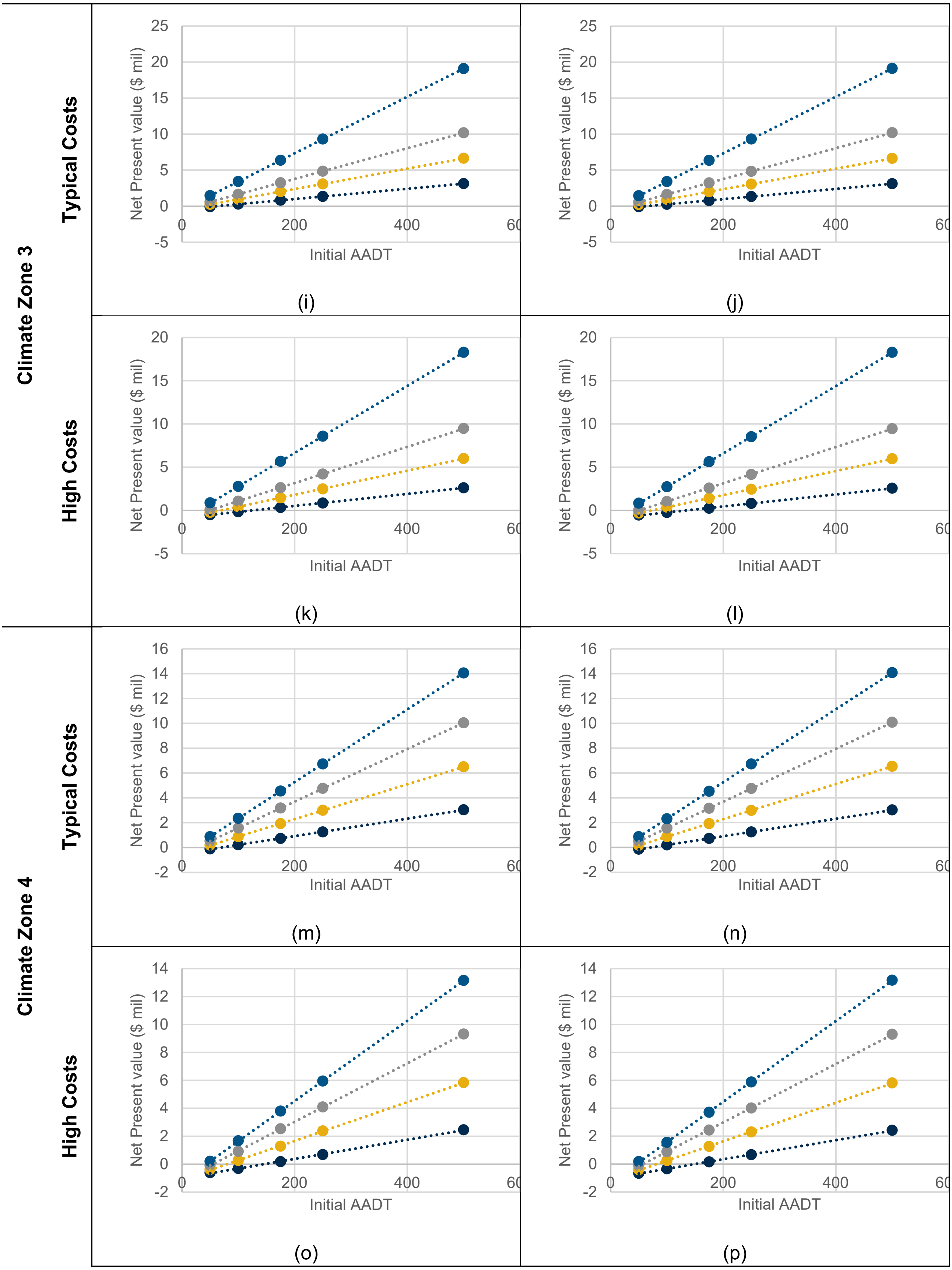
		AADT_100	Marginal	Viable	Viable	Viable	AADT_100	Marginal	Viable	Viable	Viable
		AADT_175	Viable	Viable	Viable	Viable	AADT_175	Viable	Viable	Viable	Viable
		AADT_250	Viable	Viable	Viable	Viable	AADT_250	Viable	Viable	Viable	Viable
		AADT_500	Viable	Viable	Viable	Viable	AADT_500	Viable	Viable	Viable	Viable
	High Costs		5	15	25	50		5	15	25	50
		AADT_50	Not Viable	Not Viable	Marginal	Marginal	AADT_50	Not Viable	Not Viable	Marginal	Marginal
		AADT_100	Not Viable	Marginal	Marginal	Viable	AADT_100	Not Viable	Marginal	Marginal	Viable
		AADT_175	Marginal	Viable	Viable	Viable	AADT_175	Marginal	Viable	Viable	Viable
		AADT_250	Marginal	Viable	Viable	Viable	AADT_250	Marginal	Viable	Viable	Viable
		AADT_500	Viable	Viable	Viable	Viable	AADT_500	Viable	Viable	Viable	Viable
Climate Zone 3	Typical Costs		5	15	25	50		5	15	25	50
		AADT_50	Not Viable	Marginal	Viable	Viable	AADT_50	Not Viable	Marginal	Viable	Viable
		AADT_100	Marginal	Viable	Viable	Viable	AADT_100	Marginal	Viable	Viable	Viable
		AADT_175	Viable	Viable	Viable	Viable	AADT_175	Viable	Viable	Viable	Viable
		AADT_250	Viable	Viable	Viable	Viable	AADT_250	Viable	Viable	Viable	Viable
		AADT_500	Viable	Viable	Viable	Viable	AADT_500	Viable	Viable	Viable	Viable
	High Costs		5	15	25	50		5	15	25	50
		AADT_50	Not Viable	Not Viable	Marginal	Marginal	AADT_50	Not Viable	Not Viable	Marginal	Marginal
		AADT_100	Not Viable	Marginal	Marginal	Viable	AADT_100	Not Viable	Marginal	Marginal	Viable
		AADT_175	Marginal	Viable	Viable	Viable	AADT_175	Marginal	Viable	Viable	Viable
		AADT_250	Marginal	Viable	Viable	Viable	AADT_250	Marginal	Viable	Viable	Viable
		AADT_500	Viable	Viable	Viable	Viable	AADT_500	Viable	Viable	Viable	Viable
Climate Zone 4	Typical Costs		5	15	25	50		5	15	25	50
		AADT_50	Not Viable	Marginal	Marginal	Viable	AADT_50	Not Viable	Marginal	Marginal	Viable
		AADT_100	Marginal	Viable	Viable	Viable	AADT_100	Marginal	Viable	Viable	Viable
		AADT_175	Viable	Viable	Viable	Viable	AADT_175	Viable	Viable	Viable	Viable
		AADT_250	Viable	Viable	Viable	Viable	AADT_250	Viable	Viable	Viable	Viable
		AADT_500	Viable	Viable	Viable	Viable	AADT_500	Viable	Viable	Viable	Viable
	High Costs		5	15	25	50		5	15	25	50
		AADT_50	Not Viable	Not Viable	Not Viable	Marginal	AADT_50	Not Viable	Not Viable	Not Viable	Marginal
		AADT_100	Not Viable	Marginal	Marginal	Viable	AADT_100	Not Viable	Marginal	Marginal	Viable
		AADT_175	Marginal	Marginal	Viable	Viable	AADT_175	Marginal	Marginal	Viable	Viable
		AADT_250	Marginal	Viable	Viable	Viable	AADT_250	Marginal	Viable	Viable	Viable
		AADT_500	Viable	Viable	Viable	Viable	AADT_500	Viable	Viable	Viable	Viable

To further portray the effect of HV traffic and AADT on the value of road upgrade alternatives, Figure 5.1 presents the net present value of TTC savings for typical and high-cost base and alternative road seal upgrade strategies compared to an unsealed road for each climate zone. These savings are the estimated economic benefits achieved by sealing a given road. Figure 5.1 shows that, in all cases, the benefit from sealing unsealed roads increases significantly with the proportion of HVs. It further demonstrates the point that greater numbers of road users (AADT) also increase the NPV of TTC savings.

Figure 5.1: Benefits of a sealed road upgrade by climate zone, cost level, upgrade type, and by initial AADT and HV percentage – regional distributors with good practice




Climate Zone 1
Climate Zone 2
Typical Costs
High Costs
Typical Costs
High Costs
Net Present value ($ mil))
Net Present value ($ mil)
Initial AADT
20
15
10
5
0
-5
25
16
14
12
8
6
4
2
-2
0
200
400
60
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)



This can also be analysed from a different perspective – that of breakeven AADT, i.e. the level at which NPV equals zero. A positive NPV represents positive benefits – a TTC saving. The level of initial AADT at which an investment in a base or alternative sealed road upgrade breaks even can be interpolated from these graphs, generating enough agency and user benefits to offset the upgrade cost (i.e. a NPV of TTC of at least zero).

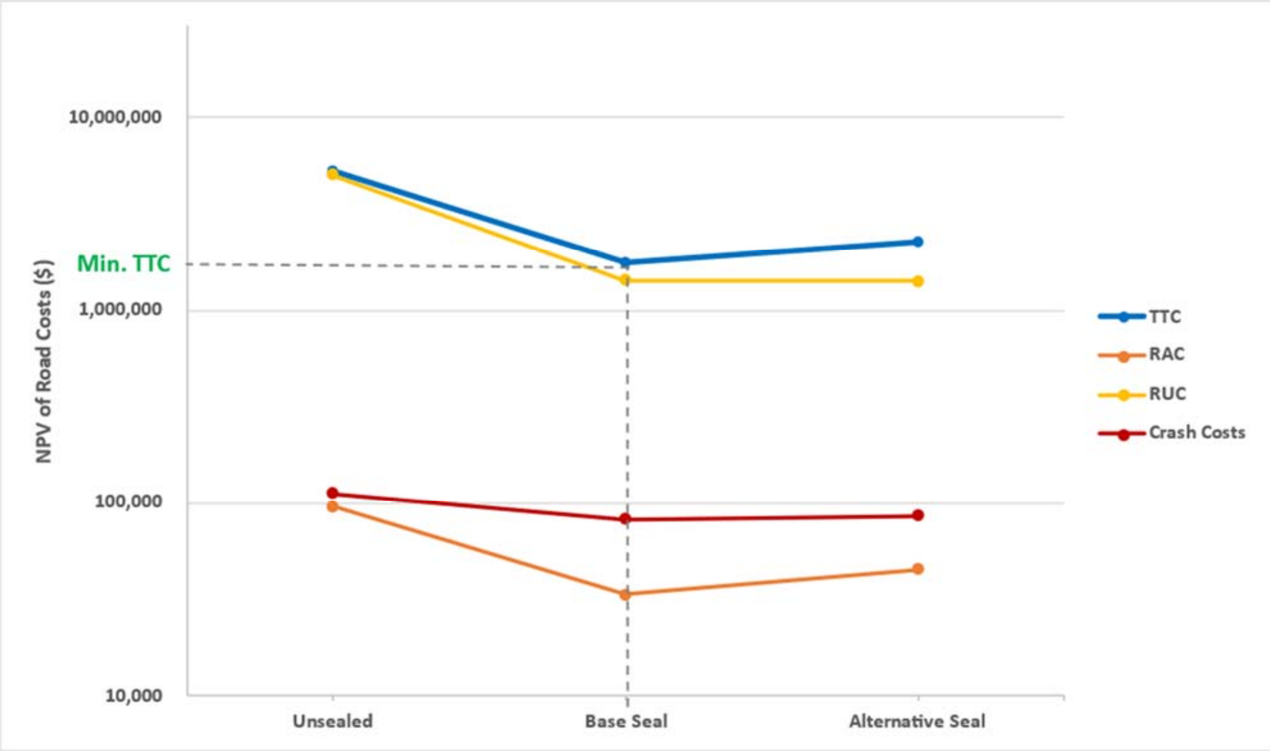
It can be seen that the breakeven AADT generally sits between 50 and 350 and varies according to the proportion of HVs. The more HV traffic a road carries, the lower the absolute level of traffic (AADT) required to offset the costs of sealing it. Table 5.4 shows the breakeven AADT values from these interpolations for all seal upgrade levels, climate zones, and cost levels. Generally, there is not a large difference between base-level versus alternative seal upgrade strategies, nor are there great differences between climate zones. The greatest variations are related to the road's HV traffic, where there is an average 80% reduction in the breakeven AADT level from 5% HV traffic to 50%. The level of upgrade costs also has a significant effect, with higher costs increasing the AADT or HV levels required to break even.

Table 5.4: Breakeven AADT for sealing an unsealed road, by HV percentage, cost level, upgrade level, climate zone – regional distributors with good practice

		Climate Zone	HV% 5	HV% 15	HV% 25	HV% 50
Typical Costs	Base Upgrade	1	59	32	22	12
		2	60	33	23	18
		3	59	32	22	12
		4	69	37	25	20
	Alternative Upgrade	1	61	33	23	13
		2	63	34	23	19
		3	64	35	24	13
		4	71	38	27	21
High Costs	Base Upgrade	1	125	70	49	29
		2	127	71	50	40
		3	125	69	49	28
		4	145	80	55	43
	Alternative Upgrade	1	129	72	50	29
		2	133	73	51	41
		3	134	74	51	30
		4	150	82	57	46

As described previously, finding the 'optimal' road upgrade strategy, whilst acting within the physical and budgetary constraints, relies on estimating the TTC (NPV of lifetime costs) of each option and selecting the one with the lowest TTC. Section 4.6.3 discussed how increasing the levels of road maintenance and quality involves trade-offs between usually greater construction and maintenance costs (RAC), and lesser road user and crash costs. In the context of the guide, the options are not maintenance standards, but choices between keeping an unsealed road and sealing the road with two different levels of upgrade and maintenance quality. Figure 5.2 demonstrates this trade off and shows the 'Goldilocks Point' of minimum TTC for the example of a road in climate zone 3 with an AADT of 175, 15% HV and typical costs. This clearly depicts that the minimum TTC is obtained with a base upgrade standard, i.e. a seal with base maintenance. It further shows decreasing RUC as the road standard increases, and that between the two road upgrade strategies, there are increasing RAC and decreasing crash costs. The unsealed road does not fit the same trend, as it requires a higher level of maintenance investment and the lower driving speeds results in lower crash costs. Note, the y-axis is presented in $\log_{10}$ form for ease of comparing costs of significantly different scales.

Figure 5.2: Road upgrade, maintenance and user costs by strategy, climate zone 3, initial AADT 175, 15% HV, typical costs, good practice



6 Stakeholder Engagement

6.1 Purpose and Process

The purpose of consulting with LGAs was to identify information relevant to the development of the guideline and to include practitioner experience in the development of the guide.

The type of information sought included:

- costs
- location related factors
- road types by hierarchy and surface type
- factors that contribute to sealing an unsealed road
- typical road conditions, maintenance practices, and frequencies
- typical traffic levels, composition, loading and patterns of use
- environmental considerations
- climate conditions, including seasonal and longer-term patterns and forecast changes
- road safety considerations
- how to identify candidates for upgrading and choosing options
- community and service level considerations
- road network performance measures
- funding sources and considerations.

The consultation involved a questionnaire emailed to LGAs, and a workshop with invited practitioners. Once the guideline was substantially completed, a presentation on the final guideline was provided to practitioners through an online video meeting.

6.2 Questionnaire

The questionnaire was sent to 113 stakeholders on 16 May 2023 by WALGA with a closing date of 2 June 2023. The questionnaire was sent to the highest-ranking engineering infrastructure officers in each LGA in WA, except for inner metropolitan LGAs, which do not have unsealed roads. The Request for Information and Questionnaire are provided in Appendix B.

Eight responses were received, with 5 from regional, 1 remote and 2 very remote LGAs. They collectively manage 12,257 km of roads, of which 7,554 km are unsealed.

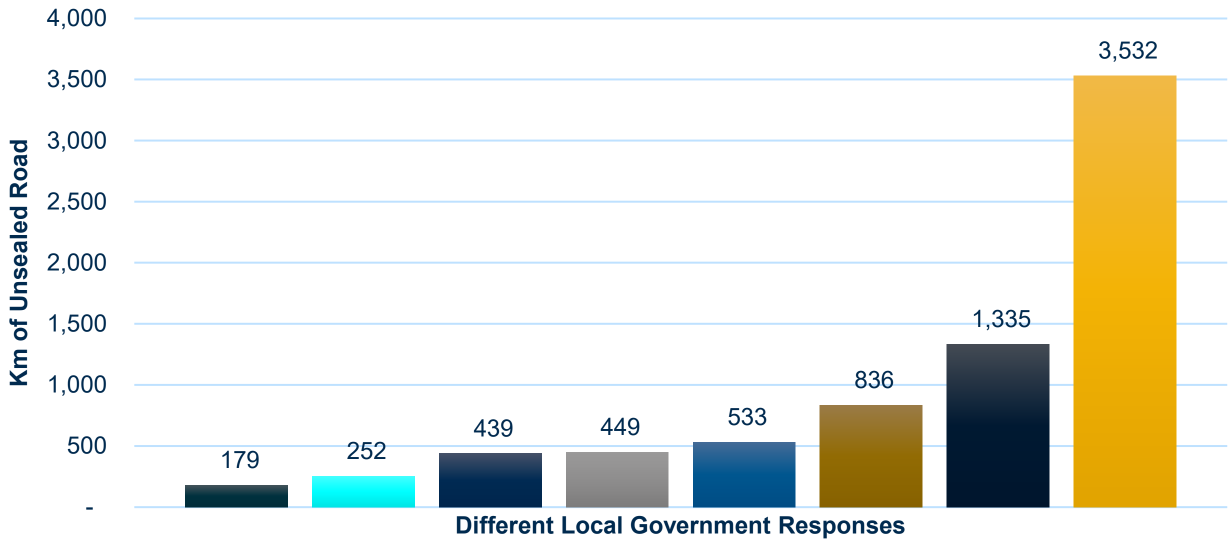
As this was not a sufficient number of responses to adequately represent 117 LGAs in WA (excluding the inner-metropolitan councils that do not have unsealed roads), any learnings and assumptions from their responses should be considered indicative and not representative.

6.2.1 Road Hierarchy and Lengths

Practitioners were asked to provide the total lengths of sealed and unsealed roads for each road hierarchy: regional distributor, local distributor, and local access. They could also nominate an 'Other' type of road. The responses to 'Other' included a bridge, quarry access road, an airstrip, restricted access vehicle route, and unnamed tracks.

There was significant variation in the lengths of unsealed road, with total lengths ranging from 179 km to 3,532 km as shown in Figure 6.1.

Figure 6.1: Total km of unsealed road in questionnaire responses



Practitioners were asked to nominate the type of unsealed road. This also generated a large range of responses. The proportion of gravel, formed earth and unformed earth roads were:

- 70% – 100% gravel
- 7% – 30% formed and unformed earth
- 1 exception stating 100% unformed earth.

Practitioners were then asked whether they thought there was a need to upgrade any roads to accommodate population growth. The responses were mixed, and no trend was evident. Some potential need for upgrades was indicated by most respondents.

6.2.2 Approach to Maintaining Unsealed Roads

Practitioners were asked about their approach to maintaining unsealed roads. They were able to respond yes or no to a series of statements ranging from proactive maintenance to mostly reactive. All practitioners responded that a combination of proactive and reactive maintenance approach was being used.

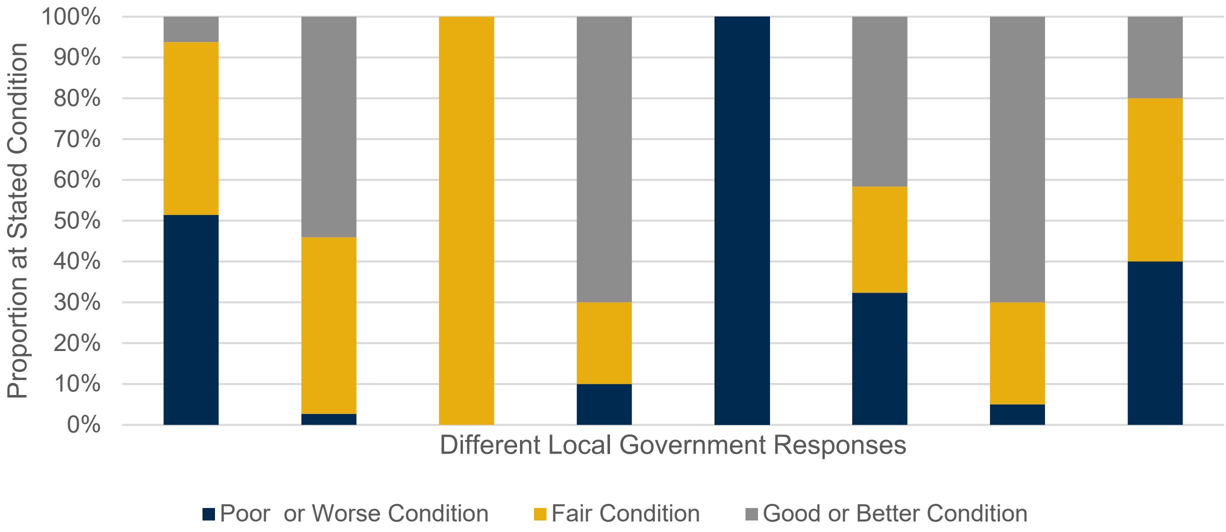
6.2.3 Road Asset Data

In terms of road inventory and traffic data, practitioners were asked to indicate:

- the proportion of unsealed roads in poor or worse condition, fair condition, and good or better condition
- the proportion or length with estimated gravel thickness within the ranges of less than 75 mm, more than 125 mm, or between
- the average and maximum daily traffic for regional distributors, local distributors, and local access roads.

With respect to condition, there was a wide range of results as shown in Figure 6.2. The most notable result was the proportion of unsealed roads considered to be in poor condition: 40% and 51% respectively. The empty column indicates no response to this question. The columns are in no particular order.

Figure 6.2: Proportion of unsealed roads at stated condition



In terms of the depths of gravel, there was some variability, with the range of 75 to 125 mm being the most common.

Limited responses were received for the average and maximum daily traffic. The most common response was that about 100 to 150 vehicles per day was a threshold between distributor roads and access roads.

6.2.4 Intervention Levels and Levels of Service

Practitioners were asked what level of service and intervention levels they use. They were able to respond to attributes of safety, accessibility, reliability, condition, sustainability, and responsiveness, for each type of road hierarchy. Common responses were that safety and condition were given higher priority.

This question generated a number of comments (provided as stated):

- '[Name][1] Road hierarchy and criteria and level of service and priorities are defined in this document.'
- 'The [Name] is undertaking a LOS review at the moment to ensure we are consistent in our approach to maintaining unsealed roads.'
- 'Hierarchy is Local Access only.'
- 'We do not have a formalized/endorsed LoS for the unsealed road network, but we aim to maintain our unsealed network at a suitable standard. We have an annual re-sheet program that covers 60 km of unsealed roads a year, and have a maintenance grading program where the frequency of maintenance is allocated according to the criticality of the road. Most roads are graded 2-3 times a year on average. High use roads up 9 times per year.'
- 'The [Name] uses a weighting on traffic volume (EqADT) [average daily traffic], hierarchy, RAV [restricted access vehicles], commodities and other unweighted parameters are bus routes and tourism destinations for prioritising resheeting and sealing gravel roads.'

The responses indicate that some LGAs have methods to determine levels of service and intervention levels, and some do not.

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1 The designation [Name] is where the respondent provided the shire, city, or road name. The names have been redacted here for confidentiality.

6.2.5 Cost and Frequency of Routine Maintenance on Unsealed Roads

Practitioners were asked to provide a range of information regarding maintenance practices on unsealed roads. They were asked how their maintenance practices varied with traffic volumes and compositions. Responses included:

- 'Resources arrangement and work planning are different for low and high volumes of traffic. Work hour restrictions during high volume and composition.'
- 'Local roads that are known to have higher traffic volumes are maintain more frequently than roads with fewer traffic volumes. Roads with high HV classes will require frequent upgrades and a substantial pavement.'
- 'High daily volume and school bus routes are prioritised.'
- 'There is consideration to the timing of the seasonal grading of our unsealed roads to be planned around peak windows to ensure safer driving conditions during periods of higher traffic.'
- 'Increased maintenance for high traffic volume roads.'
- 'Road maintenance in our unsealed network follows an annual program. Additionally, we complete both preventative and reactive maintenance on haulage roads that receive increased HV traffic during harvest season. We are in the process of establishing a system to capture traffic volumes on our unsealed network as currently is done a case by cases basis as required.'
- 'Traffic volume and type impact on the number of gradings per year.'

It is evident that LGAs prioritises higher-volume traffic roads, with some seasonal effects from tourism and harvest periods.

Practitioners were then asked for the number of gradings, number of gradings with compaction (as a practice), grading cost per kilometre, resheet interval, resheet cost per kilometre, additional cost factors for haulage and for gathering compliant materials. The data was separated by road hierarchy. The responses are presented in Table 6.1.

Table 6.1: Responses to questions on preservation of unsealed roads

Question	Distributor Roads	Access Roads
Number of gradings per annum	Wide range from 2 to 9	Ranges from 1 to 4
Number of gradings and compactions per annum	Wide range from 2 to 9 for regionals, 1 to 3 for distributors	1 or 2, based on condition, or ad hoc
Grading cost per kilometre	Significantly different prices received. Unable to see a trend	Significantly different prices received. Unable to see a trend.
Average resheet interval in years	Wide range from 1 to 20	Wide range from 10 to 20
Resheet cost per kilometre	Ranges from $21,000 to $60,000	Ranges from $21,000 to $60,000
Additional cost factor for haulage to remote sites	Four responses indicate increases like 10%	Four responses indicated increases, like 10%

For the number of gradings per year and grading and compactions per year, there was a wide range of responses from 2 to 9 across regional and local distributors. Practitioners typically reported lower frequencies for access roads of 2 to 4.

Significantly different prices for cost per kilometre for grading were received. This may be due to a lack of clarity in the questionnaire design as it appears some practitioners responded in terms of cost per kilometre for the whole network as opposed to the cost per kilometre for the graded roads in that year.

In terms of resheet cost per kilometre, there were more reliable responses, with costs ranging from $21,000 to $60,000 per kilometre from 5 respondents, regardless of road hierarchy. The average resheet interval, however, varied widely – from 1 (yearly) to 30 years.

6.2.6 Plasticity and Particle Size Characteristics of Unsealed Roads

Practitioners were asked to provide proportions of their unsealed roads that were considered to have:

- plasticity that is compliant with desirable specifications, low, or high
- particle size characteristics that are compliant with desirable specifications, and moderate to high percent oversize with low fines or with excess fines.

Most practitioners were not able to respond. This indicates that LGAs may have a lack of technical information regarding unsealed roads.

6.2.7 Costs for Typical Treatments

In terms of the typical costs per kilometre of upgrading for different types of project, there was substantial variability in the responses. It appears that practitioners made very different assumptions regarding the types of costs and scopes of project resulting with no obvious average or typical order of cost.

6.2.8 Cost and Frequency of Preservation Activities of Sealed Roads

Practitioners were asked to provide information on the cost and frequency of maintenance of sealed roads. The questions asked, and responses, are shown in Table 6.2.

Table 6.2: Responses to questions on preservation of sealed roads

Question	Distributor Roads	Access Roads
Average reseal interval for distributor roads	Ranges from 10 years to 35 years	Ranges from 10 years to 50 years
Reseal cost per kilometre	A median price of around $55,000 for regional distributors and $43,000 for local distributors	A median price of around $40,000
Average rehabilitation interval	Ranges from 30 to 80 years	Ranges from 15 to 80 years
Rehabilitation cost per kilometre	Ranges from $100,000 to $432,000	Ranges from $85,000 to $360,000
Scope of rehabilitation (light or heavy ripping)	No consistent response	Three responses indicating 'light' scope.
Additional cost factor for haulage to remote sites	Insufficient response	Insufficient response

In terms of reseal intervals, there was a wide range of responses: from 10 years to 35 years for distributor roads, and up to 50 years for access roads, whereas for rehabilitation the intervals were up to 80 years.

The median prices for resealing were about $40,000 per km for access roads, increasing to $43,000 for local distributor and $55,000 for regional distributor roads. The range of rehabilitation costs was much larger, ranging from $85,000 per kilometre for access roads up to $432,000 per kilometre for regional distributor roads.

6.2.9 Factors Influencing Decision

The final part of the questionnaire asked about the factors influencing the decision to upgrade an unsealed road. From the choice of current condition and deterioration, changing traffic, environmental impacts, climate factors and conditions, whole of life cost of maintenance and preservation, road safety, and other, the common factors indicated were:

- changing traffic composition and volumes
- environmental impacts
- whole of life cost of maintenance and preservation
- road safety.

The other factors stated were tourism, and community expectation including complaints.

Practitioners responded as to how or why these factors impacted their decision-making process as follows:

- 'The [Name] considers the above factors when making a decision to upgrade a road. The [Name] does this by using a risk prioritisation process to rank projects: Rank = Likelihood x Consequence Rank = (Hierarchy + Condition) x (Road Safety + Cost Benefit).'
- 'They influence the overall cost to maintain the asset.'
- 'Higher the volume of traffic will demand a safer user friendly road.'
- 'The [Name] has limited history of upgrading unsealed roads in recent years. The main drivers would situational to each location and be reliant on having an justification to leverage suitable grant funding to make the project viable.'
- 'Whole of life costs calculated to compare Unsealed Vs Sealed such that annualised cost to council becomes higher than the seal option. This usually occurs when very high maintenance levels are required which in turn reflects traffic volumes.'
- 'Poor drainage, Poor shape WoL costs of unsealed vs sealed have changed and it is becoming more desirable to seal but the capital costs for upgrades attract no external funding so the amount sealed pa is minimal.'

The data or documentation on how these decisions have been made was advised as:

- 'Not really but we use a rule of thumb that if the gravel road has more than 200 vehicles a day, regional or local distributor, maintenance costs and has high tourism use then the LGAs may consider sealing the road.'
- '[Name] annual maintenance and capital work programmes and council corporate decisions. The [Name] also commissioned a grain freight road network study that gives us approximate volumes of grain freight traveling down each section of road that factors into the justification of upgrading a road.'
- '[Name] road was sealed in 19/20 financial year. The decision why to seal the road in unknown.
- 'No. The last road we sealed was due to HV safety and tourism.'
- '[Name] Road may be good example case. This was taken over by Main Roads and remaining 90k of unsealed Pindan upgraded to sealed road. Refer to MRWA for details.'
- 'Yes, Whole of Life Costings.'
- 'Staged sealing of [Name] Rd – availability of HVRPP funding was a major factor or it would not have been financially viable. High RAV (7), AADT over 100, road hierarchy (connectivity as a commodity route). Scored highly as a priority but cost was out of the range of the [Name]. A business case from 2017/18 may be made available.'

When asked if guidance on when to upgrade or seal an unsealed road was available, most responded 'no' or 'not applicable'. One practitioner advised that they had a policy covering ATV (presumed to refer to all-terrain vehicles), and another responded that a guide was under development.

This indicates that there are no common methods being used to assess unsealed road upgrade needs, and that funding requirements are a key driver.

6.2.10 Factors in Scoping Upgrades

The final question asked what factors were accounted for in scoping options for upgrading to a sealed road. Almost all practitioners responded 'Almost always' for all factors. The factors listed were:

- formal thickness design
- formation widening
- formation raising

- drainage improvements
- safety improvements
- cross section geometry improvements.

6.2.11 Summary of Questionnaire Responses

As stated at the start of this section, due to only receiving 8 responses from 117 LGAs, the results need to be considered indicative only. A summary of the responses is as follows:

1. There was significant variability in responses across most questions, meaning that common practices and trends in pricing were not obvious. Most respondents indicated 70% to 100% of their roads were gravel roads.
2. Practitioners are using a combination of proactive and reactive maintenance. By proportion of unsealed roads at different conditions, the results were mixed. However, two responses showed very high proportions of poor or worse condition of unsealed roads.
3. When asked about intervention levels of service, there were indications that some have methods to determine intervention levels, and some do not. It appears that a structured methodology would be useful.
4. Based on the responses, LGAs prioritise higher-volume traffic roads, with some seasonal effects from tourism and harvest periods. Changing traffic composition and volumes was recorded as a common factor to consider when upgrading a road. When comparing the responses to the questions on proportion of traffic, however, there may be a lack of traffic data for lower-order roads to include in a decision methodology.
5. Practitioners indicated very different costs and frequencies of maintenance on unsealed roads and sealed roads. This suggests that there are strong local influences (funding, community expectations and environment) that lead to different levels of service being required.
6. There was a lack of response to the technical enquiries for unsealed roads, i.e. plasticity and particle size characteristics. This information may not be readily available and so a decision methodology would need to provide for this unavailability.
7. Costs and funding were identified as constraints, with whole-of-life costs of maintenance being a common factor when considering upgrades. There also appears to be no common methods being used to assess unsealed road upgrade needs.

Despite only receiving 8 responses, the response did provide some insight into LGA practices and concerns, and this has helped to inform the decision methodology.

6.3 Guideline Presentation

When the guideline was substantially complete, stakeholders were presented with an overview of the guideline via online video on 27 July 2023.

The presentation covered:

1. An overview of the project, including the purpose, background, project methodology, the role of local government, and the issues which are addressed in the project.
2. A summary of the fundamentals of unsealed roads asset management including definitions of unsealed and sealed roads, and the basic asset management principles.
3. A description of the process presented in the *Practitioners Guide*.
4. A description of the research presented in the *Technical Basis* report (this report).
5. An overview of the whole-of-life asset approach used to develop the case studies.
6. A summary of the presentation.

7 Implementation Opportunities

These documents equip LGAs with the necessary information to make informed decisions about the sealing of unsealed roads within their jurisdiction.

By applying the information presented in these documents, LGAs can undertake comprehensive analyses of the benefits of sealing unsealed roads, taking into consideration the whole-of-life cost implications, likely impacts of traffic growth from many sources, and road safety costs. The analyses can be used in business cases, budget preparation, bids and plans.

Road construction practices are constantly evolving to address the requirements of policy, strategic plans and societal expectations. These documents provide guidance based on current best practice. Future reviews and revisions of these documents may be required to capture new developments and maintain the currency of information.

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Appendix A Basis for Modelling and Representative Analysis Cases

A.1 Model Analysis Parameters

In the following sections, a comprehensive description of the methodology used in developing case studies, focused on the transition from unsealed to sealed roads, is presented. By incorporating specific parameters, these studies enable a thorough analysis of the costs and benefits for a 50-year analysis period. This empowers decision-makers to assess the economic feasibility and potential advantages of infrastructure upgrades using an apple-to-apple comparison, namely whole-of-life cycle costs as elaboration in Section 5.

A.1.1 Case Study Naming Parameters

Defined Road Types

This hierarchical classification provides a framework for analysing and understanding the different characteristics, requirements, and challenges associated with road infrastructure across varying levels of importance and usage. The following road types were defined with the abbreviations also shown:

- Access road – ACCESS
- Local distributor - LOC DIST
- Regional distributor – REG DIST
- District distributor – DIS DIST

These road types match the definitions used by LGAs across the State.

Defined Traffic AADT Types

The viability of choices in the case study is influenced by both the Annual Average Daily Traffic (AADT) and the proportion of HVs (HV%). AADT represents the average daily vehicle count, while HV% indicates the proportion of HVs within that traffic volume. These factors are crucial for assessing road usage, performance, and the potential damage caused by traffic and the vehicle operation costs and related travel time costs.

To ensure accurate analysis, the AADT values used in the model specifically account for typical levels of traffic on unsealed roads, as follows:

- AADT 50
- AADT 100
- AADT 175
- AADT 250
- AADT 500

In addition, the model considers the following proportions of HV:

- 5%
- 15%
- 25%
- 50%.

This breakdown provides a comprehensive understanding of traffic volume and the proportion of HVs in the analysis.

The traffic inputs used for this analysis are presented in Table A.1.

Table A.1: Traffic inputs

Austroads 12 – Class Traffic Input Type	
03. Large car	AADT minus sum of HV
08. Heavy rigid	(1/3) X HV% X AADT
12. 6 axle articulated	(1/3) X HV% X AADT
14. B-Double	(1/3) X HV% X AADT

Defined Climate Zones

Section 4.5 of the guide introduces the division of climate zones into four sections within the WA region. These climate zones have been established to account for the distinct climatic conditions experienced across different areas. Table A.2 provides a summary of the climate zones, describing their characteristics and how they have been utilised in the cases. The climate zones play a vital role in assessing the performance and resilience of road infrastructure. By considering the specific climatic conditions of each zone, valuable insights can be gained to inform the rate of road deterioration, material selection, design considerations, and maintenance strategies.

Table A.2: Climate zone details

Climate Zone	Description	Maximum average monthly temperature (oC)	Minimum average monthly temperature (oC)	Thornthwaite Moisture Index	Average annual rainfall (mm)
Climate Zone 1	Hot humid summer	33.83	20.68	-22.30	601.4
Climate Zone 2	Hot dry summer, mild winter	31.70	18.78	-19.75	435.8
Climate Zone 3	Hot dry summer, cold winter	33.34	11.8	-34.5	273.0
Climate Zone 4	Warm summer, Cold winter	22.77	10.97	7.20	713.4

A concise overview of each climate zone and its corresponding description is provided. Decision-makers can refer to this information to gain a better understanding of the climate-related factors influencing the behaviour and performance of roads within each zone. Further to this, Table A.3 illustrates the different LGAs climate zone designation.

Table A.3: Climate zone detail including LGA specific regions

Region	LGA Name	Max daily temperature (°C)	Min daily temperature (°C)	Thornthwaite Moisture Index	Climate Zones
Gascoyne	Exmouth	31.9	20	-36.4	1
Goldfields-Esperance	Coolgardie	26.3	11.8	-35.8	3
Goldfields-Esperance	Dundas	25.3	10.7	-29.8	3,4
Goldfields-Esperance	Esperance	23.1	10.9	-6.4	3,4
Goldfields-Esperance	Kalgoorlie - Boulder (C)	26.2	11.6	-36	3
Goldfields-Esperance	Laverton	27.3	12.8	-35.5	3
Goldfields-Esperance	Leonora	28.6	14.3	-36.5	3
Goldfields-Esperance	Menzies	27.4	12.8	-35.8	3
Goldfields-Esperance	Ngaanyatjarraku	29.8	14.5	-30.7	2,3
Goldfields-Esperance	Wiluna	30	14	-33.9	2,3
Great Southern	Albany (C)	20.9	10.7	16	4
Great Southern	Broomehill - Tambellup	22.5	9.6	-8.7	4
Great Southern	Cranbrook	21.8	9.9	9	4

Region	LGA Name	Max daily temperature (°C)	Min daily temperature (°C)	Thornthwaite Moisture Index	Climate Zones
Great Southern	Denmark	20.9	9.7	32.6	4
Great Southern	Gnowangerup	22.5	9.8	-13.7	4
Great Southern	Katanning	23.1	9.8	-12.8	4
Great Southern	Kent	23.6	9.7	-17.7	4
Great Southern	Kojonup	22.7	9.8	-4.2	4
Great Southern	Plantagenet	21.3	10	15.5	4
Great Southern	Woodanilling	23.3	10	-15.1	4
Great Southern	Jerramungup	22.4	9.6	-5.8	4
Great Southern	Ravensthorpe	22.8	10.8	-7	4
South West	Augusta - Margaret River	22.4	10.9	36.9	4
South West	Bridgetown - Greenbushes	22.6	9.2	26.8	4
South West	Bunbury (C)	22.7	10.9	34	4
South West	Busselton	22.9	10.6	38.2	4
South West	Capel	22.7	11	33.8	4
South West	Collie	22.9	9.8	31.2	4
South West	Dardanup	22.8	10	38	4
South West	Waroona	22.3	10.2	72	4
South West	Harvey	22.4	10.1	63.2	4
South West	Mandurah (C)	22.6	11.7	54.7	4
South West	Manjimup	21.3	9.9	52.1	4
South West	Boddington	23.7	8.5	6.2	4
South West	Murray	22.1	10.9	70.1	4
South West	Nannup	22.6	9.6	36.7	4
South West	Donnybrook - Balingup	22.8	9.4	31.2	4
South West	Boyup Brook	22.4	9.6	21.2	4
Wheat Belt South	Dumbleyung	24.2	10.2	-19.8	3,4
Wheat Belt South	Lake Grace	24	9.9	-17.2	3,4
Wheat Belt South	Wagin	23.5	10.1	-16.4	3,4
Wheat Belt South	West Arthur	23.1	9.7	-5.3	3,4
Wheat Belt South	Beverley	25.9	9.9	-24.5	3,4
Wheat Belt South	Brookton	24.8	9.9	-17.3	3,4
Wheat Belt South	Bruce Rock	25.7	10.3	-27.7	3,4
Wheat Belt South	Corrigin	25.4	10.3	-25.6	3,4
Wheat Belt South	Cuballing	24.1	10.1	-15.2	3,4
Wheat Belt South	Kondinin	25.5	10.1	-25.4	3,4
Wheat Belt South	Kulin	25.3	10.2	-24.8	3,4
Wheat Belt South	Narembeen	26	10.5	-28.6	3,4
Wheat Belt South	Narrogin (T)	23.5	10.1	-14	3,4
Wheat Belt South	Narrogin	23.9	10.1	-16.3	3,4
Wheat Belt South	Pingelly	24.4	10.1	-15.8	3,4
Wheat Belt South	Quairading	25.5	9.3	-27	3,4
Wheat Belt South	Wandering	24.7	9.9	-11.5	3,4
Wheat Belt South	Wickepin	24.6	10.2	-20.4	3,4
Wheat Belt South	Williams	23.5	9.5	-6.5	3,4
Wheatbelt North	Cunderdin	25.9	10.3	-25.8	3,4

Region	LGA Name	Max daily temperature (°C)	Min daily temperature (°C)	Thornthwaite Moisture Index	Climate Zones
Wheatbelt North	Dowerin	26	11.2	-26.6	3,4
Wheatbelt North	Goomalling	26	11	-25	3,4
Wheatbelt North	Kellerberrin	25.9	10.6	-29.1	3
Wheatbelt North	Shire of Merridan	25.8	10.5	-29.2	3
Wheatbelt North	Koorda	26	11.8	-30	3
Wheatbelt North	Trayning	26	11.4	-30	3
Wheatbelt North	Merredin	26	10.9	-29.5	3
Wheatbelt North	Mount Marshall	26.3	11.8	-30.4	3
Wheatbelt North	Mukinbudin	26.1	11.3	-30.1	3
Wheatbelt North	Northam	26	10.3	-24	3,4
Wheatbelt North	Nungarin	26.1	11.1	-29.8	3
Wheatbelt North	Tammin	25.8	10.2	-28.1	3
Wheatbelt North	Toodyay	26.1	10.5	-22.9	3,4
Wheatbelt North	Westonia	26.1	10.8	-29.3	3
Wheatbelt North	Wyalkatchem	25.9	11.6	-29.9	3
Wheatbelt North	York	25.8	10	-22.9	3,4
Wheatbelt North	Chittering	25.4	11.1	-7.7	3,4
Wheatbelt North	Dalwallinu	26.8	12.1	-30.8	3
Wheatbelt North	Dandaragan	26	12.1	-20.9	3,4
Wheatbelt North	Gingin	25.4	11.5	-6.8	3,4
Wheatbelt North	Moora	26.3	11.9	-27	3,4
Wheatbelt North	Victoria Plains	26.1	11.5	-23.7	3,4
Wheatbelt North	Wongan - Ballidu	26.1	11.7	-28.3	3
Wheatbelt North	Yilgarn	26.1	10.7	-28.8	3
Metropolitan	Armadale (C)	24.3	11.3	12	4
Metropolitan	Kalamunda	24.3	11.3	12	4
Metropolitan	Cockburn (C)	24.3	11.3	12	4
Metropolitan	Gosnells (C)	24.3	11.3	12	4
Metropolitan	Kwinana (T)	24.3	11.3	12	4
Metropolitan	Mundaring	24.9	10.9	0.5	4
Metropolitan	Rockingham (C)	22.9	11.1	50.5	4
Metropolitan	Serpentine - Jarrahdale	23.2	11.1	41.1	4
Metropolitan	Swan (C)	25	11.1	0.1	4
Metropolitan	Wanneroo (C)	25.2	11.1	-2.4	4
Metropolitan	Bassendean (T)	24.3	11.3	12	4
Metropolitan	Bayswater (C)	24.3	11.3	12	4
Metropolitan	Belmont (C)	24.3	11.3	12	4
Metropolitan	Canning (C)	24.3	11.3	12	4
Metropolitan	Claremont (T)	24.3	11.3	12	4
Metropolitan	Cottesloe (T)	24.3	11.3	12	4
Metropolitan	East Fremantle (T)	24.3	11.3	12	4
Metropolitan	Fremantle (C)	24.3	11.3	12	4
Metropolitan	Melville (C)	24.3	11.3	12	4
Metropolitan	Mosman Park (T)	24.3	11.3	12	4
Metropolitan	Nedlands (C)	24.3	11.3	12	4

Region	LGA Name	Max daily temperature (°C)	Min daily temperature (°C)	Thornthwaite Moisture Index	Climate Zones
Metropolitan	Peppermint Grove	24.3	11.3	12	4
Metropolitan	Perth (C)	24.3	11.3	12	4
Metropolitan	Stirling (C)	24.4	11.3	10.1	4
Metropolitan	South Perth (C)	24.3	11.3	12	4
Metropolitan	Subiaco (C)	24.3	11.3	12	4
Metropolitan	Cambridge (T)	24.3	11.3	12	4
Metropolitan	Victoria Park (T)	24.3	11.3	12	4
Metropolitan	Vincent (T)	24.3	11.3	12	4
Metropolitan	Joondalup (C)	25.2	11.1	-4	4
Metropolitan	Kings Park	24.3	11.3	12	4
Metropolitan	Rottnest Island	24.3	13.1	11	4
Mid West	Carnamah	27.8	12.6	-30.4	3
Mid West	Geraldton - Greenough (C)	26.6	14.4	-31.7	3
Mid West	Irwin	27.5	13.7	-30.5	3
Mid West	Mingenew	28.7	13.5	-32.8	3
Mid West	Morawa	28.6	13.1	-33.3	3
Mid West	Mullewa	28.6	13.8	-34.9	3
Mid West	Northampton	27.2	15.6	-36	3
Mid West	Perenjori	27.9	12.6	-30.9	3
Mid West	Three Springs	28.4	13	-30.8	3
Mid West	Chapman Valley	27.5	14.4	-34.3	3
Mid West	Coorow	27.3	12.5	-28	3
Mid West	Sandstone	29.1	13.5	-35.4	3
Mid West	Cue	29.7	15.6	-36.9	3
Mid West	Meekatharra	30.9	15.8	-35.5	3
Mid West	Mount Magnet	29.1	14.7	-35.8	3
Mid West	Murchison	30.3	14.4	-36	3
Mid West	Yalgoo	28.8	14	-34.4	3

Defined Upgrade Type – Sealed Upgrade

The sealed upgrade is the defined upgrade type in the case studies, representing the transition from an unsealed road to a sealed road.

This upgrade type is categorised into two levels:

- Base upgrade: This level signifies a standard quality upgrade based on design traffic from an unsealed road to a sealed road but using delayed intervention levels for cracking, rutting and roughness and not intervening on the basis of structural strength.
- Alternative upgrade: This level indicates a standard quality upgrade based on design traffic from an unsealed road to a sealed road but using desirable intervention levels for cracking, rutting and roughness and intervening on the basis of structural strength when the strength is 59% of the original in-service strength.

Cost of Sealed Upgrade

The cost of upgrade to seal is a function of the in-service structural strength required based on the projected design traffic in equivalent standard axles (ESA) and the road type, and whether the costs are defined as typical (TYP) or high (HIGH), with the latter representing more remote areas where supply costs are higher.

In determining the initial in-service structural strength, represented by the modified structural number (SNC), the following relationship has been applied and is based on an analysis of the Austroads long term pavement performance sites, as reported by Toole & Roper (2014) and Martin & Choummanivong (2018):

$$SNC0 = 2.465\ CAP0.0505 \qquad A1$$

where

CAP	=	traffic load capacity over a defined service life, defined as MESA × CGF
MESA	=	millions of equivalent standard axles per lane per year
CGF	=	cumulative growth factor for a defined service life (SL) at the annual traffic growth rate

Toole & Roper (2014) also developed a relationship between required SNC and cost, and this has been applied in estimating the cost of pavement construction in this study.

$$COST = 10.129\ e0.3459\ SNC$$

The above relationship was applied in estimating the typical (TYP) cost of upgrade from an unsealed road to a sealed road, and a value of two times the typical cost was used as the HIGH cost.

A.2 Unsealed Road Model

The unsealed model applies an adaptation of the local road deterioration study (LRDS) national model (Martin et al. 2013) as described by Toole & Hore-Lacy (2018) and Austroads (2018). Several factors have been implemented including traffic, gravel loss, type of grading, and materials used as summarised below:

- Traffic – Light Vehicle Units (LVU) where the model considers the number of LVUs that traverse the road over time. The more vehicles that travel on the road, especially heavy or overloaded vehicles, the greater the wear and tear on the road surface. The LVU represent pairs of axles with these determined for each of the four vehicle types represented in Table A.1 and is used in preference to AADT to better represent traffic composition.
- Gravel loss –dependent on mean monthly rainfall, traffic and material properties to determine the amount of gravel lost per year. Taking into account the initial gravel thickness, this directly influences when a resheet is required.
- Roughness change – adopts the original unsealed road model (Martin et al 2013) for typical practice and the revised model (Austroads 2018) based on more closely monitored sites for good practice. The two models have been applied separately based on the type and quality of grading chosen. Grading refers to the process of maintaining the road surface by reshaping the surface with or without compaction and with water added or not. Two levels of quality have been defined, where ‘typical’ practice represents circumstances where no moisture or compaction is added (light grading), and ‘good’ practice represents circumstances where the surface is moist and conducive to being trimmed and shaped with or without ‘tynes’ applied and with compaction by a free roller or a compaction machine ensuring that the road is not graded too frequently, which can lead to excess gravel loss, or nor too infrequently, which can result in a rough and uneven surface.
- Grading frequency (number of times per year) for this analysis – based on determining the ‘Goldilocks’ (or optimum frequency) for typical and good practice and for each climate accounting for traffic (in LVU).
- The materials used in constructing and maintaining unsealed roads can greatly impact their durability. The model considers the compliance of the materials used, distinguishing between compliant materials (C), and non-compliant materials with an additional calibration/deterioration factor, applied namely 0.5 for compliant materials and 2 for non-compliant materials.

By incorporating these considerations into the unsealed model, the analysis aims to provide a comprehensive basis to estimate the life cycle costs of the various case studies.

A.2.1 Traffic Light Vehicle Units

The equation used to calculate the change in Light Vehicle Units (LVU) per annum, considering a growth factor of 2.5%, is as follows:

LVU = (Initial LVU / Previous LVU + Initial LVU / Previous LVU * Growth) / 2

In this equation, the 'Initial LVU' represents the initial number of Light Vehicle Units, the 'Previous LVU' represents the number of LVUs in the previous year, and 'Growth' represents the growth rate or percentage increase in LVU over time. By using this equation, the change in LVU per annum can be determined, taking into account both the initial LVU and the growth rate.

A.2.2 Gravel Loss and Resheeting Implications

The gravel loss per annum is influenced by the LVU, MMP and weather the material is compliant or non-compliant. A summary of the annual gravel loss applied in the model is illustrated in Table A.4.

Table A.4: Annual gravel loss (mm) for initial traffic level (in LVU) by climate zone and materials compliance

Climate zone	Initial LVU	MMP	Compliant	Non-Compliant
1	50	50.1	5.9	24.9
1	100	50.1	6.8	30.3
1	175	50.1	8.1	38.4
1	250	50.1	9.5	46.5
1	500	50.1	14.0	73.5
2	50	36.3	5.1	20.4
2	100	36.3	6.0	25.8
2	175	36.3	7.4	33.9
2	250	36.3	8.7	42.0
2	500	36.3	13.2	69.0
3	50	22.7	6.1	19.2
3	100	22.7	7.0	24.6
3	175	22.7	8.4	32.7
3	250	22.7	9.7	40.7
3	500	22.7	14.2	67.7
4	50	59.4	6.4	28.0
4	100	59.4	7.3	33.4
4	175	59.4	8.6	41.5
4	250	59.4	10.0	49.6
4	500	59.4	14.5	76.5

The amount of gravel remaining (mm) can be calculated as the difference between the initial/previous amount of gravel and the gravel loss per year:

Gravel Remaining (mm) = Initial/Previous Gravel Depth - Gravel Loss per Year.

If the 'gravel remaining' depth (mm) falls below 50 mm, it indicates a significant reduction in the gravel layer. This triggers the need for a resheeting treatment to replenish and restore the gravel depth on the road.

A.2.3 Grading Frequency

The grading frequency applied for typical and good practice frequency values is summarised in Table A.5 according to climate zone and initial LVU. These were developed based on the development of the 'Goldilocks' relationship for each initial traffic level, climate and practice. For general application the grading frequency for each analysis year is based on the number of LVU over the analysis period with a set of equations of the following linear form developed for each climate zone and grading practice:

Grading frequency = a + (b * LVU)

Table A.5: Annual grading frequency for initial traffic level (in LVU) by climate zone and grading practice

Climate zone(s)	Initial LVU	Grading frequency	Climate zone(s)
1, 2 and 4	50	2	1
1, 2 and 4	100	2	1
1, 2 and 4	175	2	2
1, 2 and 4	250	3	2
1, 2 and 4	500	5	2
3	50	1	1
3	100	1	1
3	175	2	2
3	250	2	2
3	500	3	2

To calculate the grading frequency based on the number of LVU over the analysis period, a set of equations of the following linear form were developed for each climate zone and grading practice:

Grading frequency = a + (b * LVU)

A.2.4 Output Cost per Case Study Outcome

The annual average roughness was estimated for typical and good practice based on the optimum grading frequency by initial traffic level and climate is shown in Table A.6. For general application a set of equations of the following non-linear form were developed for each climate zone and grading practice:

Annual average roughness = a + (b * LVU)

Table A.6: Annual average roughness (m/km IRI) by initial traffic level (in LVU) and climate zone and grading practice

Climate zone(s)	LVU	Grading frequency	Climate zone(s)	
1, 2 and 4	50	8.6	7.3	1, 2 and 4
1, 2 and 4	100	7.9	7.0	1, 2 and 4
1, 2 and 4	175	7.3	6.7	1, 2 and 4
1, 2 and 4	250	7.0	6.6	1, 2 and 4
1, 2 and 4	500	6.4	6.3	1, 2 and 4
3	50	8.6	6.6	3
3	100	7.9	6.5	3
3	175	7.3	6.3	3
3	250	7.0	6.3	3
3	500	6.4	6.1	3

To calculate the grading frequency based on the number of LVU over the analysis period, a set of equations of the following non-linear form were developed for each climate zone and grading practice:

Grading frequency = a * LVUb

A.2.5 Output Cost per Case Study Outcome

Over a 50-year period, the Whole of Life Cost (WoLC) for unsealed roads is calculated using the following method:

> WoLC unsealed road = (Grading Frequency × Grading cost per Km) + (If gravel Resheeting is required, when the remaining gravel depth is less than 50 mm) × Regravelling cost.

This equation takes into account the cost of grading the road based on the determined grading frequency and the associated cost per kilometre. It also considers the additional cost of re-graveling if the remaining gravel depth falls below 50 mm and requires resheeting.

To further drive the economic analysis, the Present Value (PV) methodology is utilised. PV takes into account the time value of money and allows for the comparison of costs and benefits over the entire 50-year period, considering the present value of future cash flows. By applying PV, the economic implications and financial viability of different scenarios can be assessed, aiding decision-making processes related to the transition from unsealed to sealed roads.

A.3 Sealed Road Model

In the Sealed Road Model section, a comprehensive overview of the parameters used in developing a series of case studies that specifically focus on the transition from unsealed roads to sealed roads was conducted. These case studies exemplify the practical application of the Pavement Life-cycle Cost (PLCC) tool (Austroads 2021) and based on the Austroads (2010a and 2010b) road deterioration and structural deterioration models. By examining the parameters incorporated into this tool, the aim is to provide a deeper understanding of the essential factors considered in the decision-making process for road infrastructure development and maintenance.

Furthermore, the Sealed Road Case Study Options are designed to explore the viability of upgrading unsealed roads to sealed roads. The number of options considered in these case studies remains consistent with the options explored in the unsealed road case studies. This ensures a comprehensive analysis of the upgrade possibilities and facilitates a direct comparison of the results.

In assessing the condition and performance of the sealed road, roughness, rutting, cracking, Average Annual Daily Traffic (AADT), and strength are key factors considered. Roughness is a measure of the smoothness or roughness of the road surface, typically quantified using the International Roughness Index (IRI). Rutting refers to longitudinal depressions or tracks formed on the road due to repeated traffic loads. Cracking indicates the presence and extent of cracks on the road surface. AADT provides information about the daily traffic volume, and strength reflects the pavement material's ability to withstand loads and resist deformation.

By monitoring and evaluating these factors, treatment triggers are established to initiate appropriate maintenance interventions when specific conditions or thresholds are met. Treatment reset values determine when the road should be restored to its initial condition or undergo significant maintenance to ensure optimal performance.

Through a comprehensive analysis of these parameters and their influence on the sealed road's condition, the case studies provide valuable insights for decision-makers in evaluating the feasibility and benefits of upgrading unsealed roads to sealed roads.

A.3.1 Initial Condition of the Sealed Road

Upon completion of the upgrade from an unsealed road to a sealed road, the road will be considered ’brand new‘and will possess conditions that reflect its new state. In the analysis of case studies, it is crucial to take into account these initial conditions to establish a baseline for comparison and evaluate the performance and effectiveness of the upgraded road.

The following initial conditions are typically considered for a ‘brand new’ sealed road:

- Roughness IRI (International Roughness Index) (m/km) = 1.6: this metric measures the smoothness or roughness of the road surface. A lower IRI value indicates a smoother surface.
- Rutting (mm) = 1.6: Rutting refers to the longitudinal depressions or tracks formed on the road surface. The measurement of rut depth is important to assess the structural integrity and functionality of the road.
- Cracking (%) = 0: Cracking refers to the presence of cracks on the road surface. An initial condition of 0% cracking implies that the sealed road is free from any visible cracks.

These initial conditions serve as a starting point for evaluating the performance and deterioration of the sealed road over time. By monitoring these parameters and comparing them with subsequent measurements, the effectiveness of maintenance strategies and the overall durability of the road can be assessed.

A.3.2 Condition Triggers and Treatment Reset Values

In the Condition Triggers and Treatment Reset Values section of the Sealed Road Model, the treatment triggers and treatment reset values are carefully determined based on specific factors: roughness, rutting, cracking, Average Annual Daily Traffic (AADT), and strength. These factors play a significant role in assessing the condition and performance of the sealed road.

The base case represents a benchmarked level of service, serving as a reference point for treatment triggers and reset values. In contrast, the alternative case adopts a more stringent level of service, requiring higher standards and more frequent maintenance actions.

A.3.3 Key Terms Used

Treatments in the context of road infrastructure maintenance and improvement refer to specific actions or interventions carried out on the road to address various issues and extend its service life. The three primary treatments commonly used are reseal, rehabilitation, and reconstruction.

1. Resealing is a preventive maintenance treatment aimed at preserving the road surface by applying a new layer of bituminous material, such as a thin asphalt overlay or a sprayed sealing coat. This treatment helps to seal cracks, improve surface friction, and protect the underlying pavement structure from moisture and oxidation.
2. Rehabilitation treatments are more extensive than resealing and involve the repair and restoration of the road's structural integrity and ride quality. Rehabilitation may include activities such as patching damaged areas, removing and replacing the existing surface layer, and improving drainage systems. The specific rehabilitation measures applied depend on the severity of deterioration and the desired level of service.
3. Reconstruction is the most intensive treatment option. It typically involves removing the existing pavement layers down to the subbase or subgrade and building a new pavement structure. Reconstruction is usually necessary when the road has experienced significant structural failures, extensive distress, or when there is a need to accommodate increased traffic volumes or changing road geometrics.

These treatments are selected based on the triggers outlined in the Base and Alternative cases of the PLCC tool.

A.3.4 Base Case Analysis Framework

A base case is used in the Sealed Road Mode that represents a benchmarked level of service for the upgraded sealed road. This base case serves as a reference point for assessing the road's condition and determining appropriate maintenance interventions.

The condition triggers, which indicate when specific maintenance treatments should be initiated based on the road's condition, are illustrated in Table A.7.

Table A.7: Intervention parameters for the sealed road base option

Road Hierarchy	Condition Trigger	Value
Regional Distributor	Rehabilitation IRI Trigger (m/km)	5.5
	Reconstruction IRI Trigger (m/km)	7.5
	Rehabilitation Rutting Trigger (mm)	15
	Reconstruction Rutting Trigger (mm)	25
	Reseal Minimum Resurface Interval (years)	12
	Reseal Maximum Resurface Interval (years)	25
	Reseal Cracking Trigger (%)	10
	Rehabilitation Cracking Trigger (%)	20
	Reconstruction Cracking Trigger (%)	30
	Rehabilitation SNC Ratio Trigger	Not applied
	Reconstruction SNC Ratio Trigger	Not applied

A.3.5 Alternative Case Analysis Framework

In contrast to the base case, the alternative case in the Sealed Road Model sets a higher level of service for the upgraded road, resulting in a more stringent standard and increased maintenance requirements. This approach ensures that the road upgrade is maintained at a superior level of condition and performance.

Table A.8 provides a comprehensive illustration of the condition triggers employed in the alternative case.

Table A.8: Intervention parameters for the sealed road alternative option

Road Hierarchy	Condition Trigger	Value
Regional Distributor	Rehabilitation IRI Trigger	4.5
	Rehabilitation IRI Trigger (m/km)	6.5
	Reconstruction IRI Trigger (m/km)	10
	Rehabilitation Rutting Trigger (mm)	20
	Reconstruction Rutting Trigger (mm)	5
	Reseal Minimum Resurface Interval (years)	10
	Reseal Maximum Resurface Interval (years)	20
	Reseal Cracking Trigger (%)	15
	Rehabilitation Cracking Trigger (%)	25
	Reconstruction Cracking Trigger (%)	25
	Rehabilitation SNC Ratio Trigger	0.6
	Reconstruction SNC Ratio Trigger	0.5

A.3.6 Base and Alternative Case Analysis Framework

Further to the intervention level differences between base and alternative cases, the condition resets (Table A.9) and unit treatment costs for future treatments, after upgrade (Table A.10), are the same for the PLCC case studies. One of the key assumptions for detailing the resetting of the treatment effects to condition is that a spray seal treatment would be the only upgrade used for an unsealed road. This is due to the cost difference between an AC and SS pavement construction.

Table A.9: Condition resets post treatment

Road Hierarchy	Condition Trigger	Value
Regional Distributor	Resurface Min IRI (SS Pavements)	1.8
	Rehabilitation IRI (SS Pavements)	1.8
	Reconstruction IRI (SS Pavements)	1.6
	Rutting (mm)	1
	Cracking (%)	0
	Strength (SNC varies by traffic level)	4.2 – 5.3

Table A.10: Treatment rates post upgrade

Road Hierarchy	Condition Trigger	Value
Regional Distributor	Reseal (SS)	7.5
	Rehabilitation (SS)	42
	Reconstruction (SS)	52.5

A.4 Safety Treatments – Crash Implications on the Economic Output of the Model

Making the road safer by providing line marking and signs as a minimum is an important consideration and has been applied in particular options as described in Section 5. The modelling process is discussed in Section 5.1.

A.5 Basis for Estimation of Road User Costs

Vehicle operating costs (VOC), and road user costs (RUC) which, along with road agency costs, are key components in whole of life cycle costing (WOLCC). it involves an evaluation of all the component costs incurred over the whole life of a project, or indeed a network.

The impacts of the road condition, as well as road design standards and road layout, on road users are measured in terms of road user costs, and other social and environmental effects. Road user costs comprise:

- vehicle operating costs (fuel, tyres, oil, spare parts, maintenance labour, vehicle depreciation and interest costs, etc.)
- travel time costs for both passengers and cargo, due to road condition, geometry, and traffic congestion
- crash costs, i.e. loss of life, injury to road users, damage to vehicles and road infrastructure.
- environmental impacts, including vehicle emissions, energy consumption, traffic noise and other welfare impacts to the population served by the roads.

VOC and RUC were estimated for the various strategies considered in this study. They employed the published models and parameter values for uninterrupted traffic flow in the Australian Transport Assessment and Planning (ATAP) guideline PV2 (DIRD 2023) The VOC models respond to travel speed, road roughness, and gross vehicle mass for each vehicle type, as well as geometry for which typical representative values may be employed or values specific to a road section.

The impact of roughness on VOC is illustrated earlier in Figure 4.18, with the nomenclature used reflecting ATAP PV2 classifications. VOCs increase by approximately 7% and 12% for a passenger cars and trucks respectively for each increment of IRI, but with this based on the selected composition of the vehicle fleet used in this study. This assumed a representative passenger car as a large car (ATAP Vehicle 03), with the

HV composition divided equally between a heavy rigid (ATAP Vehicle 08), 6-axle artic (ATAP Vehicle 12) and a B-double (ATAP Vehicle 14). To facilitate more efficient computation of VOC, a set of relationships was developed which allowed VOC to be estimated accounting for HV proportion and the defined mix. All cases assumed relatively flat and low curvature, noting that the cost basis for upgrades was developed assuming similar geometry. The assumption is additional VOC/RUC and infrastructure costs would offset each other, i.e. no change to NPV, therefore allowing a more simplified set of solutions.

Appendix B Request for Information / Survey Questions

Good morning/afternoon XX,

The Australian Road Research Board (ARRB), in collaboration with Main Roads Western Australia and the Western Australian Local Government Association (WALGA), under the Western Australian Road Research and Innovation Program (WARRIP) – are currently undertaking research into unsealed road asset management practices in Local Governments in Western Australia. The intended outcome of this research is the development of A Practical Guide to Timeliness of Upgrade (sealing) for Local Government Roads in WA.

Information on WARRIP, can be accessed here: https://warrip.com.au/

As part of the research being undertaken for the development of this Guide, our project team are seeking to gather information on how unsealed road asset management is currently being undertaken by Local Governments, and what the decision-making process is for when to invest in capital works of sealing an unsealed road. This will lead to an understanding of the needs of Local Governments in this space including information which describes factors which influence the performance and cost of providing and managing unsealed and sealed roads in your Shire. This includes, but is not limited to:

- Location related factors and road types by hierarchy and surface types
- Asset management practices
- Factors that contribute to sealing an unsealed road
- Typical unsealed road conditions and maintenance and upkeep activities, frequencies and costs
- Typical traffic levels, composition and loading, and patterns of use
- Environmental considerations
- Climate conditions, including seasonal and longer-term patterns and forecast changes
- Road safety considerations
- Current basis for identifying candidates for upgrading and choosing options
- Community and service level considerations
- Funding sources and considerations.

As such, we have developed a list of questions (see attached), which we were hoping you could provide responses for form the perspective of your Local Government.

These questions are categories as follows:

- General information
- Asset management practices
- Unsealed road preservation and upgrade activities, costs and technical information
- Sealed road maintenance and preservation activities, costs and technical information

We are seeking responses by XXX (3 weeks from date of distribution). If you would prefer to have a discussion about your responses, please let us know and we will schedule a meeting time. If you do not feel well placed to answer any of the questions, please skip these and contact us for clarification.

In addition, this project task will include undertaking a stakeholder workshop to confirm information gathered in the Stakeholder Consultation and how it will be used in the development of the guide, including technical analysis to inform the development and provision of the catalogue of solutions to be provided in the guide and cases where more first principles-type analysis is likely to be required. This workshop will be hosted online using Microsoft Teams. Following your contributions to this stakeholder consultation, you will be extended invitation to this workshop.

Lastly, the guidance which is to be developed as part of this project will include case studies of decision-making to seal an unsealed road. Based on the outcomes of your stakeholder consultation, we will be in contact regarding the development of a potential case study.

Thank you in advance for any information which you can provide your contributions are greatly appreciated.

B.1 General Information and Asset Inventory

<table>
<tr><td>Question</td><td colspan="4">Response</td></tr>
<tr><td>What Local Government (LG) do you represent?</td><td colspan="4"></td></tr>
<tr><td>How would you describe the region of your LG (e.g. metro, regional, or remote)?</td><td colspan="4"></td></tr>
<tr><td rowspan="5">What is the Road Hierarchy used by your LG? *Classification opposite refers to Main Roads Western Australia road Hierarchy, if you use another set of identifiers please list in other.</td><td>Road Type</td><td colspan="2">Unsealed length (km)</td><td>Sealed length (km)</td></tr>
<tr><td>Local access (LA) *</td><td colspan="2"></td><td></td></tr>
<tr><td>Local distributor (LD) *</td><td colspan="2"></td><td></td></tr>
<tr><td>Regional distributor (RD) *</td><td colspan="2"></td><td></td></tr>
<tr><td>Other (describe)</td><td colspan="3"></td></tr>
<tr><td rowspan="3">Can you update your road inventory information as per the columns opposite. Does the network require upgrades to accommodate population growth?</td><td>Unsealed Type</td><td>Gravel</td><td>Formed earth</td><td>Unformed earth</td></tr>
<tr><td>% by Length</td><td></td><td></td><td></td></tr>
<tr><td>Likely .upgrade candidates (Y/N)</td><td></td><td></td><td></td></tr>
</table>

B.2 Asset Management Practices

<table>
<tr><td>Question</td><td colspan="4">Response</td></tr>
<tr><td rowspan="5">What best represents the approach in your LG to managing unsealed roads?</td><td colspan="3">Current Practice Used</td><td>Yes/No</td></tr>
<tr><td colspan="3">A well-resourced proactive maintenance regime to all road categories</td><td></td></tr>
<tr><td colspan="3">A combination of proactive maintenance used for higher order roads and a reactive maintenance approach to other roads</td><td></td></tr>
<tr><td colspan="3">Mostly a reactive approach in response to complaints and subject to available funding</td><td></td></tr>
<tr><td colspan="3">Other (please describe):</td><td></td></tr>
<tr><td rowspan="9">Do you have road asset inventory and traffic data for your unsealed roads? If so, can you contribute the information opposite?</td><td colspan="4">Proportion of gravel roads by condition category/
Level of service (LoS)</td></tr>
<tr><td>Poor or worse
(Moderate roughness and inadequate to poor
shape)</td><td>Fair
(Moderate roughness and
shape)</td><td colspan="2">Good or better
(Low to moderate roughness and good shape)</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">Estimated gravel thickness (mm)</td></tr>
<tr><td>< 75 mm</td><td>75–125 mm</td><td colspan="2">> 125 mm</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">Average and Maximum Daily Traffic</td></tr>
<tr><td>Regional Distributor</td><td>Local Distributor</td><td colspan="2">Local Access</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="4">What rural road levels of service (LoS) / intervention levels does your LG implement or target, and is there a distinction by hierarchy?</td><td>Road Hierarchy</td><td>Regional Distributor</td><td>Local Distributor</td><td>Local Access</td></tr>
<tr><td>Safety</td><td></td><td></td><td></td></tr>
<tr><td>Accessibility</td><td></td><td></td><td></td></tr>
<tr><td>Reliability</td><td></td><td></td><td></td></tr>
</table>

Question	Response			
Do you have a document for this? If so, can this be provided? If you do not have LoS developed, please put 'N/A'.	Condition			
	Sustainability			
	Responsiveness			
	Description:			
Can you outline how maintenance practices may vary for known traffic volumes and traffic compositions?				

B.3 Unsealed Road Preservation and Upgrade Activities, Costs and Technical Information

Question	Responses			
What is the cost and frequency of typical routine/ periodic maintenance on unsealed roads? *Do you have a document for this? If so, can this be provided?*	Road Hierarchy	Regional Distributor	Local Distributor	Local Access
	Upkeep – Grading practice			
	No. of gradings p.a.			
	Grading & compaction			
	Grading cost per km			
	Upkeep – Resheet			
	Average resheet interval (years)			
	Resheet cost per km			
	Upkeep - General			
	Additional cost factor for haulage to remote sites (%)			
	Additional cost for gathering compliant materials (%)			
What proportion of your engineered gravel roads possess the plasticity characteristics shown opposite relative to your climate zone? If you do not have this data, please indicate 'N/A'.	Plasticity Characteristic	Low plasticity	Compliant with desirable specifications	High plasticity
	Regional Distributor			
	Local Distributor			
	Local Access			
What proportion of your engineered gravel roads possess the particle size characteristics shown opposite? If you do not have this data, please indicate 'N/A'.	Particle Size Characteristic	Moderate to high % oversize and low fines	Compliant with desirable specifications	Moderate to high % oversize and excess fines
	Regional Distributor			
	Local Distributor			
	Local Access			

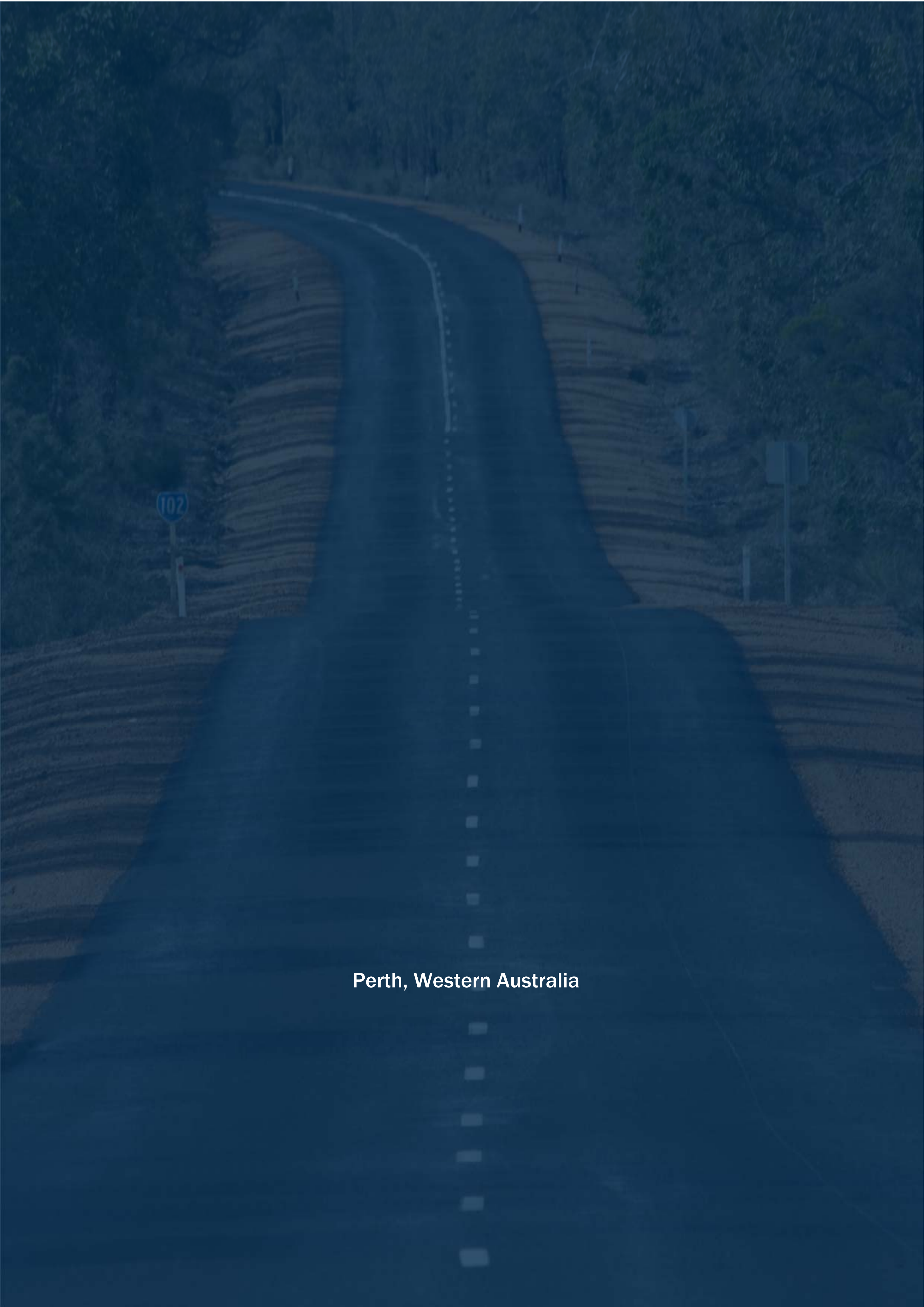
Question	Scope	Cost ($/km)
What are the typical costs of for the following treatments for upgrading your unsealed roads?	Minimum upgrade (reshape, resheet and seal)	
	Standard upgrade (formation widening, reshape, resheet by design plus minor other)	
	Vision upgrade (as Standard with drainage, safety and geometric improvements)	

B.4 Sealed Road Maintenance and Preservation Activities, Costs and Technical Information

Question	Responses			
What is the cost and frequency of typical preservation activities on sealed roads? *Do you have a document for this? If so, can this be provided?*	Road Hierarchy	Regional Distributor	Local Distributor	Local Access
	Capital Treatment - Reseal			
	Average reseal interval (years)			
	Reseal cost per km			
	Capital Treatment - Rehabilitation			
	Average rehabilitation interval (years)			
	Rehabilitation cost per km			
	Scope of rehabilitation, light (L) - rip and seal, heavy (H) - replacement			
	Capital Treatment - General			
	Additional cost factor for haulage to remote sites (%)			

B.5 Current Practices When Sealing an Unsealed Road

Question	Responses		
Which of the following factors do you see as influencing your decision-making process on when to seal an unsealed road?	Factors Influencing Change		Yes/No
	Current condition / deterioration		
	Changing traffic composition / volumes		
	Environmental Impacts		
	Climate factors / changing climate conditions		
	Whole of life cost of maintenance and preservation		
	Road safety		
	Other?		
For the factors selected, can you please provide a summary on how/why this impacts your decision-making process?			
Do you have data / documentation on previous decisions to seal an unsealed road (inc. factors which influenced this, costs, etc.). If so, can this be provided?			
Does your LG already have guidance which addresses the question of when to upgrade / seal an unsealed road? If so, please provide a copy of this.			
What factors are accounted for in scoping options for upgrading to seal (Y/N)	Scope components	Almost always	Never
	Formal thickness design		
	Formation widening		
	Formation raising		
	Drainage improvements		
	Safety improvements		
	X-S / Geometry improvements		
Any other information you wish to provide.			



Perth, Western Australia