PREDICTING TEXTURE DEFICIENCY IN PAVEMENT MANAGEMENT

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Inadequate texture is one of the key drivers for remedial treatment on the New Zealand state highway network. Indeed, on maturing networks with surface dressed/chip sealed surfacings, poor texture becomes an increasingly important issue.

This paper explores how high speed texture measurements can be used for summarising deficient texture across the network, and then taken forward for predicting future performance. It explores how appropriate the HDM 4 prediction models are, and proposes amended model forms based on experience on the New Zealand state highway network.

1. PREDICTING TEXTURE DEFICIENCY OVERVIEW

This paper provides details on the process undertaken by Transit New Zealand in developing the simplest and most effective model for predicting future macrotexture. The development has been based on a review of the high speed data collected on the state highway network, and the model has been developed for use in the national pavement management system.

Currently Transit New Zealand undertakes a comprehensive data collection process on the state highway network. This process includes data collection using high speed laser techniques for the measurement of the surface macrotexture. To utilise this data to its full potential some investigation was completed into various long-term surface macrotexture pavement models. A comparison was then completed between the actual measured macrotexture depth and the predicted performance modelled macrotexture depth. From these comparisons, with the model complexity issues, the way forward for the macrotexture model was determined.

The paper is presented in 5 stages:

- History of Macrotexture model in HDM format
- Issues found with model predictions and model complexity
- Comparisons on model variations tested
- Results from the comparisons and proposed way forward
- Feedback from users on the revised model and development plans

2. HDM – 4 MACROTEXTURE PROGRESSION MODEL BACKGROUND IN NEW ZEALAND

The original HDM-4 macrotexture model was formulated in an absolute form, being:

$$TD_t = ITD\,(1 - \Delta TDT \log_{10}(NELV)) \quad \ldots(1)$$

where

- TD_t = sand patch derived texture depth at time t, in mm
- ITD = initial texture depth which is related to aggregate size or mix type, in mm
- ΔTDT = rate of change of texture with traffic and should be constant for similar surfacing types
- NELV = number of equivalent light vehicle passes since sealing date, where one heavy commercial vehicle is equivalent to 10 light vehicles

This absolute formula was developed into the current HDM-4 macrotexture incremental model by Cenek and Griffith-Jones (1997), and takes the following form:

$$\Delta TD = K_{td}\,\{ITD - TD_a - a_0\,ITD \log_{10}(10^{[(ITD - TDa) / (a0\, ITD)]} + \Delta NELV)\} \quad \ldots(2)$$

where

- ΔTD = incremental change in sand patch derived texture depth during analysis year, in mm
- ITD = initial texture depth at construction of surfacing, in mm

TD_a = texture depth at the beginning of the analysis year, in mm
$\Delta NELV$ = number of equivalent light vehicle passes during analysis year (one heavy truck or heavy bus is equal to 10 NELV; light vehicles equal 1)
a_0 = regression coefficient
K_{td} = calibration factor for texture depth

The initial pavement performance model (PPM) developed for New Zealand contained the HDM-4 macrotexture incremental model as the basis of predicting macrotexture performance, although the model form adopted in New Zealand did not apply the calibration factor (K_{td}).

The Initial Texture Depth (ITD) and regression coefficient (a_0) values were provided as standard values for the entire network. The standard values were applied within the model based on the chip grade and traffic ranges. This was consistent with calibration completed on generic surface types on the New Zealand network, where it was observed that macrotexture depth performance varied by chip grade. The chip grade is relative to the average least dimension (ALD) of the chip size, that is, the larger the chip dimension the smaller the grade. For example a chip grade 2 has an ALD of 11mm, while a chip grade 5 has an ALD of 4.7mm. These standard calibration values for the incremental macrotexture model are contained in Table 2.1.

Table 2.1 – Default values for macrotexture progression model

Coefficient	AADT	Chip grade (ALD (mm) in brackets)				
		2 (11)	3 (9)	4 (6.7)	5 (4.7)	6 (3.5)
ITD	20,000	7	5.7	4.4	3.1	1.8
ITD	4,000	6.966	5.664	4.363	3.015	1.79
ITD	2,000	6.711	5.456	4.2	2.888	1.726
ITD	500	6.463	5.252	4.042	2.765	1.664
ITD	100	6.208	5.044	3.88	2.639	1.601
ITD	0	5.953	4.835	3.717	2.512	1.537
a_0	All	0.13	0.125	0.12	0.11	0.10

These standard values were provided as defaults for the users of the macrotexture model in New Zealand. We can see from the complexity of the incremental model expression, and range of values provided as defaults, that the HDM-4 macrotexture progression model is complicated for the model user to understand and explain. In fact, to accurately calibrate the HDM-4 macrotexture model, it is recommended to perform treatment section slice-in-time calibration[1] for each value (ITD, a_0). Performing this task on the number of sections used in the average pavement model is both time consuming and requires a high quality of data. Therefore most users in New Zealand accepted the default values in their models. The use of these default values was found to over-predict the amount of resurfacing treatment, compared to historic levels of work completed[2]. Therefore in most cases the model was not used, and macrotexture was not modelled as a long-term performance indicator, therefore rendering the high-speed data obsolete.

[1] Implementation of Predictive Modelling for Road Management, Phase II: Refining the System, Final Report DT/2000/F3, RIMS, 30 June 2000.
[2] Implementation of Predictive Modelling for Road Management, Phase I: Preliminary dTIMS System, Final Report DT/99/F2, RIMS, 6 August 1999.

3. ISSUES FOUND WITH MACROTEXTURE PROGRESSION MODEL APPLICATION

Based on the lack of use of the HDM-4 macrotexture incremental model on the Transit New Zealand state highway network, a review on the performance of the incremental model was completed. The purpose of this review was to ensure that the macrotexture model was in line with current experience of Transit New Zealand.

The first stage of the review was to complete a detailed study of the HDM-4 macrotexture incremental model. The default values supplied (refer Table 2.1), were used as the basis for the review. The review found that the profile of the HDM-4 macrotexture incremental model did NOT align with experience on the state highway network. Figure 3.1 illustrates this issue.

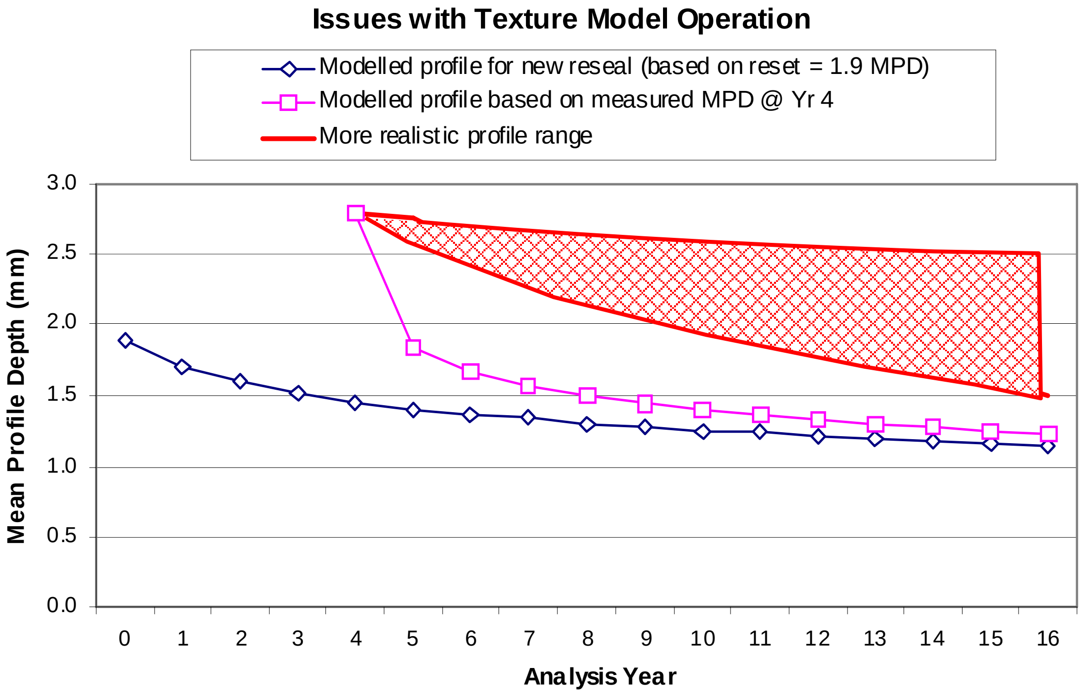

Figure 3.1 – HDM-4 Macrotexture model review outcome

The review found that the default macrotexture calibration values gave unrealistic seal lives for high traffic volumes. However, the major concern is in the form of the model in so far as it results in a substantial profile drop in the first modelled year, irrespective of whether the seal has just been applied in or is well bedded in (after a few years). This issue is illustrated in Figure 3.1.

Based on the findings of the review, various other methods of modelling surface macrotexture were investigated. The alternative methods were investigated on the basis of simplifying the model operation, and to ensure that the long-term modelled performance of macrotexture would be in line with Transit New Zealand asset management requirements. At the same time, the aim was to build on the fundamental principles of the absolute model, which was known to reflect New Zealand conditions.

4. MACROTEXTURE PROGRESSION MODEL VARIATIONS INVESTIGATED

4.1 OVERVIEW

Three variations of the macrotexture progression model were investigated. The review into the possible solution of the modelled performance of the macrotexture in New Zealand not only concentrated on the model operation, but also looked into the impact on the pavement modeller and the complexity of implementing the proposed changes into the pavement performance model. Three variations were investigated, being:

- Method 1 – Detailed Section Calibration of model coefficients using the current HDM-4 Incremental macrotexture model;
- Method 2 – National Section Calibration of model coefficients using the current HDM-4 Incremental macrotexture model; and
- Method 3 – Regional Calibration of macrotexture performance using a simplified Surface Age macrotexture model, based on absolute HDM-4 macrotexture model.

Each of these proposed methods had some advantages and disadvantages with their implementation into the pavement performance model system. Summaries of these are contained in Table 2.1.

Table 4.1 – Pros and Cons of Proposed Model Variations

Description	Advantages	Disadvantages
Method 1 – Section Calibration	• determine macrotexture issues at project level (treatment length / smallest aggregation) • macrotexture prediction is based on actual measured performance • ensure correct operation of complex macrotexture incremental model • minimal changes required to current model setup	• high amount of input/analysis required by users, • complex model operation • inappropriate once a treatment is applied since the best post treatment performance estimate would use a default
Method 2 – National Section Calibration	• minimal input required from users • minimal changes required to current model setup • section calibration based on absolute macrotexture model form	• complex model operation • national analysis used for determining performance slope (largest aggregation) • inability to recognise regional/section performance variation (i.e. potential flushed sites)
Method 3 – Regional Calibration	• easier to understand model operation • macrotexture deterioration is based on regional performance • user gains understanding of macrotexture performance on given network	• inability to recognise section performance variation (i.e. potential flushed sites), but note potential for development • changes required to model setup

Description	Advantages	Disadvantages
	• surface age contributor to macrotexture modelled performance, maintaining simplicity • ability to develop by adding additional terms whilst maintaining the simplicity (e.g. traffic)	

To determine the appropriateness of each proposed model method, a detailed performance comparison was completed. This investigation compared the predicted macrotexture model depth against the actual measured (observed) macrotexture depth, which is the measured value during the annual high-speed network survey using laser technology. The modelled macrotexture performance uses the measured macrotexture depth as the starting point and then applies the model operation to predict the macrotexture depth. The result of the comparison provided the basis for applying the appropriate macrotexture model into the pavement model for New Zealand.

As stated in the previous section, using the standard calibration factors for the HDM-4 incremental model was not providing realistic results, therefore no comparison was completed on the standard calibration values. Instead the comparison used the correct slice in time method of calibration for the HDM-4 incremental model.

The following sections describe each investigated method in more detail.

4.2 METHOD 1 – SECTION CALIBRATION OF INCREMENTAL MACROTEXTURE MODEL COEFFICIENTS

The first proposed method investigated was the calibration of the incremental macrotexture model coefficients (ITD, a_0) for each individual modelled section (treatment length). The calibration of the sections was performed using the slice-in-time method, based on the historical data. Performing this method of calibration required the following data requirements for each individual section analysed:

- Historical macrotexture data required for each section modelled;
- Surface age with respect to the historical macrotexture data; and
- Traffic information within the section, including the percentage of heavy vehicle traffic.

One of the main data issues required to be reviewed prior to determining the model coefficients was:

- The initial macrotexture reading has to be greater than the current macrotexture reading (i.e. the historic performance of macrotexture has deteriorated)

Figure 4.1 shows, in simplistic form, the process used in calculating the macrotexture model calibration coefficients for this method.

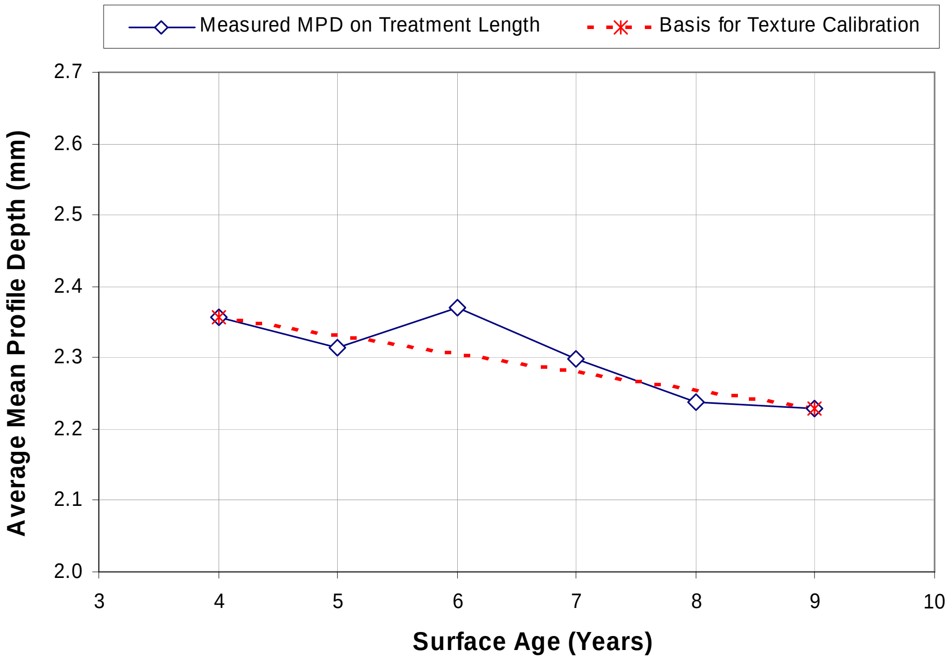

Figure 4.1 – Method 1 Section Calibration Principle (per Modelled Section)

From this historical investigated data, the macrotexture calibration coefficients were calculated for each modelled section. These coefficient values for each section were then applied in the HDM-4 incremental macrotexture model. The comparison of the section calibrated modelled performance versus the actual measured performance is discussed later.

4.3 METHOD 2 – NATIONAL SECTION CALIBRATION OF INCREMENTAL MACROTEXTURE MODEL COEFFICIENTS

The second proposed method investigated was the calibration of the incremental macrotexture model coefficients based on national macrotexture performance. This method approach was based on the historical measured performance of macrotexture on the generic seal type sections nationally. The determination of the calibration values was based on the entire high speed macrotexture datasets for the Transit New Zealand state highway network. These measured values were then used to determine the calibration factors based on the accumulated traffic on each section modelled (treatment length).

This method of model calibration was based on the calculation of the slope of deterioration for macrotexture based on the accumulated traffic (Net Equivalent Light Vehicles (NELV)) since the sealing date for various seal types and chip grades.

The application of the macrotexture incremental model used this determined performance slope from all the measured macrotexture data to determine the model coefficients for each modelled section, based on the seal type, chip grade and accumulated traffic. An example of this method principle is represented in Figure 4.2 below.

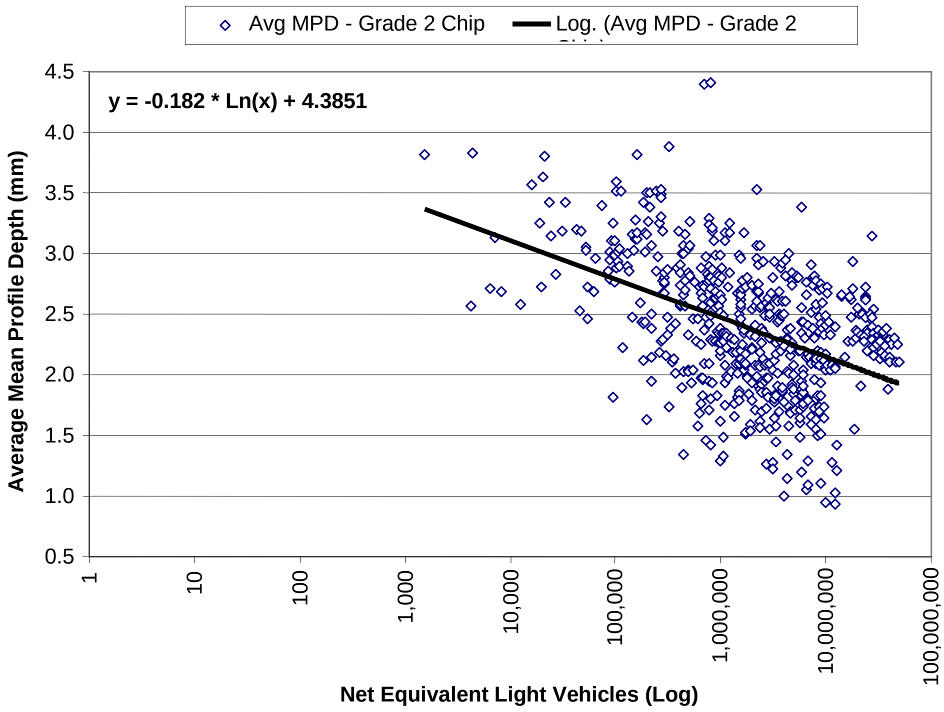

Figure 4.2 – Method 2 National Section Calibration (Grade 2 Chip Seal Example)

Performing the national section calibration of this method required the following data requirements for each section analysed:

- Surface age and material type;
- Texture depth of the current surface; and
- Traffic information (annual average daily traffic), including the percentage of heavy vehicle traffic.

Some of the data issues that needed to be resolved prior to determining the incremental calibration coefficients for each section were as follows:

- The measured texture depth needs to be representative of the current surface (i.e. no new seal should have been applied since the high speed survey)

Based on the above national analysis data, the calibration of the macrotexture model coefficients could be undertaken for each modelled section. The accumulated traffic, seal type and chip grade were determined for each section, and using the generic macrotexture performance slope for each chip type and grade, the calibration factors could be calculated for each section.

The following equations represent the process followed to determine the calibration coefficients for each section.

$$ITD = t_n + \Delta TD \log_{10}(NELV) \quad \ldots(3)$$

where t_n = current texture depth
NELV = {365.Y_n[(1-f)AADT+10fAADT]};
f = fraction of HCV's;
Y_n = surface age at date of latest macrotexture reading; and

ΔTD = generic macrotexture deterioration slope
ITD = Initial texture depth at time of surfacing

$a_0 = \Delta TD/ITD$ …(4)

where a_0 = regression coefficient

This method of determining the incremental calibration coefficients is based on the current HDM 4 absolute macrotexture model. The model operation for this method uses the current incremental macrotexture model. The comparison of the national section calibrated modelled performance versus the actual measured performance is discussed later.

4.4 METHOD 3 – REGIONAL CALIBRATION OF MACROTEXTURE PERFORMANCE

The third proposed method investigated was the regional calibration of macrotexture performance on any given network. This method is a departure from the current incremental macrotexture form currently used in the model. The method was developed from the HDM-4 absolute macrotexture model for determining texture depth, and using this expression to determine the annual change in macrotexture.

This method was put forward as a basis to encourage the users to better understand macrotexture performance on their given network. The user is encouraged to determine the macrotexture performance slope for each generic seal type and grade, similar to the process used in Method 2, looking at the accumulated traffic on the section.

Performing the calibration of this method is very similar to the Method 2 process, which required the following data for each section analysed:

- Surface age and material type;
- Texture depth of the current surface; and
- Traffic information (annual average daily traffic), including the percentage of heavy vehicle traffic.

Some of the data issues that needed to be resolved prior to determining the macrotexture performance slope for each section were as follows:

- The measured texture depth needs to be representative of the current surface (i.e. no new seal should have been applied since the high speed survey);
- Determining generic seal type groupings suitable for analysing macrotexture performance;

From the above data the user was encouraged to plot the current macrotexture mean profile depth (MPD) against the net equivalent light vehicles (NELV) on the road section. From this data the logarithmic trend was determined and the slope of the trend line is used as the value for the performance of the macrotexture on the seal type and grade investigated. An example of the principle of this method is represented in Figure 4.3.

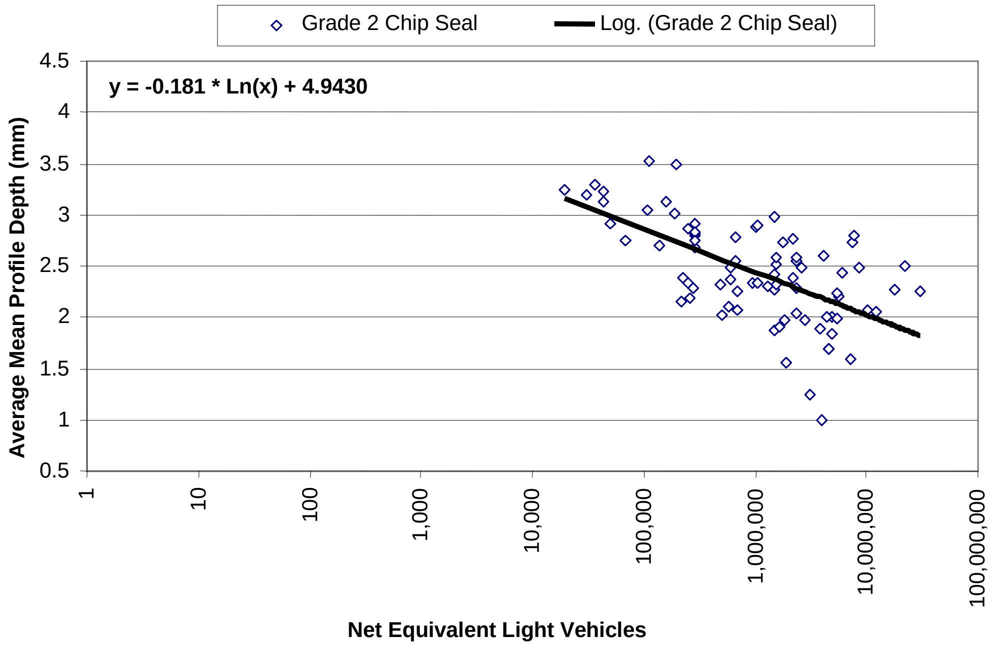

Figure 4.3 – Method 3 Regional Calibration Principle (Grade 2 Chip Seal Example)

Based on the above data and process the network macrotexture performance (slope) was then determined and used in a varied macrotexture model operation.

The developed macrotexture model used the surface age and determined performance slope of the macrotexture as variables. The comparison of the regional calibrated modelled performance versus the actual measured performance is discussed later.

4.4.1 Basis of Method 3 macrotexture model development

The simplified macrotexture model version is based on the absolute form of the HDM-4 model (equation 1). That is the predicted performance of the macrotexture on the road section will be based on the generic performance of macrotexture for the network, based on the seal type and chip size. The derivation of the proposed model is broken into the following logical steps. The basis of the model development is as follows:

$TD_{now} = -a_0 \log_{10}(NELV_{now}) + ITD$ …(5)
$TD_{next\ year} = -a_0 \log_{10}(NELV_{next\ year}) + ITD$ …(6)

The change in macrotexture is determined by the difference between these two equations:

$\Delta TD = TD_{next\ year} - TD_{now}$

which, solving the equations, simplifies to:

$\Delta TD = -a_0 \log_{10}((\text{surface age} + 1) / \text{surface age})$

where

surface age = the age of the top surface in years
a_0 = deterioration slope of macrotexture, for each generic seal type

We can see that the final expression used in Method 3 is easier to understand and has become independent of traffic or the existing macrotexture size. It is hoped that this expression will form the start of getting the model users to better understand and predict the performance of macrotexture on their road network.

Note the modelled works effects of applying a new surface, in terms of the macrotexture depth, need to be given close consideration for any of the above 3 methods. However, particularly for method 3, there is a need to introduce a traffic variable into the works effect reset given that traffic has been removed from the incremental expression. This reset aims to define, based on the absolute model, the expected macrotexture depth after one year of trafficking (rather than the very high value which might be expected immediately following resurfacing).

5. RESULTS OF MODIFIED MODEL COMPARISON

The comparison performed was of the macrotexture model predictions against actual measured macrotexture depth values, for a sample of road sections in New Zealand.

For each sample road section the appropriate macrotexture model coefficients were calculated and applied, based on each method investigated. The historic high speed data macrotexture measurements were obtained and used as the starting point for each section.

The process for determining the calibration for each section was as defined in the previous sections, therefore the sections used in the analyses were those with the suitable data for performing the comparison. Due to the data requirements of the Method 1 calibration, this reduced the sample size. It must be noted that no comparison was completed using the standard calibration values as defined in Table 2.1 due to the findings from the initial investigations.

Once the data for each section were obtained, three separate models were analysed for each proposed method, and a comparison was completed for each section against the observed (measured) macrotexture depth against the predicted macrotexture depth. Figure 5.1 shows how the comparison was performed.

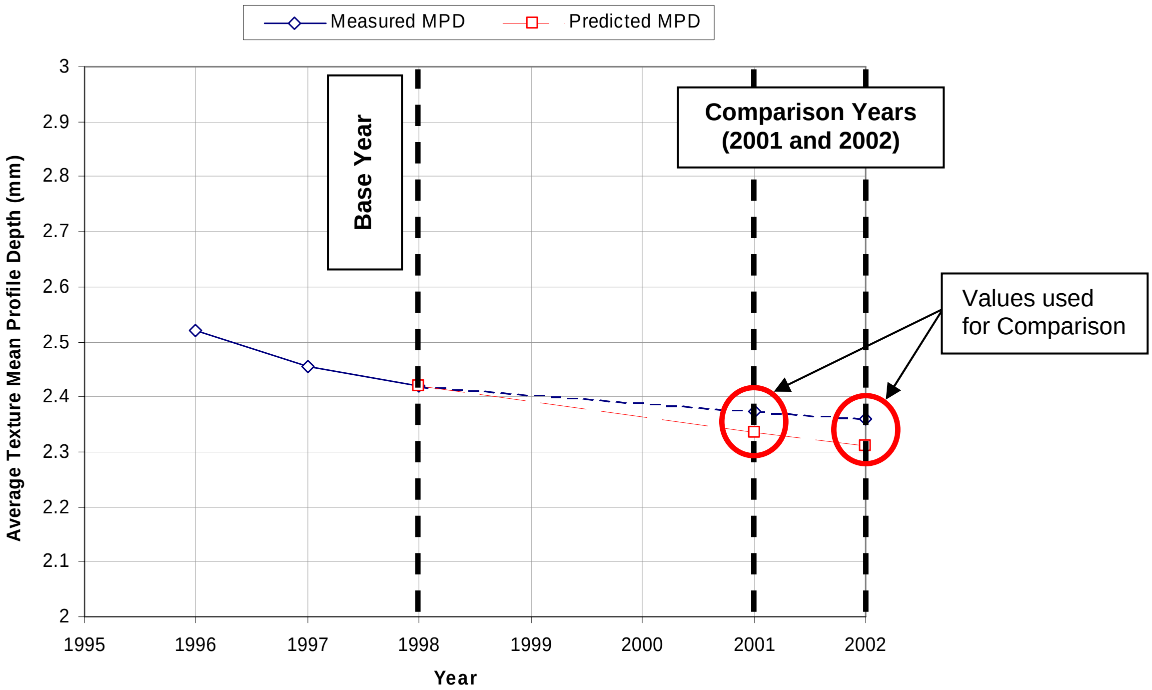

Figure 5.1 – Example of Analysis Comparison for Proposed Methods

For the purpose of reporting the results of the comparison completed, the road sections were aggregated into the generic seal types. This aggregation produced small datasets for some seal type groups (due to the data requirements for Method 1), and these have been removed from the results. Table 5.1 contains a statistical summary of the results from the comparison completed.

Table 5.1 – Results of macrotexture model variation comparison

Seal Type	Correlation (Slope)			Regression Coefficient (R^2)			Count of Analysed Sections	
	Method 1 (Section)	Method 2 (National)	Method 3 (Regional)	Method 1 (Section)	Method 2 (National)	Method 3 (Regional)	Method 1	Methods 2 & 3
Chip G2	0.886	1.041	1.080	0.521	0.495	0.304	78	93
Chip G3	0.961	1.044	1.083	0.726	0.785	0.757	163	190
Chip G4	0.939	1.040	1.112	0.724	0.922	0.867	17	22
Chip G5	1.076	1.060	1.142	0.649	0.272	0.381	21	34
AC	*0.849*	*1.142*	*1.154*	*-0.683*	*-0.111*	*0.182*	*4*	*9*
OGPA	*1.031*	*1.237*	*1.230*	*0.134*	*-0.424*	*-0.452*	*4*	*10*
All	**0.939**	**1.046**	**1.088**	**0.677**	**0.782**	**0.719**	**290**	**364**

Although it appears that Method 2 achieves the best correlation with the measured macrotexture values, this method is based on the complex incremental HDM-4 macrotexture model, and is complicated and time-consuming to determine the calibration coefficients. We can see that the simplified model used in Method 3 has performed to a similar standard in predicting the macrotexture depth when compared to the complex HDM-4 incremental macrotexture model.

Based on the results from the detailed comparison, and the simplified version of the model operation used in Method 3, the appropriate changes were incorporated into the pavement model setup used in New Zealand. To assist the users in using the refined macrotexture model, the model setup was supplied with realistic default deterioration values, based on the results from a national analysis, for each generic seal type.

6. EXPERIENCE WITH DEVELOPED MACROTEXTURE PERFORMANCE MODEL

To date the feedback received from the users of the refined macrotexture model in New Zealand has been very positive and supportive. However, no rigorous analysis has been carried out to ascertain issues in detail.

During the 2003 pavement performance modelling round for the Transit New Zealand state highway network, all users attempted to use the developed macrotexture model. In some cases it was found not to perform correctly, due to local issues that cannot be defined based on current attribute data available. These issues have been taken into consideration for the future development of the pavement management process relating to the data collection and modelled performance of surface macrotexture.

Below are an example of some of the local issues that were raised during field validation of the predicted macrotexture performance were:

- The build up of surface layers has resulted in the macrotexture to be flushed faster than predicted, and therefore the reduction in the macrotexture depth does not correlate.
- High temperatures during the summer months resulted in bleeding of the surface binder, with wheelpath tracking of the binder onto adjacent sections affecting the macrotexture depth.
- The measured macrotexture depth did not appear to correlate with the observed macrotexture depth for the section, and therefore the predicted performance of the macrotexture resulted in early intervention, that was not justified.

The feedback received from users within New Zealand with generic issues identified by representatives have formed the basis for the future improvements to the developed macrotexture model use within the New Zealand pavement performance model.

7. CONCLUSIONS ON DEVELOPMENT OF THE REFINED MACROTEXTURE MODEL

Notwithstanding the above issues, current thinking at Transit New Zealand based on the developments to date highlights two major areas on future model development. These are outlined below.

7.1 POTENTIAL FOR MODELLING

During the initial development of the macrotexture model, representatives from around the country were asked to identify the issues surrounding macrotexture performance. It was agreed that there are broadly 5 main issues of performance which drive asset management decisions related to surface macrotexture:

1. Surface Flushing
2. Chip Polishing
3. Bleeding
4. Detritus and
5. Texture Depth (MPD)

The drivers influencing each issue are detailed below, with the current view on the potential for inclusion in any pavement model.

Issue	Driver	Modelling potential
Surface Flushing	Number of seal layers (P) Pavement moisture Temperature (environment) Traffic loading (P) Turning traffic Construction/Application rate Bitumen viscosity Pavement strength (peak deflection) Life achieved of underlying surface (P) Surface age (P)	Currently not modelled. Potential for network level model using drivers indicated with (P). Environment/temperature might be used as a 'calibration' for any given locality/subnetwork.

Issue	Driver	Modelling potential
Chip Polishing	Traffic loading Turning traffic Polished stone value / aggregate hardness High horizontal forces Surface type / chip grade Broken faces	Currently considered that polishing issues should be 'designed out' when the surface is designed – so that it is not needed in a long term performance model.

Issue	Driver	Modelling potential
Bleeding	Temperature (environment) Bitumen type Traffic loading Surface age Texture depth	Usually an extreme development which develops on flushed surfaces. Probably not worth differentiating in a network level model.

Issue	Driver	Modelling potential
Detritus	Stock / carrier route Locality (wind borne contaminants) Rainfall (extreme) Geometry (brake dust, tyre wear) Junctions (diesel contaminants)	Local issue. Won't ever be modelled.

Issue	Driver	Modelling potential
General ageing /	Surface type / grade Number seal layers (P)	Basis of exisiting model but currently only age/ traffic and surface type is included.

deterioration of texture depth	Pavement strength (P) Surface age Aggregate hardness Construction / application rate	Potential for adding terms indicated with (P).

The view is that the model development will take the form of either simple additive or multiplicative terms in the refined model form as follows:

$$\Delta TD = -a_0 \log_{10}((\text{surface age} + 1) / \text{surface age}) + (\text{New terms})$$

It is again emphasised that any development of the deterioration model will need to go hand in hand with a view on how the works effect model is affected.

7.2 OUTPUT PARAMETER OF THE MODEL

Notwithstanding the above potential development areas, consideration needs to be given to the summary parameter for surface macrotexture which most closely matches the asset management decision process.

The current model attempts to predict average Mean Profile Depth (mm) but in many cases it is the degree of variation that drives decision making rather than the average value. Research needs to be carried out into whether a parameter, which gives more consideration to the *variance* of macrotexture (rather than the mean) would more nearly reflect our asset management decision making process.

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