THE INCORPORATION OF DUST PALLIATIVES AS A MAINTENANCE OPTION IN UNSEALED ROAD MANAGEMENT SYSTEMS

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ABSTRACT

Unacceptable levels of dust are generated on the unsealed road networks in most countries. In the past, dust has mostly been considered as a safety hazard and nuisance. However, research on unsealed roads has revealed that the loss of fines associated with road dust contributes to increased gravel loss and the need for more frequent maintenance. By controlling this dust, the rate of gravel loss and maintenance expenditure can be significantly reduced.

Research into the performance and benefits of using dust palliatives for unsealed road maintenance in South Africa has resulted in the development of calibration factors for unsealed road performance prediction models. These factors can be used in road management systems to determine where the dust palliation products can be used cost-effectively.

In a study with a South African road authority, the factors for calcium chloride were first validated in a pilot project, before being implemented in a computerised road management system. Output from the system indicated that calcium chloride could be cost-effectively used on 20 per cent of the road network. Considerable savings accrued to both the authority and the road user. The regravelling frequency changed from seven years to fourteen years resulting in a significant conservation of already scarce gravel resources. The performance of various other dust palliatives is currently being monitored in order to develop calibration factors for their inclusion in management systems.

INTRODUCTION

Most countries have an extensive network of unsealed roads, much of which is susceptible to the generation of unacceptable levels of dust under traffic. In the past, dust has mostly been considered as a safety hazard and nuisance. However, research on unsealed roads has revealed that the loss of fines associated with road dust contributes to increased gravel loss and the need for more frequent maintenance. By controlling this dust, the rate of gravel loss and maintenance expenditure can be significantly reduced.

Effective dust control can be achieved either with chemical dust suppressants or by upgrading the road to a sealed surface. Considerable research has been undertaken on the latter, and numerous cost/benefit models are available to determine at which point the road should be upgraded. However, no models are available for the road authority to justify expenditure on dust suppressants, as no long-term experiments had been carried out to determine the effectiveness rejuvenation needs of these products.

Given these needs, a number of controlled experiments using calcium chloride as a dust suppressant, selected from a factorial experimental design incorporating traffic, climate and material type, were monitored over a period of three years. Gravel loss, riding quality, dustiness and general performance measurements were recorded during this period and the information used to develop calibration factors for the South African Unsealed Road Performance Models. These factors were then tested by a road authority, using a Product Performance Guarantee System, on an application to a nine kilometre unsealed road link. The success of this phase led to incorporation of the factors in the road authorities' gravel road management system, which is used to justify and optimise budgeted funds at network level. The research is continuing with a range of other products.

In this paper, a background to the dust problem, unsealed road performance prediction models and research on dust palliatives is provided. The development of the calibration factors and the incorporation of the factors into a gravel road management system are discussed.

BACKGROUND

Dust Generation and Consequences

It is estimated that more than 3.1 million tonnes of dust are generated on the South African unsealed road network each year[1]. This figure was calculated using the United States Environmental Protection Agency (EPA) AP-42 Dust Prediction Model[2], calibrated for southern African conditions. Conservatively assuming that two thirds of this dust falls back onto the road, then approximately one million tonnes of fines are lost annually from the road network. The loss of this quantity of soil fines has serious implications in terms of unsealed road maintenance. Other consequences that need to be considered, including road safety and the impacts to human health, quality of life, agriculture and vehicle operating costs are documented elsewhere in the literature[1] and are not considered further in this paper.

Dust is generated from the fine material that binds larger particles in the gravel wearing course together. Once this dust is lost, the consequent increase in the rate of loss of coarser particles as a result of ravelling and abrasion of the remaining material under traffic will be apparent. Other problems associated with the loss of soil fines including potholing and corrugation will result, and these too will become more severe with time, thus contributing to increased road roughness. This leads to the need for more frequent maintenance in order to retain the riding quality within acceptable limits. A loose gravel surface deficient in binder also increases the risk of broken windscreens, headlights and damage to bodywork.

The effect of the loss of fines on the rate of gravel loss and deterioration in riding quality has been monitored as part of a number experiments[3,4]. On particularly dusty roads, it was noted that the rate of gravel loss and the frequency of blading increased with time. Although traffic volumes also increased during the period, it is believed that the loss of fines in the form of dust contributed to the increasing rate of deterioration. Typical acceleration of gravel loss and maintenance needs on an unsealed road are illustrated in Figure 1.

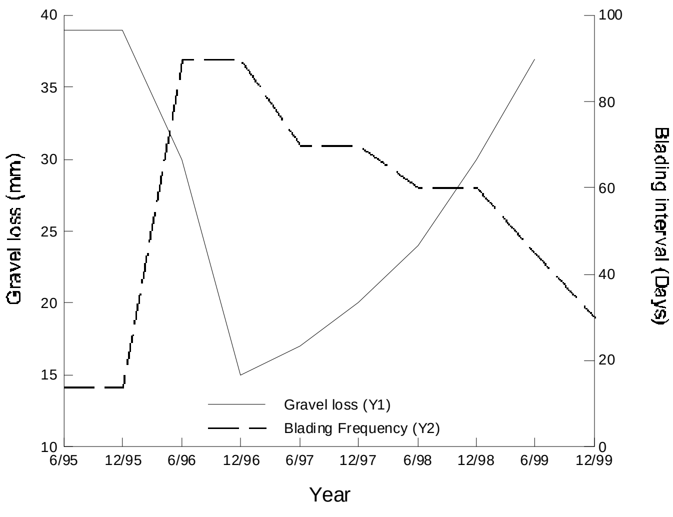

FIGURE 1: Gravel loss and blading interval over time

In the past, dust has generally been considered as a safety and nuisance factor, but given the above findings, its control should be considered as part of the asset management and road maintenance programme. In South Africa, most unsealed road networks are managed with the aid of computerised management systems that prioritise maintenance expenditure. Dust control is not included as an option in any of these systems and models to quantify the cost/benefit of using chemical dust control measures therefore needed to be developed and implemented.

Research on Unsealed Roads

Guidelines for the selection of materials for unsealed roads, together with performance prediction models (roughness progression/blading interval and gravel loss) have been developed for rural and peri-urban roads in South Africa[5,6]. These models are used in all unsealed road management systems in South Africa in preference to the World Bank HDM models, which do not predict the performance of South African Roads as accurately[4,7]. Given that these guidelines and models are widely applied in southern Africa, the research into dust palliatives, discussed below, considers relaxation of the standards wherever possible, rather than defining new parameters and models. The material selection guidelines and models currently utilised are given in Table 1 and Equations 1 to 4 below.

TABLE .1: Southern African material selection guidelines for unsealed roads

Characteristic	Guideline		
	Rural	Urban	Haul
Maximum size (mm)	37.5	37.5	75 - 100
Oversize index (%)	5	0	10
Shrinkage product[a]	100 - 365	100 - 365	100 - 365
Grading coefficient[b]	16 - 34	16 - 34	16 - 34
CBR[c] (%)	15	15	40
Hardness[d]	20 - 65	20 – 65	20 – 65

a = linear shrinkage x % passing 0.425 mm sieve
b = (% passing 26.5 mm - % passing 2.0 mm) x % passing 4.75 mm/100
c = California Bearing Ratio - soaked at 95% Mod AASHTO
d = Treton Impact Value

Roughness Progression Models

The following recommendations for implementation of the roughness progression models at network and project level are made[4]:

- For traffic volumes of less than 400 vehicles per day and blading intervals of less than 90 days, the standard SA Unsealed Road prediction model should be used (Equation 1).
- For traffic volumes of less than 400 vehicles per day and blading intervals greater than 90 days, the SA Steady State Model should be used (Equation 2).
- For traffic volumes greater than 400 vehicles per day, the maximum roughness for the particular material type should be predicted or measured and this level assumed to be reached between seven and fourteen days after blading (Equation 3).

$$\ln R = D[-13.8 + 0.00022PF + 0.064S1 + 0.137P26 + 0.0003NADT + GM(6.42 - 0.063P26)] \quad ..Eq1$$

where:
- lnR = natural logarithm of change of roughness with time;
- D = number of days since last blading (days/100);
- PF = plastic factor (plastic limit x P075 mm sieve);
- S1 = season dummy variable (1 for dry season and 0 for wet season);
- P26 = percentage passing 26.5 mm sieve;
- N = Weinert N-value[8];
- ADT = average daily traffic in both directions, and
- GM = grading modulus [(300 - P020 - P425 - P075)/100].

$RG_t = RG_{max} - p[RG_{max} - RG_a]$ ..Eq2

where:
RG_t = roughness at time t (QI counts/km);
RG_{max} = $(-30.09 + 0.03PF + 294.76GM + 3.556P26)$, and
p = $\exp\{-0.016 + [0.001(t_2 - t_1)(-0.17 - 0.000067ADT - 0.00019NADT)]\}$.
Rg_a = roughness after blading (QI counts/km);
t = time elapsed since blading (days);

$RGmax = (-30.09 + 0.03PF + 294.76GM + 3.556P26)$ ..Eq3

The recommended ranges for the various parameters are as follows. Predictions when using values outside this range should be used with caution.

Average daily traffic:	10 - 400 vehicles per day
Weinert N-value:	1 –10 (11 for higher N-values)
Per cent passing 26 mm:	87 - 100 (recalculated to 100% passing 37.5 mm)
Plastic limit:	13 - 32; 10 if non-plastic
Per cent passing 0.075 mm:	10 - 75 (recalculated to 100% passing 37.5 mm)
Grading modulus:	0.3 - 2.5
Roughness before blading:	60 – 200 (QI counts/km)
Dust ratio (P0.075/P0.425):	0.24 - 0.92
Max size:	6.7 – 58 mm

As traffic volumes are critical in the analyses, the figures used should be accurate and representative of the road. If doubt concerning their accuracy exists, the output from the models should be interpreted with careful judgement.

Gravel Loss

The standard SA Unsealed Road Gravel Loss Prediction Model (Equation 4) should be used for all traffic volumes up to 400 vehicles per day. For more than 400 vehicles per day, the model can be used, but the results should be checked against records or experience, as the dataset used to develop the models did not have traffic volumes exceeding this figure. As with roughness progression, the output should be interpreted with care given the fact that traffic data may not be accurate and traffic has the greatest influence in the model.

$GL = D[ADT(0.059 + 0.0027N - 0.0006P26) - 0.367N - 0.0014PF + 0.0474P26]$ ..Eq4

where:
GL = gravel thickness loss (mm);
D = time period under consideration (days/100);
ADT = average daily traffic in both directions;
N = Weinert N-value;
PF = plastic factor (plastic limit x percentage passing 0.075 mm sieve), and
P26 = percentage passing 26.5 mm sieve.

The recommended ranges for the various parameters are as follows. Predictions when using values outside this range should be used with caution.

Thickness of wearing course:	50 - 200 mm
Average daily traffic:	10 - 400 vehicles per day
Weinert N-value:	1 –10 (11 for higher N-values)
Per cent passing 26 mm:	70 - 100 (recalculated to 100% passing 37.5 mm)
Plastic limit:	13 - 32; 10 if non-plastic
Per cent passing 0.075 mm:	10 - 75 (recalculated to 100% passing 37.5 mm)

Research on Dust and Dust Control

A holistic study into dust and dust control on unsealed roads was initiated in South Africa in the early 1990's to determine whether chemical dust suppressants could provide cost-effective road maintenance options. At that time, numerous products claimed as dust palliatives were available commercially, but little research had been conducted and no reliable specification of their properties or records of their performance were available. Very few properly controlled comparative tests had been carried out in full-scale experiments. This, together with poor marketing strategies has resulted in a general scepticism in the industry on the usefulness of these products.

The current study has therefore investigated the consequences of dust, processes affecting the generation of dust, dust measurement, dust acceptability criteria, dust prediction as well as dust control with mechanical stabilisation and chemical additives[9].

In order to facilitate the selection of an appropriate product for particular conditions, dust palliatives have been divided into the following ten categories:

- water and wetting agents;
- hygroscopic materials;
- ligno-sulphonates;
- modified waxes;
- petroleum resins;
- synthetic polymer emulsions;
- tars and bitumens;
- sulphonated oils;
- enzymes;
- other products including waste oils.

Water and wetting agents are only suitable for very short-term applications. Other products are those such as tannin extracts, molasses and plant extracts, and industrial wastes. These products are often only available in small quantities, regionally specific and may have environmental implications in terms of leachate. Any potential use of these materials should be preceded by a detailed environmental impact analysis. Waste oils may not be used in South Africa, as the potential for groundwater pollution is too high.

For the other eight categories, research has been directed towards the development of material, climatic, construction and application, maintenance and rejuvenation guidelines and performance prediction models. Product performance has also been considered in terms of basic requirements, which include availability in sufficient quantities at realistic prices, adequate durability, product safety and environmental compatability[9].

Interim material, climatic, application and maintenance guidelines are now available for most of the above categories[10]. However, the development of performance prediction models is expensive and time consuming and models and interim models have only been developed for calcium chloride and ligno sulphonate respectively, so far.

MODEL DEVELOPMENT

Research into the development of models to predict the performance of chemically treated unsealed roads was initiated as part of a larger study into the use of calcium chloride as an additive for unsealed roads in South Africa[11]. Similar research is currently being carried out on ligno sulphonate[12].

In the calcium chloride study, the performance of 30 treated sections, selected according to a factorial experimental design which considered traffic, climate and material type, was compared with the performance of adjacent untreated control sections. Gravel loss was measured using precise levelling techniques, while roughness progression was determined using a Linear Displacement Integrator (LDI).

In the statistical analysis of the results, calibration factors for the existing South African Unsealed Road Performance Models were identified as the most appropriate mechanism for implementation of the findings into existing unsealed road management systems. Separate models were considered unnecessary, given the wide acceptance and utilisation of the existing unsealed road models. The calibration factors for calcium chloride are:

Gravel loss - multiply predicted/actual loss for untreated road by a factor of 0.5

Blading - multiply predicted/actual blading interval of untreated road as follows:

- <7 days - multiply by 14.3
- 7-14 days - multiply by 8.5
- 15-45 days - multiply by 4.0
- 46-90 days - multiply by 2.0
- 91-120 days - multiply by 3.0
- >120 days - allow 1 blade per annum

In summary, these factors indicate that the rate of gravel loss is at least halved when calcium chloride is used, while blading interval decreases significantly, but is dependent on the blading interval of the road prior to application of the product.

TRIAL IMPLEMENTATION

Prior to full implementation of the factors in unsealed road management systems, the South African road authorities requested trials to test the validity of the models. For this trial, a 9 km unsealed road carrying approximately 400 vehicles per day (50 per cent heavy) was selected by the road authority. The nature of the road and the high traffic volume demanded a high maintenance and regravelling interval, which the road authority wished to reduce, but without constructing a traditional bituminous sealed surface, for which funds were not available (the road required realignment and the construction of a bridge). The trial was to be in the form of a product performance guarantee system (PPGS) whereby the success of the application would be judged over a two year period against predetermined reductions in gravel loss, maintenance frequency and dust levels. Gravel loss and maintenance frequency were predicted with the above factors, while dust reduction was predicted with a model[3] developed as part of the study into dust and dust control described earlier. The performance criteria are summarised in Table 2[13].

TABLE 2: Performance Criteria

Parameter	Expected Performance		Guaranteed Performance
	Untreated	Treated	
Average Riding quality (QI)[a]	120	80	100
Blading interval (days)[b]	40	200	150
Gravel loss (mm/annum)[c]	19	9	14
Dust (du)[d]	50	10	15

[a] QI – Quarter- car index, measured with linear displacement integrator
[b] Based on QI
[c] Measured with rod and level survey
[d] du - dust units, measured with CSIR Dust Monitor

In the context of this study, a product performance guarantee is seen as a means to fast-track the implementation of new products or processes, with the risk being shared between the road owner and the product supplier. If the terms of the guarantee are not met by the supplier, he must carry the cost of additional product and/or maintenance in order to meet those terms. If the terms are met or exceeded, the road authority undertakes to include the prediction factors in the road management system, which will be used to identify where the product can be cost-effectively used on other roads.

Road Data

The road was located between Pretoria and Johannesburg in the Gauteng Province in South Africa. The road provides access to farms, smallholdings, brickworks and a number of small businesses. Traffic counts conducted before and during the study revealed traffic growth from approximately 400 to over 700 vehicles per day (the high growth being attributed to the good performance of the treated road, in retrospect). The road had been regravelled three years prior to commencement of the study with shale, ferricrete and chert materials and was in a generally poor condition. Laboratory testing on samples removed from the centreline of the road provided the following results (Table 3).

TABLE 3: Laboratory test results

Parameter	Average	High	Low
Grading coefficient[a]	27	34	19
Passing 0.075 mm (%)	31	42	22
Shrinkage product[b]	268	379	136
CBR[c] (%)	41	67	25
Max dry density (kg/m^3)	2052	2165	1910

a = linear shrinkage x % passing 0.425 mm sieve
b = (% passing 26.5 mm - % passing 2.0 mm) x % passing 4.75 mm/100
c = California Bearing Ratio - soaked at 95% Mod AASHTO

In terms of the material selection guideline for calcium chloride[11], the grading coefficient of the material fell within the recommended limits (16-34). However, the percentage silt and clay (ie material smaller than 0.075 mm in diameter) was generally higher than the recommended maximum of 20 per cent. The shrinkage product over much of the road was fairly high with certain sections falling outside the recommended limits for both calcium chloride (50-240 (50-365 if slipperiness is not a concern)) and unsealed roads in general (100-365). Concerns about slipperiness after rainfall were raised in correspondence with the road authority prior to application. The California Bearing Ratio (CBR) was acceptable for application of the product.

Product Application and Experiment Preparation

The road was shaped by blading before the calcium chloride was applied as a surface treatment at a rate of 2.0 ℓ/m^2. Follow-up applications of 0.3 ℓ/m^2 and 0.5 ℓ/m^2 were applied after six weeks and six months respectively. The road was rejuvenated with an application of 0.5 ℓ/m^2 after 12 months.

Three experimental sections with untreated controls were selected for monitoring purposes. For ease of application and maintenance, one section was positioned at each end of the road and one section at approximately the halfway point. Each section was 200 m long. Benchmarks, for determining gravel loss, were positioned on the side of the road at each section. For the duration of the study, dust and riding quality measurements and a visual assessment were carried out at monthly intervals, while gravel loss was measured at three monthly intervals.

Performance versus Guarantee

The measured performance versus guarantee is summarised in Table 4.

TABLE 4: Measured performance vs guarantee

Parameter	Guarantee	0 – 6 months		6 – 12 months		12 – 24 months	
		Control	Treated	Control	Treated	Control	Treated
Riding quality (QI)	100	140	80-120	100	70-110	100	70-110
Dust (du)	15	60	10-30	60	5-40	50	5-30
Gravel loss (mm/yr)	14	23-55	6	20-33	0	23-40	0-10
Blading (days)	150	40	182	40	101	50	50

The guarantee requirements for riding quality were met on most of the treated section during the course of the monitoring period. However, in poorly drained high clay areas (materials falling outside recommended limits for calcium chloride) where the road was slippery and where potholes formed, the guarantee limit was not met. In terms of dust, the guarantee requirements were met on most of the treated section during the course of the monitoring period although some dust was recorded as a result of drying of the road after heavy rainfall, before the product had restored itself to the upper layer of the pavement by evaporation and precipitation. The guarantee requirements for gravel loss were exceeded. In terms of blading interval, the guarantee requirements were exceeded during dry periods. However, after rainfall, the road required more frequent maintenance than was predicted, as a result of deformation in poorly drained soils with high clay contents. When considering average performance over the entire road, all parties agreed that the performance of the product had met expectations and that the prediction factors provided an adequate indication of expected performance.

Based on the findings of previous studies and the trial implementation, the calibration factors were incorporated into the provincial gravel road management system of the Gauteng Department of Transport and Public Works (Gautrans) with a view to wider use of the product. The gravel road network currently being managed is approximately 1 550 km with traffic volumes varying between 6 and 3 250 vehicles per day and an average of about 210 vehicles per day.

INCORPORATION OF CALIBRATION FACTORS INTO THE MANAGEMENT SYSTEM

The Gautrans Gravel Road Management System is dTIMS (Total Infrastructure Management System developed by Deighton, Canada) based and is operated by consulting engineers on behalf of the road authority. The software is completely generic and modular and provides users with a mechanism for analysing a variety of maintenance and rehabilitation alternatives over a period of time. Maintenance actions, budgets and performance models are input by the user.

In order to compare the application of calcium chloride with traditional routine maintenance on gravel roads, a benefit function was required to measure the economic benefit of the maintenance alternatives. The objective of the benefit function used in this study was to minimise the Total Transportation Costs (TTC) for the road network. The TTC includes both the costs of maintaining the road as well as the costs of vehicles operating on it. Road user costs are a function of annual average daily traffic (AADT) and the estimated road roughness (roughness is estimated according to the blading interval). Using the cost streams (maintenance costs as well as savings in road user costs), different blading intervals can be compared on each link. For any maintenance action to be beneficial, the savings in road user costs resulting from the maintenance action should exceed the costs of maintaining the road.

The entire unsealed road network and current budget of Gautrans was used for the study. On each road link the application of calcium chloride with routine blading was compared with different routine blading cycles with no dust control treatment. In all cases, it was assumed that the road would be regravelled once the gravel thickness had reduced to 30mm.

The maintenance alternatives considered on each link are listed in Table 5. Roads treated with calcium chloride and bladed every 90 and 120 days resulted in similar predicted road roughness to untreated roads bladed every 14 and 30 days respectively.

TABLE 5: Description of maintenance alternatives

Code	Description of Works
B30	Blade every 30 days and regravel once thickness < 30mm.
B60	Blade every 60 days and regravel once thickness < 30mm.
B90	Blade every 90 days and regravel once thickness < 30mm.
B120	Blade every 120 days and regravel once thickness < 30mm.
V90	Apply calcium chloride annually, blade every 90 days and regravel once thickness < 30mm.
V120	Apply calcium chloride annually, blade every 120 days and regravel once thickness < 30mm.

Table 6 summarises the benefits and costs for all the maintenance alternatives of a road with 342 vehicles per day. All costs (US$) are given in nett present value over a 20-year analysis period. It is evident that the application of calcium chloride in conjunction with a 90-day blading cycle resulted in the maximum benefit.

TABLE 6: Costs and benefits for a road link (342 vpd)

Treatment Code	NPV[1] Costs (US$)	NPV[2] VOC (US$)	NPV[3] VOC Savings (US$)	NPV[4] Benefit (US$)	Regravel[5] Frequency (years)
Do Nothing	-	1 233 402	-	-	-
B120	22 081	1 057 171	176 231	154 150	7
B60	24 023	861 151	372 251	348 229	7
B30	27 877	759 105	474 298	446 422	7
V90	29 280	692 419	540 984	511 705	13
V120	28 633	715 346	518 057	489 424	13

[1] Includes costs for regravel, application of dust control treatments (US\$0.21/m^2 construction and US\$0.14/m^2 annual rejuvenation) and blading.
[2] Vehicle Operating Costs
[3] Savings in Vehicle Operating Costs compared to the Do Nothing alternative
[4] Benefit calculated as Savings in VOC minus Costs
[5] Required regravel frequency according to gravel loss model

Figure 2 shows the predicted average gravel thickness for the network, with and without the application of dust control treatments for a constrained budget (ie insufficient funds are available to maintain the entire network at optimum levels – with the optimisation system allocating funds to ensure maximum benefit in terms of total transportation costs for the given budget). The application of calcium chloride was especially beneficial on high traffic volume roads, where the annual loss in gravel material is high. With the inclusion of dust control treatments, the overall network gravel thickness can be maintained at a higher level for the same budget constraints.

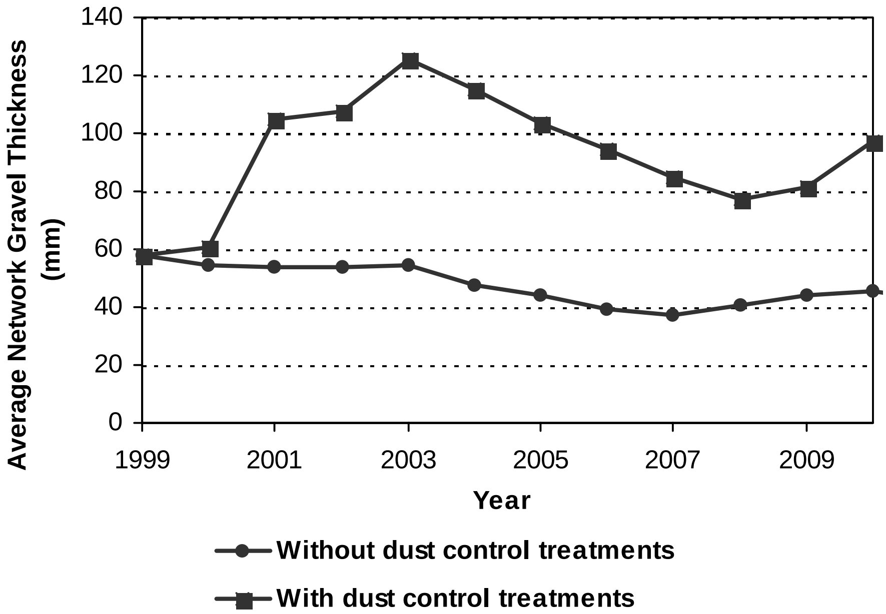

FIGURE 2: Predicted average network gravel thickness

On completion of the analysis the following conclusions were made:

- Twenty per cent of the current budget could be allocated for the application of calcium chloride.
- Calcium chloride proved to be beneficial on gravel roads with traffic as low as 125 vehicles per day.
- For the constrained budget, the average thickness of gravel material on unsealed roads increased by 45 mm.
- As a result of the reduced rate of gravel loss, scarce gravel resources can be preserved.
- Annual blade kilometres can be reduced by up to 50 per cent.
- For a constrained annual budget, the application of dust control treatments will improve the condition of the network, and subsequently increase the asset value of the network for the road authority.

Points for Consideration

Traffic

The output of the South African Unsealed Road Performance Prediction Models, and thus the factors described above, is very dependent on the traffic input data. Accurate traffic counts are therefore imperative if the models are to be used effectively.

In a study to calibrate the models for particular applications[4], the predicted performance did not correlate with actual performance on a number of the roads that were monitored. When the traffic figures were altered to reflect the experience of the monitoring team, the accuracy of the predictions improved significantly. Similar findings were noted when the World Bank HDM3 models were used.

On investigation, it was found that traffic data was in certain instances more than four years old and had been collected in a single midweek 12 hour count (06:00 – 18:00). Traffic outside these hours was not considered (one road had some 20 buses before and after the counting period) nor was the seasonality of the traffic (agricultural and tourist). Given that the output of the models is highly dependent on correct traffic data, it is recommended that accurate and representative traffic counts are obtained before the models and factors are used in any gravel road management system.

Maintenance

The application of a dust palliative will decrease the blading interval and, depending on the product used, the method of maintenance may change (eg calcium chloride and ligno sulphonate treated roads require a light watering prior to blading to prevent damage to the crust). Maintenance staff must be trained on the new methods and instructed on the revised blading intervals in order to ensure that optimum benefit is achieved.

CONCLUSION

Research into the performance and benefits of using dust palliatives for unsealed road maintenance has resulted in the development of calibration factors for unsealed road performance prediction models. These factors can be used in road management systems to determine where the dust palliation products can be used cost-effectively.

In a study with the Gauteng Department of Transport and Public Works, the factors were first validated in a pilot study before being implemented in a computerised road management system. Output from the system indicated that calcium chloride could be cost-effectively used on 20 per cent of the road network. Considerable savings accrued to both the authority and the road user. The regravelling frequency changed from seven years to fourteen years resulting in a significant conservation of already scarce gravel resources.

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