THE IMPACT OF VARIOUS MAINTENANCE STRATEGIES ON UNSEALED ROAD DETERIORATION TO ACHIEVE AN ACCEPTABLE MAINTENANCE BUDGET AND ROAD PERFORMANCE

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ABSTRACT
In Australia unsealed roads comprise nearly 60% of the total road network length. These roads play a vital role in providing agricultural, mining and tourist access across Australia. In the Northern Territory of Australia unsealed roads comprise over 70% of the total road length. ARRB has been involved in developing maintenance strategies for the unsealed road network in the Northern Territory to establish a long-term stable maintenance budget that provides a sustainable unsealed road network for all the road users. The initial basis for the analysis and estimation of the maintenance budget were the road deterioration (RD) models derived from the local roads deterioration study (LRDS) that was conducted over a 10 year period across Australia. Further refinement of these RD models and the development of Australian based works effects (WE) models was provided by a two year study of the performance of a large sample of unsealed local roads aimed at quantifying the immediate and longer term impact of grader blading and its frequency on the deterioration and surface re-sheeting on unsealed roads.

Various maintenance strategies were tested using different grader blading intervals and varying the extent of the blading across the pavements in conjunction with drainage works and the ultimate replacement of the surface materials. Using this approach maintenance strategies were found that provided an acceptable annual maintenance budget in combination with an acceptable range of rideability and pavement crossfall. The long term performance modelling of unsealed roads was trialled in the Northern Territory. Whilst the models rely on treatment (grading) frequency, modelling of several treatments within a year required a novel approach. This approach is presented in detail, together with the results on the budget and maintenance strategy development.

INTRODUCTION
ARRB was commissioned by the Northern Territory Department of Transport (NTDoT) in Australia to develop a pavement management system (PMS) for their unsealed road network based on the same platform as their sealed road pavement management system (Deighton Total Infrastructure Management System (dTIMS)) (1). As this software was already being used for the NTDoT’s sealed road network since 2001, the inclusion of the unsealed network was a logical step to extend the scope of the existing analytical tool.

UNSEALED ROAD MODELS
Deterioration models for unsealed roads for different states of Australia were developed as part of a local roads deterioration study (LRDS) conducted by ARRB (2, 3) between 2002 and 2011. The work used pavement performance data from a number of selected test sites, measured and recorded over a one year period.

A number of key pavement performance parameters were identified in the study for monitoring. Performance parameters for unsealed roads were the following:
- roughness (ride quality)
- gravel loss
- shape loss
- loose gravel
- material properties.

Data collected from the test sites was used to develop deterioration models suitable for local conditions. State specific models were developed for Western Australia, New South Wales, Victoria, South Australia and Queensland that tended to match well with the data collected locally. Models were developed based on performance data that was not influenced by any maintenance treatments. Although the Northern Territory was not included in the
study, the Western Australian data and findings were deemed applicable. A brief description of the Western Australian models is given below.

**Model for roughness prediction**
The roughness deterioration model developed in the above study was based on the HDM-4 roughness deterioration model (4). Non-linear regression analyses were performed to estimate the statistical significance of the coefficients of the various parameters in the HDM-4 roughness model and eventually some of the statistically insignificant parameters were removed. The final form of the model is shown in Equation (1):

\[
IRI_{TG2} = IRI_{max} - \exp\left\{ -0.001 \times (F_0 + F_1 \times ADL + F_2 \times ADT \times MMP/1000) \times (TG2-TG1) \times (IRI_{max} - IRI_{TG2}) \right\}
\]  

(1)

Where:
- \( IRI_{TG1} \) = roughness at time TG1, in IRI (m/km)
- \( IRI_{TG2} \) = roughness at time TG2, in IRI (m/km)
- \( IRI_{max} \) = maximum allowable roughness for specified material, in IRI (m/km)
- TG1, TG2 = time elapsed since latest grading, in days
- ADL = average daily light traffic, gross vehicle weight (GVW) < 3500kg, in both directions, in vehicle/day
- MMP = mean monthly precipitation, in mm/month
- \( F_0, F_1 & F_2 \) = model coefficients.

In Equation (1), there are three model coefficients: \( F_0 \) is a constant, \( F_1 \) for the light traffic and \( F_2 \) for the total traffic and rainfall parameters. Estimated values of the coefficients and their statistical significance are shown below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard error</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_0 ) (constant)</td>
<td>0.9822</td>
<td>0.3673</td>
<td>2.67 ( p &lt; 0.05 )</td>
</tr>
<tr>
<td>( F_1 ) (ADL)</td>
<td>-0.0193</td>
<td>0.0083</td>
<td>2.32 ( p &lt; 0.05 )</td>
</tr>
<tr>
<td>( F_2 ) (ADT &amp; MMP)</td>
<td>0.4788</td>
<td>0.2652</td>
<td>1.81 ( p &lt; 0.05 )</td>
</tr>
</tbody>
</table>

\( r^2 = 0.59, F = 16.3 \ (p < 0.05); \text{ No. samples} = 26 \)

**Model for gravel loss prediction**
The model forms derived were primarily from the Paige-Green and Visser (5) models and earlier work undertaken by Choumanivong and Martin (2). The gravel loss model is shown in Equation (2).

\[
GL = D \times (F_1 \times ADT + F_2 \times MMP + F_3 \times PF)
\]

(2)

Where:
- \( GL \) = average gravel thickness loss (mm) across roadway
- \( D \) = time period in hundreds of days (days/100)
- \( ADT \) = average daily vehicular traffic in both directions, in vehicle/day
- MMP = mean monthly precipitation, in mm/month
- PF = Plasticity factor (PI \times P075)
- P075 = amount of material passing the 0.075 mm sieve, in per cent by mass
- PI = Plasticity Index
- \( F_1, F_2 & F_3 \) = model coefficients.
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The model has three coefficients and their statistical significance is shown below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard error</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1 (ADT)</td>
<td>-0.00985</td>
<td>0.00396</td>
<td>2.49 ($p &lt; 0.05$)</td>
</tr>
<tr>
<td>F2 (MMP)</td>
<td>-0.02991</td>
<td>0.01209</td>
<td>2.48 ($p &lt; 0.05$)</td>
</tr>
<tr>
<td>F3 (PF)</td>
<td>-0.00583</td>
<td>0.00180</td>
<td>3.24 ($p &lt; 0.05$)</td>
</tr>
</tbody>
</table>

$r^2 = 0.09, F = 3.8 (p < 0.05); \text{ No. samples} = 80$

The goodness of fit ($r^2$) of the gravel loss model to the relatively limited data from Western Australia is low, as shown in Table 2. A better fit for the gravel loss model was obtained using all the available data from the LRDS (3). However, the lower data fit for the model was considered to be the trade-off for using local observational data rather than Australian wide data. The low $r^2$ value points towards the need for further, geographically more nuanced analysis.

**Model for shape loss prediction**

The loss of shape is calculated as the rate of shape loss per year (percentage change in cross fall) rather than an absolute change for a nominated period. The model for loss of shape is shown in Equation (3).

$$SL = F0 + F1 \times ADT + F2 \times P075$$

Where:

- $SL =$ shape loss, i.e. percentage (%) change in pavement lane cross-fall per year
- $ADT =$ average daily vehicular traffic in both directions, in vehicle/day
- $P075 =$ amount of material passing the 0.075 mm sieve, in per cent by mass
- $F0, F1$ & $F2 =$ model coefficients.

As shown in Equation (3), the factors contributing to the loss of shape were found to be daily vehicle traffic and material properties ($P075$). Three coefficients were included in the model. They are $F0$ as a constant, $F1$ for traffic and $F2$ for material properties. The model coefficients and their statistical significance are shown below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard error</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>F0 (constant)</td>
<td>-1.836</td>
<td>0.2580</td>
<td>7.11 ($p &lt; 0.005$)</td>
</tr>
<tr>
<td>F1 (ADT)</td>
<td>-0.0040</td>
<td>0.0011</td>
<td>3.7 ($p &lt; 0.005$)</td>
</tr>
<tr>
<td>F2 (P075)</td>
<td>0.0259</td>
<td>0.0124</td>
<td>2.09 ($p &lt; 0.01$)</td>
</tr>
</tbody>
</table>

$r^2 = 0.18; F = 10.1 (p < 0.05); \text{ No. samples} = 94$

**DATA**

**Network definition**

The analysed unsealed road network of the Northern Territory has a total length of approximately 8711 km (excluding four wheel drive tracks and those roads without surface type information). The network is categorized into six different road classes and three surface types each, each with separate treatment requirements (Table 1).

**Detailed data**
Road network data was provided by the NTDoT, which was used to represent the network in the database. Inventory data was also provided by the NTDoT as listed in Table 2. Where data was missing, assumptions had to be made and default data was used. Also, no relevant information was available for some of the physical parameters, e.g. IRI. Presumptive values for the missing data have been summarised in Table 2.

### TABLE 1 Length (km) of the road network.

<table>
<thead>
<tr>
<th>Road Class</th>
<th>Flat bladed (km)</th>
<th>Formed (km)</th>
<th>Gravel (km)</th>
<th>Total (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural - Local</td>
<td>516.60</td>
<td>869.69</td>
<td>535.31</td>
<td>1921.59</td>
</tr>
<tr>
<td>Rural - Secondary</td>
<td>1069.33</td>
<td>2400.26</td>
<td>2345.62</td>
<td>5815.22</td>
</tr>
<tr>
<td>Rural - State Arterial</td>
<td>5.87</td>
<td>361.12</td>
<td>595.03</td>
<td>962.03</td>
</tr>
<tr>
<td>Urban - Local</td>
<td>6.34</td>
<td>3.20</td>
<td>0.82</td>
<td>10.36</td>
</tr>
<tr>
<td>Urban - Primary Arterial</td>
<td></td>
<td>2.28</td>
<td></td>
<td>2.28</td>
</tr>
<tr>
<td>Total</td>
<td>1598.14</td>
<td>3636.55</td>
<td>3476.78</td>
<td>8711.48</td>
</tr>
</tbody>
</table>

### TABLE 2 Road network data.

<table>
<thead>
<tr>
<th>Inventory data provided</th>
<th>Condition and traffic data provided</th>
<th>Presumptive values to initiate analysis (when no data was supplied)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Number</td>
<td>Gravel depth</td>
<td>110 mm</td>
</tr>
<tr>
<td>From</td>
<td>P075</td>
<td>-</td>
</tr>
<tr>
<td>To</td>
<td>MMP</td>
<td>70 mm</td>
</tr>
<tr>
<td>Region</td>
<td>ADT</td>
<td>500</td>
</tr>
<tr>
<td>Width</td>
<td>ADL</td>
<td>-</td>
</tr>
<tr>
<td>Road Class</td>
<td>PCT_COMM (% commercial vehicles)</td>
<td>30</td>
</tr>
<tr>
<td>Surface type</td>
<td>IRI</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Width</td>
<td>7.5 m</td>
</tr>
<tr>
<td></td>
<td>Growth</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Crossfall</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Pct Shape Loss</td>
<td>0</td>
</tr>
</tbody>
</table>

Preventive values in Table 2 are based on empirical data. All the above data will be replaced with more recent and relevant information when it becomes available.

### SYSTEM SETUP

#### Models

Physical condition parameters that generally affect the performance of unsealed pavements are loss of gravel, loss of shape and roughness. Among these, gravel loss and loss of shape are associated with the structural performance of the pavement. Roughness influences the functional performance by affecting ride quality of the pavement. To predict deterioration of unsealed roads over time, three models were implemented. These are:
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- gravel loss model
- roughness prediction model
- shape loss prediction model.

As noted earlier, the implemented models are those developed for Western Australia as the climatic conditions are closest to those of the Northern Territory. It should be noted that the other Australian state based models may be considered later for selected areas.

Pavement Condition Index (PCI)

The PCI is a composite index calculated by aggregating a number of individual performance condition indicators (CI). Performance indicators may be formed by using measured or rated parameters. The CI is calculated by converting the measured parameter to an index value.

There are several ways to transform the measured value from one scale to another. For the purpose of the CI, a series of linear transformations were selected, to reflect the asset manager and owner’s value judgement. The selected scale of the CI and PCI is 0 to 5, where 5 represents the worst condition. This scale is consistent with the recommendations of the IIMM (6).

Three physical condition parameters are currently used in the setup to characterise unsealed roads. These are gravel depth (only for gravel surfaced roads), roughness and shape loss. These parameters are normalised into three condition indices, namely:

- gravel depth index
- roughness index
- shape loss index

Transformation of the physical parameters to indexes is described below.

Level of Service Definition

Level of service is used to express physical or measured condition in terms of a standard scale that can easily be interpreted as very good; good; fair; poor; very poor.

The measured values are converted into index values by using the transformation functions between two index ranges. It is possible to use a single transformation function covering the full range from 0 to 5; however, no single function can fit the individually defined transition points from one band to another. Consequently, a series of linear functions are used that can easily be fitted to the transition points. Equation (4) is the generic form of each of the straight lines:

\[ Y = a \times x + b \]  \hspace{1cm} (4)

Where ‘a’ is the slope of the line and ‘b’ is the intercept:

\[ a = (y_2 - y_1) / (x_2 - x_1) \]  \hspace{1cm} and  \hspace{1cm} \[ b = y_i - a \times x_i \]

where \( x_1, y_1 \) and \( x_2, y_2 \) represent transition points.

As an example, Figure 1 shows how roughness is converted into an index number between 0 and 5 representing a level of service for ‘Urban primary’ roads.

Different curves may be determined to reflect local requirements; e.g. different line slopes could be used for roughness in different road classes. The curves reflect a value judgement and the policies of the asset owner. By defining different curves for various road classes the agency’s priorities can be expressed.
The individual curves also assist to set the triggers in a rational and meaningful way; for example, by accepting a parameter to deteriorate to the borderline between fair and poor condition defines the trigger level and also is a political statement and acceptance of roads in fair condition. Determining what is ‘acceptable’ and what is considered ‘very good’, ‘good’, etc. is not only engineering, but also a political and financial decision. The use of the aggregated PCI index concept together with the transition lines connects policy decisions regarding the level of services with practical engineering. Table 3 represents the initial definition of level of services in terms of gravel depth, shape loss and roughness IRI.

<table>
<thead>
<tr>
<th>Rural State</th>
<th>Arterial</th>
<th>Rural Secondary</th>
<th>Rural Local</th>
<th>Urban Primary</th>
<th>Urban Local</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>0-1</td>
<td>200-150</td>
<td>200-150</td>
<td>200-150</td>
<td>200-150</td>
</tr>
<tr>
<td>Good</td>
<td>1-2</td>
<td>150-125</td>
<td>150-125</td>
<td>150-125</td>
<td>150-125</td>
</tr>
<tr>
<td>Fair</td>
<td>2-3</td>
<td>125-100</td>
<td>125-100</td>
<td>125-100</td>
<td>125-100</td>
</tr>
<tr>
<td>Poor</td>
<td>3-4</td>
<td>100-50</td>
<td>100-50</td>
<td>100-50</td>
<td>100-50</td>
</tr>
<tr>
<td>Very poor</td>
<td>4-5</td>
<td>&lt;50</td>
<td>&lt;50</td>
<td>&lt;50</td>
<td>&lt;50</td>
</tr>
</tbody>
</table>

It is anticipated that the CI definitions will be reviewed and adjusted as part of the refinement of the setup – hence the identical limits for all road categories.
Aggregation of individual condition indices

The individual condition indexes, CI, were aggregated to produce a general overall condition index, the PCI Index. The current unsealed road PCI is composed of gravel depth, shape loss and roughness CIs. Equation (5) was adopted for the aggregation of PCI Index taking into account individual condition variables based on the work of COST 354 Project (7).

\[
\text{PCI Index} = \frac{\text{MAX}(w_i \times \text{Index}_i) + p\left(\frac{\text{SUM}(w_i \times \text{Index}_i) - \text{MAX}(w_i \times \text{Index}_i)}{\sum(w_i) - \text{Avg}(w_i)}\right)}{}
\]

Where

- \( w_i \) = weight for individual condition criteria
- \( = 1 \text{ or } 0 \) (where surface type is not gravel) for gravel depth
- \( = 1 \) for roughness
- \( = 1 \) for shape loss
- \( \text{Index}_i \) = Index value for individual condition criteria, for roughness, gravel depth and shape loss
- \( p \) = condition factor (the current value is 0.1).

Treatments

Current desired maintenance practices (grading frequency) for different road classes as supplied by the DoT are as follows:

1. Rural State Arterial – 1 × full maintenance grade (FMG)
   1 × between batters (Half Maintenance Grade, HMG)
   2 × carriageway (Running Surface Grade, RSG)
2. Rural Secondary – 1 × full maintenance grade
   2 × carriageway (Running Surface Grade)
3. Rural local – 1 × between batters (Half Maintenance Grade)
   1 × carriageway (Running Surface Grade).

For any particular road class, several individual treatments together form the annual composite treatment to avoid shorter analysis periods of less than one year. For instance, for rural local roads, 1 half maintenance grade and 1 running surface grade are applied in a year.

As deterioration is calculated annually, for the sake of analysis, individual components of yearly treatments were aggregated to create an annual composite treatment for each road class. In addition to current desired maintenance treatments, renewal, rehabilitation and alternative grading treatments were introduced to achieve an optimal solution. It should be noted that the performance could be calculated monthly or at any other intervals. However, this would increase analysis time significantly, thus this feature was not used. Table 4 summarises all the treatments implemented in the system.
<table>
<thead>
<tr>
<th>Composite Treatment Name</th>
<th>Description</th>
<th>Surface Applied</th>
<th>Treatment Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel_HMGrade_1_RSGrade_2</td>
<td>Re-gravelling followed by 1 HM$^1$ Grade and 2 RS$^2$ Grade</td>
<td>Gravel</td>
<td>Renewal treatment</td>
</tr>
<tr>
<td>Gravel_RSGrade_3</td>
<td>Re-gravelling followed by 3 RS Grade</td>
<td>Gravel</td>
<td>Alternative renewal treatment</td>
</tr>
<tr>
<td>Reshape_HMGrade_1_RSGrade_2</td>
<td>Reshape followed by 1 HM Grade and 2 RS Grade</td>
<td>Gravel and Formed</td>
<td>Rehab Treatment</td>
</tr>
<tr>
<td>Reshape_RSGrade_3</td>
<td>Reshape followed by 3 RS Grade</td>
<td>Formed</td>
<td>Alternative Rehab treatment</td>
</tr>
<tr>
<td>FMGrade_HMGrade_1_RSGrade_2</td>
<td>FM$^3$ grade followed by 1 HM Grade and 2 RS Grade</td>
<td>Gravel, Formed and Flat Bladed</td>
<td>Desired annual maintenance treatment</td>
</tr>
<tr>
<td>HMGrade_1_RSGrade_3</td>
<td>HM Grade and 3 RS Grade</td>
<td>Gravel, Formed and Flat Bladed</td>
<td>Cheaper alternative to desired annual maintenance treatment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment options for secondary road class (rural secondary).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel_HMGrade_1_RSGrade_1</td>
</tr>
<tr>
<td>Gravel_RSGrade_2</td>
</tr>
<tr>
<td>Reshape_HMGrade_1_RSGrade_1</td>
</tr>
<tr>
<td>Reshape_RSGrade_2</td>
</tr>
<tr>
<td>FMGrade_RSGrade_2</td>
</tr>
<tr>
<td>HMGrade_1_RSGrade_2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment options for local road class (rural/urban).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel_RSGrade_1</td>
</tr>
<tr>
<td>Reshape_RSGrade_1</td>
</tr>
<tr>
<td>FMGrade_RSGrade_1</td>
</tr>
<tr>
<td>HMGrade_1_RSGrade_1</td>
</tr>
</tbody>
</table>

Notes: 1. Half maintenance grade; 2. Running surface grade; 3. Full maintenance grade

**Triggers**

Triggers specify a combination of conditions and circumstances to initiate a treatment. Treatments are triggered at this point and in every subsequent year as long as the trigger conditions are met or exceeded. Treatments triggered on the same element (road section)
during the analysis period form a strategy. Many strategies may be generated for each
section and one may be selected for the work program during the optimisation phase.

A trigger typically consists of four key components, namely:

1. trigger condition, (e.g. initiate the treatment when pavement condition is ‘fair’)
2. limit defining the boundary conditions when a treatment can be applied (e.g. no
   grading when for gravel depth <100 mm)
3. inventory or descriptive definition where the treatment can be applied (e.g. re-
   gravelling on gravel surfaced roads only )
4. special conditions, if any.

The combination of various trigger conditions forms the treatment trigger; in a trigger
all of the four trigger components must be true to trigger a treatment. Triggering a treatment
results in generating an optional treatment that will be evaluated and the final selection will
be based on a cost benefit analysis.

Trigger conditions for unsealed road treatments are summarised below:

- Composite re-gravelling treatments are only triggered when the gravel depth falls
  below 100 mm. The treatment option is available to be initiated when it is
  triggered.
- Composite reshape treatments are triggered when the total shape loss becomes
  larger than 10%. The treatment option is available to be initiated when it is
  triggered.
- Grading treatments (combination of various frequencies of full maintenance
  grade, half maintenance grade and running surface grade) are applied every year
  except the years when regravelling/reshape treatment is triggered. Grading
  treatments cannot be applied (as currently set up) if gravel depth <100 mm / total
  shape loss is > 10%.

Unit cost rates
Unit cost rates ($/km) for individual components of the treatments were supplied by the
NTDoT for the treatments. To obtain the unit cost rates ($/km) of the composite treatments,
rates for individual components of the treatments were aggregated.

Work effects
Work effects (WE) describe the impact of a treatment on a condition parameter, i.e. they
define the magnitude and nature of improvement as a consequence of a treatment. The
improvement is measured by the area between the ‘do minimum’ and the new performance
curves (Figure 2); the area is calculated as the product of the length and the width, where the
length is the time of the treatment and the width (height) is the work effect. Thus the work
effect is a critical contributor to the benefit of a treatment.

Figure 2 Illustration of benefit.
It should be noted that ‘do minimum’ refers to the minimum treatment considered; it can be for example routine maintenance; it is currently ‘do nothing’ i.e. no minimum treatment is defined.

Performance models are critical in the timing of triggering a treatment (i.e. the length of the area under the curve) and the WE models define the width (height) of the area under the curve. Consequently, the WE models are as important for the treatment selection (optimisation) as the performance models. WE models depend largely on the quality of workmanship, i.e. how much improvement can be achieved with the given remedial treatment. Overly optimistic WE models may result in significant underestimation of the budget needs.

Work effects are attached to a treatment, i.e. each treatment has its own set of work effects. WE models are defined by expressions containing a function or a simple number of the variable(s) to be changed or reset. The works effects in general re-instate a good or fair condition on the unsealed roads, depending on the function of the road. Treatment resets are established for the time since last grading, IRI, gravel depth and total shape loss for various treatment options current in unsealed road setup. It should be noted that many more variables need to be reset or recalculated after a treatment.

RESULTS

Budget scenarios
The current desirable maintenance practice requires each road section to have some form of treatment every year to ensure that the unrestricted budget was used to determine the condition outcome for the network. As treatment options vary based on road class, each road class was also analysed separately (with a separate budget scenario). The number of the strategies (treatment options) generated to treat each section in each year was quite high. Therefore the analysis period was limited to a period of five years for this study.

The annualised average of the cost for each different road class under an unrestricted budget estimated over the five year analysis period showed that the current budget was insufficient to meet desirable levels of service on all road classes at all times.

In addition to the unrestricted budget, an optimised budget scenario with an annual budget of $20 million for the whole network was evaluated as requested by the NTDoT. It should be noted that not all the sections were treated every year while using this budget.

Network condition
This section summarises the results of the current study. However, following should be taken into account while exploring the results:

- The current pilot study is based on a five year run. The length of the analysis can be expanded, if required.
- Many of the input data is assumed as actual data was not available. Funding requirements may vary significantly in reality.
- The condition of the network may have changed because of the gap between time of condition data collection and analysis work.
- Results are considered indicative of what can be achieved.

The network condition forecasts based on PCI Index for the whole network for two budget scenarios (unrestricted and optimised $20M) were estimated. Based on the average condition, for a defined budget, the whole network sits at ‘fair’ condition and may fall into ‘poor’ category over time. For unlimited budget, the whole network is in the ‘good’ band (Index 1 - 2) and stays the same over the five year analysis period.
A more realistic picture of condition can be gained by exploring the distribution of the condition classes. The overall network condition indexes (PCI) is shown in Figure 3 for a defined budget. Less than 20% of the roads fall within ‘good’ category. At the defined funding level, the proportion of ‘fair’ roads reduces significantly and ‘poor’ and ‘very poor’ roads take up that proportion over the analysis period. A longer term analysis may highlight further decline of the overall road condition.

Figure 3 PCI distribution for defined budget.

With an unrestricted budget (Figure 4), about 60% of the network is in ‘good’ condition and stays almost same over the analysis period. Current treatment design in unsealed road setup only allows renewal/rehabilitation treatments to be triggered when the condition reaches the ‘poor’ band. This explains why there is always a proportion of length within ‘fair’ band over time.

Figure 4 PCI distribution for unrestricted budget

**Treatment cost**

The allocation of funds to various treatments varies over time and with the available budget. For a defined budget, the majority of the proposed works were grading (of a different type and frequency), compared to the amount of renewal and rehabilitation works in the unconstrained budget. This difference in costs and treatments can be explained by the shortage of funds and restricted definition of treatment eligibility for certain road classes.
**SUMMARY**

A pavement management system was developed for the NTDoT unsealed road network. The setup was based on deterioration models developed for Western Australian conditions. The models reflect the relative rapid deterioration of the pavement conditions and thus the high frequency of maintenance. As the grading frequency varies between two to six treatments annually, it would require modelling and analysis at two to three monthly intervals. Whilst this is feasible with the current software, there would be a very large number of options generated, which would increase the running time significantly. To reduce the number of options, treatments were aggregated to annual treatment groups. Even with the aggregated treatments, running time is quite long, as treatments are required every year, as opposed to treatments for sealed pavements, where treatments are required approximately once in a decade.

The unlimited budget scenario indicated that either the unit rates were overestimated or the nominal treatment regime was not fully followed, as the required budget is about three times of the available one. The setup proved the viability of a PMS for unsealed roads.

To improve and refine the system, the following actions are recommended:

1. Review the database, the road list and locations in particular. There were a number of extremely short (<10 m) unsealed road sections; these should be reviewed and combined with adjacent sections as much as possible.
2. Review the composite treatment options; a wider range of options is needed to allow more options and choices to spend the budget.
3. Consider different treatments for different regions
4. Review and calibrate the deterioration models. It is suggested to explore the use of different models for the wet and dry regions.
5. Review the unit cost rates to closely follow the geographical distribution of these; consider remote access multiplier to account for the higher costs at remote areas.
6. Review the triggers to reflect current practice more closely.
7. Provide separate budgets for each region.

**REFERENCES**