A Rational Process for Management of Unsealed Roads

Bob Andrews and Kieran Sharp
ARRB Group, Australia

**ABSTRACT:** The Australian road network consists of over 500,000 km of unsealed roads, or about 60% of the total road network and operates in an environment where maintenance costs and consumption of natural materials are high. Any contribution to reducing these two prime factors will have a significant effect on triple-bottom-line considerations (i.e. cost, environment and social factors). This paper draws upon national and international research in the evaluation of performance improvement in consideration of in situ stabilisation of unsealed roads in remote locations. Issues addressed include material availability, deficiency identification and rectification, construction logistics, binder selection, pavement performance and economic evaluation. Whilst no comparisons are made regarding the performance of each product, the paper presents a rational approach to the evaluation of material selection, processing and improvement in order to provide best value management of unsealed road networks.

**KEYWORDS:** Unsealed roads, stabilised materials, asset management, dust, road performance

1. Introduction

There are millions of kilometres of unsealed roads around the world, which are managed by national road authorities, state or provincial road agencies, local authorities, the forestry and mining industries, agriculture, national park authorities, and tourism, railroad, and utility companies.

The extent of the Australian road network suggests that 700,000 kms or 60% of the network across the continent comprise unsealed roads.

The operating characteristics of unsealed roads generally display low levels of road safety, high frequency (and cost) of routine (patrol) maintenance intervention and material replenishment associated with dust, poor riding quality (roughness and loose material) and impassability in wet weather.

Even though it is acknowledged that these roads are fundamental to the economies of almost every country in the world, many of the management practices followed leave much to be desired, with programs for dust control, surface deterioration, material improvement and application of in situ stabilisation are largely overlooked.

Whilst material improvement and stabilisation on unsealed roads has been researched for decades (particularly associated with the many chemical binders on the market), the most part they do not include long-term maintenance strategies (e.g., changes in patrol grading frequencies) to help practitioners with establishing longer-term road management programs, identifying which type of additive would be most appropriate for a specific application, undertaking life-cycle analyses (which can include triple bottom line considerations i.e., quantifying environmental impacts and authority costs and social benefits, designing appropriate treatments, applying the additive, and maintaining the treated road).

This paper brings together various research activities undertaken both nationally and internationally to provide a low cost “rational template” for informed decision making in relation to material selection and improvement as well as a methodology for performance evaluation of the wearing surface.

2. Environmental considerations

**Natural material loss & consumption:**

US environmental studies of air pollution in particular “dust” (i.e., particulate matter) suggest that unsealed roads can contribute as much as 50% of the total PM$_{10}$ and 20% of PM$_{2.5}$ emissions viz:
In addition, the depletion of natural gravels is a major concern both in terms of availability and pit approval processes in place which includes both environment and cultural heritage considerations.

To provide a quantum of natural gravel consumption in Australia, the Institute of Quarrying (Ref 2) reported that 10 million tonnes of gravel and 75 million tonnes of crushed stone were extracted for use in infrastructure.

Therefore any process which reduces material loss on unsealed roads (i.e. dust and grading loose material to waste) as well as providing longevity of wearing surfaces can have a significant effect on material consumption as well as environmental and social attributes.

### Water consumption:

Water is paramount to sound road construction in terms of compaction and providing a tight wearing surface. However, In Australia where dry arid climates predominate and water is a valuable (and in some areas scarce) resource construction practices should detail efficient use with minimal evaporation loss. Other techniques such as the use of water reducing and wetting agents present opportunities to improve our construction practice.

### 3. Step 1 “Materials Suitability”

The basic principal of providing “the best material” possible in terms of source and extraction process is paramount to consideration of applying a new wearing course. This implies a rudimentary understanding and tools to assist in determining what material properties are required to optimise performance. Where these cannot be met recognising intrinsic deficiencies in these properties and correction is required.

In principal, selecting a material specification for an unsealed pavement; attributes such as grading, plasticity and CBR are typically of a lower order than that for sealed roads because of the need to use locally available materials which are predominantly natural gravels.

Whilst this is compensated by generally low traffic volumes, it should be noted that some unsealed roads even with low traffic intensities must serve as vital transport links which require higher levels of serviceability than might otherwise be considered.

The wearing course material needs to provide good wearing resistance which would otherwise lead to a high level of loose surface material, gravelly surfaces and corrugations. In addition, low permeability will reduce the likelihood of potholes, surface rutting and shoving and the related inaccessibility issues.

The properties of the underlying layers are more associated with strength (CBR) and workability to ensure that a reasonable degree of compaction is achieved. Compaction at optimum moisture content is often not possible because of the scarcity of water or the cost of carting water. The consequences of loss of shape (i.e. subgrade rutting as associated with sealed pavements) caused through the use of inferior CBR material, or insufficient structural pavement thickness, is less important in unsealed pavements as the surface is periodically reshaped by maintenance grading.

An ideal material for the wearing course of an unsealed road will have properties which result in an even, tight, relatively impermeable (erosion resistance) and wear resistant surface. The particle size distribution (PSD) and plasticity index (PI) will be such that there...
is sufficient coarse material to provide resistance to wear, adequate dry strength through mechanical interlock, fine particle bonding and low permeability to mitigate against loss of strength when the surface becomes wet. In addition, the soil fractions are required to have sufficient dry strength to hold the aggregate fractions in place to prevent ravelling and the development of loose material on the surface.

A typical material specification for use a target “mix” is shown in Fig 3

Table 1 Suggested Specification for unsealed wearing course (ref 3)

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>Per cent passing for all maximum sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>100</td>
</tr>
<tr>
<td>37.5</td>
<td>95-100</td>
</tr>
<tr>
<td>26.5</td>
<td>90-100</td>
</tr>
<tr>
<td>19</td>
<td>80-100</td>
</tr>
<tr>
<td>2.36</td>
<td>35-65</td>
</tr>
<tr>
<td>0.425</td>
<td>15-50</td>
</tr>
<tr>
<td>0.075</td>
<td>10-40</td>
</tr>
</tbody>
</table>

Plasticity

Less than 500 mm annual rainfall – max. 20
More than 500 mm annual rainfall – max. 12
OR
Weighted Plasticity Index (PI x % passing 0.425)
Max. 500 for low rainfall
Max. 250 for > high rainfall

4 day Soaked CBR

Minimum 40%

Whilst it is unlikely that these will be met from direct material extraction a number of strategies may be undertaken viz:

- blending material from another source or working the pit face to include or exclude strata as required
- Adoption of mobile crushing operations (without screening)
- importing suitable material from another source or commercial quarry operation
- particle size may be reduced by treatment in the pit or on the road bed using commercial ‘rock buster’ machines or static grid rollers; alternatively, it may be considered that, if a stabilising machine is to be used, aggregate breakdown may be achieved with this plant

Of the tools developed a “Road Base Tool Kit” has been developed by ARRB enabling simplistic low cost laboratory testing of particle size distribution and plasticity attributes and assessment of suitability.

Equipment includes a set of sieves for particle size distribution and apparatus for plasticity determination with associated electronic scales, and moisture content apparatus. In addition ancillary equipment may be added to include water salinity, soil erosion and aggregate hardness determinations.

Figure 3 ARRB Roadbase Toolkit

In achieving the right mix blend work undertaken in South Africa by Paige Green (ref 4) permits easy material selection and blending mix design is based upon two factors viz

Shrinkage Product: \( S_P = L_s \cdot P_{0.425} \)

\( L_s = \) Linear shrinkage,  
\( P_{0.425} = \% \) passing 0.425 mm

Grading Coefficient: \( G_c = \frac{(P_{26.5} - P_{2.0})P_{4.75}}{100} \)

\( P_{26.5}, P_{4.75}, P_{2.0} = \% \) passing sizes

These results are seen in chart form for easy recognition as shown below:
Simple spreadsheets are also available for calculation of mix proportions in the same manner as those used in concrete and asphalt plants. These are based upon simple proportion calculations as shown below:

### Figure 4 Analysis of material suitability (ref 4)

Alternately the capillary rise test may be conducted to evaluate effectiveness of the proposed chemical binder.

The adoption of these simple tests again provides a first base estimate of the suitability of a stabilisation binder particularly where past performance information or product knowledge is not available.

### Figure 5 Blending spreadsheet (Ref 5)

### 4. Step 2 - Stabilisation binder considerations

Where in situ stabilisation is to be considered for unsealed roads, a simple laboratory demonstration test can be conducted to evaluate the effectiveness of a particular binder using the vertical saturation test shown in below. (Ref 6)

Where lime (hydrated or quicklime only) is to be considered to correct plasticity (PI >12) or add bearing strength, the Lime Demand test is applied which defines the lime content to achieve a pH of 12.4 (ref 8). As a general guide, for PI <12 materials 2% GB cement is recommended.

### Figure 6 vertical saturation

### Figure 7 Capillary rise test
5. Step 3 - Construction Logistics

In resheeting unsealed roads (with or without a stabilisation binder) the following points can contribute to efficient use of natural resources (water & efficient mixing) resulting also in a reduction in emissions from over use of plant:

- **Transport of the binder to site**: In remote areas the use of a powder binder can require 25 tonnes per kilometre for 2% addition (by mass) for a pavement 8 metres wide and 150 mm thick. As a result, high transport costs may be involved.

- **Powder binder spreading**: The use of powder binders requires delivery by tanker or bulker bags and associated lifting equipment. In addition, a binder spreader is required to evenly apply the product to the roadbed.

- **Liquid binders**: Application of liquid binders by addition into the water truck is required to be undertaken as seamlessly as possible. A number of chemical binders in the lignin based binders are often highly acidic and require specific handing and storage on site. Other products such as the polyacrylamide group are inert and applied to the water in a granulated form. The use of a venture type system in both cases is commonly adopted.

- **Recycler Mixing**: A purpose built recycler which incorporates a mixing chamber and connected to a water truck not only provides efficient mixing but maximises water ruse ie water is injected directly into the chamber such that any loss through evaporation prior to compaction is reduced to a minimum. An important consideration in remote, hot arid areas and scarce water supply or long hauls to site.

- **Grader mixing**: Windrowing mixing with a grader and surface application of water (with or without a stabilisation binder) is a very inefficient construction methodology often achieving not much more than 1500m² per day. Furthermore, evaporation loss in hot weather coupled with a slow windrow mixing process implies high water demand to site in order to achieve compaction and surface tightness.

- **Surface finish**: In the knowledge that it is the fine material that holds aggregate in place to enhance wearing characteristics, it is common for wearing surfaces to be slurried. This practice not only requires high water consumption but brings excessive fine material to the surface which can be lost in the early weeks of trafficking leaving a gravelly surface very quickly thereby defeating the intended purpose. The use of pneumatic rollers can prove most efficient in these situations.

- **Product cost**: The construction cost using these binders can be as high as $50,000 per kilometre. However, this is offset by the increase in the life of the wearing course before replenishment is needed, the fact that the road can be kept open for most of the year, and the reduction in the frequency of patrol grading intervention. Analysis using a life cycle cost model will demonstrate the overall cost advantages.
associated with the use of the binder and the additional items of plant.

- **Health and safety**: The lifting of bulker bags and the dropping of the fine powder binders into the spreader demands that the operator be protected from dust. In addition, some binders can burn (e.g. quicklime) and some are extremely acidic in their undiluted form.

6. **Step 4 – Trial site protocols**

In establishing the need for stabilisation and the incorporation of a stabilisation binder the following protocol has been developed to assist in the evaluation of a suitable binder and the methodology for monitoring pavement performance.

1. Desk top evaluation of product or process to be trialled in terms of its application logistics to the proposed site and previous trials and performance.
2. Simple laboratory evaluation to determine suitability of the product in relation to the site material. The results may indicate a hold point in the event that benefits are not realised or unjustified.
3. HOLD POINT to determine if a field trial is necessary.
4. Selection of field trial site based on local needs and environmental factors.
5. Preparation of a ‘Scope of Works’ document if construction is to be undertaken under contract.
6. Construction of trial site and development of quality control program.
7. Establishment of performance indicators which define the benefits of the product or the process for inception recommendations.
10. Financial modelling in terms of estimated pavement life and maintenance interventions.

7. **Step 5 - Performance Monitoring**

The periodic (preferably monthly) performance monitoring of the pavement is conducted as follows:

1. Drive through: rate the severity of loose material, corrugations, potholes and erosion channels which affect the rideability of the pavement (low / medium / high) which would necessitate maintenance intervention by patrol grading.
2. Roughness: undertake a physical pavement roughness assessment using the ARRB Roughometer is easily adapted to a light vehicle to provide frequent quantitative information regarding the development of pavement roughness across a network or specific site.

![Figure 10 ARRB Roughometer](image1)

3. Surface wear: sweep away the outer and centre windrow (between the outer and inner wheelpaths) in order to bed a 3 metre straight edge on a hard surface and measure the rut depths in both wheelpaths. Use this data to estimate the resurfacing (resheeting) intervals.

![Figure 11 Straight edge measurements of deformation](image2)

4. Ravelling: use a 3 metre straight edge, located in the longitudinal direction, and measure outer windrow heights. This provides an indication of the amount of material being ravelled out of the pavement.
5. Loose material: mark a one metre square area centrally over the centre windrow (between the outer and inner wheelpaths), remove the loose material by sweeping, place it in a bag and retain for future evaluation. Clearly tag the location from which the sample was taken.

**Figure 12 Windrow loose material assessment**

6. Take a full photographic record of the site, including the testing protocols.

7. Note weather information on the day of monitoring; access rainfall records from the nearest meteorology station; install a traffic counter (e.g. pneumatic counter) to record traffic volumes.

**Figure 13 Traffic count**

It is important that the pavement cross-sections are clearly identified and marked as monitoring locations to ensure that measurements are always taken at the same location. This ensures some consistency in the data and assists in the identification of photographs, etc.

The following information should also be recorded:
- locations close to trial section boundaries: each section may have different performance attributes, e.g. dust transfer at trial section boundaries
- drainage channels and culverts
- bends where shear forces are significant in terms of promoting greater material loss.

**Figure 14 test site identification**

The adoption of this visual method, together with the elementary quantitative measurements, will provide a monitoring platform for the assessment of the protocol. It is important that sufficient budget, and time, is provided to enable the collection of sufficient data to allow trends to be properly evaluated.

**Lime stabilisation example**

The following example was undertaken by AustStab in relation to improvement using cement or lime stabilisation and applying the sampling, testing and monitoring protocol outlined above (ref 9)

**Construction Process:**

It is critical that a dedicated stabiliser/mixer machine is used to ensure thorough mixing of the binder. It is essential that water is metered to ensure optimal moisture content of the stabilised pavement.

If there is loose material in the table drains this should be returned to the pavement prior to stabilisation as this is the material that was previously used in the pavement.

**Steps:**
1. Trim existing road to shape required.
2. Add imported overlay or table drain material if applicable.
3. Spread binder evenly over width of mixing.
4. If using quicklime – slake with water.
5. Use stabiliser to mix in binder and water – it is important to achieve optimal moisture content.

6. Compaction with smooth drum roller (15 tonnes).

7. Trim surface with grader adding surface moisture as required.

8. Compact again with smooth drum followed by multi tyred roller.


Notes:

- Do not use pad foot roller as the depressions will remain, resulting in premature loss of pavement surface.
- Do not bring shoulder material on to already stabilised material. This material should be brought onto the pavement prior to spreading of binder. The introduction of non-stabilised material will cause delamination.
- Cross fall should be minimum 6% to allow for adequate drainage. This is important as adequate drainage is required for a long life. It is appreciated that traffic will flatten the crown over time but sides will remain with a good cross-fall.
- Drains should be built to allow water not to pond on pavement or shoulders
- Cracking will often appear especially for cementitious stabilised pavements. This is not a concern as loose material will fill cracks with no deleterious result.

**Construction Costs**

Stabilisation Binder $2 - $4 /m²
Spread + mixing $0.75 - $1.50 / m²
Compaction $1.00 / m²
Productivity of about 6000m²/day

**Results:**

As an example the Cowra Road trial site was stabilised using lime and a dry powder polymer and monitored over a period of four years (still ongoing). In discussion with the local authority the pavement was patrol graded between 2 to 3 times per year and re-sheeted after 8 year. After two years of monitoring the following measurements of loose material were observed indicating the significant reduction in material loss and grading intervention.

<table>
<thead>
<tr>
<th>Table 2 Loose material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder</td>
</tr>
<tr>
<td>Nil</td>
</tr>
<tr>
<td>3% lime</td>
</tr>
<tr>
<td>1.5% Polymer</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3 Direct cost over treatment life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilised</td>
</tr>
<tr>
<td>Initial cost/km</td>
</tr>
<tr>
<td>Sheeting life</td>
</tr>
<tr>
<td>Resultant cost</td>
</tr>
<tr>
<td>Maintenance Once /year</td>
</tr>
<tr>
<td>Cost/km</td>
</tr>
<tr>
<td>Cost/year</td>
</tr>
<tr>
<td>TOTAL COST</td>
</tr>
</tbody>
</table>

8. **Step 6 - Cost benefit analyses**

- **Economic life cycle assessment**

To evaluate the relative cost effectiveness of the various products trialled an economic life cycle analysis is required. An example used in Australia is the life cycle costing system developed by the Roads & Traffic Authority, NSW. In this system, the Net Present Worth (NPW) and the Equivalent Annual Cash Flow (EACF) defined by the following formulae:

\[
\text{NPW} = \sum \frac{C_n}{(1+r)^n}
\]

\[
\text{EACF} = \text{NPW} \frac{r(1+r)^N}{(1+r)^N - 1}
\]

where $C_n =$treatment cost in year ‘n’

- $r =$ discount rate of future expenditure
- $n =$ number of years projected
- $N =$ life of the strategy.

An estimate of the life of the wearing course before replenishment and grading intervention is assumed, determined from current gravel loss analyses, or from estimates based on performance monitoring using the protocol.

The analysis can also include all costs associated with the various scenarios, viz:

- blending materials
- treatment of material on the roadbed with rock-busters or grid rollers
- sourcing material from elsewhere, resulting in higher transport costs which can also be traded against avoiding road closures or major reconstruction after flooding
• additional costs associated with stabilisation, i.e. costs of binder and specialised equipment
• whether providing a bituminous chip seal is appropriate.

An example analysis relating to the relationships between the life of the wearing course prior to replenishment and patrol grading intervention viz:

<table>
<thead>
<tr>
<th>YEAR No.</th>
<th>Construction Cost</th>
<th>Annual Cash Flow Cost Per Kilometre</th>
<th>Vehicle Operating Costs</th>
<th>Maintenance Cost</th>
<th>Discount Rate</th>
<th>Life of Wearing Course</th>
<th>Annual NPW</th>
<th>Net Present Worth</th>
<th>Annual Cash Flow Cost Per Kilometre</th>
<th>Discount Rate</th>
<th>Life of Wearing Course</th>
<th>Annual NPW</th>
<th>Net Present Worth</th>
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</thead>
<tbody>
<tr>
<td>10</td>
<td>$2,144</td>
<td>$1,000</td>
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<td>15</td>
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</table>

Maintenance strategy: patrol grade 4 times per year
Daily traffic: 10 cars _ 5 semitrailers per day

**Figure 15 Life cycle analysis spreadsheet**

**Figure 16 Example: Effect of sheeting life & grading intervention**

**Road roughness considerations**

The role of VOCs in financial analyses of unsealed roads is very significant because of the influence of high roughness on performance. The model recommended for the protocol is shown below or four vehicle types are presented, viz:

- cars = $0.19 + (0.009 \times R_t)$
- medium rigid trucks = $0.31 + (0.020 \times R_t)$
- articulated (6 axle) trucks = $0.46 + (0.059 \times R_t)$
- B-double/double and road trains = $0.51 + (0.085 \times R_t)$

where VOC = vehicle operating cost ($/km)

**Figure 17 Vehicle operating costs**

An example of road roughness is shown below

**Figure 18 Road Roughness measurements**

Life cycle analyses for various sections were evaluated under a number of scenarios and incorporating roughness and associated vehicle operating costs viz:

Section 1 – As is with varying patrol grading
Section 2 Gravel overlay
Section 3 Polyacrylamide stabilisation
Section 4 Lime stabilisation

For each section, road roughness associated with each of the strategies has been considered in order to include increased vehicle operator costs. Similarly other costs associated with triple bottom line items such as:

- Road safety (accident costs)
- Vehicle operating costs (goods to market, community access)
- Dust (effect on native vegetation and agricultural activity)
- Haul road roughness and vehicle wear
- Inaccessibility (goods to market, community access)
10. Summary

This paper has highlighted opportunities to contribute to sustainability in management of the unsealed road network through both reduction in the consumption of natural road making materials and efficient use of water required for construction.

A rational approach to material selection such that “the best” natural material possible from the source location is placed on the roadbed can lead to greatly improved wearing course characteristics. Where this cannot be achieved, consideration of stabilisation by the addition of lime, cement or a chemical binder can correct performance deficiencies. Whilst the cost of this treatment is generally more expensive to construct, greater savings and benefits are realised through life cycle (triple bottom line) analyses.

The paper highlights the use of more efficient construction plant in terms of mixing water and road material to reduce evaporation loss as well as the consideration of “water reducing and wetting” agents.

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