PAVEMENT PERFORMANCE MODEL FOR FEDERAL ROADS

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Abstract: Malaysia has a matured flexible pavement road network owned by the public sector called the Federal Road. The 14,757 Km road networks are providing excellent service to road users for interstate movement. The industrialisation process of the country demands for more movements at higher load to transport products to their destination within the country sites. Over the years, The Malaysian Government through J.K.R (The Public Works Department) has spent huge amount of money to ensure the roads are in good operating condition. In year 1998 about RM 139 mil (USD 36.5 mil) is being allocated for the maintenance of the Federal Roads, the allocated fund is very much below than what is required (RM 369mil) to maintain the Federal Roads (*www.piarc.lcpc.fr*) thus prioritisation become crucial. Future performance of the pavement is required to anticipate maintenance strategy to prevent further deterioration, as it would cost more if it were not repaired at the right time. Pavement performance modelling is an important tool used by pavement managers in decision making in prioritisation and budgeting for maintenance work. The aim of this study is to develop pavement performance models for Federal Roads using available data provided by J.K.R.

Keywords: Flexible Pavement Performance Models, Rutting

1. INTRODUCTION

Pavement deterioration process is complex and involves not only structural fatigue but also involves many functional distresses of pavement. It result from the interaction between traffic, climate, material and time. Deterioration is used to represent the change in pavement performance overtime. The ability of the road to satisfy the demands of traffic and environment over its design life is referred to as performance. Due to the great complexity of the road deterioration process, performance models are the best approximate predictors of expected conditions.

There are many parameters that need to be acquired to successfully predict the rate of pavement deterioration. Among others is annual average daily traffic (AADT), percent of trucks, drainage, pavement thickness, pavement strength in term of structural number (SN) or CBR value and mix design parameters.

The objective of this study is to establish simple practicable pavement performance model for ***network level*** of the Malaysian Federal Road where rutting is the focus of the measurement. The model shall incorporate relevant variables such as pavement condition, pavement strength, traffic loading and pavement age. Statistical analysis by mean of multiple linear regressions were conducted to test and examine the data as well as to develop the model.

1.1 Rutting and Possible Influencing Factors

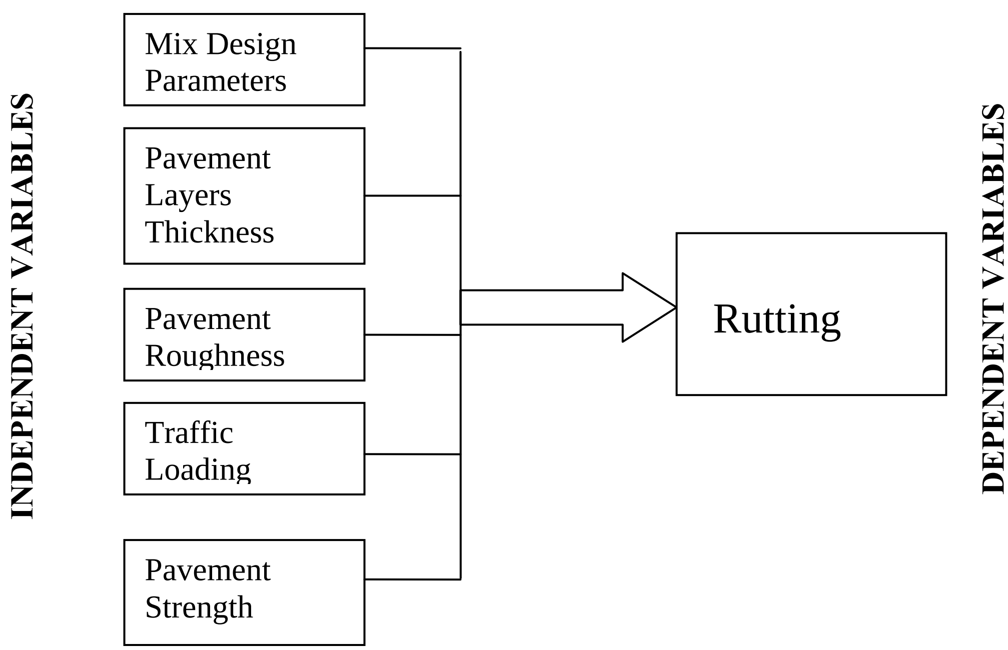

Figure 1: Among Factors Influencing Pavement Rutting in Relation to Modelling

1.1.1 Rutting

One of the most common distresses on flexible pavement is surface rutting. Rutting is defined as longitudinal deformation or depression in the wheel paths, which occur after repeated application of axle loading. It may occur in one or both wheel path of a lane. It can be categorised as either traffic load associated deformation, wear related or the combination of both. The causes include traffic load, age of pavement and deformation of the entire pavement structure or instability in the form of one or more pavement layers as explained by Figure 1. In engineering term the deformation occur due to the critical strain experience by the top layer of subgrade as shown in Figure 2.

Rutting make the road surface uneven, patchy and bumpy and subsequently affects the handling of vehicles which can lead to safety problems. The unit use to measure rut depth is millimetre (mm) .

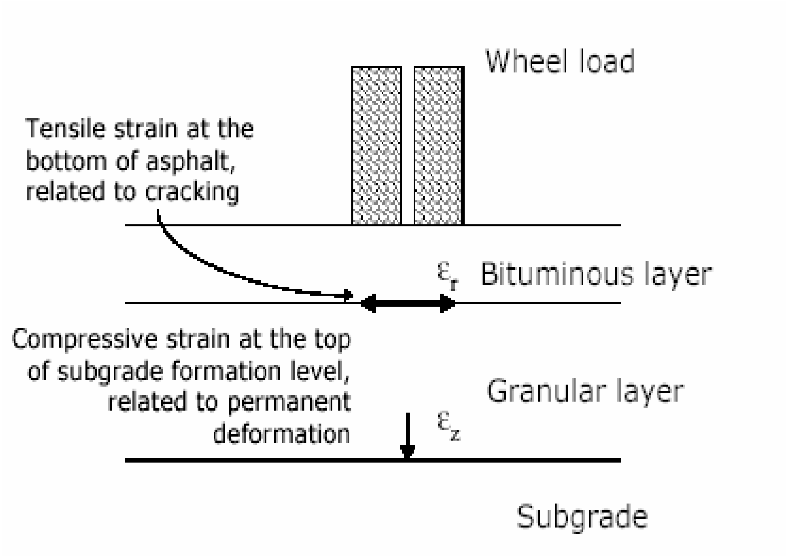

Figure 2: Vertical Critical Strain (ε_z) in Pavement Layers

1.1.2 Mix Design Properties

Mix design properties are important in resisting permanent deformation under traffic load. In particular, flow and consolidation on hot mix asphalt (HMA) design will affect the deformation of the pavement surface. Asphalt content that provides stiffer asphalt cement at higher temperature would be able to improve rutting resistance. Aggregate type, gradation and shape also affect pavement deformation; for example cubical and angular with rough surface texture aggregate will contribute to strong aggregate interlock.

1.1.3 Pavement Thickness

Pavement layers and its thickness plays very important role in distributing wheel load to underlying subgrade. More layer or thicker pavement structure would mean least load being distributed to the subgrade and subsequently reduce vertical critical strain.

1.1.4 Pavement Condition (Roughness)

Present pavement condition state will influence it future performance. As pavement surface deteriorate over time, one distress condition would add up to another distress condition if no appropriate action taken to correct the initial condition. This would lead to more costly maintenance. This paper use pavement roughness as pavement condition measure in mm/m.

1.1.5 Traffic loading

The magnitude and number of wheel load passes is the main agent to deteriorate the pavement surface. Heavy and medium trucks normally fitted with large axles would significantly damage the surface as well as deform the underlying pavement layers permanently. Normally medium truck loading is used to predict pavement deterioration and referred as annual average daily traffic (AADT), it is measured in vehicles per day (vpd).

1.1.6 Pavement Strength

Another significant element that resists permanent pavement deformation is pavement strength. The pavement can be measured in term of CBR (California Bearing Ratio) or SN (Structural Number).

2. Data Collection and Sampling

Data are being source from Institut Kerja Raya Malaysia (IKRAM) and JKR, these data are categories as historical and pavement survey data. Historical data includes the pavement thickness and pavement strength index while the survey data are traffic load and pavement condition such as rutting and roughness measurement. Initially it was the intent to use age of pavement as one of the independent variable; however data on pavement age was not available.

The data population of this study is sections of the Federal Road in Peninsular Malaysia. The division of the road sections is entirely depending on J.K.R. Total sample size gathered from J.K.R was 137 cases out of which 102 for Federal Road Route 1 (74.4%), 20 for Federal Road Route 8 (14.6%), 10 for Federal Road Route 9 (7.3%) and 5 for Federal Road Route 26 (3.7%). Out of these samples, only 42 samples were selected for the further analyses.

Table 1: Samples of Data

Ser	Section Name	Length (Km)	Rut Depth (mm)	Roughness (mm/m)	MT AADT (vpd)	SN
1	001035000-001035999-1	1	9.20	4.37	39846	3.79
2	001036000-001036999-2	1	5.13	3.02	19923	3.41
3	001036000-001036999-3	1	6.37	3.52	19923	3.41
4	001093000-001097999-1	5	9.31	4.08	13242	4.52
5	001122000-001136999-1	15	3.09	1.98	10626	5.69
6	001137000-001138999-1	2	4.03	2.73	10626	4.16
7	001155000-001156999-1	2	4.83	3.36	10626	3.98
8	001157000-001160999-1	4	3.39	2.19	10317	4.97
9	001197000-001208999-1	12	3.11	1.92	10804	5.32
10	001270000-001270999-1	1	6.75	2.04	13480	2.95
11	001318000-001319999-1	2	6.05	2.53	39718	4.20
12	001416000-001416999-1	1	5.35	2.29	45631	4.51
13	001417000-001437999-1	21	3.17	1.84	8729	5.08
14	001438000-001441999-1	4	1.96	1.98	8729	5.06
15	001444000-001446999-1	3	2.13	1.87	8729	5.67
16	001463000-001468999-1	6	3.23	1.44	9284	5.35
17	001517000-001518999-3	2	3.13	2.16	5621	5.30
18	001539000-001539999-2	1	3.18	2.93	6123	7.72
19	001539000-001539999-3	1	3.55	3.35	6123	7.72
20	001580000-001581999-1	2	6.26	3.08	24135	4.87
21	001610000-001611999-2	2	10.13	2.65	21618	3.51
22	001620300-001621999-2	2	4.18	2.20	10001	6.49
23	001623000-001633999-1	11	5.14	2.75	17681	4.74
24	001626000-001628999-2	3	4.23	2.27	8841	3.73
25	001674000-001677999-1	4	4.46	2.74	12166	5.73
26	001853000-001855999-2	3	4.89	4.37	15308	5.46
27	001856000-001857999-3	2	5.85	3.02	15308	4.39
28	008000000-008004999-1	5	3.76	3.12	9637	5.99
29	008015000-008040999-1	26	5.00	3.16	9291	4.51
30	008043000-008045999-1	3	3.59	3.03	5817	6.25
31	008115000-008118999-1	4	2.56	2.03	5485	6.85
32	008119000-008158999-1	40	3.35	1.85	5485	5.63
33	008305144-008306999-1	2	2.08	2.06	6508	7.56
34	008307877-008311999-1	5	3.13	1.98	6508	7.56
35	008312000-008331999-1	20	3.01	1.97	6508	7.56
36	008332000-008339999-1	8	3.69	1.82	13606	7.56
37	009045000-009046999-1	2	4.98	2.36	13995	3.40
38	009047000-009052999-1	6	6.42	3.01	13027	1.93
39	009053000-009054999-1	2	5.75	2.47	13027	2.56
40	009058000-009059999-1	2	5.60	2.74	13027	2.62
41	026000000-026004999-2	5	2.43	1.73	5740	7.07
42	026000100-026004999-3	5	2.57	1.49	5740	7.35

3. Developing The Pavement Performance Models

3.1 Regression Analyses and Statistical Tests

Several regression analyses were conducted on to the data set. The initial analyses are meant to see the response of among variables and statistical tests were performed on the developed models namely the coefficient of determinant and level of significant. The main tests conducted to validate the models are:

a. Coefficient of determinant (R^2).
b. Level of significant at 0.05
c. The standard error of the estimate.
d. The heteroscedasticity of variance.
e. Normality tests.

The coefficient of determinant (R^2) and level of significant at 0.05 are the main criteria to be achieved for the selection of good model. Coefficient of determinant (R^2) describes the strength of an association between variables. An association between variables means that the value of one variable can be predicted, to some extent, by the value of the other. A correlation is a special kind of association: there is a linear relation between the values of the variables.

The standard error of the estimate is a measure of the accuracy of predictions made with a regression line. The regression line seeks to minimise the sum of the squared errors of prediction. A model with lowest value of standard error of estimate is preferred.

One of the main assumptions for the ordinary least squares regression is the homogeneity of variance of the residuals. If the model is well fitted, there should be no pattern to the residuals plotted against the fitted values. If the variance of the residuals is non-constant, then the residual variance is said to be "heteroscedastic." There are graphical and non-graphical methods for detecting heteroscedasticity. In this paper, non-graphical method is use i.e. Durbin Watson Statistic (D value), D value range from 0 to 4 where best value in 2 (or close to 2) to show that the constant variance is homoscedatisity.

Final test on the models is normality test; a normality test is a statistical process used to determine if a sample or any group of data fits a standard normal distribution. A normality test can be performed mathematically or graphically. Normal distribution is the spread of information where the most frequently occurring value is in the middle of the range and other probabilities tail off symmetrically in both directions. Normal distribution is graphically categorized by a bell-shaped curve, also known as a Gaussian distribution or the data plot along the straight line in the Probability Plot (P-P). For normally distributed data, the mean and median are very close and may be identical. This paper use P-P to test the normality.

3.2 Results

Regression # 1 with Constant

After tabulating the data, first regression analysis was run using SPSS by stepwise method. Rut depth was assigned as dependent variables where as roughness, AADT and SN were assigned as independent variables. Significant level (α) of 0.05 was set. It is appear that the following models were suggested:

Table 2: Initial Regression Models With Constant

Dependent Variable: Rut Depth

Model	Constant	SN	Roughness	AADT	Std Err	R^2
1	8.620 (0.000)	-0.796 (0.000)	-	-	1.477	0.426
2	4.473 (0.000)	-0.608 (0.000)	1.243 (0.000)	-	1.217	0.620
3	3.439 (0.003)	-0.473 (0.001)	1.046 (0.000)	6.373×10^{-5} (0.005)	1.112	0.691

- Value of Durbin Watson statistic (mean constant variance) = 1.711
- Value in bracket is the significant level value (α)

The main purpose for this initial analysis is to observe the response of the variables while identifying the potential model. Constant was included in this model. From the analysis Model # 3 appear to be the best among them; it can be written in the following form:

$$\textbf{Rut Depth} = 3.439 - 0.473(SN) + 1.046\,(Roughness) + 6.373 \times 10^{-5}\,(AADT) \qquad (1)$$

Regression # 2 without Constant

Using the same data and regression technique, another regression was run. However this analysis does not include constant. The following results were obtained:

Table 3: Second Regression Models With Constant

Dependent Variable: Rut Depth

Model	Roughness	AADT	Std Err	R^2
1	1.762 (0.000)	-	1.494	0.909
2	1.281 (0.000)	9.359×10^{-5} (0.000)	1.272	0.936

- Value of Durbin Watson statistic (mean constant variance) = 1.877
- Value in bracket is the significant level value (α)

In this analysis the R^2 and Durbin Watson value seem to be good; however this model dropped the SN variable. Since SN value is an important indicator for pavement strength, it is essential that SN value to be included in the model, however Table 4 suggest model # 2 as the best model and written as follows:

$$\textbf{Rut Depth} = \mathbf{1.281\ (Roughness) + 9.359 \times 10^{-5}\ (AADT)} \qquad (2)$$

<u>Regression # 3 Using Transformed Variables Without Constant</u>

Since SN is expected to be included in the model to represent the strength of the pavement in question, transformation of variables is a possible solution. Once transformation of variables is done, another regression analysis was conducted at significant level (α) of 0.05 and without constant. The following results obtained:

Table 4: Third Regression Models of Transformed Variables without Constant

Dependent Variable: Rut Depth

Model	Roughness	AADT	SN^2	Std Err	R^2
1	1.762 (0.000)	-	-	1.495	0.909
2	1.281 (0.000)	9.359×10^{-5} (0.000)	-	1.272	0.936
3	1.565 (0.000)	8.002×10^{-5} (0.001)	-0.022 (0.030)	1.212	0.943

- Value of Durbin Watson statistic (mean constant variance) = 1.771
- Value in bracket is the significant level value (α)

The third model is the best among them and it includes all the expected variables; it can be written in the following form:

$$\textbf{Rut Depth} = 1.565\ (\text{Roughness}) + 8.002 \times 10^{-5}\ (\text{AADT}) - 0.022\ (\text{SN})^2 \quad (3)$$

Regression # 4 Using Transformed Variables With Constant

Another trial was made to obtain a model with a constant in the equation. For this analysis the dependent variable was transformed to logarithmic. The following models were suggested:

Table 5: Fourth Regression Models of Transformed Variables with Constant

Dependent Variable: Log Rut Depth

Model	Constant	SN^2	Roughness	AADT	Std Err	R^2
1	0.825 (0.000)	-0.007 (0.000)	-	-	0.130	0.454
2	0.479 (0.000)	-0.005 (0.000)	0.116 (0.000)	-	0.104	0.660
3	0.415 (0.000)	-0.004 (0.000)	0.100 (0.000)	5.473×10^{-6} (0.030)	0.095	0.723

- Value of Durbin Watson statistic (mean constant variance) = 1.470
- Value in bracket is the significant level value (α)

The equation of the third model can from the above table suggest low standard error with reasonable value of coefficient of determinant (R^2). The equation can be written as:

$$\textbf{Log Rut Depth} = 0.415 + 0.1\ (\text{Roughness}) + 5.473 \times 10^{-6}\ (\text{AADT}) - 0.004\ (\text{SN})^2 \quad (4)$$

3.3 Summary of Developed Models

From the above analyses, the following models were developed with their own characteristics.

a. Model # 1

$$\textbf{Rut Depth} = 3.439 - 0.473(\text{SN}) + 1.046\ (\text{Roughness}) + 6.373 \times 10^{-5}\ (\text{AADT}) \quad (1)$$

$R^2 = 0.691$
Durbin Watson Value = 1.711
Standard Error = 1.112

b. Model # 2

Rut Depth = 1.281 (Roughness) + 9.359 x 10^{-5} (AADT) (2)

R^2 = 0.936
Durbin Watson Value = 1.877
Standard Error = 1.272

c. Model # 3

Rut Depth = 1.565 (Roughness) + 8.002 x 10^{-5} (AADT) – 0.022 $(SN)^2$ (3)

R^2 = 0.943
Durbin Watson Value = 1.771
Standard Error = 1.212

d. Model # 4

Log Rut Depth = 0.415 + 0.1 (Roughness) + 5.473 x 10^{-6} (AADT) – 0.004 $(SN)^2$ (4)

R^2 = 0.723
Durbin Watson Value = 1.470
Standard Error = 0.954

The above models have their own strength and weaknesses based on the validity in explaining the variables and homogeneity of variance of the residual. Model # 3 has the highest value of R^2, however the model did not represented by a constant. Model # 4 is regarded as better model for this paper, for its representation of expected variables and constant. Therefore **Model # 4** is selected.

3.4 Validation of the Selected Model

The selected model validation is generated during the regression process. These values are prominent indicators to show that the model is practical or useable as pavement performance prediction.

a. Coefficient of Determination (R^2). The selected model has R^2 value of 0.723. This illustrates that 72.3% of the variation in the Rut Depth vis-à-vis roughness, AADT and SN has been explained in the regression line.

b. Standard Error of Estimate. Standard error of estimate needs to be relatively small, it mean that less error in estimating the relationship in the equation. The value of 0.954 for this model is considered small and acceptable.

c. Durbin Watson Statistic (D Value). The D value for the selected model is 1.470 which is close to 2. It mean the variance of the residual is almost constant; i.e. homoscedastic.

d. Normality Test. Normality test was conducted on the data set using probability plot and its emerged to be short tail, which means that the probability plot have non-linear pattern. This reveals that the data set does not fit normal distribution.

3.5 Using The Model

Say, the average value of roughness and structural number (SN) for the pavement surface in question are 4mm/m and 7 respectively, it is also forecasted for the next ten years of the AADT for medium truck is shown in the following table. Computing values of rutting and structural number into the final equation (Model # 4), rut depth is predicted for the next ten years.

Table 6: Predicted Rutting using the Developed Model

Years	Medium Truck AADT (vpd)	Rutting (mm)
1	35,000	**9.3**
2	40,000	**9.9**
3	45,000	**10.6**
4	50,000	**11.3**
5	55,000	**12.0**
6	60,000	**12.8**
7	65,000	**13.6**
8	70,000	**14.5**
9	75,000	**15.5**
10	80,000	**16.5**

Plotting rutting and number of year will give us the following graph which will assist the pavement managers to decide as to when to start rehabilitation or maintenance work on the pavement. If the agency only accepts rutting below than 12.0 mm; the agency will need to maintain the surface at year five.

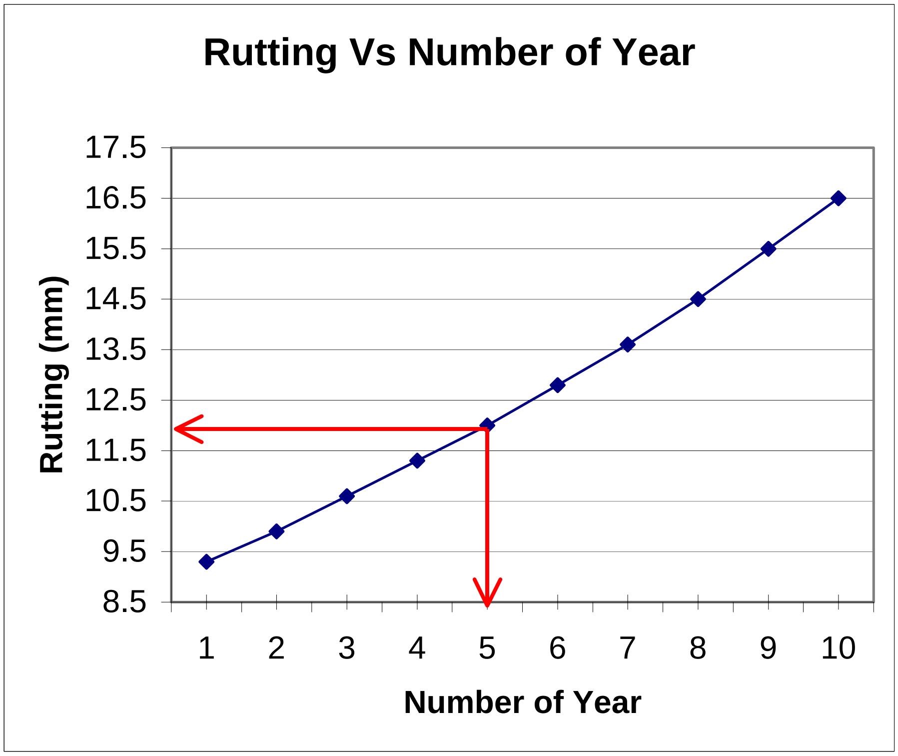

Figure 3: Rutting Prediction Graph Based on the Developed Model

Using this prediction, appropriate steps can be taken to schedule maintenance activities subsequently assist the pavement managers in budgeting and disseminating limited fund.

4. CONCLUSION

The proposed model could provide reasonable prediction of pavement performance, this it could facilitate the decision making of maintenance and rehabilitation in pavement management system. It is concluding that the regression equation to be use for particular road network take the following form:

$$\textbf{Log Rut Depth} = 0.415 + 0.1\,(\text{Roughness}) + 5.473 \times 10^{-6}\,(\text{AADT}) - 0.004\,(\text{SN})^2 \qquad (4)$$

Using the equation, rut depth can be estimated by computing value of roughness, medium trucks AADT and structural number. The factor of time can be added into this model indirectly, it can be done through forecasting AADT by method of predicting growth and compounding.

REFERENCES

a) Books

Peterson D.E. (1977) Good Road Cost Less. Utah Department of Transport, Utah

Ralph Haas. (1997) Pavement Design and Management Guide. Transportation Association of Canada

b) Journal papers

Dr. Charles Nunoo. (2002) Pavement Management System, Florida International University, Florida

Kuo et al. (2003) Development of Pavement Performance Model', Transport Research Board

Prozzi and Madanat. (2002) A Non Linear Model for Predicting Pavement Serviceability, Transport Research Board

Samer Madanat. (1997) Predicting Pavement Deterioration , Institute of Transportation Studies

Sedat Gulen et al. (2001) Development of Improved Pavement Performance Model, Indiana Department of Transport

Stephen F. Shober et al, (1998) A Pavement Preservation Strategy, Wisconsin Department of Transport

c) Other Documents

AASTHO. (1993) Guide for Design of Pavement Structures

A Guide to Visual Assessment of Flexible Pavement Surface Condition. (1992) Jabatan Kerja Raya (J.K.R)

Carey et al. (1960) Highway Research Board, Washington.

Interim Guide to Evaluation and Rehabilitation of Flexible Road Pavement. (1994) Institut Kerja Raya Malaysia (IKRAM)