UNSEALED ROADS TACTICAL ASSET MANAGEMENT GUIDE

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UNSEALED ROADS TACTICAL ASSET MANAGEMENT GUIDE

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ABBREVIATIONS

GPR	-	Ground Penetrating Radar
HCV	-	Heavy Commercial Vehicles
LA	-	Local Authority
LCC	-	Lifecycle Cost
LoS	-	Level of Service
PTR	-	Pneumatic Tyre Roller
RCA	-	Road Controlling Authority

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1. INTRODUCTION

1.1 BACKGROUND

Unsealed roads are the economic backbone of countries like New Zealand that depend on farming and forestry. Of Dunedin City Council's 690 kilometres of unsealed roads, for example, 15% carry dairy and logging traffic, 58% carry traffic to and from farm homesteads and 17% provide associated land access. Although these roads usually fall short of the high traffic numbers associated with upgrading and sealing unsealed roads, their importance cannot be overstated. Of the around 3,786 million-tonne kilometres of forestry and farm produce (*16*) carried each year on New Zealand's local roads, more than half would be carried on unsealed roads.

New Zealand's unsealed road network incorporates approximately 40% of the entire road network and approximately 20% to 25% of the overall road maintenance investment. It is an important part of the public's road infrastructure investment. Nonetheless, unsealed road maintenance planning significantly lack transparent standard practices such as those used for sealed road maintenance planning. A substantial portion of the unsealed network lacks the condition and traffic data needed to proactively manage the network and develop proper forward works programmes. This Guideline specifically addresses decision making in relation to unsealed road maintenance.

1.2 THIS GUIDELINE

There are numerous documents providing best practice advice for unsealed road maintenance and management (Refer to Section 1.3). This guide's purpose is to clarify how New Zealand agencies can best use the existing documentation to find the best approach to manage and maintain their roads.

Research into unsealed road management systems shows significant reliance on intensive data collection (*1*). The issues with data sourcing for these management systems are:

- Material specific characteristics normally do not exist for individual unsealed roads
- The condition of unsealed roads changes rapidly, often leading to existing data being out of date soon after it has been collected
- To make the management system sufficiently robust, more frequent data collection is required. However, more frequent data collection may not be cost effective and may be onerous from an administrative perspective.

In summary, current data collection efforts for unsealed roads is of questionable value. This is because as asset management science has developed, the tendency has been to apply sealed road asset management techniques to unsealed roads.

In contrast, this guideline's aim is to maximise understanding of material performance on the basis of its characteristics. This data could be collected from borrow pits and other material sources, with a geospatial link to the road sections constructed using this material.

1.3 COVERAGE OF UNSEALED ROADS GUIDELINES

Table 1: Unsealed Road Guidelines

GUIDE	FUNCTIONAL CATEGORISATION	DESIGN	CONSTRUCTION	MATERIAL SPECIFICATION	MAINTENANCE PRACTICES	ASSET MANAGEMENT	MAINTENANCE PLANNING	ECONOMIC AND FINANCIAL ASPECTS	ALTERNATIVE SURFACES AND STABILISERS
Austroads Part 6 (2)	✓	✓	✓	✓	✓	○	○	✓	✓
ARRB unsealed roads manual (3)	✓	✓	✓	✓	✓	✓	○	○	✓
RRU TR8 unsealed roads manual (4)	✓	✓	✓	✓	✓	○	○	○	✓
TRH 20 Unsealed roads design construction and maintenance (5)	✓	✓	✓	✓	✓	○	○	○	○
NZTA Research Report 348 (Henning et al, 2008) (6)	✓		✓		✓	○	○	○	✓
SADC	✓	✓	✓	✓	✓	○	○	✓	○

Legend:

✓ Strong coverage directly relevant to New Zealand conditions

○ Cover the topic but not always directly applicable to New Zealand conditions

Not covered

This Guide aims to address existing guidelines' shortcomings.

2. UNDERSTANDING UNSEALED ROADS

2.1 THE STRATEGIC FIT OF UNSEALED ROADS IN A NETWORK

Dust emissions and uncomfortable driving conditions often lead motorists and farmers to apply political pressure to get unsealed roads upgraded. However, it is important to realise that unsealed roads may be the most cost effective infrastructure for lower volume roads. The historical promotion of seal extension has resulted in a number of sealed roads that cannot be maintained within councils' investment priorities. There is evidence of some sealed roads being reverted back to unsealed roads and even ownership of some roads being returned to local communities and the industry.

For these reasons, there are two fundamental principles in asset management for lower volume roads including:

- Deciding the appropriate surface technology for the given traffic loading and environmental conditions. Figure 1 illustrates a typical continuum of road technology that normally varies according to the traffic load. Other factors that may influence surfacing technology may include specific geometric and application situations. Sections 4 and 5 go into more detail on selecting appropriate surfacing for some special situations and conditions.
- Constructing and maintaining unsealed roads to a standard that will a) satisfy a target Level of Service (LoS) and b) operate at the optimal maintenance investment from a long-term perspective. Measures to ensure unsealed roads receive optimal investment are discussed in the following chapters.

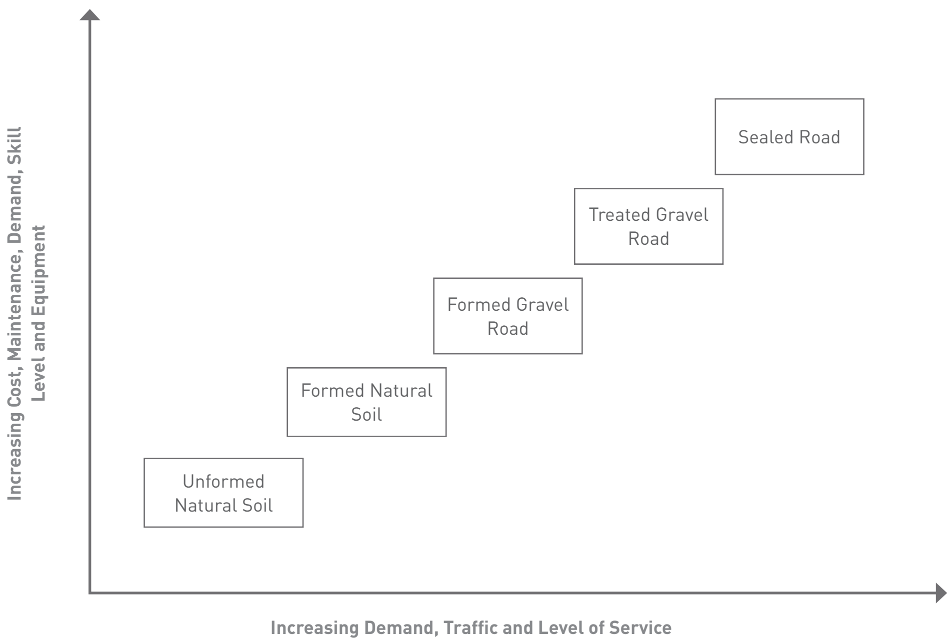
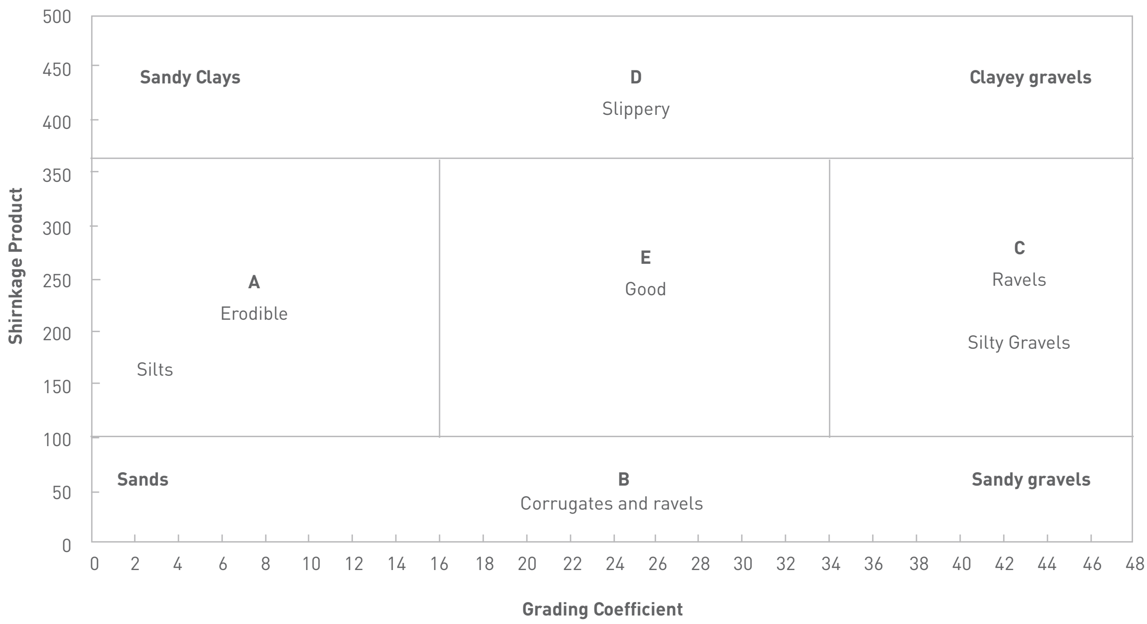


Figure 1: The Continuum of Road Technology (7)

2.2 MATERIAL PROPERTIES AND PERFORMANCE OF UNSEALED ROADS

Based on the research completed by Paige-Green (*8*) all materials used in unsealed roads can be classified according to their behaviour (see Figure 2). The Figure shows in terms of grading and plasticity, zone "E" material characteristics are ideal for unsealed roads. It also shows the wearing course would be prone to corrugation and ravelling with any material that has a shrinkage product of less than 100. If materials have a shrinkage product > 360 the road will become slippery and rutting may become an issue. If the grading coefficient is < 16, the material will be sandy and silty, which leads to the materials eroding. If the grading co-efficient >34, the material will be too coarse. In these cases, ravelling and stoniness may be typical defects.



Legend

A	Erodible	Comprises sandy and clayey silts with insufficient plasticity to provide tight bonding. Erosion sensitive withcrosfall runoff and inclines
B	Corrogates and ravels	Comprises sands and sandy gravels with little plasticity, therefore aggregate becomes loose (ravelling) and corrogations develop from vehicle suspension oscillation. Can also erode in high rainfall areas.
C	Ravels	Comprises coarse gravels with little fines or plasticity to bind the aggregate and therefore ravels quickly.
D	Slippery	Comprises silty clays and clayay gravels with high fines content producing slippery surfaces when wet.
E	Good	Comprises well-graded soil aggregate mixes with sufficient plasticity to find aggregate fractions into a hard wearing tight surface. Higher fines content can produce a dusty surface.

Figure 2: Material Classification and Expected Behavior (2)

Note: Grading is a function calculated from a grading test (wet sieve test)
Shrinkage is a function of linear shrinkage x 0.425mm from sieve analysis
Refer to Section 3.9 of ARRB's Unsealed Roads Manual: Guideline (3)
Standard tests are also described in Sections 2.3, 2.4, 2.5, and 2.6 from NZS 4402:1986.

Traditionally the Paige-Green classification has mostly been used to select and design the material used on unsealed roads. This Guide takes the concept a bit further by making the Paige-Green classification an integral part of unsealed road management. This is because knowing how roads will perform, given their materials characteristics, minimises the need for further condition monitoring. This concept can also be used to determine performance expectations of alternative sources. An outcome of this is that trade-offs between materials that perform better but may be more expensive can be made with cheaper materials that may offer lower levels of service. Incorporating material characteristics in a trade-off with haulage costs is further discussed in subsequent sections.

2.3 TYPICAL UNSEALED ROAD MANAGEMENT ISSUES

2.3.1 DIFFICULTY TO FORECAST BEHAVIOUR

Many international studies have attempted to forecast unsealed road the behaviour. (*1, 3 &6*). A common difficulty with all the forecasting models is the complex interaction between material properties (characteristics), maintenance regimes, climate, drainage, construction quality, geometric design and subgrade conditions.

In their research Van Zyl et al (*1*) compared the outcomes predicted by forecasting models with roads' actual performance. The roads Van Zyl et al selected for the study were mostly constructed using ideal material according to the Page-Green classification. Most of the materials plotted within Zone "E" on Figure 2. The comparison between the predicted roughness and gravel LoS versus the actual behaviour are depicted in Figure 3 and 4.

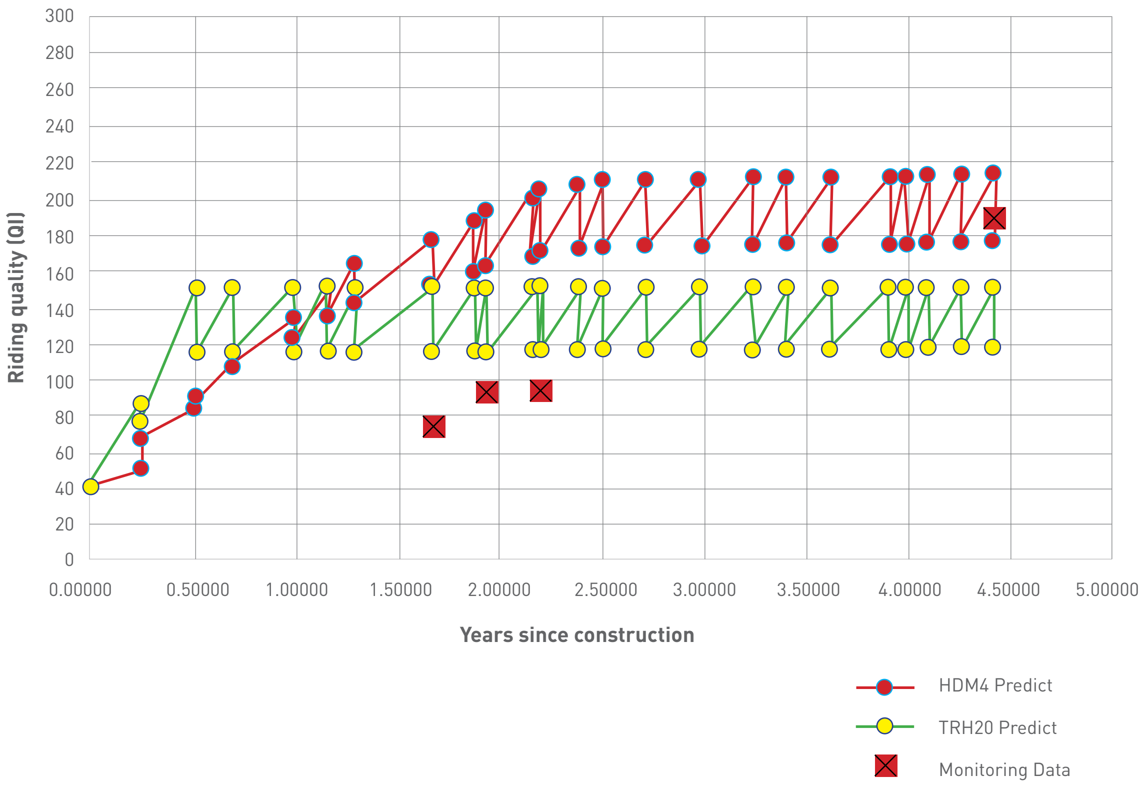
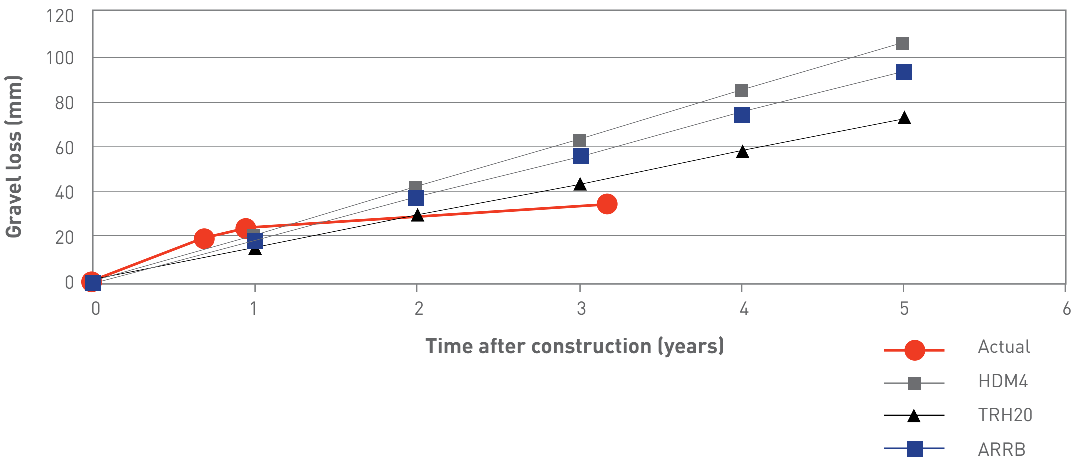


Figure 3: Poor Correlation between Forecast Roughness and Actual Behaviour (1)

Figure 3 shows a change in roughness over time for smooth, newly constructed roads. Roughness increases until a steady state is reached at a higher level which remains through the latter years of their life. During the later stage of deterioration, the variation of roughness within the upper and lower range is a function of the blading cycles (this is a typical saw-tooth trend). The Figure also shows the actual roughness values measured during the same period. It is apparent that the roughness after 4.5 years was close to the roughness forecast by the HDM-4 model. However, for the most part the actual roughness was much lower throughout the life of the unsealed roads. It is important to keep in mind that these roads were constructed with ideal material, and the roughness deterioration may well be worse for roads constructed with less than ideal material.

Road Section A



Road Section B

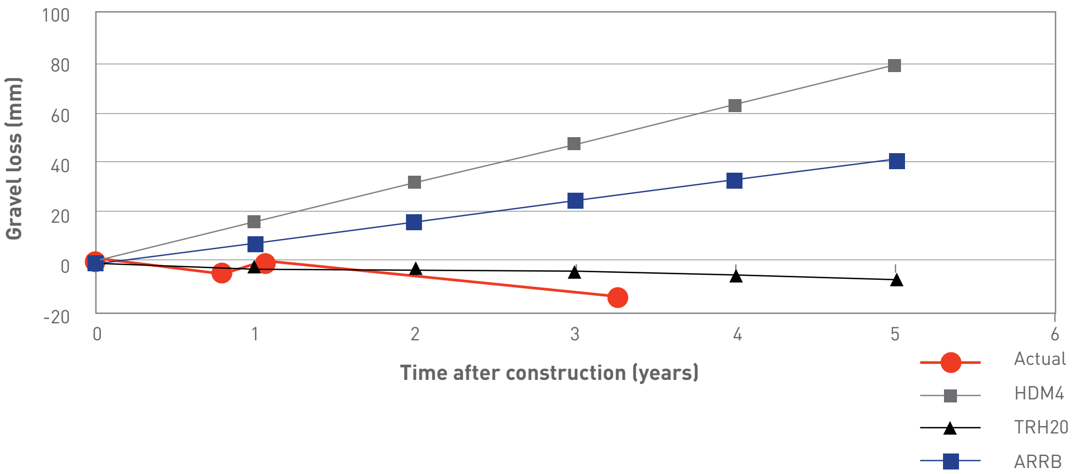


Figure 4: of Forecast versus Actual Gravel loss in Two Road Sections (1)

A similar observation about forecast versus actual outcomes was also made regarding actual gravel loss, which was significantly lower than forecast. In the two road sections being monitored, a common trend was observed in Road Section B where a gravel increase was measured over time. The reason for the increase was because the grading operator was cutting a significant amount of extra material from the side drains onto the road profile. Observing true gravel loss in these situations could be problematic.

The main findings from Van Zyl et al's paper are that there are a significant number of variables influencing the deterioration of unsealed roads, and that getting a strong statistical model from the available data is near impossible.

2.3.2 SIGNIFICANT DATA COLLECTION NEEDS

There are two approaches to unsealed road data collection. One is to collect a significant amount of condition data at frequent intervals (9). The alternative is to depend on frequent road inspections by experienced engineers to assess the over-all condition of the unsealed network. The first approach causes a significant onus on authorities, while latter does not provide satisfactory information for longer term planning processes. Because neither approach is completely satisfactory, data collection practice in New Zealand varies significantly according to ad-hoc processes.

A more efficient method of data collection on unsealed roads could be to record borrow pit material characteristics, actual maintenance and actual costs.

2.3.3 VARIABILITY IN LEVEL OF SERVICE AND MAINTENANCE PRACTICES

As a result of the relative flexibility in accepted specifications for unsealed roads in comparison with sealed roads, there is a great variation in both the levels of service on unsealed roads and the maintenance practices. There are also significant differences in the geology, topography, subgrades, climate and material between regions, which lead to big differences in unsealed road performance. A consistent planning approach that caters for these differences is difficult to establish.

3. LONG-TERM MAINTENANCE PLANNING FOR UNSEALED ROADS

3.1 LINKING MATERIAL PROPERTIES TO THE UNSEALED ROAD NETWORK

The Paige-Green concept (refer to Section 2.2) has been officially adopted in a number of design guidelines including the Austroads Part 6 (2) and the TRH 20 Unsealed Roads Design Construction and Maintenance (5). Elis and Andrew (14) have taken the concept a step further by using it to optimise gravel selection on a network basis. This Guide uses Elis and Andrew's concept as a starting point to develop a complete tactical planning tool for managing unsealed road networks.

The fundamental principle for decision making on unsealed roads is to link each road to its origin material source on the basis of a geospatial platform (Refer to Figure 5). This will involve having material tests undertaken on each borrow pit or other material source. With this information available, principles from Figure 2 are applied to forecast the behaviour of the unsealed road section and to associate it with a particular material source. This method makes it possible to associate a low or high blading and gravelling cycle with a specific material and within a specific location and topography on the network. The outcome would yield an economic zone associated with each borrow pit (see Figure 6). Note this Figure shows 3 material sources and indicates the extent of the roads for where the best long term value for money is achieved using material from each source.

The suggested decision framework and associated data inputs are shown in Figure 7.

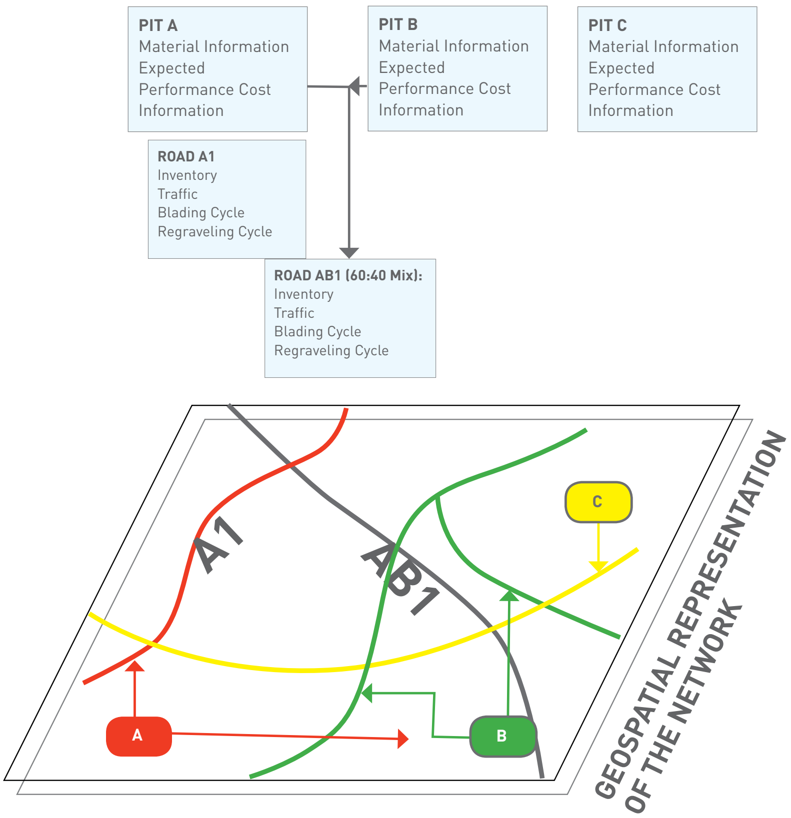


Figure 5: Linking Gravel Source to Unsealed Road Network

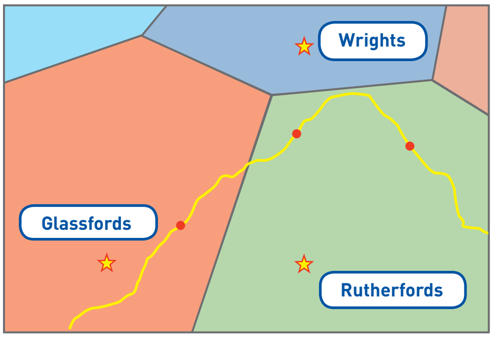


Figure 6: Example Outcome from the Analysis: Economic Zones around Borrow Pits

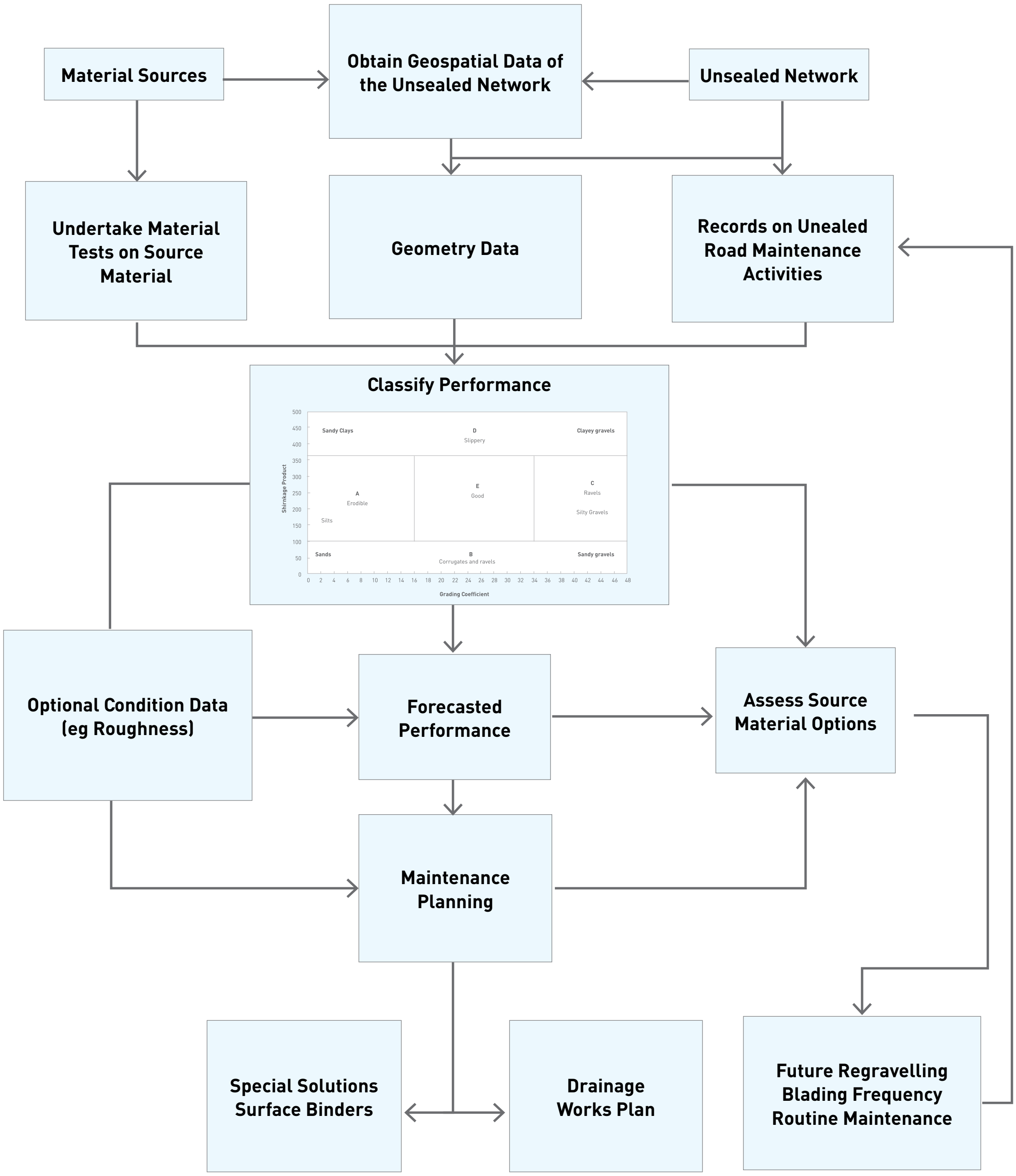


Figure 7: A Framework for Long-Term Maintenance of Unsealed Roads

The Framework consists of three core data items, including laboratory information from borrow pits, geometry data and any available maintenance records on the unsealed roads. All this information is integrated in a geospatial platform. Specific analysis within the geospatial platform is discussed in later sections. Once the material class and subsequent performance are linked to each individual road section, the long-term planning of investment requirements and subsequent work programme becomes possible.

The Framework is a self-learning system that can take account of any additional information. Examples would be condition data and/or problem areas identified through recording repeated routine maintenance within a given location (and stored and analysed on the geospatial system). As a result, the system will grow in robustness as more information becomes available.

3.2 IMPLEMENTATION STEPS

Implementation was tested in a case study on the Central Otago District Council (CODC) network. The outcome of this study is presented in Appendix A. The following implementation process was developed as a result of the experience gained on the CODC network.

Table 2: Implementation Stages of the Forecasting System

IMPLEMENTATION STAGE	DETAILS OF ACTIVITIES	NOTES
1. Data Collection	**Borrow Pits:** Laboratory test results and classification on Paige-Green charts **Network Wide Data Required:** ▪ An inventory of all unsealed roads ▪ A qualitative horizontal geometry classification (Tortuous, Some Curves, Straight) ▪ A qualitative vertical alignment classification (Hilly, Rolling, Flat) ▪ Links between each road section and the source borrow pit (geospatially or on a map) ▪ Traffic counts, including truck numbers *Maintenance cost records for each road **Optional:** Geospatial data for the network Additional strength, layer information and/or some condition records	* Initially complete maintenance cost records may not be available. For the initial stages of the implementation, approximate blading frequencies and gravelling cycles for each road may be sufficient. Once the process is established, more detail and accurate maintenance cost data should be recorded. With an increase in cost data, the system will become more robust in its forecast and economic analysis.

<table>
<tr><th>IMPLEMENTATION STAGE</th><th>DETAILS OF ACTIVITIES</th><th>NOTES</th></tr>
<tr><td>2. Set up relationship for blading and gravelling</td><td>Firstly, group roads together for borrow pits that plot in similar zones on the Paige-Green chart. Further relationship models are developed for each one of the cluster groups of pits.

Then undertake a linear regression to develop a specific model for each peer group. The model formats are:

* BF = B – a_1* AGE + a_2* EVL + a_3*G_H
* GrafLife = D –c_1* EVL + c_2*G_H

Where:
BF = Blading Frequency
AGE = Average current gravel layer age
GrafLife= gravel life of pavement (Re-gravel Frequency)
EVL = Equivalent Average Daily Traffic (where one heavy commercial vehicle is equal to ten equivalent light vehicles)
Horizontal geometry factor (GH)

<table>
<tr><td>1</td><td>Straight road with very few bends. Bends at obtuse angle so speed is not restricted.</td></tr>
<tr><td>2</td><td>Some curves are present which limit driver speed, but do not induce significant discomfort. Acceleration and deceleration is necessary to safely navigate corners.</td></tr>
<tr><td>3</td><td>Curvature severely restricts driver speed. Significant acceleration and deceleration is necessary to safely navigate corners.</td></tr>
</table></td><td>Note the climate plays a significant role in the gravel road deterioration. If a network includes more than one climatic region, separate relationships have to be developed for each region.</td></tr>
</table>

IMPLEMENTATION STAGE	DETAILS OF ACTIVITIES	NOTES
3. Undertake economic outcomes for each peer group	**Option 1** Undertake the economic analysis for each road in relation to the most likely borrow pits that could be used. **Option 2 (Geospatial)** For each borrow pit carry out an economic analysis that determines a zone around the pit (as shown in Figure 6) where best value is gained relative to adjacent pits. Traffic loading is an input and could define roads in 3 categories say.	
4. Undertake Strategic/Tactical Analysis	Assess the value return between the pit and road combinations to yield the following outcomes: ▪ Determine the most cost efficient pits in the region ▪ Determine the most optimal gravel selection for each road ▪ Identify problem roads (Refer to Section 4) ▪ Consider mixing different pit material to yield better outcomes on the network ▪ Consider surfacing options for gravel road with significant LoS issues and or uneconomic operation costs.	

* **Note**: *Blading and gravelling are co-linear variables (i.e. they are dependent on each other). The expression could be used as noted in the table. However, if the Gravel Life (GrafLife) formula is used in isolation it should include a factor for the blading frequency.*

3.3 UNSEALED ROAD MAINTENANCE STRUCTURE

The unsealed road maintenance is divided into two strategies: periodic maintenance carried out on an annually developed programme and monthly routine maintenance undertaken on a cyclic programme.

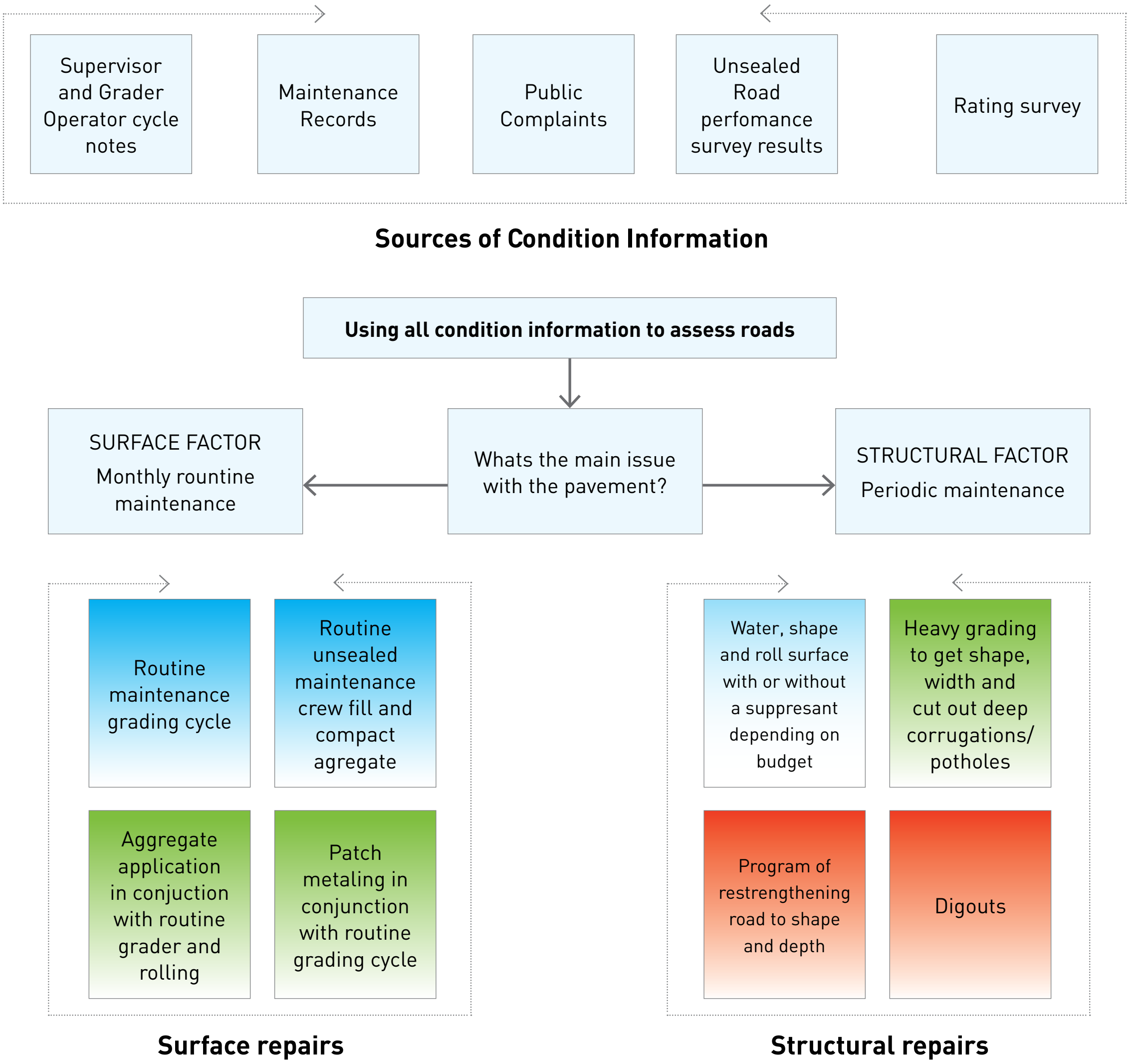


Figure 8: Determining the Maintenance Needs of an Unsealed Road Network

3.4 PERIODIC MAINTENANCE

3.4.1 PLANNING RE-GRAVELLING

Target Questions to Answer:

When creating long term plans for re-gravelling, the main questions are: What is the optimal re gravelling timing for specific roads? How much material should be placed on each road? Should the material properties be enhanced before construction? What are the trade-offs involved with using superior performing materials?

3.4.2 SUGGESTED DECISION FRAMEWORK FOR RE-GRAVELLING ACTIVITIES

> *"Aggregates used for sealed roads differ from those required in an unsealed environment. There is a fundamental difference between them. Sealed roads are designed to let water out while unsealed roads keep water out."*
>
> *IPENZ Transactions, Vol. 25, No. 1/GEN, 1998 Unsealed roads are sustainable by Allen Ferry*

The suggested decision activities involved with the re-gravelling considerations are listed in Table 3

Table 3: Decision Framework for Re-gravelling Activities

QUESTION	FACTORS INFLUENCING DECISIONS	DECISION CRITERIA
5. What is the optimal re -gravelling timing for a specific road?	The remaining gravel on a particular road length The point where the LoS (safety and roughness) drops below a certain point where it cannot be addressed through periodic and routine maintenance Situations where gravel was lost as a result of a flood.	Depending on the material properties plotted on Figure 2, an expected performance is established. (For example, less clayey material would probably have a higher rate of gravel LoS. The re-gravelling rates can also be established through analysis of historical replacement records for specific material.
6. How much material should be placed on each road?	Rate of gravel loss Design life Traffic loading HCV per day Geometry Exposure of subgrade material Grading frequency Historical re-gravelling records	The routine grader operator gives the best indication of where gravel is needed and the quantities required. Test pitting of roads with edge of grader blade can be undertaken during the routine cycle to determine existing depths. Base course application when clay/soft spots occur would be to 100mm compacted depth, increasing to 150mm where HCV loading is frequent i.e. forestry access, milk tankers.
7. Should the material properties be enhanced before construction?	Properties of candidate material. Geometry. Site specific issues that can affect performance Past maintenance and performance experience and records Traffic volume	Depending on the material properties plotted on Figure 2, it may be apparent that the material needs to be enhanced to achieve better performance and expected life from the gravel overlay. Options to achieve this include: Like-for-like replacement Thickness Mixing with another material (of similar or different origin source) until the ideal mix is achieved (Zone "E") Achieving optimum water content before compacting either using watercart or utilising rain Stabilising it using lime or other chemical additives.

QUESTION	FACTORS INFLUENCING DECISIONS	DECISION CRITERIA
8. What are the trade-offs involved with using superior performing materials	Quality of the material or material quality enhancement options Depth of design/material Cost of the material Hauling distance Expected life-cycle performance Construction costs Social and environmental considerations specific to some options	Geospatially analyse the long-term economics of using superior material, at presumably a higher direct or hauling costs, against the benefits of reduced periodic maintenance and future re gravelling.

3.5 PERIODIC MAINTENANCE

3.5.1 ROUTINE MAINTENANCE STRATEGIES

The routine maintenance of unsealed roads involves treating the mainly surface defects that arise from the passage of traffic and effect of weather. The majority of this maintenance is addressed with the routine grader cycle.

3.5.2 TYPES OF GRADING AND LEVEL OF SERVICE

Routine grading – This involves maintaining the running course in a smooth condition, and removing roughness from potholes and corrugation without major change to the pavement profile shape. It includes understanding the metal attrition costs of this routine operation versus the time period of benefits should not be overlooked

Wide grading –This involves grading from water table to water table, by bringing in material from the shoulders at the start of autumn when moisture is in the pavement. This enables aggregate lost to the edge of the pavement to be recycled and surface water channel blockages to be removed prior to winter so drainage is functional.

Cut out grading – Cuts in windrows on road edge or high shoulders forming barriers are made short distances apart allowing runoff to get away from the pavement surface.

Dry weather grading – This grading that can be done in drought conditions when there is no moisture in pavement. This is mainly to remove loose aggregate or trim corrugations from the surface by depositing the material at the side of the pavement from where it can be recovered, re-spread and compacted at a later date when the pavement has adequate moisture in it.

Wet weather grading – The autumn and early winter when the pavement has optimum moisture content in the aggregates is the best time to do heavy grading, reshaping and re-gravelling. During periods of heavy rainfall, the road material may be over saturated and moisture can penetrate the "crust" of the basecourse causing soft spots to be generated. The optimum time for grading is after rain.

Grade, water and roll – This is a dry weather operation where high traffic volumes experienced in different seasons makes it necessary to do heavy grading (e.g. summer holiday traffic on unsealed roads in coastal networks). This carried out with various methodologies such as use of rollers and water carts in conjunction with the grader or a rolling attachment fixed to the rear of the grader (walk and roll). Both these methodologies are used extensively in different networks with some success.

3.5.3 DETERMINING GRADING CYCLES

Deciding when to grade a road or to specify when to programme grading is subject to numerous factors.

Factors that influence frequency of unsealed pavement grading include:

- Traffic volumes and HCV (heavy commercial vehicles) per day
- Road condition
- Seasonal conditions i.e. winter freeze, summer drought conditions
- Coordination with renewal works e.g. the gravelling and strengthening programmes
- Public complaints/political pressures
- Procurement Strategy – the basis of risk/payment for work by contractors e.g. lump-sum per month or kilometres per month
- Level of service the client requires.

3.6 ROUTINE MAINTENANCE – LOCALISED REPAIRS

3.6.1 TYPES OF MAINTENANCE

Localised repairs are defined as maintenance where work is required in localised "discrete" positions, rather than a "treatment of a full section" of the road. As aggregate metalling programmes are normally set at between four to 10 year frequencies with between one and 12 monthly blading cycles, some additional work may be expected. This is particularly likely where budget restrictions preclude all roads being included in routine metalling programmes.

Spot Patch Metalling of Clay Soft Spots

Clay soft spots occur when the pavement cover over a subgrade has reduced to point where there is no visible aggregate. This is a sign the traffic load over the pavement material has worn or pushed the aggregate down into a soft (normally wet) subgrade foundation.

When pavement aggregate is worn away until sub-base "cobbles" are exposed and the surface is not able to be graded, an overlay of wearing course aggregate in patches is required. Sometimes this is placed and compacted in conjunction with routine grader cycle or spread and rolled by trucks.

Digout Repairs

These are is similar to clay patches in terms of identifying the need. The cause is attributed to a subgrade foundation weakening in a localised spot rather than through the full section of the road. This is likely to be a result of a drainage problem.

Grade, Water and Roll

This is necessary where the pavement aggregate is unravelling with fine materials lost as dust because of the passage of traffic. The repair is typically carried out with a water cart and a pneumatic tyre roller following the grader, or a walk and roll attachment to grader when there is moisture in the in-situ pavement aggregates. Note the use of a roller with blading activities is becoming standard practice in many regions given its benefits in terms of enhanced performance over time. It is appreciated, however, that this approach is dependent on rainfall at the right time.

Repairing Excessive Potholes

Where excessive potholing occurs in flat areas of the pavement that have been subject to rainfall and traffic, scarifying with "sandvick" tips on the blade of the grader during the routine cycle can be a temporary fix until reshaping and/or aggregate application can be planned. Other options are to patch spread metal the localised area and truck roll the spread.

3.6.2 INSPECTION REGIMES

Periodic Condition Surveys

- Ground Penetrating Radar (GPR) surveys
  Although the measuring antenna for GPR and the software used to analyse the results have been refined, a common misconception is that the GPR can provide precise gravel layer thicknesses. In fact, in most cases the results are qualitative more than quantitative. The analysis of the resulting data is time consuming, requiring expert interpretation, and is expensive. As an example of the difficulties, clay to gravel interfaces are not always easily identified.
- Unsealed Road Roughness surveys
  Roughometer type surveys using roughness meters and cell phone applications such as RoadRoid can be used. In recent years the developments of robust basic roughometer devices that can give a snapshot measure of roughness on an unsealed road have become more common. These devices work in a similar manner to ¼ car roughness measures by measuring movement of axles and suspension on the rear axle of a utility or car.
  By installing a device in a maintenance supervisor's utility, regular spot checks of high demand roads in conjunction with a regular quarterly full network inspection regime are undertaken, and a history of performance in each season can be recorded. The devices record a roughness value and a global positioning system location using an internal GPS receiver. This enables input data to be loaded into a global information system to graphically map the results for a comparison with previous surveys.
  The more frequent, regular surveys can be utilised in assessing maintenance needs in problem areas or "black spots", by comparing surveys at the same season in previous years.
- Drainage Inspections
  Good drainage is a key factor in maintaining the road in good condition and is often a prerequisite to any pavement maintenance or renewals.

Routine Inspections

- RAMM Patrol and the Global Information System
  The use of RAMM Patrol as a recorder of the maintenance grader's locations and activities is now possible. With a RAMM netbook or tablet fitted into the grader, simple "one touch" records of roads being graded and locations on the roads where grading is required enables the network to be mapped for visual analysis. These records can be viewed on screen within RAMM or exported to a GIS system for further comparison
- Cyclic Inspections
  The Foreman makes monthly inspections of half to two thirds of an unsealed network during a normal month's works. This may result in the cyclic maintenance crew carrying out repairs filling small, isolated potholes on unsealed pavements with an aggregate.
- Routine Grading
  The routine grader operator, especially if he or she has been the regular driver for a period of time and has developed an intimate knowledge of the network, acts as the maintenance team's eyes while out grading. The operator driver can tell by the way the grader reacts where soft spots exist or where drainage is affecting the road, and they may be the first to see where third parties are damaging the road. They are thus a valuable resource to use to when determining where aggregate is required, and where tension/stress from heavy traffic movements occur. The grader operator is also able to direct routine crews repairing potholes in the unsealed pavements to get most efficient use of that resource. It is important the grader operator be given the tools (technology) and the responsibility to collect and record key information for asset management decision making and be recognised for carrying out these functions.
- Client Audits – Performance
  In some network/contracts the RCA carries out performance audit/inspections as part of monitoring the Contractor's performance. These are performance type contracts where the end result criteria is specified. Results from these and trends are used to aid in planning of maintenance cyclic routes and frequencies.
- Complaints - Response
  Most Road Controlling Authorities (RCAs) will have a customer request management (CRM) system to record and track calls from their customers or road users using the RCA network. These CRM are either inspected by a council officer or passed to a maintenance contractor to inspect, analyse and determine needs for maintenance work. Analysis of these of an annual cycle can aid in planning of renewal programs and frequencies of routine maintenance.

3.6.3 UNECONOMIC LOCALISED MAINTENANCE

When does it become uneconomical to maintain small localised spots rather than treating full section length?

The frequency of return visits to a road or site, the quantum of work required and the available budget will determine when localised short repairs are no longer an efficient strategy for a road section.

Ai deciding factor would be repeat repairs in the same month on same road and repeated routine work in problem areas. As an estimate, if around 30% of the road carriageway is affected, an area wide periodic treatment should be considered before planning isolated small repairs. The area wide treatment may involve, for example, heavy grading, or including the area re-gravelling programmes.

Another key issue is when the frequency of isolated, short grading sections increases.

An example could be when a maintenance grader is required to make repeat visits to an unsealed road within a month (or within next programmed cycle), and the road is not predetermined to have a high frequency grading cycle. The work would be expected to be outside of the contractors control and would be carried out on an hourly day work rate basis. This is likely to be mainly as a result of customer/ road user requests to the RCA.

4. TREATMENT SELECTION FOR PROBLEM AREAS

4.1 MAINTENANCE REPAIRS

Repair programmes for the unsealed network need to factor in each road's use and the demands placed on it. This will help determine the extent of reactive repair required to ensure a fit for purpose pavement is maintained. A two wheel track road with one or two residents using it and no heavy traffic, for example, would have a lower priority than a three wheel track access road used frequently by logging or dairy traffic.

Maintenance requirements, their causes and, the normal "toolbox" of maintenance repair options are well detailed in the ARRB Unsealed Roads Manual Section 2.

Failure types and mechanisms are treated differently within different climatic environments throughout New Zealand. Most of the defects detailed in the Manual include remedial options. In most cases there are three main factors that combine to cause most of the defects (refer to Figure 99).

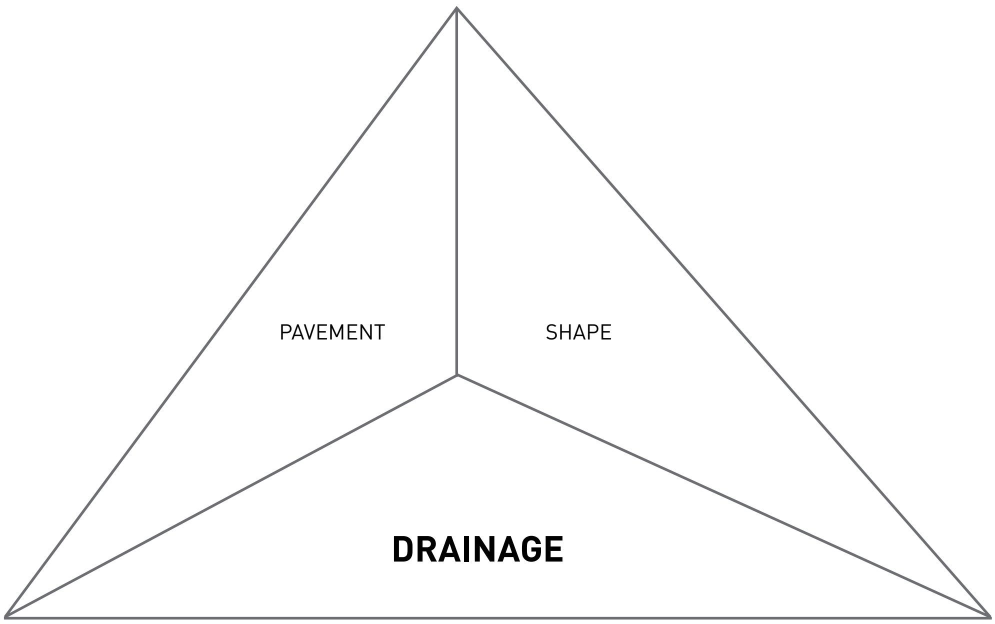


Figure 9: Main Factors Causing Defects on Unsealed Roads

- Shape of road – Road shape and crossfall to get the water off the road and away from the traffic wheel paths. The ride and comfort customers require while using the road.
- Drainage of pavement – Move water away from pavement layers as efficiently as possible.
- Pavement materials (including subgrade material) – Gradations, fines properties and depth of the pavement aggregates. Use the most cost effective material available containing the suitable grading analysis and fines.

4.1.1 ROUTINE MAINTENANCE – SURFACE DEFECTS

Inappropriate intervention is expensive during the pavement lifecycle and is detrimental to the LoS. Reactive strategies for unsealed road maintenance should not be encouraged, as in many cases this requires road users to be educated. In many cases, a superior long term LoS will be achieved if you do nothing.

Table 4: Surface Defects and Routine Maintenance

DEFECT TYPE	FACTORS TO CONSIDER	REPAIR
Dust	Is this a short term or an ongoing long term issue? Check the existing aggregate properties in terms of fines.	Options include using a blended aggregate during re-gravelling, or stabilising the surface with a dust surfactant prior to the dry season. In a dry period, applying a proprietary suppressant can be cost effective for short periods of two to three months, or if the suppressant costs less than $5/m2.
Loose material	Is the material a single sized aggregate across a road that is unsafe to drive on?	In a dry season, grade to windrow on edge away from traffic wheel tracks. In wet periods apply new fine material and/or spread windrow from the summer across the pavement. Moisture and compaction are required during operation.
Corrugations	Is this a fine material in shallow corrugations on surface in summer, or is this deep corrugations due to vehicle action?	Light – grade across pavement to spread Deep - Grade out corrugations with scarifiers during grading cycle
Potholes	Are the potholes localised or in large groups. What maintenance aggregate with high binder fines is available? Are potholes in flat areas due to the cross fall shape breaking down?	Individual potholes can be filled with new aggregate and compacted by the cyclic maintenance crew. Large groups of potholes caused by the road shape can be treated with reshaping during the routine grader cycle. Localised areas can benefit from a spread of gravel with or without the grader and compacted using the truck or leaving for normal traffic to compact

DEFECT TYPE	FACTORS TO CONSIDER	REPAIR
Surface scouring	Is scour along the road in wheel tracks or does it cross from one side to the other? Is scour a problem caused by the pavement aggregates properties? Is the drainage channel under capacity or blocked and inefficient?	Scour along the road wheel track can be remedied by routine grading of aggregate across the surface to cut and fill. Sufficient compaction will assist in preventing scouring. Scour ruts along the wheel track can be remedied with regular cut-outs to water channels, and increasing adjacent water channel depths to reduce pavement materials becoming saturated. Scour across road in a localised position can be remedied by checking for blocked channels or culverts and ensuring all are clear of build-up.
Slippery surfaces	Is area shaded and wet all the time? Check the pavement aggregate for fines.	

4.1.2 PERIODIC MAINTENANCE – FOUNDATION AND PAVEMENT DEFECTS

Table 5: Periodic Maintenance for Foundations and Pavement Defects

DEFECT TYPE	FACTORS TO CONSIDER	REPAIR
Rutting	Is water penetrating the pavement or subgrade due to inadequate surface drainage or seepage from the surrounding environment? Rutting factors along with drainage to consider ▪ Poor aggregate material ▪ Poor compaction of the pavement aggregates ▪ Inadequate pavement depth for the traffic.	Heavy cut with grader to reinstate cross fall and compacting the running surface. For subgrade failure additional material is required to top up and increase pavement depth. Ruts forming in wet weather but not dry indicate that surface is softened by water. This would indicate too much fine material is present in the pavement. This can be remedied by mechanical stabilisation with a course aggregate to improve the grading and strength.
Subgrade deformation (Soft spots)	Is water penetrating the pavement or subgrade due to inadequate surface drainage or seepage from surrounding environment? Is there movement of either fines or moisture in the pavement layers in the wheel paths?	Dig out material and replace with good quality graded aggregate and compact well. There should be some restoration of good super-elevation and crossfall in conjunction with the digout to ensure adequate drainage. In some cases in flat low lying areas subsoil drainage should be considered to reduce the chance of water entering the pavement.
Frost damage weakened pavement materials	The silt faction in aggregates used in frost/ice prone high altitude areas. (3-10%)*. Pavement and upper subgrade drainage.	Pavement drainage of pavement by building up in embankment shape where possible. A suitable gap graded crushed rock stabilised with cement in high risk areas.

Source Allan Ferry – RRU TR8 (1986) Unsealed roads a manual of repair and maintenance of pavements.

4.2 REACTIVE MAINTENANCE REFERENCES

A number of current sources provide experienced practitioners knowledge and experience in the frequently asked questions sections of RCA web pages.

The only major controllable ways to maximise the life of gravel pavements are: Regular grading using the correct technique to ensure defects are removed and the retrieved material is compacted uniformly, at the optimum moisture content to ensure maximum stability and long life. Re – gravelling the road with better quality gravel materials will ensure the decrease of gravel LoS over time and reduce the frequency of grading required.
www.unsealedroads.com
It is not possible to keep unsealed roads in a steady state. Because they are made of stones mixed with clay and silts, just how well they last between grading is very dependent on the weather.

Roads that carry heavy vehicles such as logging trucks and milk tankers can also suffer increased wear.

Most metal roads are graded on a monthly basis. Those with less traffic need to be graded less frequently and those with more traffic may require more frequent grading.

> "Roads carrying logging trucks are generally left unsealed despite the visibly higher wear rates on both vehicles and road surface resulting in extra maintenance. A reason for this is that logging traffic is often short lived during harvesting and between long growing periods, and damage occurring during the heavy loading is more easily repaired afterwards than if the road was sealed. In one case reshaping with a grader may be all that is required but if a seal coat is ruptured a complete rehabilitation treatment may be required."
>
> *IPENZ Transactions, Vol. 25, No. 1/GEN, 1998 Unsealed roads are sustainable by Allen Ferry*

1. "Material to surface "unsealed" roads is higher in fines than bases for seals

2. Fines in the aggregate are needed to shed water, keep it from getting into lower layers (hence an "unsealed" (meaning no chip seal) road is actually sealed by this surfacing layer of high-fines gravel)."

   Low Volume Roads: less expensive but still safe, efficient? June 2005
   Robert A Douglas, BASc (CE), PhD, PEng, MNZIF, IPENZ
   Associate Professor, Director of Studies (Forest Engineering) NZ School of Forestry
   University of Canterbury

4.3 DRAINAGE

Preventing water from entering the road is important. The water can come from rain or surface flow, underground seepage, springs or capillary action. It is important to remember the unsealed road pavement requires some "held" moisture within to help bind (or glue) the fine fractions together. Too much or too little leads to problems within the pavement materials.

Drainage on the sides of the road must be in good order – fix drainage first.

It is important to remember, with unsealed roads certain aspects require extra attention

- The crossfall of an unsealed road is steeper than a sealed road so water can run off the surface quickly.
- Organic material within the unsealed pavement is unstable when wet.

- Drainage from pavement edges into side drains and watertables is important, especially in areas where scour is likely unless water is directed away quickly.

  "Foundations are susceptible to ground water conditions, so in most situations whatever else is done the first move is to check the drainage"

  Allan Ferry – RRU TR8 (1986) Unsealed roads a manual of repair and maintenance of pavements

4.3.1 DETERMINING DRAINAGE MAINTENANCE NEEDS

Factors that determine when drainage maintenance work is required include:

- Pavement scouring caused by the runoff not draining away from the trafficable surface
- Culvert and stormwater structures blockages or filling so as to reduce operating capacity
- Scouring from over topping of culverts as a result of size or length of pipe restrictions
- Low spots where outlet paths are blocked or restricted causing ponding and soft spots in the pavement
- Water table and drain capacity reducing so runoff ponds and saturates pavement layers
- Risk of frost heave in snow risk pavement areas, where snow melt runoff is not efficiently moving away and saturating the pavement.

Surface Water Flow

Surface flow defects are attributable to:

- Steep road sections where pavement scour occurs along wheel paths but potholes don't form, as water flows to the lowest point.
- Flat sections where water ponds and traffic movement causes fines to be "washed" away, causing to potholes to form.
- Soft spots in pavement in flat low lying areas, where runoff cannot get away from the pavement edge causing foundation and pavement materials to soften.

Options for Repair

- Grade the shape of road so the surface flow is shed from traffic wheel paths as quickly as possible: this may mean steeper crossfalls on steep slopes to encourage the runoff to flow to the side rather than down wheel paths
- Good crossfalls on straights and super elevations on curves are key to preventing water ponding in the traffic lanes. Problems still occur in flat areas as one curve super elevation as it transitions to the other direction, or at approaches to sealed roads or bridges which typically have flatter than the ideal unsealed pavement cross falls.

- Once the surface flow is at the edge of the pavement, the path away from the pavement must be as clear as possible. This means built-up detritus and vegetation impeding the flow should be periodically "flanked off" with the grader to create watertables, or have cut outs shaped at regular intervals for the flow to run into.
- Where practicable the invert of the surface water channel should be below the pavement layers.

Sub Surface infiltration

Sub surface pavement defects are attributable to:

- Groundwater from higher ground
- Seasonal high water table levels
- Capillary action from watertables below the road.

Options

- Periodically cleaning the side drains outside the watertables with excavators especially in moisture sensitive areas
- Installing subsoil drains along the roadside
- Installing cut-off drains above roadways to catch both surface and sub-surface flows.

5. SPECIAL SURFACE TREATMENTS

5.1 ROAD SURFACE TECHNOLOGY CONTINUUM

Often engineers think of only one of two options for unsealed roads: surfaced (i.e. chip seal) or unsurfaced (unsealed roads). As indicated in Figure 1, road surface technology is a continuum of options that ranges between unsealed, unsealed treated roads and alternative surface roads. If warranted, these can be upgrade to sealed road standards.

5.2 APPLICATION AREAS FOR SPECIAL SURFACES AND BINDERS

Typical application areas for special binders and surfaces are summarised in Table 6.

Table 6: Application Areas for Special Surfaces and Binders

PROBLEM AREA	DESCRIPTION	RECOMMENDED SOLUTION
Steep grades, curves and intersections	Steep grades, curves and approaches to intersections result in increased stresses between the vehicle tyre and the surface material. Whatever defects are associated with a particular material are noticed early on these high stress areas, and the rate of deterioration would be much higher than in other areas.	It may become uneconomical to blade isolated areas more frequently; therefore these areas may require special treatments that include some binding agents and/or Otta Seals. Caution is advised in selecting Otta seal as a general recommended treatment. This is because the short lifecycle and difficulty of renewal needs to be compared with more conventional surfacing solutions. Note: any chemical treatment that does not result in binding the material is not appropriate for this situation. Better graded performing aggregates may contribute towards a better outcome on these areas (refer to Figure 2)
Bridge approaches	Bridge approaches normally have higher moisture due to the geometry leading up to the bridge. In addition these areas are under high vehicle stress due to impact loads of coming off a rigid structure onto a flexible pavement.	It is important to address drainage in the bridge approach. Any alternative options would still fail if the water and moisture issue is not addressed first. Otherwise, any application that binds the material and increases the surface strength would be mitigating the problems with these approaches. Better graded performing aggregates may also contribute towards a better outcome in these areas (refer to Figure 2)
Excess dust	Normally a dry, summer problem, excess dust is not only a nuisance issue for drivers but may also be a safety concern.	Dustiness is normally found on road with too high a proportion of fines, in particular clayey soils. The appropriate dust palliative and or Otta seal may be the appropriate solution depending on traffic volumes. Better graded performing aggregates may also contribute towards a better outcome on these areas (refer to Figure 2).

PROBLEM AREA	DESCRIPTION	RECOMMENDED SOLUTION
Commercial access points	Commercial access points suffer a combination of similar issues to the bridge approaches, with sharp turning curves. In many cases drainage problems may aggravate these areas' poor performance.	Address the drainage first. Nothing will work if the drainage is not in good order. Any application that binds the material and increases the surface strength will mitigate the problems with these access points. Better graded performing aggregates may also contribute towards better results (refer to Figure 2).
Specific farming areas	Some farm types, like horticulture (particularly mushroom farms), may have specific dust related concerns. All farming activities may suffer from dust's negative impact.	Better graded performing aggregates may contribute towards a better outcome (refer to Figure 2). If this is not possible or cost effective, the existing material may be treated for dustiness. Refer to Section 5.3. In addition to that an alternative surfacing material may be considered.

5.3 DUST PALLIATIVES

Unfortunately some alternative binding and dust suppressant agents have a bad name in the industry because they claim to offer a "Dust Free Solution" that works in all situations. This is not true. However, they could work well if applied correctly and on the appropriate material. These technologies all have particular chemical reactions that make them more effective on certain materials. Table 7 summarises the typical use of some dust palliatives. In addition, the guidelines indicated in Table 1 offer further guidance and information.

Table 7: Dust Palliatives and Binding Agents (Source 7)

CATEGORY	EFFECT ON UNSEALED MATERIAL	APPLICATION
	DUST PALLIATIVES	
Wetting agents (surfactants)	Surfactants reduce surface tension so moisture can wet particles. Due to the increased moisture, binding with the soil improves. Natural water, detergents or soaps are typical wetting agents.	The action of surfactants is typically short term: and they need to be applied regularly, even daily. Their use is limited and needs to be justified by special circumstances. Some applications may include mine haul roads and construction sites.
Salts/Chlorides	Chlorides reduce the repulsive forces between soil particles by increasing moisture content. Chlorides typically draw moisture from the air due to their hydroscopic and deliquescent properties.	As the source of the moisture is the air, the underlying requirement for the effective working of these treatments is a relatively humid climate. None of the chlorides work in arid areas. Typically, calcium and magnesium require at least 30-40% humidity, whilst sodium ceases to be effective below 70% humidity (ARRB 2000). Consequently, sodium is used less frequently and it is less effective.

Natural polymers	They are based on lingosulfonate which is a by-product of the pulp milling industry. They act as clay-dispersants, making the clay more plastic at low-moisture content.	Polymers physically bind particles of the road material together. These products are highly soluble in water thus requiring re-application; they could be an effective interim option before a permanent surface is provided. Application areas include mine and forest haul roads. These products can be sprayed or mixed in during construction.
Modified waxes	Waxes are manufactured by the petrochemical industry. They act as soil binders and can expel absorbed water from the soil. By doing so, the air voids decrease and compaction increases.	The performance is a function of road and ambient temperature. Above 35 ˚C, the wax softens and penetrates the road. Waxes could be used in conjunction with calcium chloride and lignosulfonate to improve performance in wet weather
Petroleum resins	These usually are a blend of natural polymers and petroleum based additives. Some research has been conducted in the USA.	Natural polymers have the potential as dust palliatives and stabilisers but their cost is relatively high.
Bitumen	Bitumen additives are often a by-product of the petrochemical and bitumen supplier's product line. Tar based applications are a by-product from the coal industry or synthetic fuel distillates.	Products are sprayed onto the road and in some cases blended with sand, which performs similarly to a sand seal and can last for up to three years.
COMPACTION AIDS AND STABILISERS		
Synthetic polymer emulsions	Polymer dispersions are suspensions of synthetic polymers. Many formulations have been developed as soil "conditioning" applications, which are potentially useful for dust control and stabilisation of unsealed roads.	Most documented research originates from the agricultural industry. Limited research is undertaken for road applications.
Bitumen	See above	
Sulfonated oils	Sulfonated oils consist of strongly acidic sulphur based organic mineral oils. These products were developed in the USA during the 1960's.	The stabilisation process is complex and material dependant. The oils have the ability to displace and replace exchange cations in clay and waterproof clay They may also improve the soaked strength of high plasticity soils.
Enzymes and biological agents	Most of these product types will reduce the surface tension of water, thereby acting as a compaction aid. Some enzymes may result in a bond between particles due to crystallisation.	Few publications exist on the application of these material types.

5.4 OTTA SEALS

Otta seals are, in essence, lower grade surfaced roads. This methodology was introduced in Norway during the 1960's and now accounts for approximately 12,000 km of roads in Norway (*12*). Otta Seals consist of graded aggregate placed on a thick film of relatively soft binder. Following rolling and further traffic compaction, the bitumen migrates to the top of the surface until it gives the appearance of a surfaced road.

Otta Seals have been proven as a cost effective solution for New Zealand's unsealed roads, where seal extensions are not warranted (*13*). In his research, Waters (*13*) found compared to waste oils and bitumen emulsions, Otta Seals become cost effective after three years and in many cases they are still serviceable after eight years which provides added benefit (refer to Figure 10)

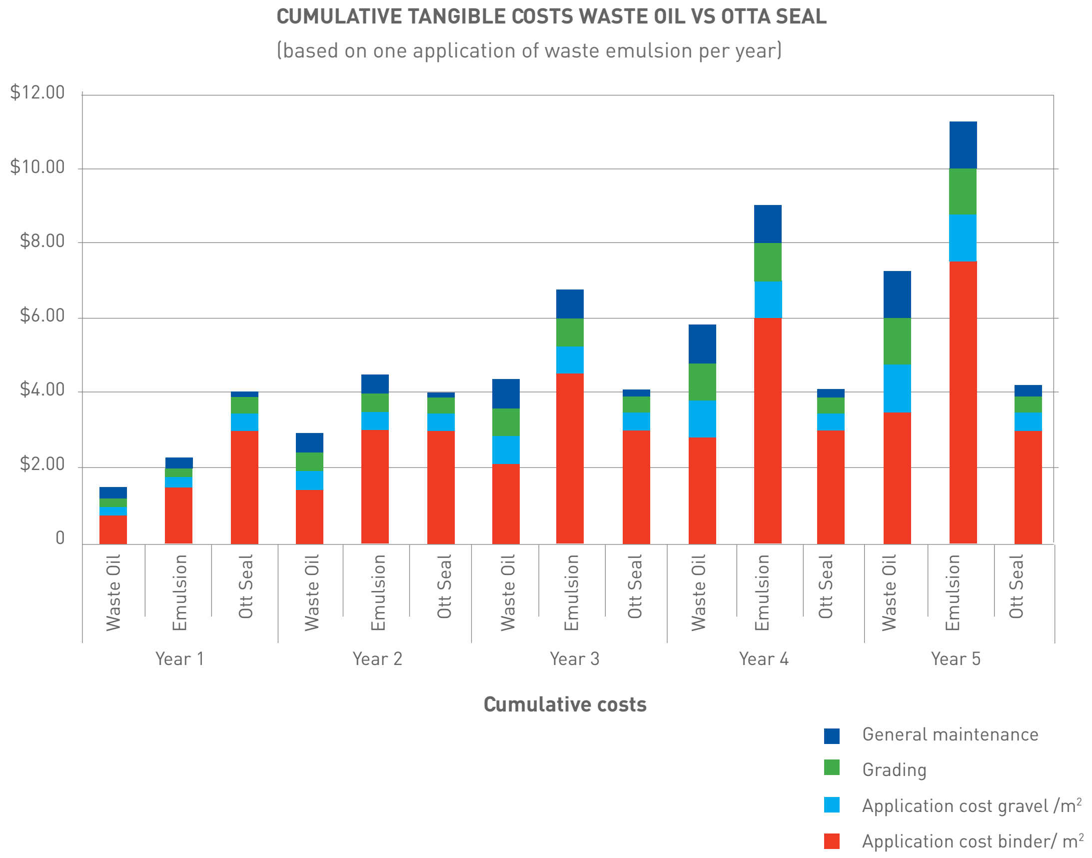


Figure 10: Comparing Cumulative Cost of Otta Seals with Waste Oil and Emulsions (13)

Typical application areas for Otta Seals are:

- When a sealed road or seal extension is too costly or not warranted
- Where the life cycle costs are favourable compared to other dust suppression solutions such as dust palliatives;
- Where sections of low volume roads are subject to vehicle stresses that cause high maintenance costs and a traction seal is not an economic option.

6. ECONOMIC JUSTIFICATION FOR WORKS

6.1 LIFE CYCLE COSTING VERSUS APPROPRIATE LEVEL OF SERVICE

Construction and maintenance costs are possibly the most crucial data to maintain for unsealed roads. An international study of unsealed road owners showed that in New Zealand, road authorities mostly use their public complaint system to indicate periodic and re-graveling activities (7). This suggests most of New Zealand's unsealed roads are being maintained at an optimal Life Cycle Cost (LCC) or better. It is important that the economic analysis of unsealed road options should take account of the community's agreed LoS. However, it also important that there are many options that could drastically reduce the classical LCC for unsealed roads. Figure 11 shows the typical LCC lay-out for unsealed roads. Variations to this example may include:

- Alternating the maintenance regime – e.g.by reducing the re-gravelling cycle
- Using a better quality material that may cost more initially but extend the return period for both blading and re-gravelling cycles
- Using an alternative surface option.

These options are further discussed in subsequent sections.

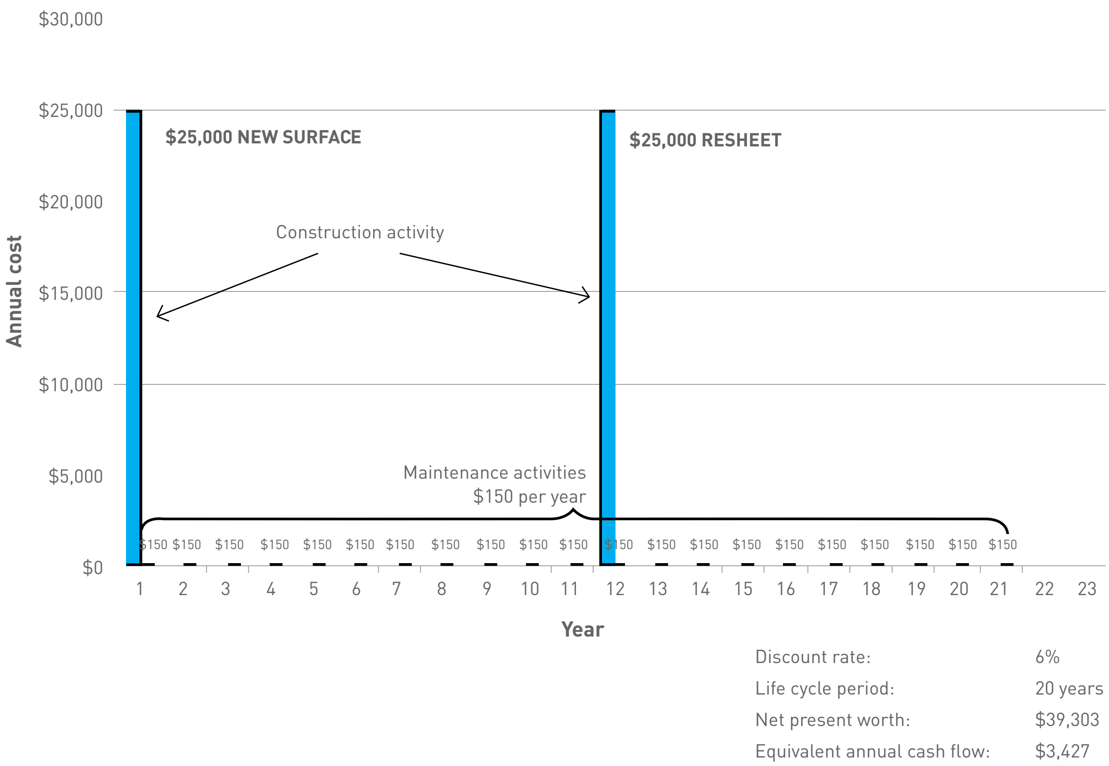


Figure 11: Typical Life Cycle Cost for an Unsealed Road (2)

6.2 DIFFERENT MAINTENANCE REGIMES

Expenditure on unsealed roads could be significantly varied by altering the maintenance regime. This not only applies to the timing of typical periodic maintenance activities, but also by varying the maintenance intensity e.g. blading technique. For example, Central Otago District Council has realised significant savings on its blading programme by adopting a heavier blade operation that compacts the material (the graders were equipped with tow rollers). Network managers are encouraged to investigate the maintenance regime from a cost perspective more often. Figure 12 shows typical annualised costs for different blading and re-gravelling cycles. It shows a strong relationship between more frequent re-gravelling with lower blading needs, and between lower re-gravelling frequencies requiring more frequent blading.

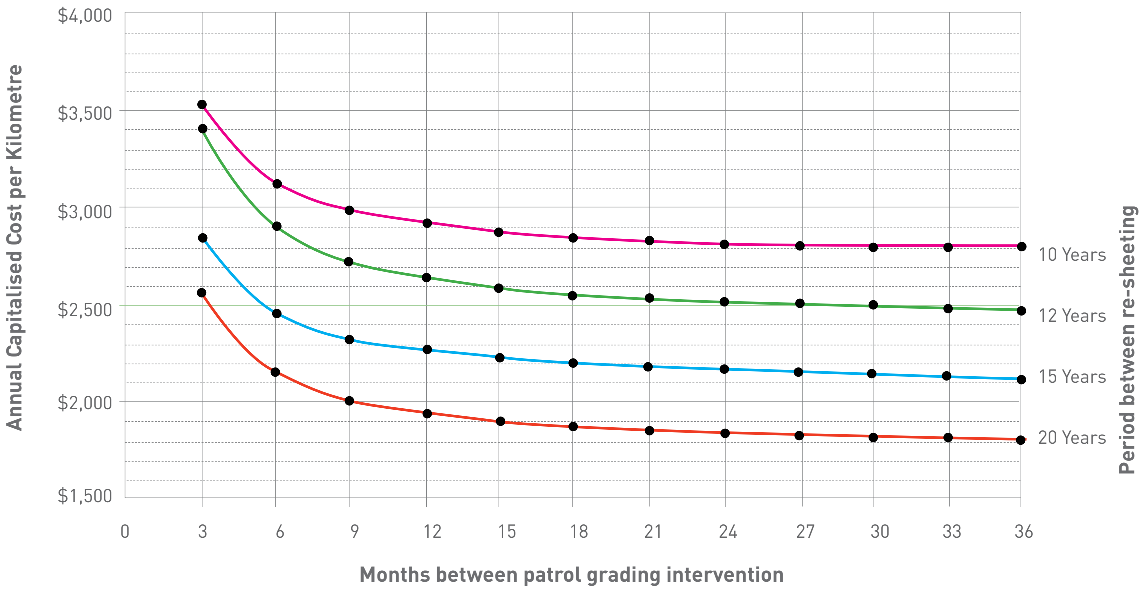


Figure 12: Annualised Costs for Blading and Gravelling Cycles (2)

6.3 DIFFERENT WEARING COURSE MATERIAL

By having a superior performing material, a significant saving in terms of periodic treatment and re-gravelling costs may be expected. However, better performing material may come at additional costs, which can include direct purchase costs and/or additional transportation costs.

This concern has been investigated by Jones and Roodenburg (15) via a case study at Central Otago District Council. The study concluded that each borrow pit has an "economic zone" in which the material is most cost effective. As expected, good quality material may be more expensive and may be transported over longer distances given its ability to yield increased performance benefits as a result of its inherit properties.

6.4 ALTERNATIVE SURFACES AND COMPACTION AIDS

Alternative surfaces often promise real LCC savings because of the reduction in blading costs. There are also some indirect savings as dust will not be affecting farming and other activities adjacent to unsealed road. Some considerations in the LCC calculation of alternative surfaces and compactions are:

- Performance aspects of each product should be confirmed for the specific gravel it is used on. Care should be taken not to apply claimed LCC aspects to any material – refer to Table 7 to ensure the appropriate product is used for the given circumstances
- Take account of rejuvenation application needs. For example, some products may leach during rainy seasons and will require a re-application prior to dry seasons
- No product is completely maintenance free, so allow for some routine maintenance to be undertaken
- Include drainage improvements in the budget estimation of all options. Poor drainage is often the cause of poor performance of the unsealed roads, and drainage issues cannot be solved through alternative surfaces. This will not make a difference to the outcome of the LCC calculation, but the complete cost calculation must be realistic.

Table 8 and Table 9 give some examples of the LCC analysis process comparing different surfacing options. An interesting addition to these calculations is the costs related to dust related complaints. Although not currently present in the New Zealand funding guideline, it is a real cost authorities experience. A dust related complaint is often followed by a site inspection before additional work is scheduled.

	OTTA SEAL	WASTE OIL	EMULSION	UNTREATED
INITIAL CONSTRUCTIONS COSTS				
Grading	✓✓	✓	✓	✓
Aggregate	✓✓	✓	✓	✓
Waste oil		✓		
Emulsion			✓	
Norwegian Road Oil	✓			
ANNUAL MAINTENANCE COSTS				
Pothole and edgebreak repairs	✓	✓✓	✓✓	✓✓✓
Grading		✓	✓	✓✓
Aggregate		✓	✓	✓
Waste oil		✓		
Emulsion			✓	
ANNUAL INTANGIBLE COSTS				
Dust contamination		✓	✓	✓✓
Dust complaints		✓	✓	✓✓
Additional VOC cf Otta seal VOC		✓	✓	✓✓

Table 8: Cost Associated with Different Surfacing Options (13)

	NORMAL MAINTENANCE	EMULSION	WASTE OIL	OTTA SEAL
MAINTENANCE COSTS				
Grading	$440	$220	$220	$0
Metalling	$2,000	$2,000	$2,000	$0
Pothole repairs	$250	$150	$100	$50
Emulsion application	$0	$11,000	$0	$0
Oil application	$0	$0	$5,040	$0
Total maintenance costs	$2,690	$13,370	$7,360	$50
CONSTRUCTION COSTS				
Grading	$110	$110	$110	$220
Metalling	$2,000	$2,000	$2,000	$5,000
Emulsion application	$0	$10,000	$0	$0
Oil application	$0	$0	$4,200	$0
NRO application	$0	$0	$0	$24,500
Initial construction costs	$2,110	$12,110	$6,310	$29,790
INTANGIBLE COSTS				
Dust contamination	$2,000	$1,000	$600	$0
Dust complaints	$6,400	$1,600	$800	$0
Additional vehicle operating costs	$1,387	$2,373	$2,373	$0
Total intangible costs	$9,787	$4,973	$3,773	$0
Area/m^2	6,000	6,000	6,000	6,000
NET PRESENT VALUE CALCULATION	**NORMAL MAINTENANCE**	**EMULSION**	**WASTE OIL**	**OTTA SEAL**
Initial construction costs NPV	$0.35	$2.02	$1.05	$4.97
Total construction costs NPV	$1.78	$8.86	$4.88	$0.03
Total intangible costs NPV	$6.49	$3.30	$2.50	$0.00
Total costs NPV	$8.62	$14.18	$8.43	$5.00
Maintenance costs annual	$0.45	$2.23	$1.23	$0.01
Intangible costs annual	$1.63	$0.83	$0.63	$0.00

Table 9: Outcome from an LCC Calculation (13)

7. PROCUREMENT OF UNSEALED ROAD NETWORK MAINTENANCE CONTRACTS

A maintenance network contract states the framework of a contractual relationship between the asset owner and the contractor who performs the maintenance work. Ultimately, the contractor's ability to maintain a network according to the client's expectations while satisfying the company's commercial interest will depend on the contract:

- Specifying the maintenance work's expected outcome
- Being fair to all parties, including acknowledging the contractor's right to a reasonable profit, while providing the owners and road users with value for their investment by maintaining the network in an optimal manner
- Allocating risk to each party of the contract appropriately. (Normally risk is assigned to the party who has the ability to control the specific risk items)
- Being flexible enough to handle changing circumstances on the network
- Being able to promote behaviours that best with the cost-effective delivery of maintenance services

It is also accepted, however, that there is no single "one size fits all" contract for the whole country, as each area has specific requirements and situations that influence the contract requirements.

7.1 CONTRACT FORMS

The contractual format sets the foundation for the relationship between the client and the contractor. Table 10 provides some examples of contractual formats, the reasons authorities may consider these for their networks and some potential pitfalls with some of the contracts.

> *"Grading under a performance criteria contract rather than a specified grading cycle is done to meet funded levels of service, as opposed to a cyclical program where work is carried out whether or not it is required."*
>
> *Western Bay District Council webpage - Unsealed roads - Frequently asked questions*
>
> *"Grading works are programmed on an adopted level of service, for the road surface determines when a road is graded"*
>
> *"Council utilises a systematic approach to manage road maintenance requirements, recording and prioritising defects to enable programming when the intervention level is reached"*
>
> *Rockhampton Regional Council Queensland FAQs – Maintenance/grading of unsealed rural roads*
>
> *www.rockhamptonregion.qld.gov.au*

Table 10: Contract Styles for Managing Unsealed Road Networks

CONTRACT STYLE	EXAMPLE NETWORK	CONSIDERATIONS FOR ADOPTING CONTRACT STYLE	POTENTIAL PITFALL FOR AVOIDING THIS CONTRACT STYLE
Alliance Payment Cost Plus	Central Otago District Council	▪ Alignment in objectives/ drivers of both parties ▪ More flexibility in contract ▪ Drive different outcomes to traditional contracts ▪ More council involvement in decision making ▪ Certainty around funding requirements ▪ Aiming at a risk sharing model with contractor ▪ Promoting higher quality blading ▪ Fewer conflicting initiatives ▪ Drive innovation in collaborative work ▪ Both parties attempt to satisfy rate payers	▪ Requires a cultural change for both council and contractors ▪ Relationship dependant - management of personalities is important ▪ Difficulty in demonstrating value for money (in short term) ▪ May have initial higher costs ▪ Contract award not necessarily on lowest price
Performance Specified Maintenance Contracts	Western Bay of Plenty District Council	▪ Reduced management onus on council ▪ Certainty around funding requirements ▪ Aiming at a risk sharing model with contractor ▪ LoS fixed for the duration of the contract ▪ Clients need to define and understand performance	▪ May drive perverse behaviour ▪ Fixed around LoS inflexibility to change ▪ Locked longer time ▪ Process based ▪ Council has an auditing role, thus a different relationship compared to an Alliance
Time Base Lump Sum		▪ Financial assurance ▪ No cost risk for client ▪ Transfer planning control to contractor ▪ Monitoring control with client ▪ Audit role for client	▪ Risky for contractor ▪ Difficult to price ▪ Higher contractor risk ▪ May steer perverse behaviour ▪ Does not focus on "big picture" network issues ▪ Only client carries ratepayers interest
Unit Rate Monthly Schedule		▪ Easier to let ▪ Client control ▪ Easy to price for the contractor	▪ No end-point in sight; most Authorities will keep spending the maintenance funds until the budget runs out ▪ May drive perverse behaviour ▪ May incur unnecessary costs

CONTRACT STYLE	EXAMPLE NETWORK	CONSIDERATIONS FOR ADOPTING CONTRACT STYLE	POTENTIAL PITFALL FOR AVOIDING THIS CONTRACT STYLE
Hybrid – part Lump Sum Performance and part Measure and Value	Dunedin City Council	▪ Reduced management onus on council ▪ Client involvement in decision making for significant activities ▪ LoS set for routine items ▪ Promotes client/contractor relationship ▪ Asset management approach to maintenance	▪ Audit LoS for routine maintenance ▪ Audit treatment selection for Measure and Value works

Examples of Performance criteria used in a lump sum type contract

Whangarei District Council Road Maintenance Contract

- Corrugations shall not exceed 25mm deep
- Rutting shall not exceed 50mm deep
- Loose surface depth at any time shall not exceed 25mm
- All unsealed roads will have a good, safe, riding surface that provides:
    - A free draining surface to roadside water tables
    - A smooth transitions between the road and intersections, sealed roads, bridge decks and entranceways
    - The correct cross fall
    - Clean cut outs that permit water to disperse clear of the roadway
    - Requirements to protect all drainage facilities, traffic aids, and the like
    - Requirements to grade the full width of the road.

To achieve these criteria the Whangarei District Council Maintenance Contract specifies:

- Surface grading comprise the smoothing of unsealed road surfaces by motor grader to provide motorists with a safe, comfortable ride and to provide a free draining surface
- The contractor's programme of surface grading is based on inspection requirements in the contract. Each unsealed road inspection must identify road lengths with insufficient cross fall and road lengths with corrugations, rutting, shoving and clusters of potholes
- Roads shall be graded for full road width including into water tables
- All existing cut outs shall be maintained as part of the surface grading operations
- The surface must be cut to the correct cross fall – this is 6-8% on straights and 8-12% corner super elevations
- At no time will a grader make a final pass down the centre of the road with the blade in the horizontal position
- Grading operations will be undertaken, outside periods of heavy rain or long dry periods, ideally when the road surface is damp
- Grading must be undertaken at a frequency that ensures the specifications are met
- A record of grading must be kept and reported in the monthly works claim
- Wairoa District has a compliance system based on a corridor of tolerance for the entire network - i.e. a bucket system

7.2 PREVENTING PERVERSE BEHAVIOUR - CONTRACT DRIVERS AND INCENTIVES

Human nature encourages people to react on incentives and disincentives to steer their behaviour. It is a procurement challenge to develop a set of rules that will deliver the desired outcome from the client perspective and steer the contractor towards these outcomes. However, to achieve this, it is important to accept the realities of a commercial world including:

- The contractor has to consider every opportunity to maximise their profits. In addition, there is a desire by the contractor to "look good" in the clients' eyes, thus maximising the potential of winning future projects
- The council representative's main responsibility, which is to carry the ratepayer's interest in managing the road networks. This person would also like to be perceived by his/her executives as someone who stretches the funds and maximise the LoS to the ratepayer.

These two realities need to conflict; yet some contractual formats encourage alignment of these objectives better than others. Therefore in adopting a specific contractual format the following points need to be considered to maximise the likelihood of a successful contractual outcome:

- Aligning objectives –The two contracting parties' objectives can be used to develop a contract that aims at achieving a balanced outcome for both parties
- A clear vision on future desired performance – The client has to give a clear vision of desired network of the network, and the constraints in achieving these
- Basis of payment –This should be tested to ensure it will incentivise the appropriate behaviour from the contractor
- Risk sharing – This should be planned so the party who has the best ability to mitigate a particular risk is the party responsible for the risk. Too much risk being allocated to the contractor leads to inflated prices, even though contractors are normally capable of managing risks on their clients' behalf
- Measurement techniques and reporting –Techniques such as condition monitoring linked to performance measures should be indisputable in terms of their accuracy and repeatability.

8. DATA COLLECTION REQUIREMENTS

8.1 PURPOSE OF CONDITION DATA COLLECTION

The framework this Guide recommends attempts to be less reliant on condition data collection regimes. However, it would be unwise to promote "no data collection" as it will always have a place in the unsealed road maintenance planning. In using the decision process promoted in this Guide for data collection, contractors are required to:

- Identify outlier sections in terms of poor performance
- Undertake a regular (annual) snapshot of the entire network's overall condition for performance monitoring purposes
- Collect the data specified by the contract if performance measures are prescribed in a performance based contract.

8.2 TECHNOLOGY

The recommended use of different technologies is summarised in Table 11.

Table 11: Recommended use of Data Collection Techniques on Unsealed Roads

TECHNOLOGY	APPLICATION
Response type roughness measures	Undertake a snapshot network survey for performance monitoring purposes Survey a sub-network before determining exact works programme for an area. Measurements are used to identify outlier areas.
Cell phone roughness measures	Routine monitoring for identifying outlier performance sections –these surveys are part of the regular foreman inspections
Dynamic Cone Penetrometer (Scala) or Clegg Hammer	Design tool to establish re-gravelling thickness and treatment of subgrade/sub-base layers.
Ground Penetrating Radar	Qualitative survey to establish weak spots on road sections

8.2.1 PERFORMANCE MONITORING

To improve asset management effectiveness of the unsealed road network it is important to monitor its performance over time. Some measures may be subjective and the performance framework may not be perfect, yet there is always value in tracking data over time. A suggested performance framework for the managing of unsealed road networks is presented in Table 12.

Table 12: Recommended Performance Framework for Unsealed Roads

PERFORMANCE AREA	OBJECTIVES	PERFORMANCE MEASURE
Safety	Reduce the number of road related crashes	Number of road related serious crashes / VKT
	Reduce the number of safety related complaints	Number of winter month complaints / VKT
		Number of summer month complaints / VKT
	Reduce the number of crash "black spots"	Number of high crash areas (> 2/ year or 4 over-all)
Public satisfaction	Achieve overall target of public satisfaction for unsealed roads	Satisfaction score
	Achieve overall target for number of complaints	Number of complaints
Performance	Achieve a target overall LoS in term of roughness	75^{th} percentile roughness less than IRI x (say above 3.5 to 4.5)
	Achieve a target level of road sections having an un-acceptably high roughness	Percentage of the road network above an IRI of X
	Having an appropriate annual gravel demand	Achieved volume of re-gravelling over past three years
Investment	Achieve an optimal blading cycle	75^{th} percentile summer blading cycle
		75^{th} percentile winter blading cycle
	Have an optimal re-gravelling cycle	75^{th} percentile planned gravelling cycle
	Keep reactive maintenance to the minimum	$ per km of (non-weather related) reactive maintenance
	Investment into drainage	$ per km of reactive flood damage repairs

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APPENDIX A:

CASE STUDIES FOR USING THE PROPOSED GUIDELINES

DEVELOPMENT OF A FRAMEWORK FOR MAINTENANCE ON UNSEALED ROADS

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Disclaimer – All these conference papers have been submitted as partial fulfilment for the project requirement for the BE (Hon) degree. Although they have been assessed, no errors or factual information have been corrected or checked.

ABSTRACT

The unsealed road network is intricately linked to the New Zealand economy as they provide access to rural communities and industries. Existing asset management systems are not widely used by authorities as they are considered labour intensive and unrepresentative of the true condition. This study began the development of a more effective and efficient management system in the Central Otago District, where over two thirds of their network is unsealed. It was expected that the material properties of surface aggregates could be used to predict surface performance, removing the dependence on condition data collection.

The study used historical maintenance records and visual inspection to predict the rate and mode of failure. The use of the Paige-Green (1989) theory, found the geological properties gave an accurate indication of the mode of failure. The key variables that influenced the rate of failure were: geometric horizontal curvature, average daily traffic, and age of the pavement surface. This influence varied depending on the geological properties of the surface aggregate. The model developed, relies solely on the three variables, collected regularly as part of network operations, for routine maintenance scheduling. Condition data is not required ensuring this asset management system meets the study requirements.

Keywords: unsealed roads, gravel roads, gravel road management system, material properties

1. INTRODUCTION

The economic viability of a country is directly influenced by the effectiveness of its infrastructure to transport goods and services; roads are an integral part of this (Paige-Green, 1999). Unsealed roads, typically located in rural, sparsely populated areas, account for nearly 40 per cent of New Zealand's road network (New Zealand Transport Agency (NZTA), 2010). The prosperity of rural communities and industries such as primary exports, rely on these rural unsealed roads for access and transport. In 2012, the primary industries accounted for 7.6 per cent of New Zealand's Gross Domestic Product, and contributed to over 50 per cent of the total export earnings (The Treasury, 2012).

1.1 Background

Unsealed roads, when maintained efficiently, are far more cost effective than sealed roads, for low volume roads (Paige-Green, 1999). However the dynamic and changeable nature of unsealed roads makes it difficult to forecast optimal expenditures and allocation of resources. Existing asset management guidelines have focused on regular data collection of a wide range of variables to ensure an effective condition models (Henning et al., 2014; Huntington & Ksaibati, 2011a). In rural districts such as the Central Otago District Council (CODC), with over 1300 km of unsealed roads to maintain, comprehensive and regular data collection for their entire network is impractical. A new asset management system is required to effectively manage the network that does not rely on the collection of condition data.

Huntington & Ksaibati (2011a) studied small road authorities in the United States, to conclude that complicated software, extensive data collection and a lack of staff were the main barriers to the implementation of Gravel Road Management Systems (GRMS). Other barriers were identified by Van Zyl et al. (2007) when the actual condition of an unsealed road was compare to selected prediction models. Generally the modelled condition showed little resemblance to the actual condition of the road. These have been the main stumbling blocks in the widespread use of prediction model-based maintenance scheduling with condition data input amongst local authorities. As a result, many road authorities attempt to make complex effective decisions based on local knowledge and experience.

1.2 Introduction to the study

During the late 1980's Paige-Green (1989) implemented a comprehensive field study of the performance of unsealed roads in relation to the material properties, in South Africa and Namibia. Further research by Paige-Green (1999) developed a diagrammatic indication of an unsealed road's expected performance by plotting the material's shrinkage product against the grading coefficient. Development of a process that will use this research in a financial decision-making process may be found in a parallel study undertaken by Rodenburg, (2014).

1.3 Objectives of this research

This research aimed to establish a relationship between Paige-Green's performance prediction and the frequency of grading maintenance, to be used as a new approach to GRMS'. This study presents the analysis of historical data collected from a sample of the CODC unsealed road network.

The objectives of this paper are to:

- Validate the application of the Paige-Green (1989) performance indicators for unsealed roads in New Zealand conditions.
- Identify the key variables that affect the performance of unsealed roads through the analysis of historical road maintenance data.
- Develop a practical framework to predict unsealed road maintenance scheduling.

1.4 Scope

This research is focused on the identification of historical maintenance for the development of an effective GRMS for the CODC. It assumes the climate to be consistent throughout the district and excludes the effects of shading, and seasonal variations. Geometric curvature and grade severity ratings given to the roads in the sample were qualitative. While the direct findings are not appropriate for other areas, the process outlined in this paper can be applied throughout New Zealand.

2.0 LITERATURE REVIEW

This literature review discusses unsealed roads in terms of; surface performance, material properties, maintenance treatments and current management systems. Notable academics identified in the field of unsealed road management include: Paige-Green, P.; Jones, D.; Huntington, G.; and Henning, T. F. P.

2.1 Surface performance

The deterioration and gravel LoS of unsealed roads is influenced by four inter-related factors: material properties, road geometry and drainage, environmental influences, and traffic conditions (Henning et al., 2008; Paige-Green, 1999; van Zyl et al., 2007). Condition deterioration may be further categorised into the following surface wear types; rutting, dust, loose material, stoniness, corrugations, potholes and scouring.

2.1.1 Material properties

Poor material selection can result in acute reactions to environmental and traffic conditions. Henning et al. (2008) attributes the choice of replacement aggregate to as much as 60 per cent of the total maintenance costs of unsealed roads. A well-graded gravel sand mixture with a small portion of clay fines, in most cases, performs well as a wearing course material. The distribution of materials from coarse to fine, creates shear strength in the wearing surface that performs well in traffic and weather conditions. The presence of a high level of fines makes the surface more susceptible to erosion and scouring actions, as well as high dust emissions in dry seasons. In contrast, a very coarse mixture causes stoniness and ravelling, resulting in punctured vehicle tyres, and driving instability.

2.1.2 Road geometry and drainage

Road performance greatly depends significantly on alignment and drainage capacity. Tight curves with insufficient super-elevation result in sharp acceleration and deceleration of vehicles. Henning et al. (2008) attributes this change in speed and exertion of the sideways force around the curve to increased wearing and deterioration on these sections of road. Steep grades also increase erosion forces, significantly straining the binding properties of the wearing course. Henning also attributes inadequate drainage, super-elevation and a road profile for the formation of potholes and scour.

2.1.3 Environmental influences

Seasonal dryness and increased traffic volumes can result in higher dust emissions and raveling. According to Paige-Green (1999) drier areas tend to form corrugations under traffic due to the local materials being of lower plasticity; hence increasing the demand on maintenance regimes. When cold, however, wet weather can introduce further deficiencies such as: scouring and washouts, freeze-thaw (causing impassible slushy surfaces), and less daylight available to dry out the road surface.

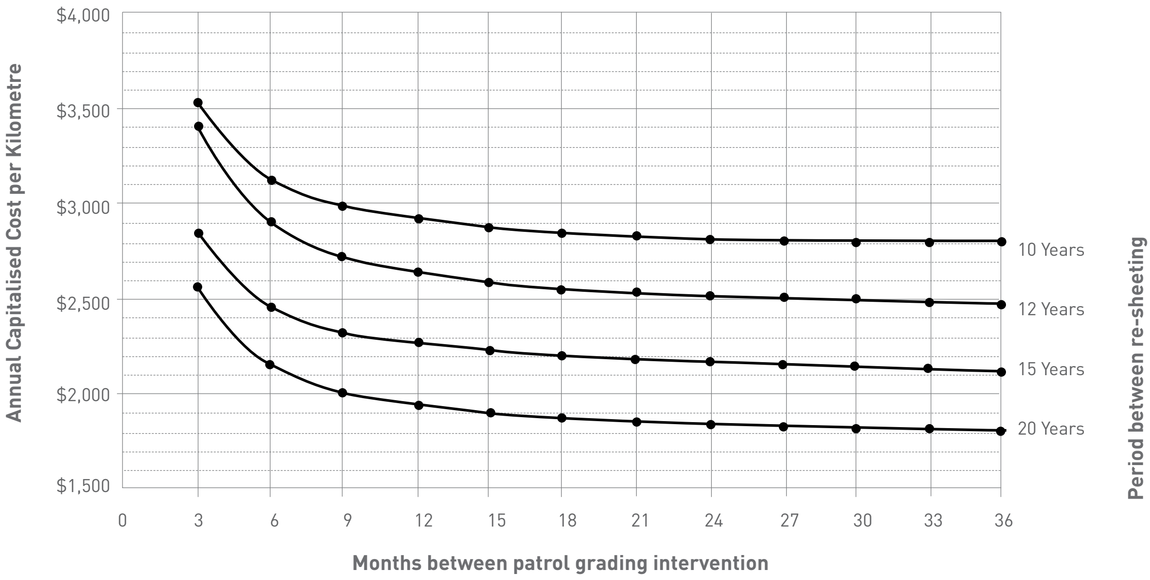

Figure 1 - Life cycle analysis of wearing course life and grading intervention, reproduced from Austroads (2009)

2.1.4 Traffic conditions

According to the NZTA (2005), one heavy commercial vehicle (HCV) is equal to ten light vehicles in terms of the load exerted on the pavement causing deformations. Actions such as dust attrition, gravel flick-off, acceleration/deceleration and pavement loading increase in tandem with traffic volumes. Unsealed roads tend to become uneconomical to maintain when traffic volumes exceed 100 vehicles per day, typically where commercial vehicle activities occur (Paige-Green, 1999).

The four elements of material properties, road geometry and drainage, environmental influences, and traffic conditions all interact to influence the functional performance of an unsealed road network. Efficient routine maintenance is key to preventing significant road surface deterioration. Figure 1 shows the influence gravel re-sheeting and patrol grading intervals has on the annual capitalised cost of a pavement. The figure compares the cost savings that can be achieved by extending the time intervals between the two maintenance mechanisms. Extending the time interval between re-sheeting from 10 to 20 years yields twice the cost benefit that can be achieved by increasing the intervals between patrol gradings (Austroads, 2009). Therefore, quality materials that extend the life of the pavement achieve considerable savings to the annual capitilised cost of a pavement.

2.2 Paige-Green performance forecasting

Unsealed roads are dynamic systems, with traffic, environment, the road profile and material conditions influencing their performance. However, the material is the only element that can be controlled, making it one of the one of most interest for improvement. Paige-Green (1989) carried out a comprehensive field study to determine the performance of wearing course gravels in relation to their material properties, in South Africa and Namibia. The study found that engineering geological classification of a material was insufficient for accurate prediction of its performance in unsealed roads. Instead, two new measures; Shrinkage Product and Grading Coefficient are more appropriate for classification purposes. Figure 2 (in results section) graphically represents the material specifications for a more effective comparison between the performances of wearing course materials.

Further research by Paige-Green (1999) discussed the advantages of blending wearing course materials together to improve their properties and hence performance. Known as mechanical stabilization, it is an effective method to utilize and enhance available materials while reducing road user operating costs.

Paige-Green (2007) found the advantage of evaluating the material properties of the wearing courses is consistency; tests need only be performed once per material. The appropriate selection of a wearing course material can extend the life of the road surface and result in a significant decrease in the demand on resources for maintenance and inspections, as shown in Figure 1. This research aims to leverage the understanding and prediction of wearing course material performance, shown in Figure 2. To develop a maintenance management framework that does not rely on intensive data collection.

The gravel LoS prediction model for unsealed roads developed by Paige-Green (1989) is defined in equation (1) below. Lea et al. (1999) specified that a wearing course is typically applied as a 150 mm layer, and should not be allowed to wear down less than 50 mm. This is to prevent pavement surface distresses that reduce the riding quality of the road. Hence, accurate gravel LoS prediction is a vital component to any proactive GRMS.

$GL = 0.01D\,(ADT(0.059 + 0.027N - 0.0006P_{2.65})$ (1)

$- 0.367N - 0.0014PF + 00474P_{26.5})$

(1) where:

(2) GL = Gravel thickness LoS (mm);

(3) D = Time period under consideration (days);

(4) ADT = Average Daily Traffic (*sum of both directions*);

(5) N = N value, *(Weinert, 1980) (ranges from 1 in wet areas to more than 10 in arid areas and incorporates annual rainfall)*;

(6) PF = Plastic Factor (PL x $P_{0.075}$);

(7) PL = Plastic Limit, and

(8) $P_{26.5}$, $P_{0.075}$ = Percentage passing 26.5 mm and 0.75 mm sieves respectively.

(9) The Paige-Green (1989) research and model has been recognised and adopted internationally by specifications for the: Technical Recommendations for Highways 20 (TRH20) in southern Africa, (CSRA, 1990) and Austroads (2009). Reinforcing the relevance and importance of this study.

2.3 Gravel road management systems

The two basic goals of a GRMS are to: allow road authorities to manage their network more effectively, and provide officials with enough information to make informed decisions about unsealed road funding (Huntington & Ksaibati, 2011a). The consensus of their study was that any GRMS that facilitates these goals, must also not significantly demand too much of staff's time.

Effective GRMS' must facilitate proactive decision making for the scheduling of maintenance treatment. According to Austroads (2009) defines these treatments as:

- Patrol grading – light grading performed on a routine basis to reduce the rate of deterioration by reappropriating the windrow material over the surface.
- Reshaping – heavier grading that scarifies the existing road surface to yield an optimal blend of aggregate particle sizes and to reshape the road profile.
- Regravelling – ensures a suitable thickness of wearing course is maintained to prevent deformations in the subgrade. Thickness of this gravel is ideally between 100 and 150 mm.

Almost 80% of road authorities use visual inspection methods, to evaluate the condition of their network (Huntington & Ksaibati, 2011a). Physical measurement, where the extent of defects is recorded, provides for a thorough and quality assessment, but is an impractical for authorities that manage large networks. Automated data collection systems only measure specific parameters such as dust (Jones, 1999) or surface roughness (Brown et al., 2003). There is currently no automated system that encompasses measurement for multiple surface defects. No technique is efficient in terms of both time and accuracy.

In the absence of a GRMS, authorities determine maintenance schedules through customer complaints or maintain each road in a cycle regardless of engineering or economical concerns (Huntington & Ksaibati, 2011a). Such scheduling techniques cannot ensure a consistent level of service is maintained for all customers in an economic manner.

In New Zealand it is common for road authorities to out-source road maintenance to private contractors using a performance-based system. Difficulties with this system include quantifying the requirements and agreeing on an acceptable criterion for assessing performance (Douglas et al., 2007).

More advanced GRMS' use existing prediction models to forecast the condition of unsealed roads in order to schedule maintenance. Often these GRMS use technical software programs, requiring a lengthy list of inputs that are outside of the means of many local road authorities (Huntington & Ksaibati, 2011b). It is essential to ensure this barrier to implementing an effective GRMS is not repeated in this study.

3. METHODOLOGY

3.1 Study area

The Central Otago District is located inland of Dunedin in the South Island of New Zealand. It has a semi-arid climate, dominated by the strong landscapes of ranges and basins. The geology of the region is predominantly schist (metamorphosed greywacke) with areas of sandstone also common (Department of Conservation, 2014). The extreme variation in weather conditions (temperature from -6 to 30+ °C) creates difficulties for the CODC to ensure the required level of service on the unsealed network is provided throughout the year. The hot, dry periods result in dust and corrugations, whereas cold, freeze/thaw conditions result in wet slippery surfaces. There is no material that is suited to all conditions.

The study sample was selected in relation to the objectives of this study. The sample represented the range of gravel materials and varied terrain severities present in the CODC's network. Five of their gravel pits were selected with varying levels of performance. The five pits in the sample were Glassfords, Kellihers, Parkers, Rutherfords, and Wrights. For each gravel pit, three roads were selected to represent the different traffic spectra, age groups and geometric alignments, as much as possible.

3.2 Data collection

Material tests were conducted by Central Testinf Services of Alexandra to determine the parameters necessary to calculate the plasticity index and grading coefficient. Standard test methods used were: 2.3, 2.4, 2.5, and 2.6 from NZS 4402:1986. The plasticity index, linear shrinkage and grading curve were determined for each of the five gravel pits in the sample.

CODC provided historical records they had developed for their network. Data extracted from these records includes: average daily traffic counts or estimates; percentage of heavy vehicles; date of new gravel placement; and forecasted grading plans for all the roads in our sample.

The limited time available in Alexandra and the remote locations of many roads made visual inspections the most practical solution. Windshield inspections identified and recorded the curvature and modes of deterioration present on the sample roads. To simplify the data collection for future implementation, a road's geometric curvature and grade was rated in terms of severity. The factors were rated based on the categories outlines in Table 1. This qualitative rating of the curvature and grade severity was the most appropriate method to reduce the reliance on intensive data collection.

Table 13: Horizontal geometry factor (GH)

1	Straight road with very few bends. Bends at obtuse angle of such that speed is not restricted.
2	Some curves are present which limit driver speed, but do not induce significant discomfort. Acceleration and deceleration necessary to safely navigate corners.
3	Curvature severely restricts driver speed. Significant acceleration and deceleration necessary to safely navigate corners.

3.3 Analysis methods

The two software packages used for the analysis were Microsoft Excel and R. Excel is currently used by the CODC council for maintenance scheduling. R is a more specialised statistical software package that was chosen because of its versatility and capability. The software was required to derive a blading frequency model for each gravel pit, a task that would not need to be repeated by the CODC once all gravel pit models were derived. It is not envisioned that the CODC would be required to use R in their everyday GRMS.

Relevant road data was extracted from the historical data provided by the CODC, as identified in the literature review. These were: the average daily traffic count (ADT); percentage heavy commercial vehicles (HCV); the age of the wearing course, in years; the geometric curvature and grade rating; and the material properties for the five gravel pits. The HCV's were converted into equivalent light vehicles (ELV), using the NZTA (2005) method given earlier.

Explanatory and response variables were analysed using R. Due to the small size of each gravel pit group, it was not possible to quantify the within-group interactions. Therefore the three gravel pits that showed similar properties on the Paige-Green (1999) graph were analysed together to see if the trends identified were different to those of the full group. These results were subsequently used to estimate a model to guide the GRMS decision making process.

4. RESULTS

All raw data, photographs, analysis, model output and results can be sourced in the compendium.

4.1 Corroboration of Paige-Green Theory

The CODC gravel pit material properties are shown in Figure 2, the Paige-Green performance indication graph. Three of the gravels plotted in the bottom left section of Zone E; Glassfords, Parkers and Rutherfords. The graph indicates that these materials are good materials that may be prone to small levels of erosion, corrugation and ravelling. Visual inspection did confirm this expectation, with some of the roads showing signs of ravelling while others appearing to have isolated occurrences of corrugations and scouring. Varying but universal degrees of potholes were observed. This is an indication of inadequate drainage and the absence of a raised cross profile.

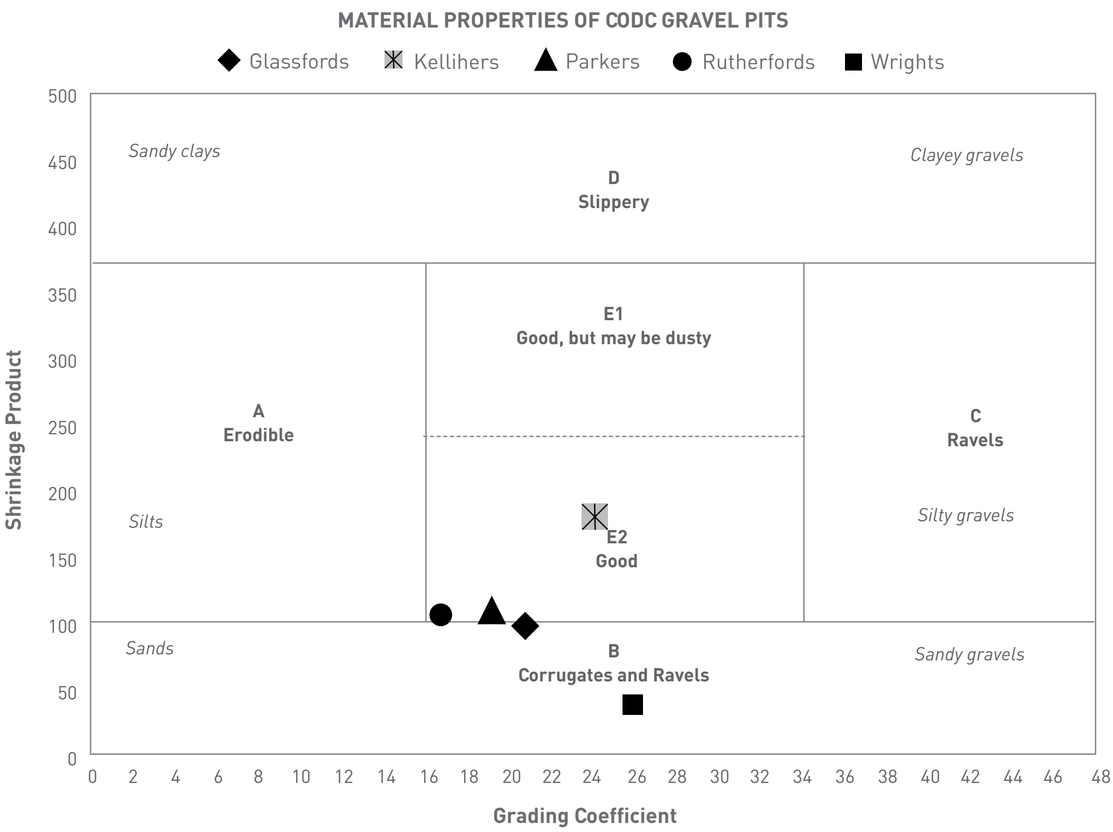

Figure 2 – Relationship between shrinkage product, grading coefficient, and performance, adapted from Paige-Green (1999)

Table 14 - Explanation of the five zones in Figure 2, reproduced from Henning et al. (2014)

A	Sandy and clayey silts with insufficient plasticity to provide cohesive bond. Erosion sensitive under steep grades and cross falls.
B	Sands and gravels with little to no plasticity. Lack of cohesion results in loose raveled surface and corrugations due to vehicle loads.
C	Course gravels with low level of fines and plasticity results in rapid raveling.
D	Silty clays and clayey gravels with high level of fines and plasticity that produces slippery surfaces in wet conditions.
E	Well-graded material with appropriate plasticity to provide cohesive bond for wearing course. Higher plasticity can produce a dusty surface.

The Kellihers pit aggregate was located in Zone E, indicating a good soil-aggregate mixture with sufficient plasticity to bind the material for good surface wear. The Kellihers roads displayed signs of stoniness, perhaps as a result of large hard aggregates (size > 37.5 mm (Paige-Green (1999)) not being removed. Some road sections had areas of poor drainage where isolated defects, such as potholes had formed. A few road surfaces were also slippery and slushy in areas of shade after periods of wet weather. Wrights pit aggregate had a very different colour appearance to the other four aggregates studied. Roads surfaced with this aggregate showed signs of ravelling as indicated on Figure 2. Overall the failure modes

4.2 Key explanatory variables

The most influential variables on the blading frequency (BF), were, the geometric horizontal curvature (GH), age of the pavement surface (Age), and average daily traffic (ADT) in terms of equivalent light vehicles.

The expectation was that the influence of these variables would differ between each pit. This was unable to be quantified due to inadequacies in the data available. However, a grouping based on the similar material properties of the Glassfords, Parkers and Rutherfords pits (referred to as 'three pit') was created to be compared with the 'all pit' sample. The equations derived are:

All pit sample

$$B_F = 3.527 - 0.173Age + 0.012ADT + 1.156G_H \quad (1)$$

Three pit sample

$$B_F = 3.784 - 0.109Age + 0.006ADT + 0.825G_H \quad (2)$$

The average daily traffic (ADT) count was the most influential variable and this is consistent with the literature. The age of the pavement surface (Age), and the geometric horizontal curvature (G_H) were found to have an equal level of influence, marginally behind the ADT.

Model (1) of the 'all pit' sample was estimated to explain 55% of the blading frequency, whereas model (2) of the 'three pit' sample only explained 29%. The author hypothesizes that the greater accuracy of the all pit model is due to the large sample size reducing the influence of random variations. However, both models present promising indication that it is possible to forecast maintenance scheduling with a model that does not rely on the collection of condition data.

5. DISCUSSION

5.1 Paige-Green theory validation

The CODC roading team had already found through experience that the Kellihers pit was their best source of wearing course material. Their team had determined this based on their experience and continued reflection. They had already implemented initiatives to gravel highly trafficked roads with the Kellihers material because of its proven performance. This provides further evidence to validate the Paige-Green (1999) performance prediction chart as the Kellihers material plotted in the 'Good' Zone E. The alignment between the Paige-Green (1999) chart and council experience pertaining to the Kellihers Pit provides a practical reinforcement to the theory's validity.

The alignment between the Paige-Green (1999) prediction chart and council experience also provides practical evidence of the model's application for maintenance scheduling. However, this is just one element of GRMS. Failure modes such as potholes are localised defects, and are predominantly determined by deficiencies in the grade, road profile and drainage provisions rather than with the material properties. Therefore, the need for visual inspections of the road network has been reduced. Inspections to determine deficiencies in the road alignment will still need to be performed.

The materials in Central Otago, originated from greywacke and sandstone; overall these materials tended to be well graded with a good to low plasticity. Four of the five pits plotted within Zone E. According to the Paige-Green (1999) chart, such properties provide a good basis for gravel road aggregates. The CODC is in a comparatively fortunate position to other regions in the country that do not have the same access to such reliable wearing course materials. In other regions it is necessary to physically stabilise materials through mixing of aggregates, to achieve similar material properties. Therefore in this instance, there is a simplification that may not be applicable in other areas.

The data used to estimate the blading frequency model was the council's planned number of grades per year. It was not a representation of when the material failed and required grading. This meant that in the early analysis of the data, the Kellihers pit appeared to be the worst performing material, as it was associated with a higher number of planned grades, increased traffic loads, and more severe curvature. As the weaker materials were not used on these high volume roads, there was no direct comparison to be made between a good and poor material's performance respectively. The development of this model is an iterative process that requires continued improvement and development by the council.

By focusing on the material properties to determine the performance (indicated by the Paige-Green chart), it is a less labour intensive method of data collection as it is only tested once per source pit. Therefore, this indicates improved performance and is far more effective to determine the surface performance than the visual inspection methods.

It is imperative that testing methods follow the correct standards for consistency. Testing standards used in New Zealand may differ to the standards used to develop the Paige-Green (1989) chart in southern Africa. Paige-Green (2007) quantified the difference between the South African and British Standards; this calibration moved the limits of the zones on the graph as a result. In terms of this research, such a calibration may affect the categorisation of the 'three pit' group located on the limit of Zone E (figure 2). If more specific validation were to be made for the Paige-Green theory, further research would be needed in this area. However it is not considered that such a calibration would affect the blading frequency prediction model as the actual material properties would not change. The Paige-Green chart simply provided an indication as to the type of failure mode to be expected and the grouping of materials with similar material properties could affect the categorisation of the 'three pit' group; which plotted close to the Zone E limit. While this does not affect the model developed, it is expected that the coefficients will still remain the same.

5.2 Key Variables

The geometric curvature and grade rating was collected through windshield inspections based on a set of qualitative guidelines and is open to discrepancies between different personnel. However, because this variable only needs to be collected once per road, and usually the personnel have quite a good knowledge of the network and can discuss any differences of opinion. The same person for consistency could determine the network wide ratings.

Initially the pavement surface age was not considered to be a key variable and was not included in the original versions of the blading frequency model. None of the models reviewed in the literature had this input variable. The availability of data that dated the last regravelling on the road made it possible to analyse in the data set. It was not until the multi-regression model in R quantified the influence the age of the surface had on the blading frequency, that it was considered a key variable. However upon reflection upon the behaviour of unsealed road deterioration, (the older a gravel surface gets, the more maintenance it requires), this variable was an important variable in the blading frequency model.

The method developed in this study requires historical maintenance operations data for its application. The output cannot be more accurate than the input data. This is not a silver bullet solution to such a complex problem. It provides a guide to inform a better decision-making process to achieve optimal network expenditures. This is an iterative process that needs to be continually improved with a focus on collection of more representative traffic data.

The diversion of resources from condition data collection is definitely a step in the right direction. However, effort must still to be made to collect more up to date traffic count data that includes percentage HCV.

NZTA's heavy to light vehicle ratio of 1:10 equivalent light vehicles attempted to address the greater impact heavy commercial vehicles (HCV) had on the pavement deterioration. Upon reflection, this ratio may not adequately represent the full impact HCV's have on unsealed road deterioration. An unsealed roads' pavement structure a more vulnerable surface than that of a chip seal pavement, hence the ratio between HCV and equivalent light vehicles impact on deformation will not be the same on unsealed roads. In consideration of the affects caused by wider axles of multiple tyre arrangements, both manoeuvring and tonnage significantly increases the effects of deformation on the pavement. HCV's may exacerbate subgrade deformations and concentration of corner deterioration at a significantly greater rate than 10 light vehicles.

In the Central Otago region dairy farm conversions are increasing. This intensification of farming activates will have an associated increase in HCV traffic. Vehicles such as milk tankers, livestock truck and trailers, fertilizer spreaders, and cultivation machinery will become more common place.

While surveying the roads, a truck and trailer that was making a delivery to a farmer. The truck had nowhere to pull off the road and had parked up on the very narrow road for unloading. The wheels extended right to the edge of the windrows where the subgrade would have been weak. As many rural access roads are quite narrow, this type of HCV activity contributes greatly to the road's deterioration. Therefore, HCV must be given priority in the data collection process as their impact on the pavement structure is far greater than that of a chip seal road. The equivalent light vehicle ratio needs to be investigated further to better represent the impact unique to unsealed road networks. Further research is needed in this area.

The effects of climate variation on the rate of failure were ignored in this study, as it was assumed that variation within the region was nominal. As a result this model is only applicable to the CODC region. However, this process and basis for the framework for informed decision-making could be applied to other regions, for use in that region. Where the climate could be considered consistent.

Literature indicated that the recommended time for road inspections is during summer because conditions are more ideal. Due to University semester constraints, the author conducted the surveys during winter in less than ideal conditions. However, the Paige-Green (1999) chart still roved to be representative of the failure modes on the roads. Further reinforcing the validity of this theory.

6. CONCLUSIONS

The data for the model produced in the study needs to be collected only once which a more practical and economical approach. Therefore, freeing resources to focus on high quality traffic data collection. The transition from a visual based assessment to a more quantifiable method makes the data more representative and accurate for GRMS's.

The comparison between HCV and light traffic on the pavement deformation may be greater than this study suggests because the ratio of 1:10 used was developed for chipseal surfaces. More focus on collecting accurate data that is representative of the number of HCV on the road network is needed.

The blading frequency model developed in this study is only applicable in the CODC region, as effects from climate variation were not considered in the process. However, the process and basis behind the development could still theoretically be applied to other regions for use in that region.

In conclusion, the study has proved to be a useful tool in the development of a practical solution to the problems associated with the management of unsealed roads in the CODC.

6.1 Further research

- Expand the size of each gravel source pit sample so that models estimating the blading frequency on each gravel pit can be developed. The goal would be to have a prediction model that estimates the blading frequency of every source pit in the district to enable a comprehensive cost trade-off analysis to be made for the CODC unsealed road network.
- Development of a more representative method for equating the greater impact HCV vehicles have on unsealed roads specifically.
- Quantify the differences between the New Zealand and South African testing methods used to develop the Paige-Green (1989) chart zone limits. Calibration may be required for differences in the methods.

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THE INFLUENCE OF MATERIAL PROPERTIES, TRAFFIC AND GEOMETRY ON THE LIFE CYCLE COSTS OF GRAVEL ROADS; A CASE STUDY

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Abstract

Despite over 38% of New Zealand's local roads being unsealed, asset management of this portion of the network is typically poor. The high variability and complex nature of pavement failure makes it difficult to ensure condition data is up-to-date. A literature review shows that for an asset management system to be effective it must use readily available software, and not require significant technical data inputs nor add considerably to staff workload. The alternative methodology presented in this paper relies on only the fundamental geological properties of the aggregate and historical maintenance records, with no reliance on condition data for the decision making process.

The study found that the influence of horizontal geometry, average daily traffic and age of the pavement on the rate of failure differed depending on the geological properties. Knowledge of these three factors allows the user to undertake a trade-off analysis, projecting the life cycle maintenance costs associated with the use of alternate aggregates. This decision making process has been outlined as a case study of Crawford Hills Road in Central Otago, subsequently identifying that savings of almost 25% could be achieved, by using the optimum material to replace the current surface aggregate.

Keywords; **gravel roads, unsealed roads, material properties, life cycle cost analysis**

1. INTRODUCTION

1.1 Background

New Zealand has more than 30,000 km of unsealed local roads, 38% of the total road network (Motor Trade Association New Zealand, 2014). For predominantly rural districts such as Central Otago unsealed roads make up greater than two thirds of the total network length (Central Otago District Council, 2014). These roads provide access to communities and businesses located in rural areas, this access often required year round and in all weather conditions. Furthermore, primary industries located in these areas; specifically agriculture, mining and forestry, are very important to the economy, contributing over 50% of the national export earnings (The Treasury, 2012). It is important that maintenance operators anticipate problems and take preventative measures to reduce the risk of closure or restriction to certain road users.

Responsibility for the administration, design, construction and maintenance of the local road network is divided between the New Zealand Transport Agency (NZTA) and seventy-seven district councils. Maintenance priorities for these agencies, when based on economic principles, tend to favour higher volume sealed roads. Furthermore, a lower population density in rural districts means that higher proportions of council funds are required to maintain their low volume road networks. In attempts to minimise costs, many councils manage their network with a reactive maintenance system. This system relies on public complaints to determine which areas require attention, which can create a bias it towards more vocal members of the community (Dowling, 2006). Furthermore, roads not brought to the attention of the maintenance operator may degrade past the point of repair to a stage where they are required to be replaced. Use of this system may result in an inefficient allocation of maintenance resources.

Despite the existence of a significant number of management and maintenance guidelines for gravel roads, relatively few are well-used (Henning, Flockhart, & Water, 2014). Huntington and Ksaibati (2011) identified three primary barriers to the implementation of an asset management system; 87% of roading authorities found that software was a moderate or strong barrier, with data collection difficulties and lack of staff being an issue for 64% and 52% respectively. This would imply that any acceptable asset management system must use readily available software, not require significant technical data inputs, and will not add considerably to staff workload.

1.2 Objective

This paper presents the application of an alternative decision making process to an unsealed road network. This process has little or no reliance on condition or performance data, using only the fundamental geological properties and historical investment to predict the periodic (blading) and renewal (re-gravelling) treatments required.

The objectives of this paper are to:

- Identify the costs associated with gravel road maintenance;
- Relate the fundamental geological properties to the rate of failure;
- Present the financial trade-off procedure developed as the focus of this work, and;
- Illustrate this process using a practical scenario.

2. LITERATURE REVIEW

2.1 Introduction

Unsealed, or gravel, roads are identified as having a designed layer of imported material which provides a year-round, all-weather surface. They differ from earth roads by the use of imported materials, but lack the binder (bitumen or cement) that characterises sealed pavements. Understanding the maintenance requirements of such a network involves appreciation of three interdependent elements. The defects of the pavement determine the most appropriate form of treatment, and how frequently this needs to occur. Maintenance treatments are required to resolve these issues, and must be scheduled using either a proactive or reactive approach. Economic analysis is required to determine the most cost effective way of ensuring the entire road network is maintained to an appropriate level of service. There are serious implications to the state of the network if these elements are not sufficiently understood.

2.2 Defects of unsealed roads

Gravel LoS is a reduction in thickness of the imported layer of material on the surface of the road, primarily influenced by the average daily traffic (ADT), horizontal curvature and aggregate properties (Jones, 2014). Fine material is commonly lost to the surrounding area through scour (erosion) and dust. Larger aggregates stripped from the pavement through corrugations (parallel crests of material perpendicular to the direction of travel) and ravelling (the generation of loose gravel under traffic). Typical LoS rates in New Zealand range between 8 and 15 mm/year (Austroads, 2009; Thew, 2009), although this rate increases in places where maintenance or other failure modes disturb the surface crust.

Riding quality is defined as the ability of the road user to travel at their desired speed without undue comfort or safety concerns. Influences of riding quality include the ADT, aggregate properties and horizontal curvature (Jones, 2014). Corrugations, ravelling, potholes and stoniness (the presence of aggregates with a diameter greater than 37.5 mm) create issues with excessive roughness and poor vehicle directional stability (Skorseth & Selim, 2000). Dust affects visibility significantly, and can create very unsafe following and passing conditions. Dust also has an impact on non-road users, and is considered an especial problem within 100 m of a residence (Skorseth & Selim, 2000). Slipperiness, the lack of wheel friction associated with excessive percentages of silt sized particles (2-75 μm) at the surface of the pavement, has serious safety implications. Where these defects reach excessive levels maintenance, typically blading, must be undertaken to return the road to an adequate condition.

2.3 Maintenance practices

Maintenance of a road can be defined as the activities required to ensure the safety of road users, and to sustain the serviceability and appearance of the road. Typical maintenance treatments include light blading, hard blading and re-gravelling. Scheduling of these treatments may be with a reactive approach that responds to identified failures, or proactive methods that uses predictive modelling to determine the time between maintenance interventions.

Blading reduces the rate of deterioration by relocating material across the road section. Light blading uses material recovered from windrows or the road verge to resolve defects less than 25mm in height (Van Zyl, 2011). At no point is the hard crust of the existing road surface disturbed. In contrast hard blading scarifies the road surface to loosen an appropriate amount of material. This constant reshaping and loosening of the road surface can lead to accelerated rates of gravel LoS, necessitating the use of compaction or addition of fines. Re-gravelling is carried out when the imported gravel on the road has been almost completely lost, before the subgrade has been exposed. This layer of imported gravel, usually between 100 and 150 mm thick (Austroads, 2009), protects the subgrade from experiencing excessive deformations and a LoS of strength. Other maintenance treatments may include spot gravelling, maintenance of drainage systems, vegetation control and signage maintenance (Van Zyl, 2011). Rehabilitation procedures such as realignment incur significant one-off costs and are beyond the scope of this analysis.

Reactive maintenance strategies require collection of pavement condition data in order to prioritise the maintenance schedule. The most common method of data collection is visual inspection, used by over 70% of roading authorities (Huntington & Ksaibati, 2011). Typically this is achieved through a windshield survey from a vehicle travelling slowly (10 km/hr) on the verge of the roadway. Physical measurement, while providing the highest quality of pavement assessment, has significantly higher labour inputs, on site often taking two people between 20 and 40 minutes (Zhang, 2008). Satellite imagery and other automated systems are currently of limited use as although pavement condition can be broadly quantified, specific parameters such as corrugations and dust are considered undetectable (NCRST, 2003). No technique allows the collection of high quality data in a timely and cost effective manner.

In order to adequately maintain the network it is necessary to undertake this inspection on at least an annual basis, and more frequently for problem areas. Proactive strategies minimise this inspection requirement by using vehicle counts, road alignment and surface materials to determine the time between maintenance interventions. While some reactive maintenance will still be necessary due to unforeseen circumstances such as bad weather or machine breakdown, the future scheduling generally leads to a more efficient use of resources. Furthermore, when receiving calls from the public, managers can refer to a specific maintenance policy rather than negotiating each request on a case by case basis (Jahren, 2001). However, forming a database with the necessary information for the predictive model is time consuming, and the quality of this data has direct implications on the accuracy of the predictions, limiting the applicability of this approach in data deficient areas.

2.4 Economic analysis

In order to undertake sound fiscal management, each of the options for a project must be investigated to give the minimum life cycle cost (LCC). A focus on the immediate short term costs, such as the selection of an appropriate aggregate for re-gravelling works, may have negative impacts on the LCC of the asset. Despite this, many agencies continue to focus on the short term cost of alternate solutions (Van Zyl, 2011). The public nature of road funding in New Zealand means that it is necessary to prove to ratepayers that roading authorities are providing the best level of service for the available funds. While this does not preclude the implementation of LCC analysis, a clear and robust comparison framework must be used to display the optimal solution to parties not intimately familiar with road maintenance activities.

There are multiple ways to achieve the optimal LCC. Some more common methods include undertaking a different maintenance regime, use of an alternate material, and modification of the existing material (Henning, Bennett, & Kadar, 2007). While this study has focussed on the use of alternate materials, it does not preclude the use of any other improvement methods. It is expected that premium materials would command a higher price, and the purpose of LCC analysis is to determine if the reduced maintenance cost outweighs the increase in expenditure associated with the use of these materials.

It is not possible to directly compare costs incurred at different times. The opportunity cost associated with investment in the asset now rather than later has led to the concept of the time value of money. Therefore cash flows occurring at different times must be discounted to their Present Values (PV's). The NZ Transport Agency's Economic Evaluation Manual (EEM) presents a number of ways to calculate the PV, and is the required method that must be followed when applying for national funding (NZTA, 2013). Similar equations are found in other roading manuals around the world, such as Austroads.

3. METHODOLOGY

3.1 Study area

Central Otago is New Zealand's most inland district, located in the southern half of the South Island. It is a semi-arid region with hot, dry summers, and cold, still winters. Temperatures range from -6 to 30+ degrees in winter and summer respectively (Central Otago NZ, 2014). Mean annual precipitation is 360 mm (NIWA, 2014), with a marginal increase of between 5 and 10% by the end of the century (NIWA, 2008). The geology of the region mostly consists of Greywacke and other sedimentary rocks (McKinnon, 2012). The extreme range of weather conditions experienced by Central Otago makes it difficult to ensure an appropriate level of service is provided on unsealed surfaces year round. Hot dry spells result in dust and corrugations, while roads become wet and slippery during freeze/thaw conditions. There is no material that will be perfect in all conditions.

Over 70%, or 1376 km, of Central Otago district's 1850 km road network is unsealed (Ministry of Transport, 2013). Typically the roads are considered low volume; of the 1743km of rural roads only 22km carry more than 1000 vehicles per day. (Central Otago District Council, 2014). This has meant that a higher proportion of council funds are required to maintain this network to an appropriate level of service when compared with more densely populated districts. This means that any cost savings made will have a significant impact on the council, and by extension, the rate payers of Central Otago.

It was necessary to restrict this study to an investigation of just five source pits. Selection of appropriate pits was guided by CODC personnel, and aimed to investigate pits with significantly different performances. The spatial location of the pits selected is shown in Figure 1 (below). While other source pits are used in this area, Figure 1 only shows those investigated. Likewise selection of roads for inspection aimed to provide a dataset with a wide range of traffic and curvature values, in order to provide a robust and comprehensive analysis.

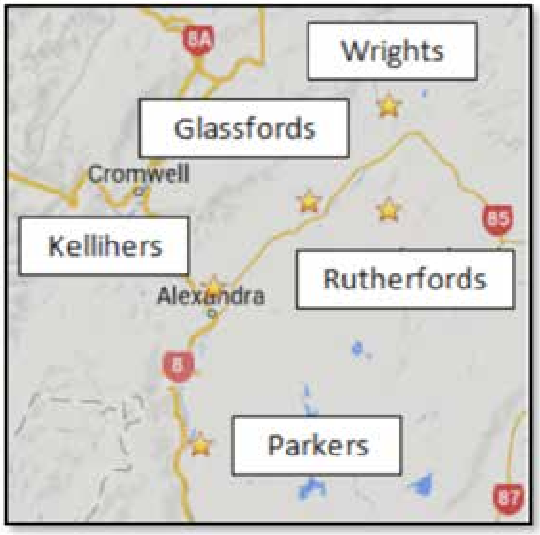

Figure 13: Location of source pits

3.2 Collection of data

The long term nature of asset management meant that it was not possible for the author to gain a full understanding of failure rates of selected roads during the study period. As such, the majority of the information used for analysis has been supplied by Central Otago District Council (CODC). To augment this information it was necessary for the author to visually inspect the selected roads. This allowed an appreciation of the condition of the surface, and ability to rate the horizontal and vertical geometry using a pre-determined three-tier system. Furthermore, informal discussions with council personnel revealed some of the rationale behind operational decisions and highlighted those areas that may require further investigation.

Specific data targeted in the historical records obtained from CODC included maintenance frequencies, costs and traffic values. Average daily traffic (ADT) and heavy commercial vehicle (HCV) counts were available for the majority of the roads studied, with estimates by CODC personnel sufficing for the remainder. Contractor invoices for work undertaken provided high quality data relating to both the date and expense of the maintenance activities. Where contradictions or anomalies were present CODC personnel selected the most accurate value, although this did lead to some additional uncertainty in the data.

3.3 Analysis methods

Two software platforms were used in this analysis, Microsoft Excel and R. Microsoft Excel is used for data analysis throughout the world, and requires little explanation. R is a specialised statistical platform, chosen because it has versatility, interactivity, freedom, popularity and excellent critical reviews (Velten, 2009; Faraway, 2009). Both these platforms are available to the average user at little or no expense. This was necessary to ensure that the framework outlined in this paper is able to be used by the wider public.

There were five distinct stages to the analysis, outlined below. The rate of failure is defined as the required blading frequency or years between re-gravelling cycles.

- Identify the factors affecting the failure rate of unsealed pavements;
- Quantify the influence of each of these factors on the rate of failure;
- Apply the factors to calculate the expected failure rates;
- Identify and quantify the costs associated with maintenance, and;
- Calculate the net present value (NPV) of all maintenance costs required over the analysis period

The first stage is part of a parallel study (Jones, 2014), hence is only briefly detailed in this paper. This study further develops Jones' enquiry to show how the findings can be applied in a practical situation, using the example of Crawford Hills Road near Alexandra.

4. RESULTS

4.1 Frequencies

Jones (2014) determined the three factors having the most significant effect on blading frequency (B_F) as average daily traffic (ADT), the age of the pavement surface (Age) and the horizontal geometry (G_H).

Table 15: Horizontal geometry factor (G_H)

1	Straight road with very few bends. Bends at obtuse angle of such that speed is not restricted.
2	Some curves are present which limit driver speed, but do not induce significant discomfort. Acceleration and deceleration required to safely navigate corners.
3	Curvature severely restricts driver speed. Significant acceleration and deceleration necessary to safely navigate corners.

Similarly, the re-gravelling frequency, subsequently referred to as the 'life' of the pavement, was most influenced by the average daily traffic (ADT), horizontal geometry (G_H) and the blading frequency (B_F). The interdependence between blading and re-gravelling frequencies creates a circular equation. To avoid triviality it was decided to omit the blading frequency from the calculation of pavement life.

It was expected that the degree of influence of each of the parameters would be dependent on the source pit. The author was unable to qualify this expectation due to insufficiencies in the data. However, the similarities in aggregate properties between Rutherfords, Glassfords and Parkers pits meant it was appropriate to group them together as Group 6. When the Group 6 model was compared with that of the total dataset there were clear differences in the coefficients for each of the parameters, indicating this would also be the case if similar models were developed on a pit-by-pit basis. The models derived are;

Total dataset;

$$BF = 3.527 - 0.173*Age + 0.012*ADT + 1.156*G_H \quad (R^2 = 0.55) \qquad (1)$$

$$Life = 9.656 + 0.002*ADT - 0.089*G_H \quad (R^2 = 0.01) \qquad (2)$$

Group 6;

$$BF = 3.748 - 0.109*Age + 0.006*ADT + 0.825*G_H \quad (R^2 = 0.29) \qquad (3)$$

$$Life = 11.64 - 0.035*ADT + 0.566*G_H \quad (R^2 = 0.43) \qquad (4)$$

Where:

BF = Blading Frequency

Age = 0.5*Life (average age of pavement)

ADT = Average Daily Traffic (where one heavy commercial vehicle is equal to ten equivalent light vehicles)

G_H = Horizontal Geometry Factor

The frequencies for the practical scenario were calculated with the developed models, using the coefficient values given below in Table 2.

Table 16: Frequency calculation values (Crawford Hills Road)

G_H		3
ADT(ELV)	veh/day	97

4.2 Costs

Maintenance costs for the CODC administered network were available as invoices for work done over the previous two financial years. It has been assumed that all machine operators are equally skilled and drive identical vehicles, a necessity for the simplification of the analysis process. Only blading and re-gravelling claims were considered, as other routine maintenance including sign renewal and vegetation clearing is not impacted by the choice of surface gravel. For direct comparison these claims were converted to cost per km or m3 for blading and re-gravelling respectively. Re-gravelling costs were further broken down into pit fees, transportation and construction costs.

There was no evidence that the source pit had an influence on the cost of blading or transportation of the aggregate per kilometre (p-values of 0.68 and 0.56 respectively). Therefore the dataset average costs of $230.00/km (blading) and $0.12/m3/km (transport) were used throughout the analysis. Pit fees, charged by private landowners for extraction of the aggregate, are individually negotiated and have been supplied by CODC. Construction costs were calculated individually for Rutherfords, Glassfords and Parkers pits, with very strong, strong and some confidence in the prediction respectively (p-values of 0, 0.002 and 0.028). Insufficient data for Kellihers and Wrights pits meant there was no confidence in the construction costs prediction, so the dataset average was used for these pits. The application rate is the aggregate required to construct a 150 mm thick surface layer on a six metre wide road. All costs detailed above may be found below in Table 3.

Table 17: Input costs for each source pit

PIT		RUTHERFORDS	GLASSFORDS	PARKERS	KELLIHERS	WRIGHTS
Pit Fee	$/m3	2	2	3	7.5	1
Transport Cost	$/m3/km	0.12	0.12	0.12	0.12	0.12
Construction Cost	$/m3	13	12	15	16	16
Application Rate	m3/m	0.9	0.9	0.9	0.9	0.9
Blading cost	$/m	0.23	0.23	0.23	0.23	0.23

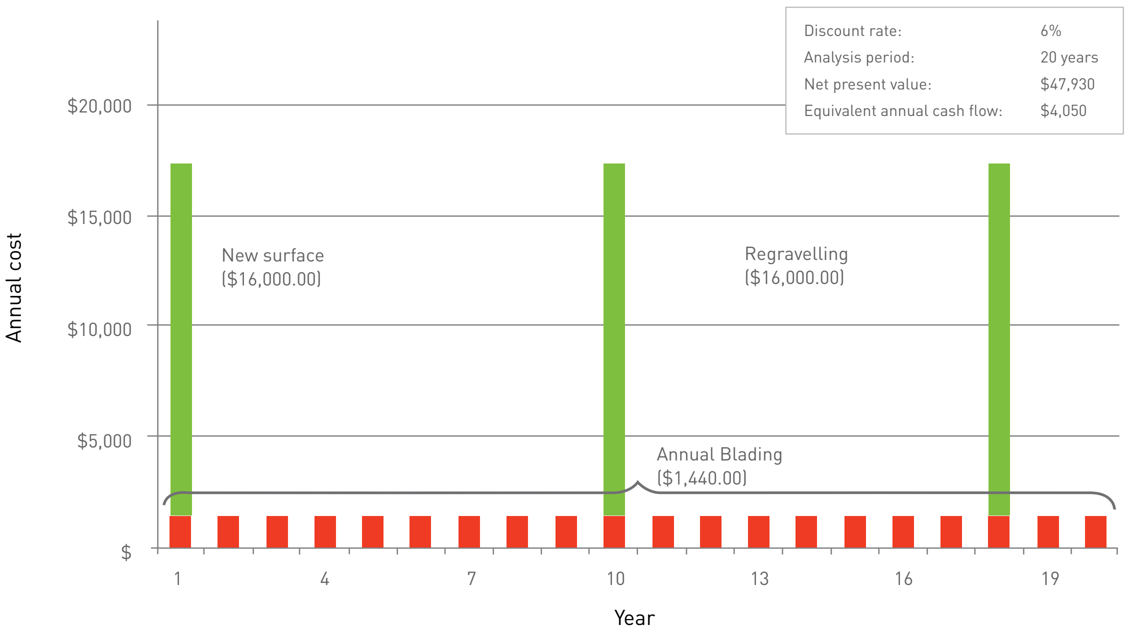

Figure 14: Life cycle costs for Crawford Hills Road (Source Pit: Glassfords).

4.3 Net present value calculation

A graphical illustration of life-cycle costs is shown in Figure 2. Significant capital expenditure is required during the re-gravelling cycle, and there is an annual maintenance cost associated with blading. While there would likely be an increase in maintenance cost towards the end of the re-gravelling cycle, for simplicity this amount was assumed to be a constant throughout the analysis period. This assumption is conservative and marginally over-estimates the life cycle costs. This is also an additional cost associate with the residual quality of the asset at the end of the analysis period. Having discounted these costs back to time zero there are two methods of comparison. The present value method calculates the sum required to cover all maintenance requirements for the life of the asset. In contrast, the equivalent annual cash flow method determines the annual sum required for each year of the analysis period. Inflation is not included in either calculation. Equations for each of these methods are shown below.

The Single Payment Present Value (SPV) is used to calculate the present value of a payment made at a single point in time at some point in the future (i.e. re-gravelling). It is defined as;

$$SPV := \frac{P}{(1+i)^2} \qquad (5)$$

The Uniform Series Present Value (UPV) determines the present value of a set cost paid annually of the asset life (i.e. blading). It is defined as;

$$UPV := \frac{[1-(1-i)^{-N}]}{1n(1+i)} F \qquad (5)$$

The Present Value (PV) of all costs associated with maintaining the asset is defined as;

$$PV := \sum_{T=0}^{N} (UPV + SPV) \qquad (5)$$

The Equivalent Annual Cash Flow (EACF) required to undertake the maintenance activities is defined as;

$$EACF := PV^2 \left[\frac{i\,(i=1)^N}{(1+i)^N - 1} \right] \qquad (8)$$

Where:

i - Discount rate; 6% (Austroads, 2009)

n - Number of years projected into the future

N - Expected life of the asset; 20 years (Land Transport NZ, 2013)

Table 18: Economic analysis (Crawford Hills Road)

SOURCE PIT	DISTANCE OF PIT FROM ROAD (KM)	B_F	LIFE (YEARS)	ANNUAL BLADING COST† ($/KM)	RE-GRAVELLING COST‡ ($/KM)	PRESENT VALUE
Rutherfords	35	6.26	9.9	1440	17500	$50,820.00
Glassfords	36	6.26	9.9	1440	16000	$47,930.00
Parkers	53	6.26	9.9	1440	22000	$59,530.00
Kellihers	14	7.33	9.6	1690	22500	$64,450.00
Wrights	67	7.33	9.6	1690	22000	$63,460.00

† *Annual Blading Cost = Unit Cost*Blading Frequency*

‡ *Re-gravelling Cost = (Pit Fee + Transport Cost*Distance Travelled + Construction Cost)*Application Rate*

Table 4 (above) presents a summary of the present value calculations for each source pit. The distance is that which the aggregate is required to be transported, typically one of key parameters considered when choosing an aggregate source option. The blading and re-gravelling frequencies have been calculated using the models (1) – (4) outlined previously, according to their appropriate group. Table 4 clearly show that the minimum present value of life cycle costs is achieved by using aggregate sourced from Glassfords pit.

The current source pit used for Crawford Hills Road is Kellihers. The author hypothesizes this is due both to the proximity of the pit and the quality of the aggregate. However, this quality comes at a much higher cost (see Table 3). Subsequently, cost benefits in the order of 25% (see Table 5) could be achieved by replacing the current source option (Kellihers) with Glassfords pit. It is probable that optimization on other roads in the network would also result in cost benefits, although overall benefits are likely to be more limited.

Table 19: Source pit comparison (Crawford Hills Road)

SOURCE PIT	PRESENT VALUE	% SAVING
Kellihers	$64,451.00	NA
Glassfords	$47,928.00	25%
Rutherfords	$50,821.00	21%
Parkers	$59,526.00	8%
Wrights	$63,459.00	2%

One of the requirements for this decision making process indentified in the literature review was that the process not add significantly to staff workload. The full process outlined previously does not meet this requirement. However, the critical distance matrix displayed opposite does allow quick and easy selection of the optimum aggregate source for the road being investigated. Each table is only appropriate for a set range of parameters (as shown below), therefore requiring a number of these tables to be developed for practical use. Application of the matrix is outlined below in Example 1.

Table 20: Critical distance (in km) matrix for roads where $G_H = 3$ and $90 < ADT < 100$

	Glassfords	Parkers	Kellihers	Wrights
Rutherfords	-15	21	59	5
Glassfords		36	74	20
Parkers			38	-16
Kellihers				-54

Example 1

Road A is located 20 and 33 km's from Parkers and Wrights pits respectively.

$33 + (-16) = 17 < 20$

Therefore sourcing aggregate from Wrights pit will minimise the life cycle cost.

The critical point occurs when the left and right had sides of the inequality are equal. At that point either option entails the same life cycle cost.

Further application of the critical distance matrix is possible in the geospatial environment. Such a process would allow users to input key parameters (GH and ADT) into a map system, subsequently indentifying the critical points in the network. These critical points could then be linked to create a 'zone of influence' about each pit for the specific parameters. Simple visual inspection would identify which zone the target road was located in; hereby identifying the optimum aggregate source.

5. DISCUSSION

Throughout the development of this decision making process much effort has been focussed towards meeting the requirements for such a system as identified in the literature review.

These requirements have directed all facets of the process, from the choice of analysis program to the data inputs required. This process, therefore, provides a relatively simple method that ensures life cycle costs of an unsealed network are minimised, appropriate for use by any authority both locally and internationally. It is hoped that the ease with which this process can be implemented will facilitate its use in places currently unwilling to commit resources to understanding and operating an efficient asset management system.

The case study of Crawford Hills Road used to outline the process clearly showed the benefits of undertaking life cycle cost analysis. Although it is recognised that this is an extreme case, it is undeniable that network wide benefits upon the implementation of the process would be significant. Furthermore, using an objective and clearly defined decision making process provides managers fielding calls from the public with a system with which to refer, rather than negotiating on a case by case basis. It also provides transparency within an organisation. Accurate predictions of future costs will allow organisations to plan budget requirements, not requiring sudden increases in rates to meet unforeseen expenses. This gives confidence to ratepayers and aids the entire locality.

The models were developed using historical maintenance records and visual inspection. No measurement or condition data was required for this process. Having collected the necessary inventory data, the only inputs required to be updated on a frequent basis are the average daily traffic, collected as part of everyday operations, and the unit costs of maintenance activities. These inputs should be readily available to all road maintenance authorities, reducing the necessity of specific road inspection teams.

An effective asset management system must use widely available software, not require significant technical data inputs, nor add considerably to staff workload. The inputs required are generally readily available, therefore ensuring the implementation and operation of this decision making process does not require significant amounts of staff time or capital expenditure. Of the two programs used for analysis, Microsoft Excel is commonly used worldwide, while R is freely available over the internet. Terms not readily familiar to the average user have been identified, to aid with use and ensure the process can be implemented by all users. Therefore, this process clearly meets each of the identified requirements.

While this paper outlines the process required, further development should take place. The critical distance matrix provides ease of comparison, but is not flexible enough to adapt when circumstances change on the network, typically a frequent occurrence. Integration of the process outlined into a geospatial software application would correct this issue. The input of the variables of unit costs and model parameters could produce outputs in terms of the zone of influence (outlined above in results, and displayed below), further increasing the ease of use, and facilitating the implementation of this process into practical situations.

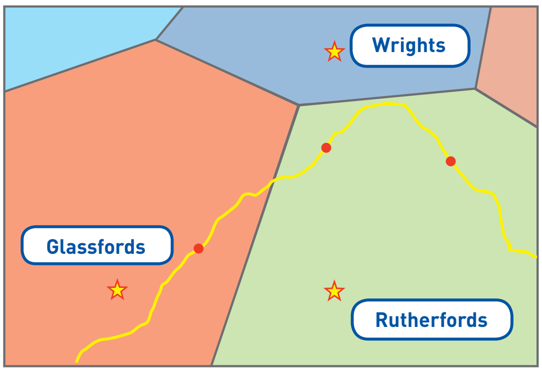

Figure 15: Example zones of influence

The current process outlined has other limitations beyond flexibility. When considering the optimum material other factors beyond life cycle costs must be evaluated. Supply constraints, access restrictions or owner relations may all influence the choice of aggregate, and must be considered in tandem with the projected costs. Reactive maintenance must still be undertaken after extreme events (typically climatic), although this should be on a limited basis. Low temporal variability across the network studied meant it was not necessary to consider climate during this analysis, although this may not be true in other areas. Any unavailable data was estimated by CODC personnel, so may not be representative of the true situation. However, these limitations do not detract significantly from the developed process, and merely guide future refinements to this system.

With large proportions of council funds required to maintain low volume road networks, it is imperative that an effective asset management system be put in place to ensure efficient use of these funds. Attempts to minimise costs, typically through reactive maintenance systems, have often resulted in inefficient allocation of maintenance resources. This process has addressed the issues present with existing systems, and the case study outlined clearly showed significant economic benefits can be achieved. Further development of the process will allow present limitations to be minimised, creating a robust and effective asset management system appropriate for all users.

6. CONCLUSIONS

This paper has presented the application of life cycle cost (LCC) analysis in relation to the decision making process for an unsealed road network. This process has no reliance on condition or performance data, using only the fundamental geological properties and historical investment to predict the periodic (blading) and renewal (re-gravelling) treatments required. Furthermore, it does not require technical data inputs, such as condition data, is highly time effective and uses readily available programs, hereby meeting the requirements identified.

The key findings of this paper are:

- Expenses associated with gravel road maintenance include pit fees, transport, construction and blading costs;
- The influence of horizontal geometry, average daily traffic and age of the pavement on the rate of failure differs depending on the fundamental geological properties, and;
- Using this decision making process to forecast the life cycle costs of unsealed roads may result in significant economic benefits.

The decision making process was outlined as a case study of Crawford Hills Road in Central Otago. It found that replacement of the current source pit, Kellihers, with the optimum material (Glassfords) would minimise life cycle costs to the order of 25%. This illustrated that the decision of the optimal source pit should not be based on proximity and quality alone. By applying this process to a network it is likely to generate significant economic benefits for the roading authority, allowing the cost of maintenance to be minimised over the life cycle of each unsealed road.

7. FUTURE OPPORTUNITIES

The process outlined in this study is applicable to any gravel road network. Data required in order to implement this procedure includes:

- Inventory data containing geospatial locations and a qualitative assessment of the geometry;
- Traffic volumes, including percentage of heavy vehicles;
- Blading and re-gravelling frequencies from historical records;
- Unit costs recorded for all maintenance activities performed on the network, and;
- Measures of the fundamental geological properties of each source pit.

Further development of this process should be focused on creating an interactive geospatial environment in which the user may input key parameters and receive a map of the relevant zones of influence. This will further streamline the decision making process, allowing it to be easily interpreted by all users regardless of experience.

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Disclaimer
While every effort has been made to ensure the accuracy of the costs and frequencies stated in this paper, they are appropriate only for the network being investigated. In no way should these values be construed to be representative of the true cost of undertaking such activities in other districts. Accurate network specific costs may be calculated from historical records or via a competitive tender process.

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