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Maintenance Strategies at Project Level for Low Volume Urban Roads

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Abstract: This paper presents a methodology for maintenance and rehabilitation strategies for low volume roads based on developed pavement distress models. Saudi Arabia has made huge investments in constructing a large road network. To sustain this network, periodic evaluation and timely maintenance to keep the network operating are necessary. Historical data of pavement distress on low volume urban roads in five cities were collected--Riyadh, Jeddah, Dammam, AL-Madinah, and Jazan. These data were processed and analyzed, and the results have been employed to generate prediction models for pavement distress for the Saudi Urban Road Network (SURN) in order to develop the current approach. A sigmoid function was found to be the best fit for the data. Six prediction models for different pavement distress type have been developed. Maintenance and rehabilitation strategies have been proposed as applications of these prediction models.

Key words*: Maintenance & rehabilitation; Pavement distress, Sigmoid, Project level, Urban.*

Introduction

According to the Al-Swailmi study [1], the Saudi road network had reached over 118,060 miles by the year 2000. Asphalt paved roads totaled over 54,059 miles, and agricultural roads totaled 64,001 miles. The total cost of constructing the kingdom's road networks up to the year 2000 was over $40.44 billion. On the other hand, more than $0.6 billion was spent on maintenance programs in the last ten years, indicating that the total cost of maintenance over ten years is around 5.06% of the cost of road construction (0.51% per year). In the United States, the maintenance ratio in a year is 2.94%. The cost of pavements represents one-half of total highway expenditures; moreover, expenditures on pavements continue to grow as maintenance and rehabilitation are required, as mentioned by Haas *et al* [2]. The problems relating to road maintenance are still more complex due to the dynamic nature of road networks, as its elements are constantly changing, being added, or being removed. Also, the preparation and evaluation of the best ways to manage this expenditure is an extremely difficult task because many factors affect the deterioration of these elements. Thus, there is a need to apply a scientific approach to manage the maintenance of the road network effectively.

In two studies by AL-Mansour *et al*, and AL-Mansour and Sinha, the current practice of most highway authorities is to concentrate on reactive maintenance, with minor attention given to preventive maintenance, has shown that the cost savings resulting from preventive maintenance is 25% of the total cost [3-4]. Techniques based on worst-first or spot repair are not appropriate due to errors in pavement evaluation, and the allocated funds are not utilized efficiently. Rural and urban roads are the same in terms of service function and land service. However, the characteristics of urban and rural networks are not the same. In brief, the differences can be grouped into four areas: technical issues such as the types of maintenance work, administrative issues such as sharing of the network by different organizations, the nature of pavement distress types, and the size of the network and traffic volumes.

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Objectives and Data Analysis

Proposed maintenance and rehabilitation programs at the project level are the focus of this paper, in which maintenance and rehabilitation programs for the Secondary Urban Roads Network (SURN) will be proposed. In order to do that, pavement distress models were developed first, and then the maintenance and rehabilitation programs were proposed.

In order to achieve the objective of this paper, the following points are mentioned to clarify the proposed methodology. The data was collected from urban roads in five cities across Saudi Arabia. The data contain pavement condition for flexible pavements that accommodate low traffic volumes. These roads were constructed by the Ministry of Municipal and Rural Affairs (MOMRA). Since MOMRA has constructed these roads throughout the municipalities across Saudi Arabia, the general procedure for construction is similar everywhere. These flexible pavements are typical in structures consisting of a wearing course of 4 cm, binder course of 5 cm, base course, and then the natural sub grade.

For this paper, the dataset was developed through different steps and considerations as follows:

- Some apparent outliers exist within the data but all data was analyzed so that extreme values could be identified as part of the modeling process.
- Only overlaid sections were included in the study to ensure that the initial pavement condition was excellent.
- Section boundary modifications were checked. Any section that had been merged with another due to any reason was removed to ensure accuracy for the selected sections used in building the research dataset.
- Maintenance ratio was also checked to ensure that most of the sections had been maintained by overlay. Any section with less than 90% was removed. The maintenance ratio is the ratio of the maintenance area to the survey area for a given section.

- Any section that was exposed to maintenance activities after the overlay date was removed.
- Each section contained a different number of sample units depending on the geometry of the section.
- Each sample unit contained one or more pavement distress type record (type, severity, density) (these values form the database at each municipality).
- Each value was used as one reading in the dataset.
- For the pavement distress type dataset, weighting values were used for each distress type and severity. These weighting values were developed by the MOMRA.

This work used the average for each distress type at each severity level. For instance, consider a sample unit with only one pothole record, three block cracking records with two different severity levels (two medium and one high), and five longitudinal cracking records with three different severity levels (two low, two medium and one high). In this case, the average distress density is that of the one pothole. For block cracking, the average distress density is calculated for the two values of medium severity level, the weighting is applied and the total distress is the sum of the medium and single high severity weighted values. For longitudinal cracking, the average distress density is calculated for the two values of low and medium severity level, the weighting is applied and the total distress is the sum of the low, medium, and single high severity weighted values.

A specific database was developed for this study in a systematic and coherent way. This database included information on pavement characteristics, pavement distress data, and pavement maintenance data. Pavement characteristics data included information on pavement class, pavement type, pavement age, traffic volume, and availability of a drainage system. Pavement distress data included information on distress type, severity, extent and location. Six common distress types, as mentioned by Mubaraki and Thom [6], were considered as they occurred most frequently: block cracking, longitudinal and transverse cracking, patching, potholes, depressions, weathering, and raveling. A total of 228 regions containing overlaid low volume urban pavement sections were found to be applicable for the study constraints. A region is an area within a district that contains a number of secondary streets surrounded by four main streets. To study the significant factors, 641 observations on all selected pavement sections for each distress type were used. The layout of the experimental design along for low volume urban roads with data included in the study is presented in Table 1. Experimental design of the study shows that the study is a two factor experimental design. The independent variables are pavement age and availability of drainage system. These independent variables are called factors. Each single factor has different categories.

Low volume urban road sections were grouped into three categories of pavement age as follows: young (0 to 2 years), moderate (2 to 5 years), and old (>5 years). As expected, all distress types tended to increase with time. However, this increase was relatively varied from distress to distress. The availability of a drainage system can also affect distress propagation. Therefore, pavement sections were grouped into two sub sections—with drainage system and without drainage system. It was expected that distress on drained sections would propagate less than distress on not drained sections.

Table 1. Experimental Design for the Study.

	Number of Observations on the Selected Sections		
Pavement Age	Old Sections	Moderate Sections	Young Sections
	78	143	420
Drainage Condition	With Drainage System		
	202		
	Without Drainage System		
	420		

Inferences and descriptive analyses from normality tests, parametric tests, nonparametric tests, numerical summaries, and scatter plots showed the following points:

- Variation in the data is noticeable,
- Data are not normally distributed,
- Nonlinearity is clear more than linearity,
- The pavement age has a dominant effect on pavement distress propagation while drainage plays a statistically less important role in pavement deterioration.

Why is pavement age so significant in the prediction of pavement deterioration? The answer can be expressed from two secondary standpoints. The first is the data; the second is the designed traffic level. The data show that the age alone can account for a substantial proportion of the decline in serviceability. Age is significant because it is a common factor in the estimation of both traffic and the effect of drainage over the cycle period. Therefore, age can be a surrogate for the effect of traffic and drainage in the prediction model. Thus it can be concluded that age plays a pivotal role in predicting pavement deterioration. The second possible reason behind this is the fact that the pavements were designed to perform for the expected traffic level, which in this case is low traffic volume.

Modelling the Data

Background

Sources of uncertainty in modeling are important. "All models are wrong, but some are useful," Box and Draper said [7]. Therefore uncertainty is always present. The most difficult source of uncertainty to deal with is the possibility of unknown factors that might affect the model and this problem is called "lurking variable" as Hauser wrote [8]. The other major source of uncertainty is the data itself due to unnatural variability such as mistakes in measurement and misunderstanding.

- From an engineering point of view, the pavement deteriorates in a particular pattern. Put simply, a priori conditions that must be met by prediction models, which will limit the form to those appropriate for the modeling process, may be summarized as follows: The initial value of all damage is zero.
- Most damage has a slope that is initially zero. However, some damage types such as roughness or rutting have an initial upsurge.
- Most damage is irreversible; the slope must always show a worsening condition unless a treatment is applied.
- Many of the damage functions under study have a final slope of zero, with damage reaching the horizontal line at 100%. By

contrast, other types of damage such as roughness or rutting do not have this constraint.

- The minimum value for damage should not be negative at any value of pavement age.
- The maximum value of damage has an upper limit only for those types of distresses for which the final slope is zero.

Distress Prediction Equations

Nonlinear regression models were tested and evaluated. These were exponential models, power models, yield density models, growth models, sigmoid models, and miscellaneous models. The evaluation was based on the boundary conditions and the form of equations that provide the best fit to the actual data. The sigmoid model family was selected to fit the data because it is one which can suit the research methodology and fits the boundary conditions as mentioned by Ratkowsky and Shahin *et al* [9-10]. These curves start at a fixed point and increase their rate to reach an inflection point and then the rate decreases to approach asymptotically to a final value.

Several equations of sigmoid form appear to fit the data with more or less the same coefficients. The criterion that dictated the selection of a particular function for each distress was its ability to satisfy the initial and possibly the end of life boundary conditions. Evidence from the literature has indicated the suitability of sigmoid functions to represent distress predictions as mentioned by George *et al*, and Robinson *et al* [11-12]. As result, this study adopted one form for each distress model for uniformity, general flexibility, and calibration.

The choice of function among a number of useful and applicable functions can be considered in terms of qualitative considerations like the appearance of forecast plots, intuitive reasonableness of the model, simplicity of the form of the model, and ease of use. After careful consideration for ease of use and ability to fit the data, 3 of the 12 equations were selected to explore their differences in order to select the best one.

The equations are:

$$y(t) = a * [\frac{t^b}{c + t^b}] \tag{1}$$

where a, b, and c are constant values that define the shape of the sigmoid; or

$$y(t) = \frac{a}{1 + e^{-(t-m)/s}} + \mathrm{d} \tag{2}$$

where
the (a) parameter controls the upper asymptote,
the (m) parameter controls the time of maximum growth,
the (s) parameter controls the growth rate,
the (d) parameter allows the representation of a lower asymptote in a similar manner in the generalized form,
the (t) parameter is the time; or

$$y(t) = \frac{a}{e^{(\beta/t)^{\omega}}} \tag{3}$$

where
α = an asymptote that controls the upper limit= 100,
β = the position of the first inflection point on the curve,
ω = a coefficient that controls the shape of the curve.

All the three equations are satisfactory in modelling pavement prediction based on research methodology, boundary condition, available data, and the engineering principle for this research and achieving the objectives. However, a single form must be selected to implement it for pavement management.

The most popular criteria for comparing different models are standard error of the model, mean square of error (MSE) and coefficient of determination of the model R^2. R^2 statistics does not always lead to sensible conclusions in comparisons between/among models because R^2 statistics are not directly comparable, as Hauser writes [8]. Moreover, for nonlinear analysis, R^2 is not always as reliable a parameter to measure the goodness of fit as for linear regression analysis, as mentioned by Ratkowsky [9].

It can be concluded that Eq. (3) records the lowest values of standard error in most cases. Therefore, the proposed distress equation of the model will be:

$$y(t) = \frac{\alpha}{e^{(\beta/t)^{\omega}}} \tag{4}$$

where
α = an asymptote that controls the upper limit= 100,
β = the position of the first inflection point on the curve,
ω = a coefficient that controls the shape of the curve.

This form has only one predictor variable, which is the pavement age time t. The form has one known parameter, α, to control the upper limit not to exceed 100, and it has a zero intercept because damage has a slope that is initially zero as discussed above. The form has two unknown parameters, β, and, ω, to build the shape characteristics of a prediction model for each pavement distress type. The other two predictor variables, traffic and drainage, are not included in the proposed equation due to their minor importance in deterioration prediction.

The nonlinear regression procedure in the Minitab software package was used to calculate coefficients for the proposed sigmoid function for each distress type. Minitab is an all-in-one statistical and graphical analysis software package. Trusted by quality professionals worldwide, Minitab is known for unsurpassed ease-of-use, reliability, and a comprehensive collection of methods.

The nonlinear regression procedure allows for the specification of any equation form, any number of dependent variables and the ranges in which the dependent variables are expected to fall. Table 1 summarizes the calculated shape coefficients for the urban secondary roads distress prediction models. The proposed form has one predictor variable, which is the pavement age.

Calibration Methodology

As discussed and concluded above, the pavement age is the only factor that shows significance in the prediction modeling. If we consider the other two predictor variables, which are the traffic and the drainage, the proposed distress equation would have been in the following form:

$$y(t) = \frac{\alpha}{e^{(\chi^*\delta^*\beta/t)^{\omega}}} \quad (5)$$

where

α = an asymptote that controls the upper limit= 100,

β = the position of the first inflection point on the curve,

ω = a coefficient that controls the shape on the curve,

χ = a modifying coefficient for traffic,

δ = a modifying coefficient for drainage.

The purpose of the traffic and drainage coefficients specified in the proposed distress model is to modify the distress equation to be as accurate as possible provided the data are available. The proposed distress equation makes use only of the variables β and ω, which have numerical values calibrated to all observed data for a particular distress type. From an engineering point of view, the development of pavement distress is affected by a variety of variables other than age, such as traffic and drainage. The availability of data for these variables allows the calibration of the modifying coefficients in the sigmoid models. However, the results have shown no significance for the all parameters together in the model.

Each modifying coefficient was calculated by the nonlinear regression technique in Minitab. For this analysis, the model coefficients were held as constant, and the only variables under consideration were the traffic and the drainage. The 95% confidence interval in the parameter estimates, using the nonlinear regression procedure was performed on the data to determine which variables were significant in the prediction of each distress type. Table 3 shows 0 within the upper and lower bounds. This means the two predictors, traffic and drainage, cannot be assumed to be different than 0. Therefore, the traffic and drainage are not significant and consequently will be not included in the modeling process. The result strongly supports the inductive and descriptive analysis results. Therefore, neither the traffic nor the drainage has influence on the distress equation.

Table 2. Shape Coefficients for Prediction Models for the Proposed Distress Equation.

	Model Shape Coefficients	
Distress Name	B	ω
Block Cracks	27.768	0.598
Longitudinal & Transverse Cracking	31.83	0.491
Patching	14.179	0.415
Potholes	33.543	0.608
Depressions	30.407	0.749
Weathering & Ravelling	47.375	0.328

The T-test result indicates that the modifying coefficients are not important in the prediction equation. The t ratio is calculated by dividing the parameter estimate by the standard error for the parameter (5). The result is not significant for the 4-parameter together. Table 4 summarizes the results. These results indicate that the modifying coefficients are not important in the prediction equation. Again, these results support the inductive and descriptive analysis result.

In addition to that, test of error distribution was performed to determine whether the prediction accuracy of the distress models was significantly improved by using the modifying coefficients.

The purpose of this test was to determine whether the prediction accuracy of the distress models was significantly improved by using the modifying coefficients. Two estimates were made of each distress, one each with and without modifying coefficients. Absolute error was then calculated for each value as follows:

Error (with Coefficients) = observed-predicted (with Coefficients)

Error (without Coefficients) = observed-predicted (without Coefficients)

If the coefficients are helpful in prediction, then the error distribution with the coefficients should have a smaller variance than the error distribution without the coefficients. The null

Table 3. Modifying Coefficients and 95% Confidence Interval.

	Numerical Values for Modifying Coefficients	
Distress Code	Δ	Upper and Lower 95% CI
Block Cracks	15.3	0 Within the Bounds for Traffic and Drainage
Longitudinal & Transverse Cracking	14.4	0 Within the Bounds for Traffic and Drainage
Patching	7.3	0 Within the Bounds for Traffic and Drainage
Potholes	16.5	0 Within the Bounds for Traffic and Drainage
Depressions	20.5	0 Within the Bounds for Traffic and Drainage
Weathering & Ravelling	10.8	0 Within the Bounds for Traffic and Drainage

Table 4. Shape Coefficients for Prediction Models with Modifying Coefficient and t Test.

	Model Shape Coefficients			t-ratio
Distress Code	δ	β	ω	
Block Cracks	1.384	27.000	0.598	Not Significant for the 4-parameter
Long.& Trans. Cracking	1.210	32.500	0.491	Not Significant for the 4-parameter
Patching	0.678	15.000	0.415	Not Significant for the 4-parameter
Potholes	1.276	30.000	0.608	Not Significant for the 4-parameter
Depressions	0.900	30.000	0.749	Not Significant for the 4-parameter
Weathering & Ravelling	0.913	50.000	0.328	Not Significant for the 4-parameter

Table 5. Results of F-Test.

F-test Results				
Output of the Test	F-test		Significance	
Distress	F-Calculated	F-Tabulated	P-value	Test Result
Block Cracks	0.93	1.000	0.000	Accept *Ho*
Longitudinal & Transverse Cracking	0.95	1.000	0.000	Accept *Ho*
Patching	0.94	1.000	0.000	Accept *Ho*
Potholes	0.97	1.000	0.000	Accept *Ho*
Depressions	0.95	1.000	0.000	Accept *Ho*
Weathering & Ravelling	0.94	1.000	0.000	Accept *Ho*

hypothesis *Ho* and the alternative hypothesis *Ha* can be stated in statistical terminology as:

Ha: σ (Without Coefficients) = σ (With)
Ha: σ (Without Coefficients) > σ (With)

The test static for this hypothesis was calculated by the following formula

F= S (without)/S (with)

For 120 degree of freedom (the limit for most statistical tables), the hypothesis is rejected for values of F>=1, with 95% confidence limit. The modifying coefficients interact with the other in the distress equation; therefore, the error term for all significant variables for each distress type were grouped into one population for conducting the F-test for that distress model. The F-test statistics calculated for the various distress types are given in Table 5. The results of the test indicate that no significant improvement in prediction accuracy is made for all distress types. This result supports the result in the previous section, which suggests the traffic and drainage should not be in the sigmoid distress prediction or should be set equal to 1.0 in the sigmoid distress prediction at this stage of the pavement management system (PMS) implementation.

Assessing the Selected Models

Measures of adequacy are very important before adopting a model and implementing it in a PMS, according to Fwa [13]. In any nonlinear analysis, it is necessary to assess the fit of the model to the data and to assess the appropriateness of the assumptions about the regression analysis, according to Box and Draper as well as Hauser [7-8], namely sensibleness of parameter values, comparison of mean squares and extra sums of squares, and plots of residuals. If there are any inadequacies in the model, or if any of the assumptions do not seem to be appropriate, then the model must be modified and the analysis continued until a satisfactory result is obtained. Analysis of residuals must be checked to measure the model adequacy. Three methods were conducted, namely, non-variance constant, non-independence of error variable, and non-normality, as written in Hauser's book [8]. The variance of the error variable is required to be constant. When this requirement is violated, the condition is called "heteroscedasticity," as mentioned by Ratkowsky [9]. In this case there is no significant appearance change in the variation of the residuals for each distress type. Therefore, there are no obvious model defects in each distress model.

Error terms that are correlated over time are said to be "autocorrelated" as mentioned by Ratkowsky [9]. In this case, the result shows that the residuals appear to be randomly distributed over time periods for each distress. A normal probability plot of the standardized residuals is frequently used for checking the normality assumption of the error. The result shows that the normality assumption is satisfied, so the model shows an acceptable accuracy.

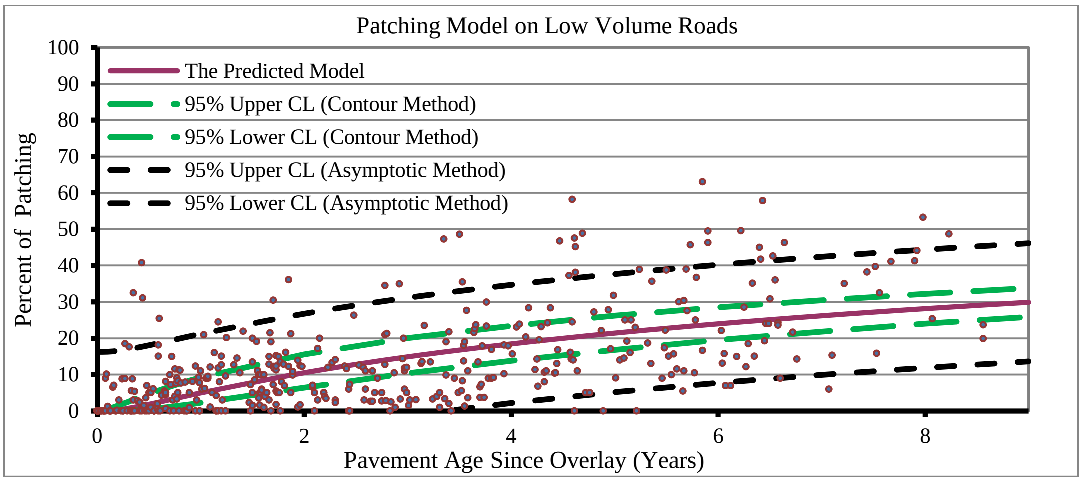

Fig. 1. Patching Model with 95% Confidence Limits of both Asymptotic and Contour Methods.

Suggested Plan to Insure the Right Treatment to the Right Pavement at the Right Time

The Right Pavement	The Right Time	The Right Treatment
STEP ONE All Pavement Sections Must be Inventoried	STEP ONE Pavement Distress Models Must be used	STEP ONE Determine the Possible Treatment
	This study has developed six pavement distress models to extrapolate the future:	Based on Experience, the following treatments are suggested
STEP TWO All Pavement Sections Must be Surveyed to Know:	Urban Secondary Roads Distress Models (USRDM) as mentioned before	. Shallow Patching . Deep Patching . Slurry Seal . Thin Overlay (3-5 cm) . Mill & Repave . Structural Overlay (8 cm) . Reconstruction
Distress Types | Distress Severity | Distress Density	STEP TWO Timely Maintenance Program	
This Study has Developed Models for Each Distress Type on SURN	Construct a Maintenance Construction Program in a Timely Manner Based on Step One	STEP TWO Treatment Selection for Individual Sections
Urban Secondary Roads Distress Models (USRDM)	STEP THREE Dedicating Funding	• Based on USRDM • Based on Time Since Construction or Major Rehabilitation • Based on Cost Effectiveness
Block Cracking Model Longitudinal & Transverse Cracking Model Patching Model Potholes Model Depressions Model Weathering & Ravelling Model	Funding for Maintenance Programs Must be Made Available in Time Because Timing is Essential for Achieving Cost Effectiveness	
		STEP THREE Select the Most Promising Treatments Especially the Preventive Maintenance Program
		By help of
		1. Cost -Benefit Evaluation
		Cost Effectiveness is a Ratio of Unit Costs and Benefits (Additional yYears the Pavement is Expected to Last)
		2. Life-cycle Cost
		The Municipalities Must Consider the Following: The Preventive Maintenance Program Postpones More Expensive Treatment The Preventive Maintenance Program Must be Done Without Delay in Time The Cost of Preventive Maintenance Program Must be Paid Without Delay because Money has Changing Economic Value Over Time.
		STEP FOUR Listing the Priorities
		A priority Listing of all Maintenance Programs Needs Especially the Preventive Program Because the Amount of Recommended Work May Exceed the Available Funds.
		STEP FIVE Selection of Materials and Construction Methods

Fig. 2. Flow Chart of A Maintenance Plan.

Model Adaption

Once a proposed model that gives a good description of the process has been identified, and the assessed results appear reasonable, the time has come to adopt it. However, the proposed model gives the predicted values only. It is not enough to know the best fit values for the model and its precision is also important. Therefore, confidence intervals should be investigated to obtain a good understanding of the prediction. The asymptotic method and region contour method were used for this purpose. The asymptotic method determines a standard error for each parameter. The region contour method is a set of points in an *n*-dimensional space, often represented as an ellipsoid around a point which is an estimated solution to a problem, although any shape can occur.

Six urban secondary pavement distress models (USPDM) have been developed using Eq. (3). The models are; Block Cracking, Longitudinal & Transverse Cracking, Patching, Potholes, Depressions, and Weathering & Raveling. The shape coefficients have been calculated for each distress. The models can be used for estimation or prediction. Fig. 1 is an example, and the shape coefficients of the models are presented in Table 2.

Maintenance Treatment at Project Level

The Methodology Approach

Assigning critical levels or trigger values for pavement condition is significant in modern pavement management. Usually, on the scale of 0 to 100, where 100 represents a new pavement, most, if not all, road agencies worldwide assign one minimum recommended condition level, typically 50 or 55. This prevents the need for major maintenance, saving the investment in road infrastructure, Shahin said [14].

In this study, the proposed methodology is based on the assumption that it is more economical to maintain pavements above rather than below the critical pavement condition. The critical pavement condition can be defined as a pavement condition value or index at which the rate of the pavement condition loss increases with associated increase in the cost of applying maintenance. However, in order to implement the proposed methodology, evidence from real practice is needed. This experience is not available at present, so the approach proposed is to develop a family of curves for different maintenance strategies and to monitor the cost of each of them.

Considering the effects of applying different strategies is important. Applying major maintenance will increase the condition of the pavement to 100; applying preventive maintenance is likely to increase the life of the pavement section (but to a condition less than 100); and applying corrective maintenance is not likely to increase the life of the pavement section, but it will ensure safe operation. Furthermore, it will be necessary to perform many life-cycle cost analyses on different projects. Therefore, it is recommended that a study of extended pavement life due to preventive maintenance types is carried out in order to draw a family of curves for every possible treatment and to select the critical levels based on a scientific approach and engineering judgment rather than on engineering judgment alone.

At project level, road agencies suggest maintenance treatment based on distress density and severity. However, this study has proposed distress density propagation models to be used as interim guidance. These models need to be verified with time and linked to pavement condition models to be useful for practical engineers.

The suggested guidelines and plans are adopted from reports published by well-known organizations such as the American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA), Departments of Transport (DOTs), and the Transportation Association of Canada (TAC). Most of these organizations propose maintenance treatment based on severity level and distress density whereas in this study the proposed methodology is based on the distress density from the developed models. They are also based on local practice and experience, international practice and experience, and engineering judgment. The author's suggested plan to ensure the right treatment to the right pavement at the right time is summarized in Fig. 2.

Suggested Plan for Block Cracking

Corrective maintenance including shallow and deep patching and crack sealing can be used to repair the block cracking to distress density up to 20%. Preventive maintenance programs such as slurry seal will be used if the distress density increases because slurry seal will be more cost effective. However, both corrective and preventive maintenance programs are not cost effective if block cracking

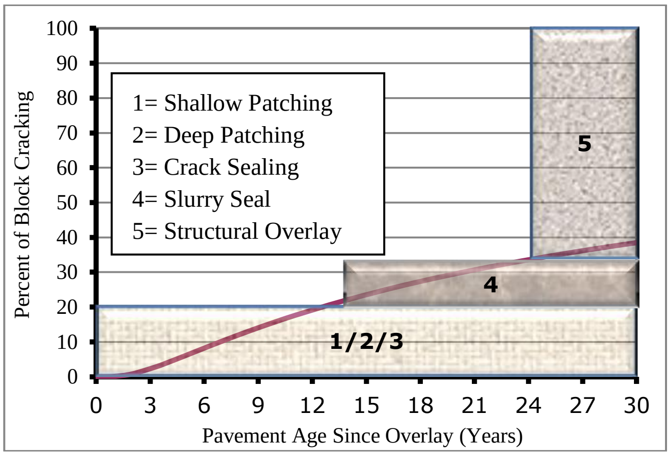

Fig. 3. Relations Between the Percent of Block Cracking and Maintenance Strategies on Low Volume Roads.

Table 6. Maintenance Guide at Project Level.

Density %	Recommended Maintenance Based on Developed Models
	For Block Cracking
0-20	Shallow Patching/Deep Patching/Crack Sealing
26-35	Slurry Seal
>35	Structural Overlay (8 cm)
	For Longitudinal & Transverse Cracking
0-30	Crack Sealing
>30	Structural Overlay (8 cm)
	For Patching
0-35	Shallow Patching/Deep Patching
36-45	Slurry Seal/Thin Overlay(3-5 cm)
>45	Structural Overlay (8 cm)
	For Potholes
0-30	Shallow Patching/Deep Patching
>30	Structural Overlay (8 cm)
	For Depressions
0-20	Shallow Patching/Deep Patching
21-30	Mill & Thin overlay (3-5 cm)
>30	Structural Overlay (8 cm)
	For Weathering & Ravelling
0-30	Slurry Seal
>30	Structural Overlay (8 cm)

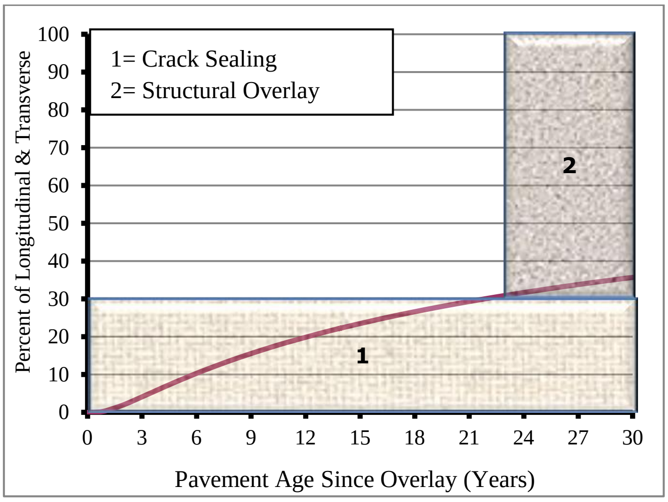

Fig. 4. Relations Between the Percent of Longitudinal & Transverse Cracking and Maintenance Strategies on Low Volume Roads.

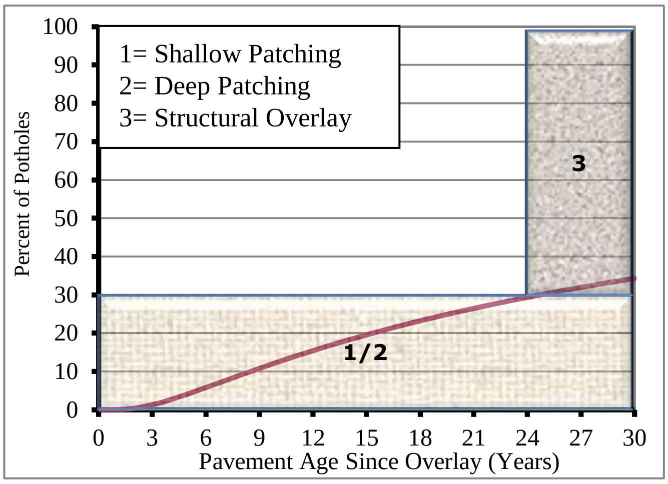

Fig. 6. Relations between the Percent of Potholes and Maintenance Strategies on Low Volume Roads.

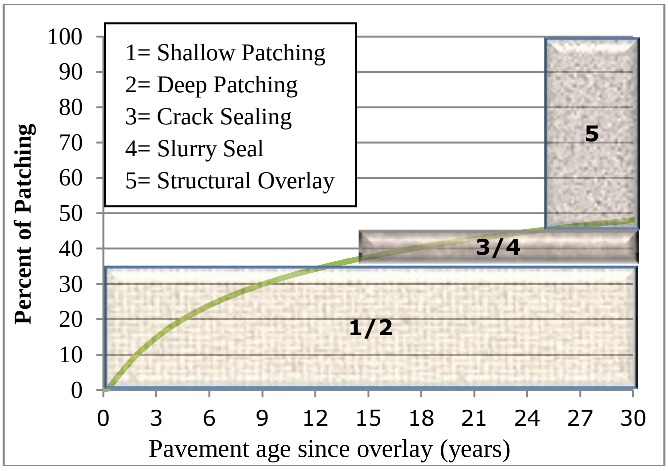

Fig. 5. Relations between the Percent of Patching and Maintenance Strategies on Low Volume Roads.

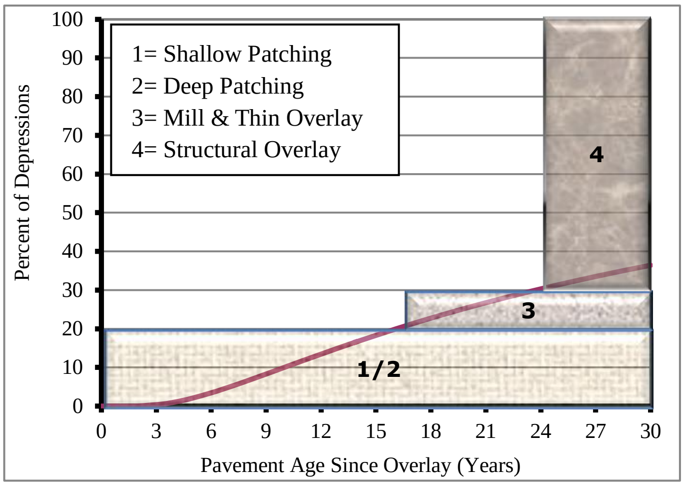

Fig. 7. Relations between the Percent of Depressions and Maintenance Strategies on Low Volume Roads

density increases more than 35%, and the structural overlay will be the most cost effective. Fig. 3 explains the situation for block cracking treatments at project level for secondary roads. Table 6 expresses guidance on maintenance treatment for block cracking.

Suggested Plan for Longitudinal & Transverse Cracking

Fig. 4 shows that crack sealing is the cost effective treatment for limited longitudinal and transverse cracking. However, a structural overlay will be more cost effective if damage density reaches more than 35%. Table 6 shows guidance on maintenance treatment for longitudinal & transverse cracking on secondary roads at project level.

Suggested Plan for Patching

Corrective maintenance is cost effective for distress density up to 35%. Preventive maintenance includes slurry seal and thin overlay, which are cost effective for distress density greater than 35% and less than 45%. Fig. 5 depicts the suggested plan for patching treatment at project level, and Table 6 gives the suggested guidance for patching.

Suggested Plan for Potholes

As explained earlier, the potholes need immediate action because it causes dangerous driving. Therefore, shallow or deep patching must be performed to keep the pavement safe. Fig. 6 shows that the potholes should be treated immediately by crack sealing or deep patching before reaching distress density value of 25%. If 25% has been passed, crack sealing and deep patching are not any more cost effective. The option of structural overlay will be carried out. Table 6 shows the suggested guidance for pothole treatment.

Suggested Plan for Depression

Shallow and deep patching can be performed to keep the pavement safe if damage is relatively small (less than 15%). Damage greater than 15% to 30% needs a mill and repave. However, reconstruction is the possible treatment in cases of increased damage. Fig. 7 shows that the depressions should be treated immediately by deep patching or mill and repave before structural overlaying takes place. Table 6

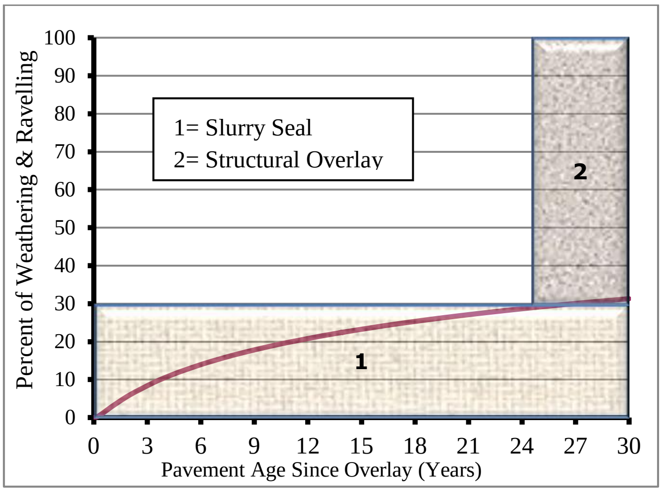

Fig. 8. Relations between the Percent of Weathering & Raveling and Maintenance Strategies on Low Volume Roads.

shows the suggested guidance for depressions treatment on secondary roads at project level.

Suggested Plan for Weathering & Raveling

At an early age of a pavement, it is recommended to start crack sealing the damage by weathering and raveling. According to the mechanism behavior in Fig. 8, if the amount of damage is greater than 30%, structural overlay is the most effective maintenance application. Table 6 shows guidance on maintenance treatment for weathering and raveling on secondary roads at project level.

Conclusion

The methodology approach presented in this paper for maintenance and rehabilitation programs uses pavement distress data for application in project level maintenance management. Municipalities are responsible for the preservation of many roads. Thus, procedures need to be developed to identify those sections that would benefit most from a preventive maintenance program, to identify pavement needs in a timely manner, and to select the most beneficial treatment. This paper includes a suggested flow chart plan to insure cost effectiveness of maintenance treatment. The flow chart contains three important pillars, or components, in a maintenance program. They are the pavement, time, and the treatment. The flow chart suggests steps under each component. Inferences and descriptive analyses from normality tests, parametric tests, nonparametric tests, numerical summaries, and scatter plots showed that variation in the data is noticeable, data are not normally distributed, nonlinearity is clear more than linearity, and the pavement age has a dominant effect on pavement distress propagation while drainage plays a statistically less important role in pavement deterioration. Age can be a surrogate for the effect of traffic and drainage in the prediction model, and for the fact that the pavements were designed to perform for the expected traffic level. Six models on form of sigmoid function have been developed, and consequently, the most cost effective maintenance treatment for pavements can be obtained using the developed sigmoid function for each pavement distress type. All the developed models have been subjected to measures of adequacy before adoption and implementation in a PMS. Testing also assessed the fit of the model to the data and the appropriateness of the assumptions about the regression analysis, namely sensibleness of parameter values and compared mean squares, extra sums of squares, and plots of residuals. Different treatments are recommended to be performed to keep the network at an acceptable level, related to the passage of time and to six different distress types.

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