THE CALIBRATION AND VALIDATION OF HDM PERFORMANCE MODELS IN THE GAUTENG PMS

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ABSTRACT

The newest generation pavement management system utilises pavement performance models to predict the pavement conditions and the consequences of inadequate funding. In Gauteng, the HDM pavement performance models developed by the World Bank were incorporated into the pavement management system. These models are used on an annual basis to determine the programme for maintenance and rehabilitation and to determine the funding need and fund allocation. It is well recognised that the HDM models require regional calibration in order to be effective. Since 1993, the performance of 36 calibration sections within the region were annually monitored and utilised to determine calibration factors.

This paper examines the validity of the models and calibration factors on the surfaced network of Gauteng. Observed performances of the network over the previous 10 years are compared to the predicted performances of the network, using the calibrated HDM models and the RMS condition data from 1990. The validity check was carried out on some 2268 km of provincial roads in Gauteng.

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1. INTRODUCTION

The Pavement Management System (PMS) of the Gauteng Provincial Government provides information required to maintain and manage the Road Network. One of the sub-systems of the PMS is the optimisation system (dTIMS), which is used to model future pavement deterioration and to determine optimal maintenance and rehabilitation programs for given budget constraints.

The estimated pavement performance is based on models developed by the World Bank and captured in the software HDM. In Gauteng these models were incorporated into the sub-system dTIMS. The models are universally applicable; but require regional calibration to be effective. To ensure local accuracy, 36 calibration sections have been set up in 1993 (*Rohde et al, 1993*) and have been carefully monitored annually by the province using a defined procedure (*Van Zyl, 1994*). The HDM prediction models were calibrated based on the observed deterioration of these 36 sections and the performance models are annually adjusted. The models as calibrated on these 36 sections are then used to model the entire network.

This paper examines the validity of the models and calibration factors on the entire surfaced road network of Gautrans. The observed performance of the network over the last 10 years is compared to the predicted performance of the network, using the HDM models and calibration factors.

2. BACKGROUND

The HDM performance models (*Paterson, 1987*) attempt to model the complex interaction between vehicles, the environment, the pavement structure and surface. Pavement performance is principally a function of the combined effects of traffic and weather. Traffic loads induce stresses and strains within the pavement layers. The magnitude of these responses depends on the load characteristics and the layer thickness and stiffness. Under repeated loads these stresses and strains cause fatigue in bound materials and deformation of all pavement layers. Weathering and solar radiation causes asphalt materials to age, become brittle and is therefore more susceptible to cracking and disintegration. Once cracking has been initiated, it increases in both intensity and severity and eventually potholes are formed. Open cracks further allow surface water to infiltrate the pavement layers hastening the process of disintegration, reducing the shear strength of the bound materials, thus increasing the rate of deformation under traffic. The cumulative deformation under

By 2001 the calibration coefficients listed in Table 2 were in use. These coefficients were used in the evaluation study.

TABLE 2: CALIBRATION FACTORS [illegible] STUDIES AND THOSE USED IN 2001						
CALIBRATION COEFFICIENT	DESCRIPTION	COEFFICIENTS RECOMMENDED AFTER ANNUAL CALIBRATION				2001*
		[illegible]	[illegible]	[illegible]	2000	
K_{ci}	Crack initiation	0.80	0.80[1] 0.31[2]	0.80	0.62[1] 0.95[3]	0.62 0.95
K_{cp}	Crack progression	0.10	0.30	0.30	0.26	0.26
K_{vi}	Ravel initiation	1.20	0.89	1.10	0.58	0.58
K_{vp}	Ravel progression	1.20	0.80	1.10	0.15	0.15
K_{pp}	Pothole progression	1.00	1.00	1.00	1.00	1.00
K_{rp}	Rut progression	0.50	39.0	14.80	0.30	3.00
K_{rp2}	Rut standard deviation progression	0.50	0.24	0.71	0.80	0.80
K_{ge}	Riding quality	0.349	1.00	0.90	0.38	1.00
K_{gp}	Riding quality	1.00	1.00	1.00	1.00	1.00

[1] Chip seals
[2] Slurry seals
[3] Asphalt overlay
* Coefficients in use by 2001 and used in the evaluation.

3. THE NETWORK WIDE MODEL EVALUATION

3.1 The Database Used for the Evaluation

In order to evaluate the calibrated performance models on the network the RMS database was used extensively.

Two sets of condition data were extracted from the PMS, namely data for 1990 and 1999. The historic data of 1990 was used as input and consists of traffic, visual evaluations, measured roughness and pavement structure detail of surfaced road sections. The input data (1990) and 10 year provincial maintenance data was used to model performance over a period of 10 years. The predicted condition by 1999 was then compared to the actual condition of the network according to the network observations and measurements in 1999.

Not all sections of the Gautrans surfaced network could be used for the purposes of this study and sections were filtered using the following criteria:

- Both 1990 and 1999 data had to be available.
- The year of latest reseal and pavement age of the section must be available on the database.
- Measured roughness data for 1999 had to be available.

wheel loads manifest in wheel path rutting. This in effect increases the pavement roughness, which in turn is further increased by weather and seasonal changes. Pavement roughness, the main indicator of pavement service, is therefore the result of a chain of distress mechanisms and the combination of various modes of distresses. This complex interaction between various distress types and the environment is reflected in the pavement performance models used in HDM.

The HDM performance models (*Watanatada et al, 1985*) have been derived for five modes of distress as defined in Table1. The complex interaction of these variables is graphically shown in Figure 1.

[illegible] MODELLED BY HDM	
[illegible]	Description
All Cracking	The area of narrow and wide cracking (greater than 1 mm in width) as a percent of the total carriageway area.
Wide Cracking	The area of wide cracking (greater than 3 mm in width) as a percent of the total carriageway area.
Ravelling	The total area ravelled as a percent of the total carriageway.
Potholing	The total area of open potholes (minimum depth of 25 mm and diameter of 150 mm) as a percent of the total carriageway.
Rutting	The mean and standard deviation of rut depth as measured in mm under a 1.2 m straightedge.
Road Roughness	Roughness in HRI or QI units as defined by Sayers et al (1986)

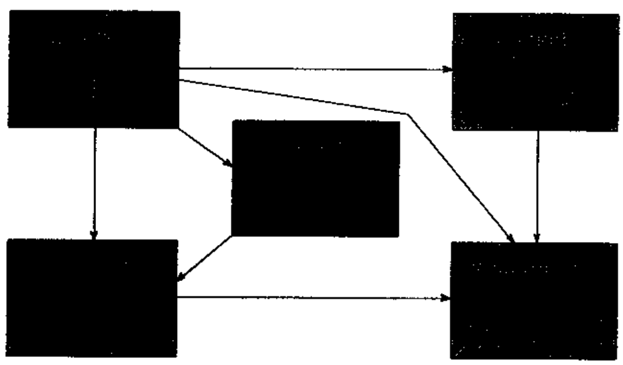

Figure 1: Interaction of the Distress Types as Modelled in HDM

The HDM performance models are captured in a series of relationships. To allow for local calibration each relationship contains a calibration coefficient or scaling factor. A significant effort has been made in Gauteng to establish coefficients which will ensure accurate predictions.

The monitored performance of the 36 long-term pavement performance calibration sections was used to annually adjust the calibration factors. (PNBS Consortium, 1993, 1996, 1997, 1999, 2002). Each year more data is available for calibration purposes and subsequently the calibration factors led to improved performance predictions after every calibration analysis.

- Sections without recorded maintenance had to deteriorate by at least 5% in overall condition from 1990 to 1999. This filter ensured that a section where maintenance was done, but probably not recorded, was excluded.
- The seal age had to be 20 years or less. This filter excluded 'over achievers' and/or 'questionable data' from the list. According to the PMS data 278 km of surfaced roads have seal ages greater than 20 years and thus excluded.
- In the RMS database some sections not maintained during the 10-year analysis period showed improved performance or insufficient deterioration according to engineering judgement. A total of 619km of roads were excluded for this reason.

The total length of the network was 3540 km according to the 1990 PMS data, and after setting the above criteria 2268 km (64 %) of the network was filtered for use in this study. Table 3 contains the detail on the portions of the network excluded from the evaluation.

[illegible]	[illegible]
Network from 1990 visuals	3 540
Excluding sections:	
With insufficient 1999 data	98
With insufficient seal and pavement ages	147
With no roughness data in 1999	27
With less than 5% VCI deterioration from 1990 to 1999	277
With seal age of more than 20 years	101
Which show improved performance or insufficient deterioration although no record of maintenance was found over the 10-year analysis period	619
Network selected for use in this analysis	2 268

3.2 The Evaluation Methodology

The analysis was completed using the dTIMS optimization software with the customized and calibrated performance models for Gautrans. The selected roads of historic data for 1990 was imported into the dTIMS software and the calibrated HDM performance models were utilized to predict the pavement performance after 10 years (1999). Maintenance was simulated according to the year and maintenance type recorded in the PMS maintenance database. The predicted performances of the selected roads for 1999 were exported and compared to the observed values for 1999. Figure 2 outlines the analysis procedure.

Step 1: Obtain the 1990 Condition from the RMS;
Step 2: Use RMS traffic, strength, condition, and pavement composition to predict 1999 condition using the calibrated models;
Step 3: Compare predicted 1999 condition to Observed 1999 condition from RMS.

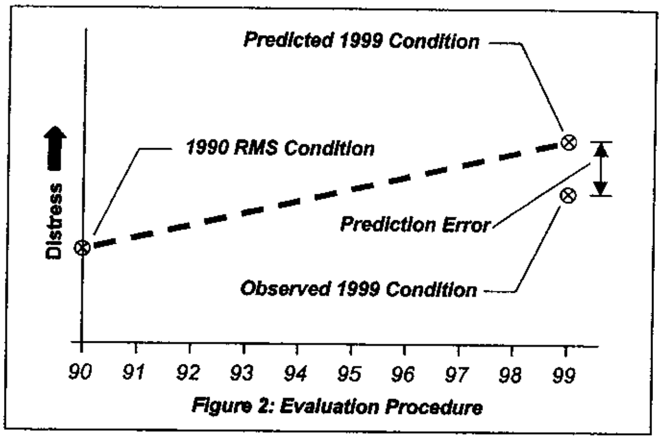

Figure 2: : Evaluation Procedure

3.3 Results

During the initial stages of the analysis it became evident that the outcome of the network performance depends heavily on whether the road sections were maintained during the 10-year analysis period or not. Thus, the network selected for use in this study was divided into two groups and the results for each group were assessed separately. The predicted performance of each group is compared to the actual (observed) performance from the 1999 data and questionable performances can more easily be examined according to the validity of the data and the maintenance history. The two groups are described in Table 4.

[illegible]	[illegible]	[illegible]
Maintained Roads	All road sections that were maintained during the analysis period of 1990 to 1999. Maintenance actions includes reseals and rehabilitations.	1943 (86 %)
Roads without Recorded Maintenance	All road sections with no maintenance recorded for the analysis period.	325 (14 %)

The accuracy of the calibrated models was assessed by comparing the difference in predicted and observed (actual) performance over a 10 year period. The assessment of the model accuracy over 10 years was established in terms of the:

1. cracking percentage,
2. rut depth,
3. roughness and
4. condition index.

3.3.1 Cracking

The difference between predicted and measured cracking over a 10 year prediction is shown in Figure 3 through Figure 6. Figure 3 shows the comparison for the maintained group of roads (1 943 km). The results are good with approximately 50% of the group showing predicted cracking values within 2% of the observed values. 80% of the predicted values were within 8% of the actual observed values.

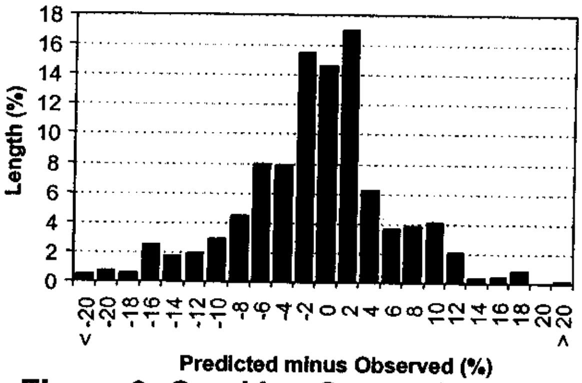

Figure 3: Cracking Comparison on Maintained Roads

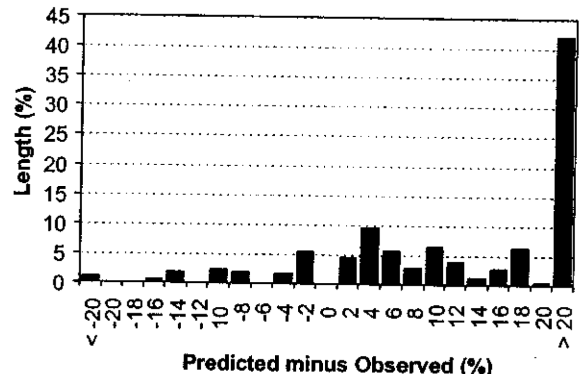

Figure 4: Cracking Comparison on Roads without Recorded Maintenance in 10 years

For the roads without recorded maintenance the cracking on the majority of sections were over-predicted (see Figure 4). It should be noted that no records were available on these sections for routine maintenance, such as crack sealing and the over-prediction of cracking could be a result of unrecorded routine maintenance in the PMS. The percentage cracking was over-predicted by more than 20% on 40% (138 km) of the roads. The over-prediction on the roads with unrecorded maintenance could therefore be due to sections with slow crack progression and/or inaccurate maintenance records.

Figure 5 depicts the findings for all roads. Overall 42% of roads showed predicted values within 2% of the observed values and 74% of the sections showed predicted values within 8% of the observed values.

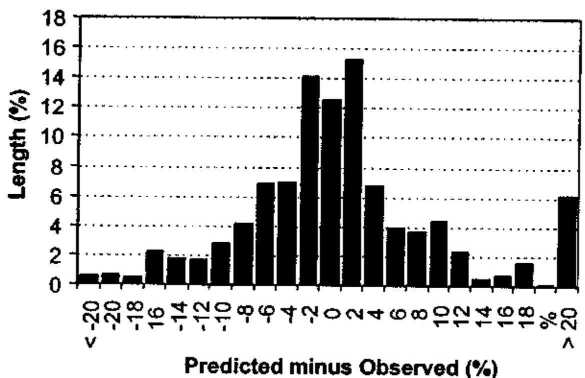

Figure 5: Cracking Comparison on All Roads

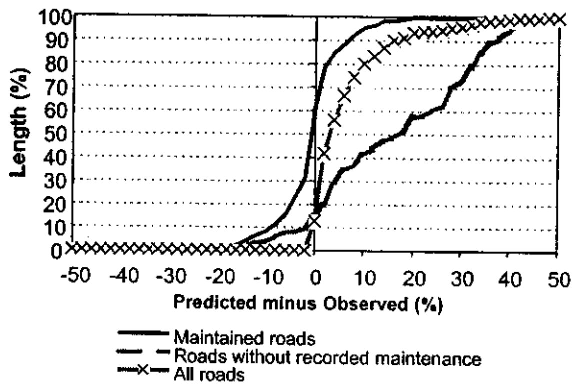

Figure 6: Cracking: Cumulative Predicted minus Observed

Figure 6 shows the cumulative distribution of the error (predicted minus observed). From this plot it seems that on average the models are slightly conservative. For the maintained group of roads the average cracking is accurate. For all roads the average prediction is 5 % higher that the observed.

3.3.2 Rutting

The calibration factor for rut depth progression was calculated as 0.5 in 1994, 14.8 in 1996 and 39.0 in 1997 and 0.30 in 2000. This fluctuation is an indication that the rut depth progression model needs further investigation. By 2001 the provincial RMS was using a rut calibration coefficient of 3.0.

Figure 7 through Figure 10 show the comparison of prediction versus observed values using a calibration factor of 3.0. As shown in Figure 7, 30 % of all predictions for roads with maintenance records were within 1 mm of the observed values. Figure 8 shows that rutting on sections with no recorded maintenance are under-predicted.

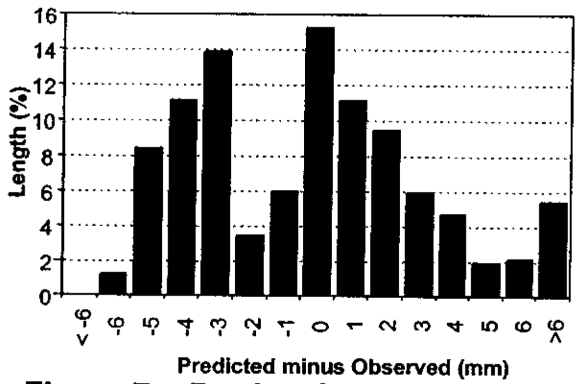

Figure 7: Rutting Comparison on Maintained Roads

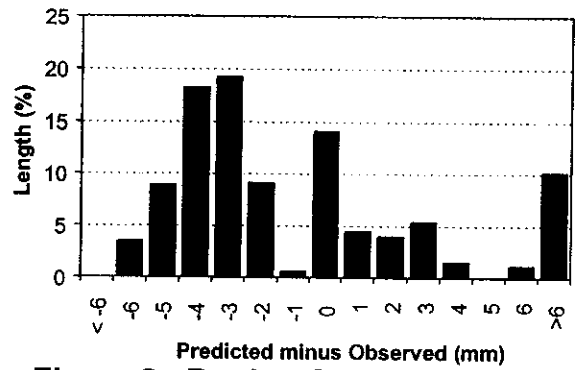

Figure 8: Rutting Comparison for Roads Without Recorded Maintenance Over 10 Years

Figure 9 and Figure 10 show an even spread of over-predictions and under-predictions on all the roads. It appears that the model is accurate on average but a fairly large distribution indicates that the model is not performing accurately.

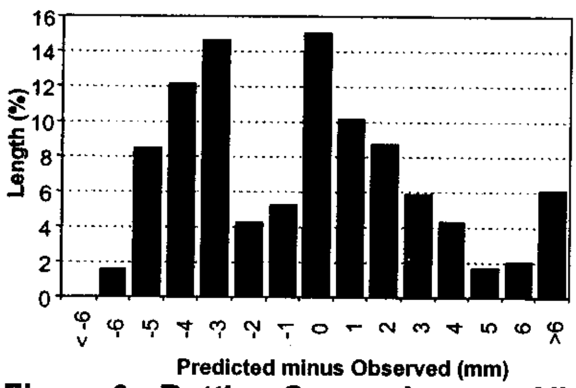

Figure 9: Rutting Comparison on All Roads

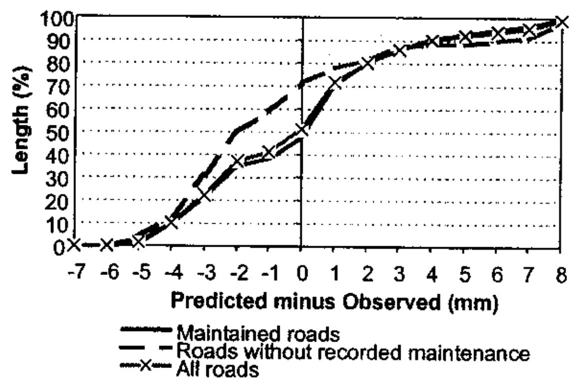

Figure 10: Rutting: Cumulative Predicted minus Observed

3.3.3 Roughness

Roughness is an important factor when calculating savings in road user costs and for the calculation of the condition index using the performance models of HDM. The calibration factors listed in Table 2 were used in the assessment.

Approximately 80 % of all predictions for maintained roads were within 0.5 HRI of the actual observed values. The frequency of predicted minus observed values are slightly skew with the majority of prediction smoother than the observed values. Overall the predictions can be rated as good (see Figure 11).

Figure 12 shows a major proportion (90%) of the predictions for roads without recorded maintenance were within 0.5 HRI of the observed values.

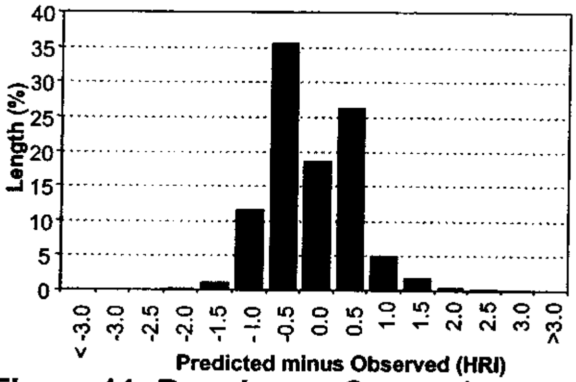

Figure 11: Roughness Comparison on Maintained Roads

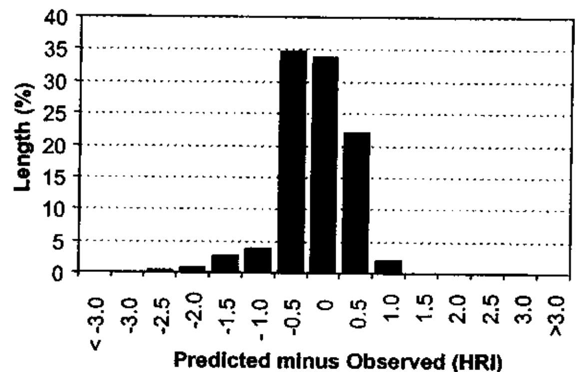

Figure 12: Roughness Comparison on Roads without Recorded Maintenance Over 10 Years

Roughness prediction is similar for the two groups of roads investigated by this report and correlations between the predicted and observed values are very good. The error between the predicted and observed values was less then 0.5 HRI on 82 % of the investigated roads (see Figure 13).

Figure 14 shows a mean value of approximately 0 HRI for the predicted minus the observed value on all the roads. The predictions can be rated as good.

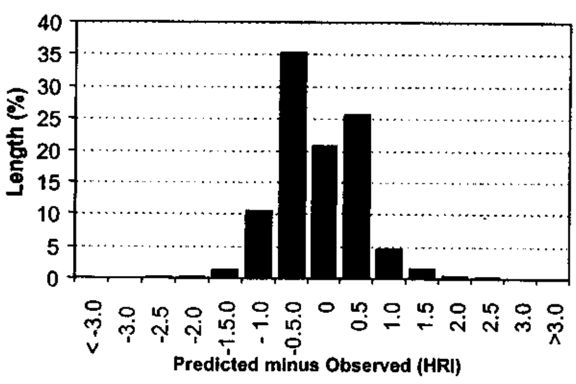

Figure 13: Roughness Comparison on All Roads

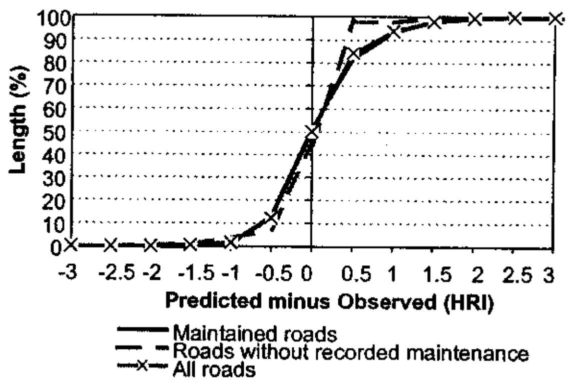

Figure 14: Roughness: Cumulative Predicted minus Observed

3.3.4 Condition Index

The condition index is a composite index calculated from the HDM prediction models for cracking, rut depth, potholes and roughness. Observed values for condition index were calculated using the observed distresses from the 1999 visual evaluations. The predicted values for cracking, rutting, roughness, etc., were used for the calculation of the predicted condition index for 1999.

Maintained roads (Figure 15) showed good results with 65 % of the predictions within 10 % of the observed condition value.

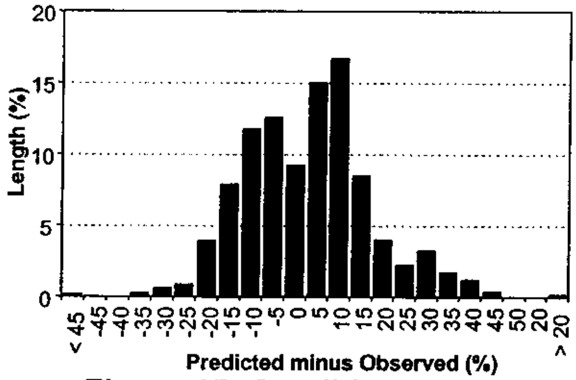

Figure 15: Condition Index Comparison on Maintained Roads

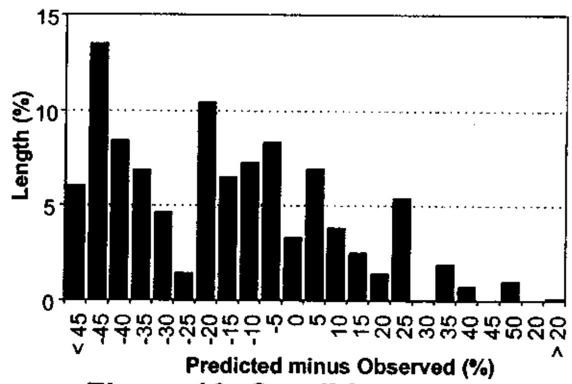

Figure 16: Condition Index Comparison on Roads without Recorded Maintenance Over 10 Years

The variability of the predicted minus observed condition indices is much higher for roads with no recorded maintenance, (see Figure 16). This is a result of the variability in the predictions for the distresses used to calculate the condition index where cracking is over-predicted for this group of roads. The prediction of condition for the roads with no recorded maintenance is therefore unsatisfactorily although this could be a result of unrecorded maintenance data and/or sections that show slower deterioration than the majority of the network.

According to Figure 17, approximately 60% of all predictions were within 10% of the observed values. This comparison is good and an improvement in any of the previous individual distress predictions will improve the prediction of the condition index.

Figure 18 shows the mean value for all roads at approximately 0 % for predicted minus observed values. Roads without recorded maintenance predicted conditions better (higher) than the observed values for almost 80 % of the network. Overall (all roads) the predictions for condition can be rated as good.

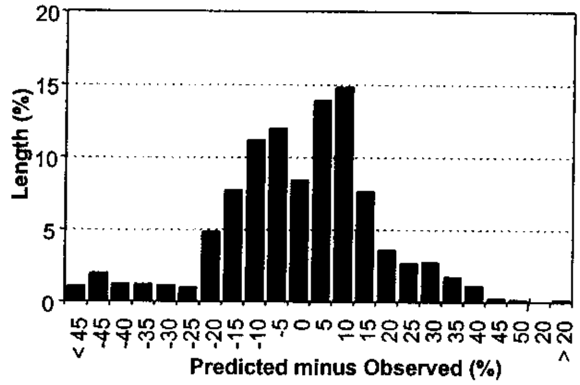

Figure 17: Condition Index Comparison on All Roads

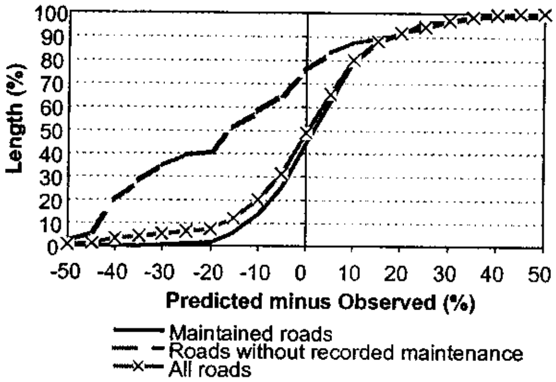

Figure 18: Condition Index: Cumulative Predicted minus Observed

3.3.5 Condition Distribution

Annually the condition of the paved roads in Gauteng is measured against the conditions in previous years using the condition distribution graph. The condition distributions of the observed and predicted values, over the last 10 years are given in Figure 19. The bars illustrate the bins for the predicted values of condition and the lines illustrate the bins for the observed values of condition index.

The correlation of predictions vs. observations for 1999 is good.

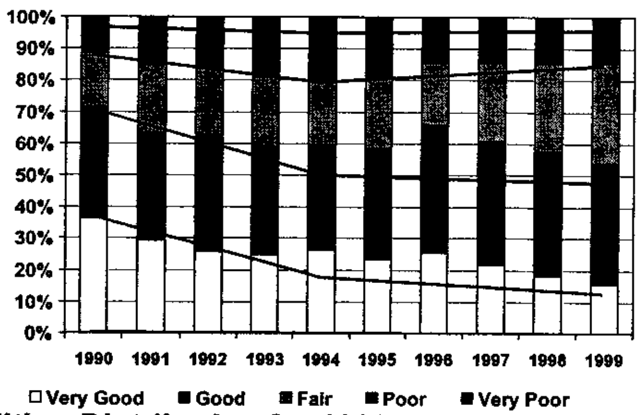

Figure 19: Condition Distribution for 1990 to 1999, Predicted (Bars) versus Observed (Lines)

4. OVERALL FINDINGS

In the investigation the calibrated PMS models were used on the Gauteng road network and the theoretical prediction of condition over a 9 year period was compared with actual deterioration.

During the investigation it became evident that the level of accuracy is highly dependent on whether road sections were maintained during the 10-year analysis period or not. All road sections selected for this study were divided into two groups, namely road sections with recorded maintenance and road sections without recorded maintenance. A total of 2268 km (64% of the network) of the 1990 paved road network of Gautrans was selected for investigation. Sections were excluded for the following reasons; insufficient data, improved condition or insufficient deterioration without recorded maintenance.

Sections with recorded maintenance data showed a good degree of correlation in terms of cracking progression. Rut depth and roughness progression also showed very good comparisons. The accuracy of the rutting model can probably be improved. 65% of the predictions for the condition were within a range of 10% of the condition index calculated from the observed values. On average all the models gave satisfactory comparisons.

The predicted condition indices showed a high variability of predicted versus observed values for **sections with no recorded maintenance**. The condition index is dependant on roughness, cracking and rutting and the results for these distresses varied from over-predictions for cracking to under-predictions for rutting. Overall the predicted values for the condition index were calculated as being in a better condition than the observed values.

At completion of this study the following recommendations were made:

1. Utilize the calibrated HDM cracking model. Especially on roads with good maintenance records the predictions are satisfactory.
2. Use the calibrated HDM rutting model but consider changing or improving the model. The current predictions are not satisfactory and there are too many significant over and under-predictions.
3. The roughness model is performing satisfactory.
4. The overall condition indices are being predicted satisfactorily.
5. The network condition distributions predicted using the calibrated models are satisfactory and correlate well with observed trends.

Based on the performance of the 36 calibration sections and a network wide 9 year comparison on the Gautrans network it is evident that the HDM models with the following calibration coefficients are resulting in satisfactory performance predictions. This finding improved the credibility of system decisions and output. Table 5 list the calibration coefficients verified in this evaluation.

Table 5: Calibration Coefficients		
Calibration Coefficient	Coefficient Description	2001
K_{ci}	Crack initiation	0.62 0.95
K_{cp}	Crack progression	0.26
K_{vi}	Ravel initiation	0.58
K_{vp}	Ravel progression	0.15
K_{pp}	Pothole progression	1.00
K_{rp}	Rut progression	3.00
K_{rp2}	Rut standard deviation progression	0.80
K_{ge}	Riding quality	1.00
K_{gp}	Riding quality	1.00

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