OPPORTUNITIES FOR IMPROVED UNSEALED ROAD ASSET MANAGEMENT WITH CHEMICAL STABILISATION

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ABSTRACT

This paper details a quantitative evaluation of six commercially available chemical stabilising agents on a section of unsealed road in the far north of South Australia. Trial sections of unsealed road monitored over a three year period are reported. Evaluations included measurement of pavement stiffness, roughness, loose surface material and rutting. A concurrent rating survey of road user perceptions of surface conditions was undertaken during the full assessment period to link with quantitative assessments. Life cycle models were developed for estimating the rate of wear of sheeting and subsequent life cycle costing for three maintenance strategies evaluated for each product.

INTRODUCTION

Transport SA has responsibility for the management of some 10,100 kilometres of unsealed roads comprising a vast network across the far north and west of the state and the eastern pastoral area. The roads in the outback of South Australia are vital links for local communities and provide access to the region for important economic activities such as mining, pastoral activities and tourism [1]. Such links include the Strezlecki, Birdsville, Oodnadatta tracks whose performance is typified by:

- Low traffic volumes but high wear from heavy freight road trains.
- High operating costs for routine maintenance grading and re-sheeting.
- Restricted access in times of heavy rain and “crisis” pavement damage.
- High accident risk due to loose and rough surfaces and visibility reductions through dust
- High environmental and heritage impact of material borrow pits.

Because of the length of the network and associated operating costs it is realised that small improvements offer significant benefits viz:

- Improved skidding and braking safety with less loose gravel on the road.
- Improved road safety with increased visibility through less dust.
- Less stone damage to vehicles eg. broken windscreens.
- Less routine maintenance grading resulting in lower operating costs.
- Increased periods between re-sheeting resulting in conservation of natural materials.
- Reduced environment and heritage impact due to less material extraction.
- Reduced impact of loose material on roadside habitat.
- More timely application of maintenance intervention to suit the behavioural pattern of the unsealed surface.
- Evaluation of improvements in operating costs by use of life cycle costing techniques

Commercially there are a large number of chemical stabilisation products marketed as “dust suppressants” to improve the performance of unsealed surfaces. However, little quantitative evidence under long-term operating periods and routine maintenance activities is readily available. For this project pavement performance was evaluated using a number of quantitative tools used on sealed networks as part of pavement management systems (PMS) with a view to adapting them for similar management of unsealed networks.

This paper details the three year performance of an 8 kilometre section of unsealed road in the far north of South Australia incorporating a select number of chemical stabilising products. Pavement condition has been used to determine appropriate levels of maintenance intervention and evaluate degrees of asset management improvement each product offers.

CURRENT ASSET MANAGEMENT

Traditionally, maintenance intervention and re-sheeting of major unsealed roads is a continuos process based upon subjective assessments by area supervisors. Up until 1994, routine maintenance comprised dry grading the surface to improve roughness generally every three months. Re-sheeting was also undertaken working with dry materials approximately every eighth year. In addition, periods of intense routine grading activity would be undertaken following rain.

Since 1994, Transport SA Northern & Western Region have progressively introduced "wet maintenance practices" that produced a longer lasting and better quality riding surface . The benefits of wet maintenance are achieved from

- Higher compacted densities being achieved to lower permeability and decrease surface erosion and softening.
- Fine material being mobilised by dilation during compaction leaving a tight surface with improved gravel retention.

The result has been a reduction in maintenance intervention to annual intervention and re-sheeting frequencies between 12 and 20 years. However, significant investment in bores, pumps and storage ponds to provide a local construction water supply, as well as increases in plant, equipment and labour has been necessary.

To determine if the wet maintenance process is justified and sustainable a life cycle cost analysis was undertaken by ARRB Transport Research[8] in association with evaluation of environmental impacts of unsealed road construction and maintenance operations. This analysis suggested that the equivalent annual cash flows (EACF) of wet maintenance was marginally higher than dry maintenance viz: $5 118 (dry) per kilometre and $5 217 (wet) per kilometre.

CHEMICAL STABILISATION

Wet maintenance practices are ideally suited to incorporate liquid or easily dissolved chemical stabilising agents. By contrast, traditional powder binders like cement require spreading which is impractical in remote areas in terms of cartage of product eg. 48 tonnes per kilometre of powder stabiliser requiring specialised spreading and mixing equipment as compared to 180 litres per kilometre of liquid chemical stabiliser applied with a water cart and grader mixed.

Over the whole range of chemical stabilising products, most are applicable to materials with significant fines contents and moderate plasticities, which generally typify the qualities required for unsealed surfaces. As natural dispersants, they mobilise the fine fraction within the material and provide bonding characteristics by "gluing" or ionic exchange. This tight fine matrix would therefore be expected to lock in aggregate and suppress dust (surface wear) and their often oily nature provide waterproofing to the pavement surface. Their application to unsealed surfaces therefore suggests some potential benefits in terms of increased surface longevity and reduced operating costs.

Binder Selection

Traditionally strength tests like the soaked CBR test have been used to evaluate the effectiveness of adding a chemical stabiliser. However, such laboratory tests relate more to single rainfall events rather than on-going performance in a predominantly dry environment. In addition, no simple evaluation test to determine the likelihood of product effectiveness on a particular soils type exists.

Prior to incorporation of products in the trial an assessment of product suitability was determined from a specially devised laboratory "drip test" Figure 1. The test was made deliberately simple and requiring no specialised equipment in order that it can be used by local authorities with limited laboratory resources and expertise.

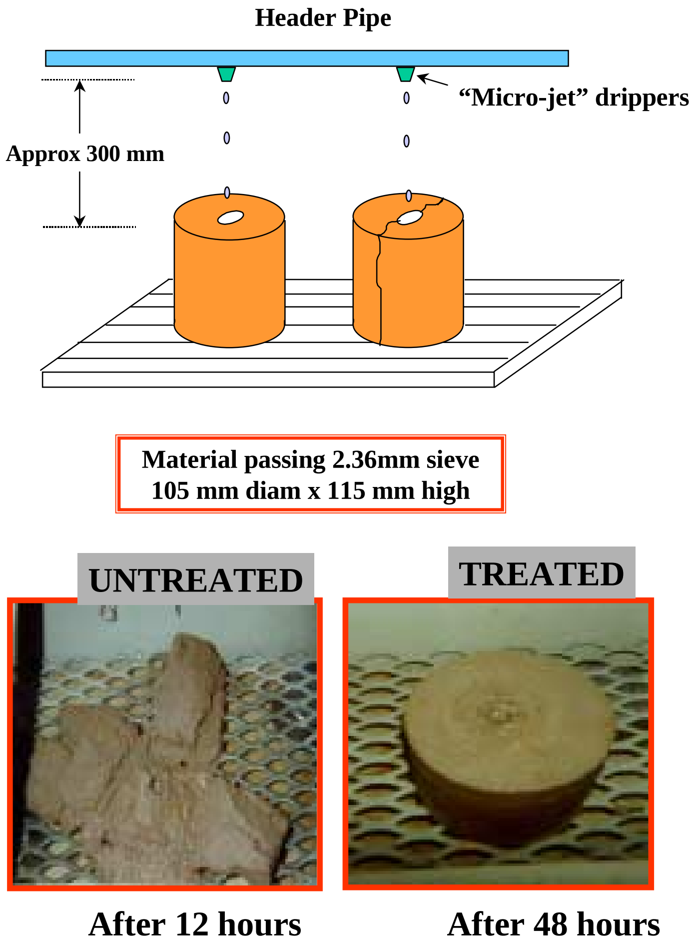

Figure 1 Simple Laboratory Evaluation

TRIAL ESTABLISHMENT

A trial site was established to quantitatively evaluate the performance of an unsealed road in outback South Australia. This work was associated with re-sheeting of the Copley – Balcanoona road as part of the *Flinders Ranges Tourist Road Strategy*. The Copley area is very arid with an annual rainfall of 200mm most of which occurs in about four events during spring and autumn. The daily traffic is mostly light vehicles averaging 60 vehicles per day with higher volumes in the tourist seasons of spring and autumn.

One kilometre long product trial sections were constructed interspersed with shorter untreated sections (wet maintenance) acting as controls as detailed in Table 1.

Table 1 Trial Section Layout

Trial Section	Length	Product/Treatment
1	388	Wet maintenance
2	1135	Roadbond EN – 1
3	805	Reynolds RT 12
4	575	Wet maintenance
5	819	Reynolds RT 20
6	293	Wet maintenance
7	1146	2% Bitumen Emulsion
8	1000	Dustex

The sheeting material comprised weathered shale, raised from *borrow* pits by ripping and stockpiling, from where it was subsequently carted to site and placed on the formation and further processed by grid rolling. Water (with chemical) is added, grade mixed and shaped and subsequently compacted to a finished surface. Post construction properties of the material are shown in Figure 2.

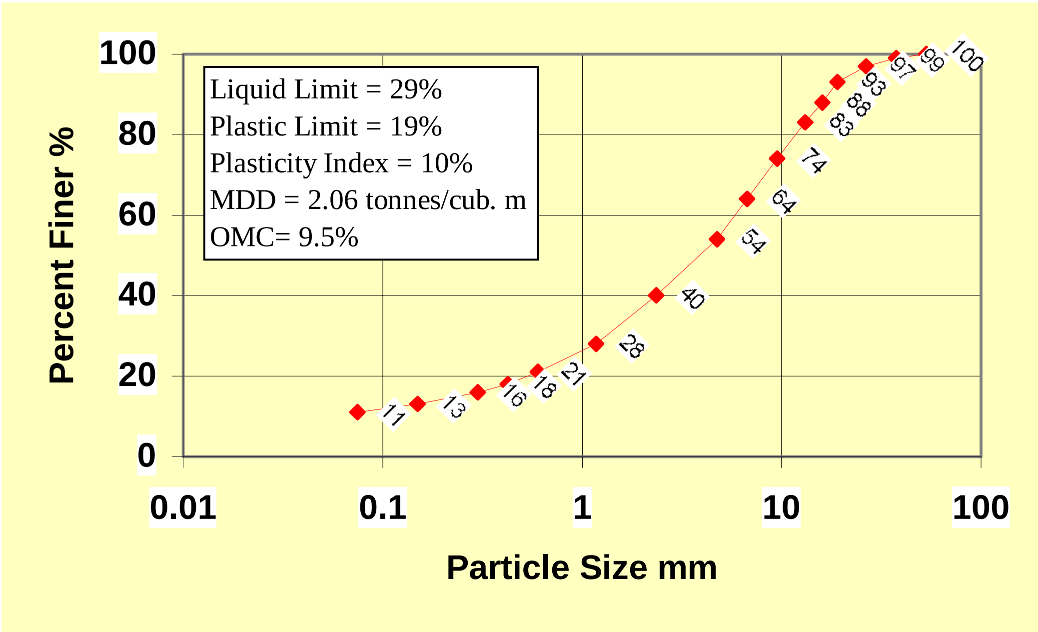

Figure 2 Sheeting Material Post Compaction Classification Properties

RATIONAL PERFORMANCE MONITORING

The performance of the trial sections were assessed quantitatively in a number of ways viz.

1. *Structural condition* from Falling Weight Deflectometer (FWD) data.
2. *Riding condition* from Two-Laser Profilometer (2LP) surface roughness measurements.
3. *Surface deterioration* from measurements of loose material in wheel paths.
4. *Surface wear* from measurements of wheel path rutting
5. *Visual condition* from Unsealed Roads Management System (URMS)
6. *Road user perceptions* of Safety (vehicle control), Visibility (dustiness) and Condition (roughness).

Structural Condition [Deflection & Stiffness]

Chemical stabilisation product literature frequently refers to increased CBR strengths as the major attribute of using a particular product. Generally, increases are reported to be up to 100% increase CBR but on review it is sometimes not clear whether the increase is solely due to the products or different moisture contents and/or increased densities of the test specimens. No quantitative evaluations of actual constructed pavements via traditional pavement deflection or insitu strength techniques were found in product literature.

The insitu structural characteristics of the product sections was therefore determined using the FWD. Testing was undertaken in late June 1998 (6 months after construction) to allow some time for the chemicals to take effect (drying) and the surface still intact to permit suitable measurements to be undertaken..

The average maximum deflection and back calculated (Elmod) pavement stiffness' for each trial section is shown in Figure 3 and 4. These results reflect those of a typical rural granular pavement and in consideration of the accuracy of the testing only minor increases in strength could be attributed to the products. This conflicts with the expectations indicated in laboratory evaluations in product literature suggesting significant increases in CBR.

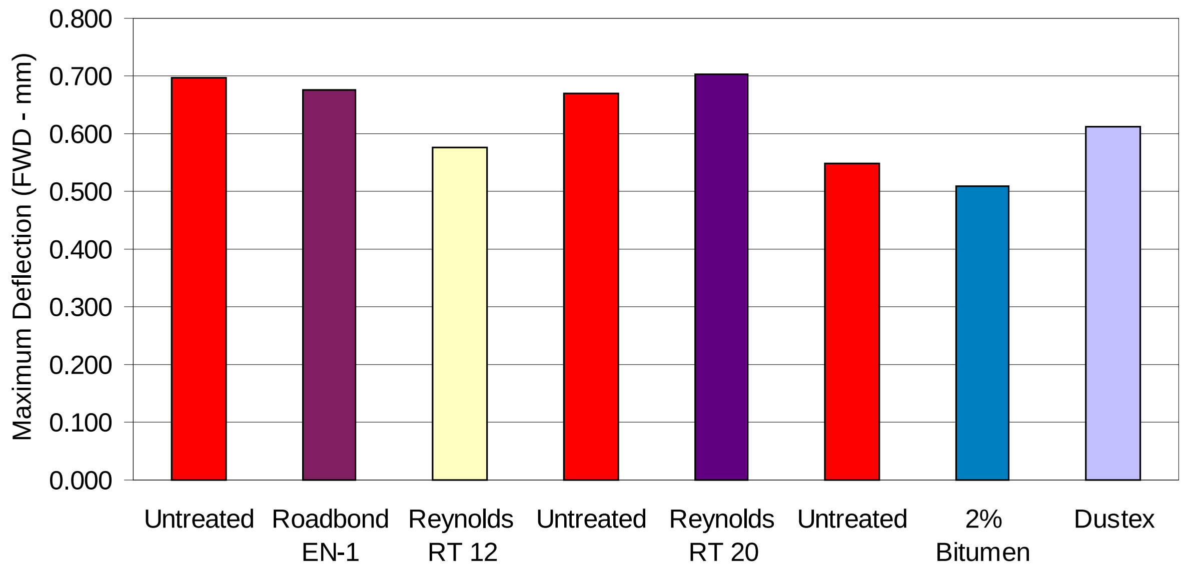

Figure 3 Maximum Deflection (mean)

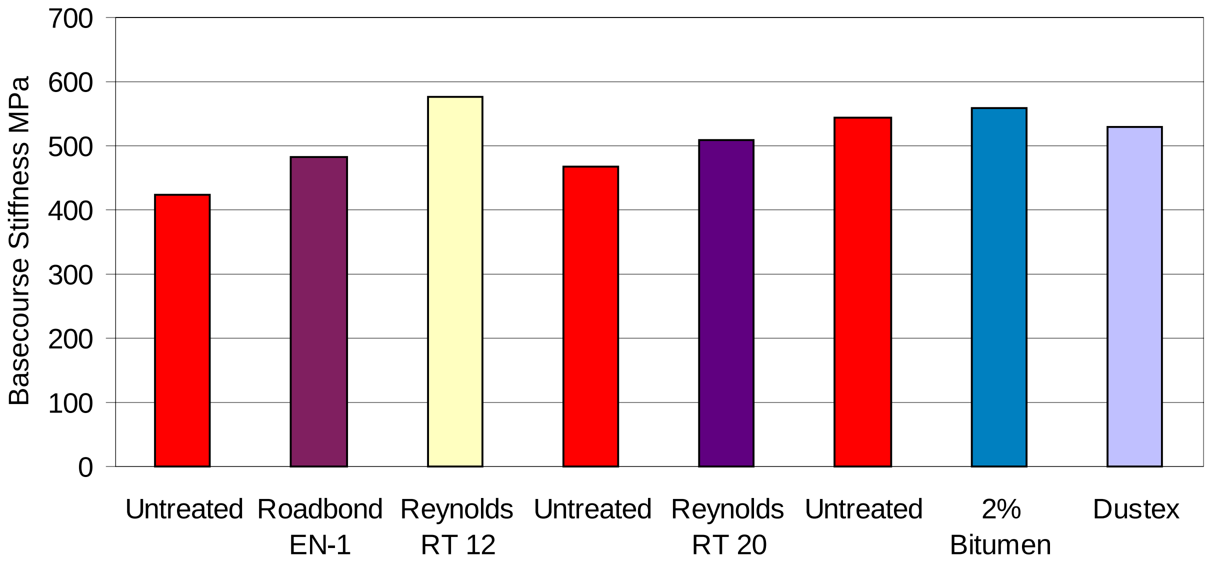

Figure 4 Basecourse Stiffness (Elmod back-calculated Resilient Modulus)

Riding Condition [Roughness]

The *as constructed* riding condition of the pavement was quantified from determining surface roughness using a Two-Laser Profilometer. The equipment was specially adapted by mounting the lasers on the front of the vehicle and data averaged over each section. It was anticipated that trialing the Profilometer on an unsealed road could lead to incorporation into URMS by:

- Defining a maintenance intervention condition
- Defining an unacceptable road user condition
- Giving some indication of time dependent deterioration

The data taken five months after construction is shown in Figure 5.

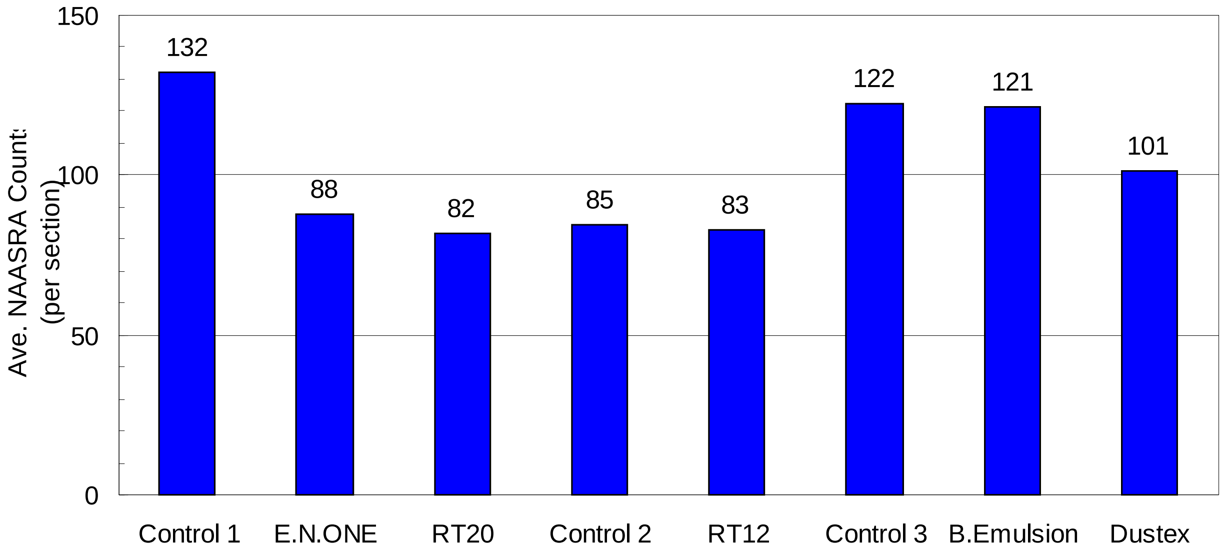

Figure 5 NAASRA Roughness after 6 months

Whilst it was observed that two untreated sections show higher roughness, the third remained compatible with treated sections. The Bitumen and Dustex sections showed higher roughness because of the early setting nature of the product. In the case of the emulsion, it as found that the bitumen broke during blade mixing and in the case of Dustex early cementation through drying prevented a smooth final finish being achieved.

Surface Deterioration [Loose Surface Material]

Measuring the amount of loose material generated from trafficking was used as one tool to indicate surface deterioration. It was considered that this represented a quantitative measure of the relative abilities of products to bind (stabilise) the fine material matrix holding the gravel in place. Surface deterioration occurs as fine material is loosened (dust) under traffic which exposes the gravel which is subsequently loosened and lost.

A simple test was devised as shown in Figure 6 involving a frame sectioning off one square metre of pavement from which all loose material was removed by soft brushing and vacuuming.

Figure 6 Removal of loose Surface Material

Sites were selected in the outer wheel path of both lanes with each test being undertaken in the same vicinity to reduce the influences of material variations, topography and climatic influences. The material recovered was subsequently fractionated on a 0.425mm sieve to indicate a measure of "Dust" and "Gravel." Results were NOT averaged because of the individuality of each site.

The progressive results for each trial section up until October 2000 (985 days) are graphed in Figure 7 and the visible condition of the pavement sections at day 450 relative to the quantity of loose surface material is shown in Figures 8 and 9.

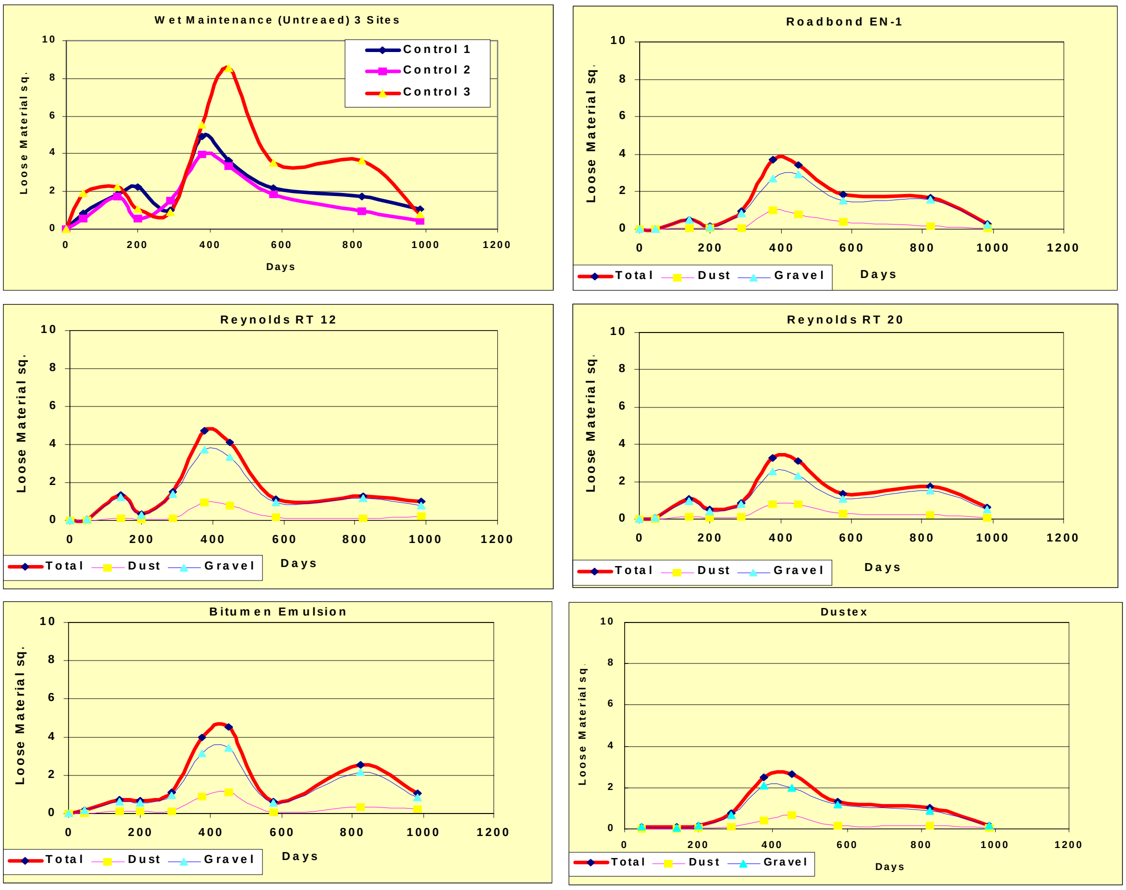

Figure 7 Loose Material January 1998 – October 2000

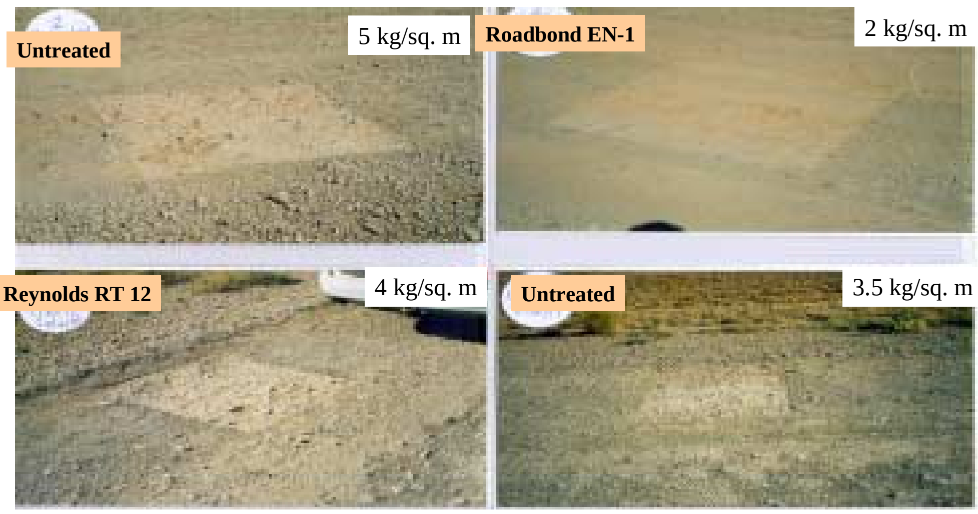

Figure 8 Pavement Condition after 450 days (June 1999)

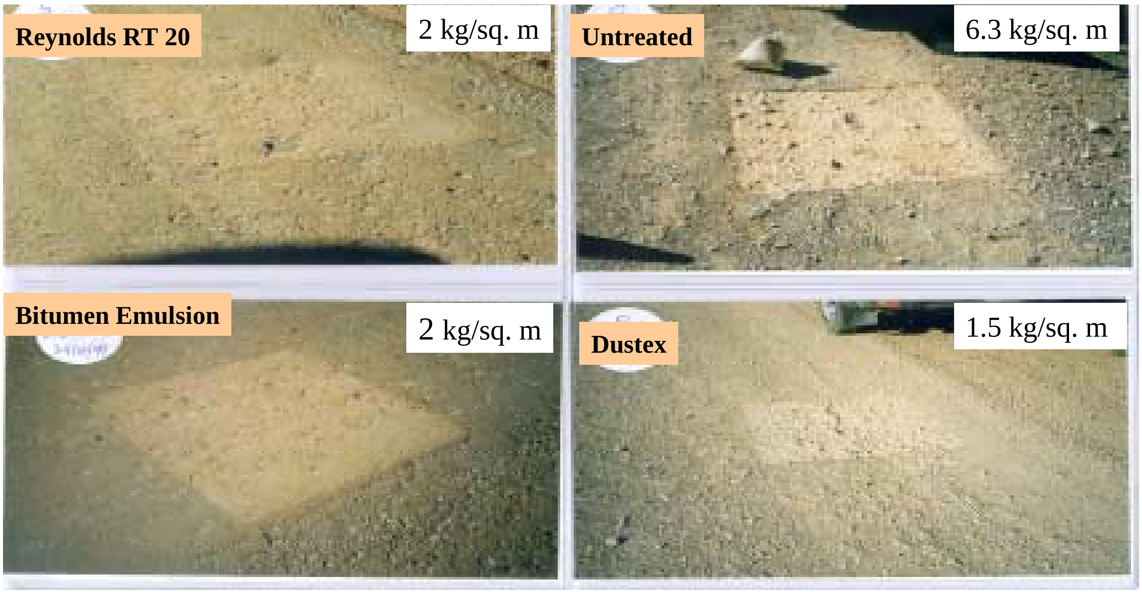

Figure 9 Pavement Condition after 450 days (June 1999)

For the first 10 months (approx. 300 days) trafficking all sections displayed little deterioration in generation of loose *dust* and *gravel*. Immediate and higher deterioration was recorded in the untreated *wet maintenance* sections reflecting the binding properties of the products on the soil matrix. However, from November 1998 rapid deterioration of the pavement was observed in all sections with the treated sections performing marginally better than the untreated sections. After day 450, a maintenance intervention occurred in which the pavement was wetted, graded and compacted to provide a new riding surface.

Surface Wear [Rutting]

Rut depths were measured after 15 months trafficking (April '99) using a 1.5 metre straight edge as illustrated in Figure 10. Six locations within each trial section were selected for measurement of rut depth in both wheel paths. At each location ten of measurements were taken in the centre third of the wheelpath to determine the average value.

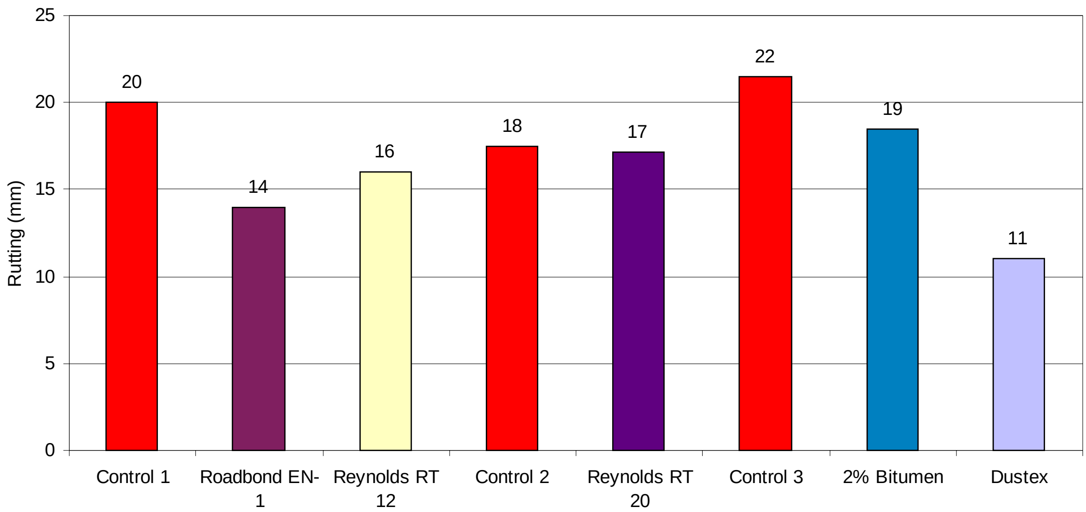

Figure 10 OWP Rut Depth

Visual Surface Rating (URMS)URMS divides the network into 3 – 5 km sections and the rating system is based on a numbering hierarchy considering degrees of: Corrugation, ravelling, wet rutting, bulldust holes, and coarse texture.

The system to the trial sections on a *micro* scale to quantify the road condition with time and test the systems sensitivity to identifying deteriorating surface condition. The ratings over the period are shown in Table 2.

Table 2 URMS Ratings

Corrugations	Rating 1. No corrugations evident throughout stabilised sections. Some corrugations noted in untreated sections Rating 3.
Ravelling	Rating at start 1, on completion 2 some loose stones of varying degrees.
Wet ruts	Rating 1 (Not applicable)
Bulldust holes	Rating 1 (Not applicable)
Coarse texture	Rating 1, reverted to 2 at completion of trial due to presence of loose gravel.

The results show that the rating system was generally insensitive to depict significant changes in the wearing condition of the road.

Road User Assessments

A public survey of road condition was established and ran over 2 years by making available specially designed response forms at local retail outlets. The scheme was also promoted through schools and the progress association at Copley and Leigh Creek.

Ratings were included for roughness (corrugations and pot holes), visibility (dust) and safety (loose gravel). The respective public ranking after 18 months are shown in Table 3

Table 3 Public Ranking

Section	Roughness	Safety	Visibility
Untreated	8	6	7
Roadbond EN-1	4	2	2
Reynolds RT12	1	1	4
Untreated	5	5	6
Reynolds RT20	2	3	3
Untreated	6	8	8
Bitumen Emulsion	7	7	5
Dustex	3	4	1

Although the public were unaware of the composition of sections, Table 3 illustrates to poor rating of untreated sections with marginal differences (bitumen emulsion excepted) between products.

In addition to ranking sections, public responses recognised deteriorating trends and dissatisfaction could be gleaned from some of the comments received. It was evident that for the untreated sections, the public considered intervention should have occurred within nine months and 18 months for most stabilised sections.

PERFORMANCE MODELS

Work undertaken by Paige Green [1989][4] developed relationships between sheeting material performance and intrinsic classification parameters viz:

Shrinkage Product: $S_P = L_S.P_{0.425}$ [L_s = Linear shrinkage, $P_{0.425}$ = Percent passing 0.425mm]

Grading Coefficient $G_c = \frac{(P_{26..5} - P_{2.0}).P_{4.75}}{100}$ [$P_{26.5}$, $P_{4.75}$, $P_{2.0}$ = Percent passing sieve sizes]

The relationship between these two parameters performance is illustrated in Figure 11

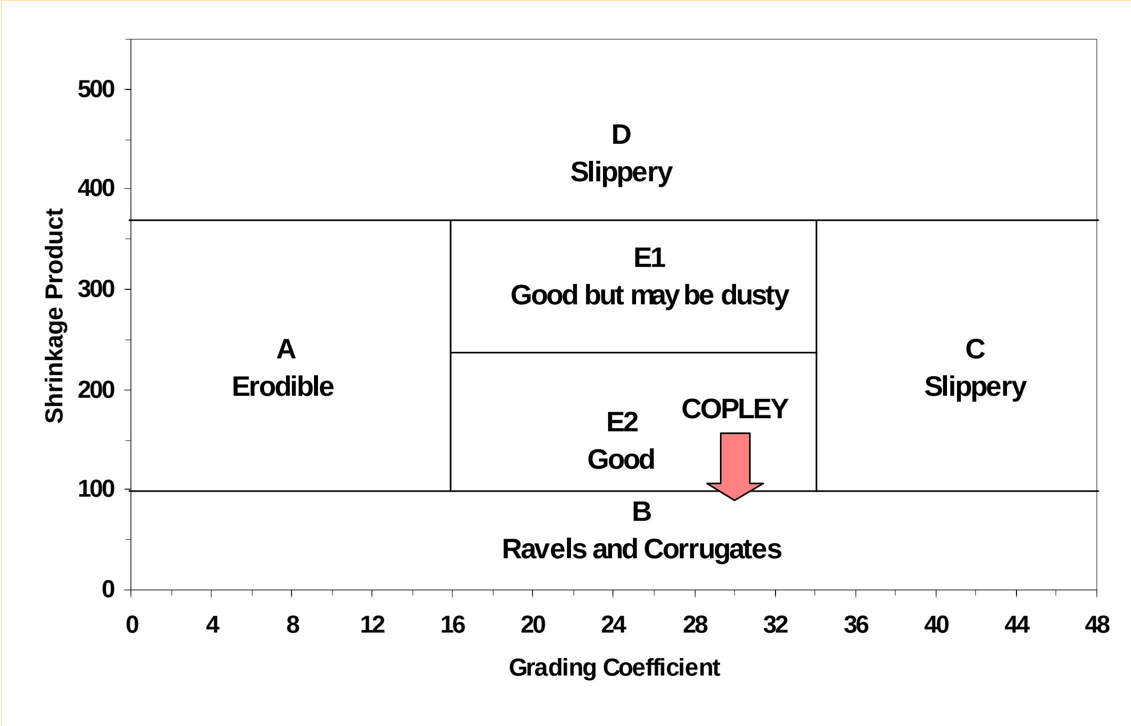

Figure 11 Grading/Plasticity and Unsealed Surface Performance [4]

For the Copley material, S_P = 90 and G_C = 31 ie. zone B, indicating that the material is relatively good but with some potential for ravelling and corrugating.

International studies of the performance of unsealed roads have led to a number of development models in particular relating to World Bank considerations in developing countries. These models considered inter relationships between construction, maintenance and vehicle operating costs. These studies were initiated by the Transport and Road Research Laboratory (UK) TRRL in association with the Kenyan Ministry of Transportation and Communications (MOTC) [6].
In this study the following were considered:

- Gravel loss as an impact on re sheeting intervention
- Surface looseness as an impact on vehicle operating costs (VOC)
- Surface roughness as an impact on VOC and maintenance intervention
- Rut depth as an impact on maintenance and re sheeting intervention
- Journey times as a measure of road condition
- Traffic volumes (both ways) as a measure of pavement wear
- Climate as an impact on surface dust and erosion characteristics
- Geometry (slope and camber) in terms of an indicator of erosion

In the Kenyan studies, gravel loss was measured from optical surveys with the following relationship being developed for particular materials:

Gravel Loss: $$G = f\left(\frac{T_A^{\,2}}{T_A^{\,2}+50}\right)\left(4.2+0.092T_A+3.5R_L^{\,2}+1.88VC\right)$$

G_L = annual gravel loss in millimetres
T_A = annual traffic in both directions in vehicle thousands (Copley = 25 000vpa)
R_L = annual rainfall in metres (Copley = 0.2 m)
VC = percent gradient (Copley = flat)
f = material constant viz; laterite (0.94), quartzite (1.1), Volcanic(0.7), coral(1.5) essentially relating to stone hardness. (Copley = 1.0)

Using this relationship for the Copley material, the annual gravel loss is **6.1mm** per annum.

Considering a sheeting life being the point at which half the thickness is lost (75mm) this rate of attrition suggest that a sheeting life of 12 years can be expected.

In terms of loose surface material, considering that all minus 0.425mm material is blown away, a 6.1mm loss of sheeting material equates to about 10kgms per square metre of loose gravel being on the surface.

Sheeting Life Estimates Based on Wheel Path Rutting

To provide an estimate of relative re-sheeting intervals for the various stabiliser products, the estimated re-sheeting interval from the untreated section (12 years) has been factored by the proportionate measured rut depths of each section relative to that of the untreated section viz.

$$\textit{Stabilised Re-Sheeting Interval} = \textit{Untreated re-sheeting interval} \times \frac{\textit{Rut depth of untreated section}}{\textit{Rut depth of stabilised section}}$$

Table 4 Estimated Sheeting Life from Annual Rut Depths

Treatment	Average Rut Depth (mm)	Factor	Re-sheeting interval (years)
Wet Maintenance	20	1.00	12
Roadbond EN-1	14	1.43	17
Reynolds RT12	16	1.25	15
Reynolds RT20	17	1.18	14
Bitumen Emulsion	19	1.05	12
Dustex	13	1.54	18

LIFE CYCLE COSTS FOR ASSET MANAGEMENT STRATEGIES

Construction & Maintenance Costs

The *per kilometre costs* for re-sheeting are summarised in Table 5[2]

Table 5 Re-Sheeting Costs Per Kilometre

Activity	Assumptions	Parameters	Wet Construction $ per km
Materials Search & Approvals	One pit per 10 kms	$5000 per pit	$500
Raise, process, shape & compact	Construct 500 metres per day	600 cub m	$24,500
Bore & Dam Construction	Serves 40 km/bore	$25,000 each	$750
Pump Operating Costs	$50 litres fuel + pump	$60 per day	$60
Water Carting	Per km	120 000 litres	$2,000
Stabiliser addition	Product cost per km	$1600 - $10 000	
Total Sheeting Cost	cost per km		$27,810

The cost of incorporating a stabilising agent in wet maintenance is assumed to simply be the added cost of the product. However the added cost of disposing the containers or transportation costs if the containers are returned and recycled have not been included in the analysis.

The costs associated with routine maintenance are:

- Dry maintenance per intervention $240 per kilometre
- Wet maintenance per intervention $2,170 per kilometre

Operational Strategies

Three operational strategies have been considered based upon the sheeting lives determined from rutting in each section viz:

Strategy 1. Annual wet maintenance ie maintaining current practice
Strategy 2. 18 month wet maintenance where no further product is added

Strategy 3. 24 month 25% of normal dilution rate of product is added as stabilised wet maintenance

The construction and maintenance intervention costs for each strategy are shown in Table 6.

Table 6 Activity Costs for Life Cycle Cost Analyses

Treatment	Construction	Strategy 1	Strategy 2	Strategy 3
Untreated	$28 000	$2 170	N/A	N/A
Roadbond EN-1	$32 280	$2 170	$1 455	$3 240
Reynolds RT12	$32 200	$2 170	$1 455	$3 220
Reynolds RT20	$29 600	$2 170	$1 455	$2 57
Bitumen	$32 000	$2 170	$1 455	$3 170
Dustex	$38 340	$2 170	$1 455	$4 755

Note: Strategy 2 and 3 cannot be applied to untreated sections because the road is unserviceable.

Relative Product Life Cycle Comparisons

For the life cycle cost analysis the equivalent annual cash flow (EACF) has been used for comparisons because of the differing sheeting lives estimated for each treatment. In the analysis for dry and wet maintenance treatments, strategies 2 and 3 cannot be applied because the pavement condition becomes unserviceable. Therefore the comparative EACF,s are those for strategy 1.

For this financial analysis, the estimates of sheeting life determined from the rutting measurements are considered to be the most appropriate since they are a direct measurement of surface wear directly attributable to traffic.

The LCC analysis has assumed a fixed discount rate of 6%over the life of the respective treatment. The results are shown in Table 7.

Table 7 EACF Life Cycle Cost Analyses for Three Maintenance Strategies

Treatment	Sheeting Life	Strategy 1	Strategy 2	Strategy 3
Dry (quarterly)	8	$5 120	N/A	N/A
Wet maintenance	12	$5 217	N/A	N/A
Roadbond EN-1	17	$5 081	$4 389	$4 449
Reynolds RT12	15	$5 271	$4 584	$4 601
Reynolds RT20	14	$5 125	$4 440	$4 243
Bitumen	12	$5 669	$4 992	$5 072
Dustex	18	$5 541	$4 847	$5 67

The above analysis indicates that current practice with wet or dry maintenance is not the most economical strategy. Rather, some products because they provide both extended sheeting life and longer periods between maintenance intervention can offer significant savings over the network.

EACF for the Reynolds RT20 reflects the low cost of the product viz half the cost of any other. The Roadbond and Reynolds RT12 products are similar in cost and reflect improved sheeting life. Bitumen content was selected to be the same cost as Roadbond and Reynolds RT12 and the EACF reflects no improvement in sheeting life whilst carrying the product on-cost. Dustex was the most expensive of all products 2.5 times that of Roadbond and Reynolds RT12 and this works against the highest sheeting life offered.

The optimum strategy in Table 7 is Strategy 2 suggesting that a wet maintenance intervention period of 18 months could be adopted and associated with any of the products trialed. If strategy 2 were implemented, the annual savings to Transport SA could be as illustrated in Table 8. The analysis is based upon the fact that approximately 650 kilometres of road is maintained annually using wet maintenance.

Table 8 Potential Reduction in Annual Operating Cost (compared to wet untreated)

Treatment	Strategy1	Strategy 2	Strategy 3
Dry untreated (quarterly maintenance)	$63 050	$63 050	$63 050
Wet untreated (annual maintenance)	CONTROL	CONTROL	CONTROL
Roadbond EN-1	$88 400	$538 200	$499 200
Reynolds RT-12	-$35 100	$411 450	$399 750
Reynolds RT-20	$59 800	$505 050	$633 100
2% Bitumen	-$293 800	$146 250	$94 250
Dustex	-$210 600	$240 500	-$298 350

CONCLUSIONS

Monitoring of the Copley trial sections over a two year period has indicated that immediate benefits are realised from using chemical stabilisation. Observations and quantitative assessments show that an improved pavement condition in terms of roughness, loose surface material and rutting is sustained over an 18 month period before maintenance interventions are required.

Continued monitoring will be undertaken and observations to date following a wet maintenance intervention in August 1999 suggest that the stabilised surfaces are rejuvenated to their original condition.

It was evident that there were significant improvements in the wearing qualities of the surface during the first 12 months of the trial which were again realised after wet maintenance grading had been undertaken after 18 months. With a further light application of chemical stabiliser after 18 months even further improved performance could be realised.

In undertaking the economic analysis it was recognised that the sheeting life was a far more dominant factor than wet or dry grading interventions. Therefore using both rut development and measurement of loose material on the surface as measures of sheeting wear, the product do offer economic improvements.

For chemical stabilisation to be successfully adopted on outback roads, the liquid forms are far easier and more suited to use. In addition, with the low dosage rates, a semitrailer load of product will stabilise many kilometres whereas the amount of powder stabiliser to cover the same distance will be much more.

RECOMMENDATIONS

1. To realise both the identified annual cost savings and maximise road user benefits of chemical stabilisation it is recommended that the technology be applied to areas of greatest need in terms of enhancing road safety. This implies that initially it should concentrate on improving sections such as:

Heavy wear areas: *Corners, intersections, slopes*

High impact areas: *Grid approach & departures*

Access difficulties: *Swamps, creeks*

2. The laboratory procedure for preliminary evaluation of chemical stabilisers to determine their suitability for a particular soil be further developed and submitted to AustStab for consideration as a national procedure. Additional developmental work on the method and tests undertake on a range of stabiliser products and materials is recommended to be undertaken as part of a final year engineering undergraduate project.

3. To improve the URMS rating system and make it more quantitative, the determination of the total amount of loose material on the surface combined with rut depth are recommended as good measurable indicators of pavement condition and benchmarks for implementing maintenance intervention.

The recommended values are:

- Maximum mass of loose material per square metre > 5kgms/m^2
- Maximum rut depth < 15mm.

4. Monitoring of the Copley site should continue in order to a develop behavioural model for the unsealed surface. The monitoring will affirm the predictions of sheeting life and appropriate maintenance intervention periods. As a more informed understanding of the performance of unsealed roads is gained, so too the pavement management system is improved, the associated operating costs decreased and road user benefits increased.
5. Technology transfer seminars should be organised at strategic locations throughout the State where the technology will be of greatest benefit to local government, mining, quarrying and other industries.
6. Additional monitoring sites should be established throughout the unsealed road network to evaluate the benefits of chemical stabilisation on a variety of soil types. This could be undertake in consultation with local government agencies within all three Transport SA rural regions.

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Bob specialises in the performance characteristics of unbound, recycled and stabilised pavement materials, pavement design and rehabilitation. His expertise has been recognised both nationally and internationally serving on a number of Austroads groups, and as member of the US Transportation Research Board Committee for Chemical Stabilisation.

By reputation, Bob has been invited to a number of countries throughout the world as an expert consultant or key speaker. He is the author of over 30 international papers on materials and pavements technology associated with both sealed and unsealed roads.