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DEVELOPMENT OF FLEXIBLE PAVEMENT DISTRESS MODEL FOR RIYADH CITY - SAUDI ARABIA

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ABSTRACT

The Pavement Maintenance Management System (PMMS) of Riyadh city performs comprehensive pavement visual survey prior to each maintenance program. In the condition survey, detailed information related to type, severity and density of existing distresses is collected. The collected data is then used to determine needed maintenance activities on the network and a project level. This process was proven to be costly and very time consuming. In the condition survey, detailed information related to type, severity and density of existing distresses is collected. The collected data is then used to determine needed maintenance activities on the network and a project level. This process was proven to be costly and very time consuming.
The objective of this paper is to develop distress prediction models. The model cover all common types of distress exist on Riyadh's street network. The model predicts distress density over time associated with each severity level, pavement condition and traffic level The model developed for a total of 61 cases for main and streets. All the developed models were found to be statistically significant in predicting distress density. The models were validated using reserved data points. The validation process indicated that the models can adequately predict the distress density with reasonable accuracy. Therefore, the developed models may be used to update distress data prior to each maintenance program. This will minimize the need for comprehensive visual inspection.

INTRODUCTION

Pavement distresses are visible imperfections on the surface of pavements. They are symptoms of the deterioration of pavement structures. Most, if not all, agencies that have implemented a Pavement Maintenance Management System (PMMS) collect periodic surface distress information on their pavements through distress surveys [1]. Generally, four categories of surface distresses are collected: surface defects, permanent deformation or distortion, cracking, and patching. Several specific types of distresses are included within each condition. Although an extremely wide variation exists in the manner in which the distress surveys are conducted, recorded, analyzed, summarized, and stored, information on distress type, severity, density, and sometimes location is usually gathered.

Modeling pavement condition is an essential activity of PMMS. Prediction models play a crucial role in determining maintenance requirements and planning rehabilitation. For immediate maintenance requirements, it is necessary that the details of individual distresses types, severity, and density must be known. However, for pavement design and long-range rehabilitation planning, more approximate and aggregate data are sufficient [2].

There are two broad approaches used for predicting pavement performance and its relation to pavement maintenance expenditures. One approach predicts the performance of pavement as an aggregate measure. The other approach predicts the pavement performance by estimating the extent and severity of individual pavement distresses. The basic measurement of pavement condition is existing distresses. In general, two classes of pavement distresses can be found: structural and functional. The structural distress is associated with the ability of the pavement to carry the design load. The functional distress deals mainly with ride quality and safety of pavement surface. The two approaches differ significantly in the form of data required. The disaggregate approach requires detailed damage data for individual distress types. The aggregate approach requires one condition index that is updated each analysis period.

A composite distress index has been used successfully by Riyadh PMMS to evaluate pavement condition on the network level. The index was called Urban Distress Index (UDI) and composes of fifteen functional and structural distresses [3]. The Index has to be updated periodically to reflect the existing pavement condition. Pavement performance models were developed to update UDI on the network level [4]. The models did not predict changes in individual distress data. The condition of individual distress over time is very essential in planning maintenance activities on a project level.

STUDY OBJECTIVE

The main objective of this paper is to develop distress prediction model for flexible pavements. The model parameters cover the common types of pavement distresses appear on Riyadh's main streets network. Pavement distress density is used as the dependent variable for the developed model.

DATABASE DEVELOPMENT

Riyadh Pavement Maintenance Management System (RPMMS) is the main source for pavement condition and information related to the street network [5]. The Urban Distress Index (UDI) is used to reflect pavement condition. Urban Distress Index (UDI) is a combined local index of fifteen pavement distresses developed for the Riyadh Pavement Maintenance Management System (PMMS). The index ranges from zero to 100, where 100 represents excellent pavement condition. The UDI is calculated based on pavement distresses type, severity and density for a specific sample. Pavement condition rating was based on four categories adopted for the UDI system: Poor (zero – 39), Fair (40 – 69), Good (70 – 89) and Excellent (90 – 100) [3]. Three comprehensive pavement condition surveys were already completed for main streets. A period of two years separate between two consecutive surveys. This resulted in a total observation period of four years for each main street pavement section. The percentages of the distresses on the network considering the three surveys are shown on Table 1. Six common distress types on main streets were identified. These common distresses are longitudinal and transverse cracks, patching, weathering and raveling, potholes, block cracks, and depression. After defining the common distresses, sections that were subjected to maintenance during the analysis period were removed from the raw data. The data was then checked for outliers. The collected data were also checked for any irrational, irregular, or illogical behavior like unexpected rate of deterioration.

Table 1. Distribution of common distress types on the network for the three surveys

Type of Distress	Percentage
Long. &Trans. Cracks	31.97
Patching	22.37
Weathering & Raveling	17.63
Potholes	3.71
Depression	2.03

Each survey was subjected to checking and filtering individually to ensure consistency of the collected data. The filtered data was then summarized and tabulated with the parameters required for model development.

MODEL FORMULATION

Pavement distress behavior is expected to be affected by several parameters. Considering types of collected data, distress behavior can be expressed as a function of:

- Distress type, (the common distresses);
- Distress Severity, (three levels: low, medium, high)
- Percentage of distress density
- Urban Distress Index (UDI)
- Time, in years
- Traffic Level, (either low or high)

The hypothesis is that distress severity, traffic level and time are directly proportional to the distress density. The pavement condition (UDI) is expected to decrees with increase in distress density. Based on the literature review and engineering judgment, the following assumptions can give a general idea about the expected shape and behavior of the distress density prediction model:

- In general, distress density starts its propagation process very slowly, but this propagation accelerates more at a later stage. This can be represented in distress density model by the power, exponential function, or polynomial function.
- Distress density propagation, on a new or recently overlaid pavement section having poor UDI, will deteriorate faster than pavement section having excellent UDI.
- Distress density behavior on pavement sections that are subjected to high traffic will be damaged more than pavement sections that have low traffic.
- Distress severity levels have an affect on behavior and propagation of distress density. For example, high severity level will propagate faster than low severity level.

From the above set of logical assumptions and hypothesis, it can be said that the exponential function reasonably represents the distress density behavior. Therefore, it was used for model generation.

MODEL DEVELOPMENT

The process of building distress density prediction model from the collected data included running regression analysis for each distress survey data. The exponential function was used to generate different possible regression models. Due to the many numbers of significant parameters that affect the distress density, the following classification groups were investigated:

- The model was developed for each type of common distresses;
- Traffic was divided into two levels, high and low traffic level.
- Pavement sections were grouped based on the UDI categories that are excellent, good, fair, and poor.
- Finally, the model was developed based on the three distress severity levels: low, medium and high for each of the traffic levels and UDI categories.

To improve the fit and the ability to predicate the distress density, non-linear transformation function was tried. The transformed function used has the following form:

$$\ln(DEN) = \ln(a + bT) \quad \text{.......................................} \quad (1)$$

$$DEN = ae^{bT} \quad \text{.......................................} \quad (2)$$

Where,

DEN = Distress density in percentage
T = Time in years
a and b = Regression coefficients.

Distress Density Prediction Model

Six common types of distress were considered. Each distress was investigated individually and the density for each distress was regressed against time for all possible cases. The possible cases include classification of high and low traffic level, four categories of UDI (Excellent, good, fair, and poor) and three levels of distress severity (low, medium, high). A total of 61 models for main streets were developed. Reported results include regression equation and its coefficient, adjusted R^2 and analysis of variance. Table 2 shows the estimated coefficient of the model and the overall model statistics that were obtained for common distresses on main streets. All cases have P-values of zeros indicating that the developed relationships are significant.

The R^2 and the adjusted R^2 for the developed models vary from 42% to 99%. The predicted distress density was then plotted for each distress. An example of this plot is presented in Figure 1 for longitudinal and transverse cracks. The following sections discuss the model developed for each distress:

Model for Longitudinal and Transverse Cracks

There were twelve cases developed for longitudinal and transverse cracking. The propagation behavior, of longitudinal and transverse cracking distress on main streets for different pavement conditions and different traffic levels, was shown in Figure 1. At excellent pavement condition and in high traffic, three curves were drawn. These curves indicated the effect of severity level on rate of deterioration. The rate of change of distress density deterioration at high severity level was 62.5% during 4 years while the changes for low and medium were 86.36% and 57.69%, respectively for the same period. The rates of change for distress density were relatively similar for low and medium severity at excellent pavement condition and low traffic. At good pavement condition and high traffic level, rates of changes of distress density were 66.67% and 71.43% in low and medium severity levels, respectively.

Model for Patching

The patching distress is characterized by one severity level. Six models were developed for patching. The highest rate of change of distress density deterioration (71%) was observed for
fair pavement condition and high traffic level. The lowest rate of change of distress density was on excellent pavement condition and low traffic level, that was 42%.

Model for Weathering and Raveling

There were fourteen different combinations of the model developed for weathering and raveling. The distress density deterioration rates during the analysis period, for excellent pavement condition and high traffic level, were 66.67%, 63.33%, and 72.22% for low, medium, and high severity levels, respectively. The rates were 44%, 42.67%, and 48.86% in low, medium, and high severity levels, respectively for excellent pavement and low traffic level. At good pavement and low traffic level, the rate of change of distress density was 58% for low severity level and 52% for medium severity level. At fair pavement condition and low traffic level, the changes in distress density were observed to be of 66.15%, 71.25%, and 71.76% for low, medium, and high severity levels, respectively.

Model for Potholes

Thirteen cases were developed for Potholes. At excellent pavement and low traffic, the rate of change in distress density were 43.33%, 50%, and 49.33% for low, medium, and high severity levels, respectively. The rates of change of distress density were 82.86%, 80%, and 80.77% for low, medium, and high severity levels, respectively, at good pavement condition and low traffic level. At fair pavement condition and low traffic level, rates of change in distress density were observed as 85.71%, 69.83%, and 85.57% for low, medium, and high severity level, respectively. Rates of change of distress density for low severity level at low traffic level for excellent and good pavement conditions were noticed to be of 56.92% and 68%, respectively.

Model for Block Cracks

Three severity levels were drawn for excellent pavement condition with high traffic level. Low severity curve shows a deterioration rate of 60% compared to 52% with high severity. The rates of change of distress density for low severity level for between good and fair pavement condition with high traffic were similar. The rate of change of distress density at poor pavement condition with high traffic was 52%, while the rate of change for excellent pavement condition with low traffic was 41%.

Model for Depression

Eight combinations were developed for depression distress. Medium and low severity depression has the same behavior for pavement with excellent pavement condition and high traffic. The rate of change of distress density at good pavement condition and low traffic for both low and medium severity level was observed to be 55%.

Table 2. Statistical Summary of Distress Density Models for Main Streets

Distress Density = $a\ e^{bT}$

Distress Type	Parameters		Estimated Coefficient		Overall Models Statistics			
	Pavement Condition and Traffic Level	Severity	a	b	N	R^2	Adj R^2	P-value
Longitudinal and Transverse Cracks	Excellent Condition -High Traffic Level	Low	2.36	0.568	171	68.6	68.5	0.000
		Medium	21.98	0.219	12	71.7	68.8	0.001
		High	33.45	0.238	15	86.5	85.4	0.000
	Good Condition - High Traffic Level	Low	5.00	0.275	33	57.3	55.9	0.000
		Medium	6.23	0.298	32	59.0	57.6	0.000
	Excellent Condition-Low Traffic Level	Low	1.73	0.164	153	52.4	42.1	0.000
		Medium	5.81	0.164	12	50.3	45.4	0.010
	Good Condition-Low Traffic Level	Low	4.71	0.508	96	80.2	80.0	0.000
		Medium	19.30	0.197	15	74.6	72.7	0.000
	Fair Condition-Low Traffic Level	Low	7.17	0.275	12	70.6	67.7	0.001
		Medium	19.30	0.275	15	78.0	76.3	0.000
	Poor Condition - Low Traffic Level	Low	26.31	0.292	18	80.5	79.3	0.000
Patching	Excellent Condition - High Traffic Level	Low	1.12	0.208	96	55.2	54.7	0.000
	Good Condition - High Traffic Level	Low	1.22	0.264	12	75.8	73.3	0.000
	Fair Condition - High Traffic Level	Low	1.95	0.32	15	76.8	75.0	0.000
	Excellent Condition - Low Traffic Level	Low	1.03	0.125	334	45.7	45.6	0.000
	Good Condition - Low Traffic Level	Low	4.18	0.208	9	66.1	61.2	0.008
	Fair Condition - Low Traffic Level	Low	15.03	0.264	12	65.7	62.2	0.001
Weathering and Raveling	Excellent Condition - High Traffic Level	Low	21.12	0.257	21	74.5	73.2	0.000
		Medium	23.10	0.287	21	81.6	80.7	0.000
		High	25.28	0.318	21	89.9	89.4	0.000
	Good Condition - High Traffic Level	Low	30.88	0.28	12	95.6	95.2	0.000
	Fair Condition - High Traffic Level	Low	31.82	0.295	12	98.4	98.2	0.000
	Excellent Condition - Low Traffic Level	Low	41.68	0.147	30	62.3	60.9	0.000
		Medium	42.52	0.147	30	64.5	63.3	0.000
		High	45.15	0.167	30	81.9	81.3	0.000
	Good Condition - Low Traffic Level	Low	42.95	0.219	15	81.6	80.2	0.000
		Medium	45.60	0.239	15	87.0	86.0	0.000
		High	46.06	0.239	15	87.5	86.6	0.000
	Fair Condition - Low Traffic Level	Low	21.76	0.295	12	82.2	80.5	0.000
		Medium	23.10	0.308	12	86.4	85.1	0.000
		High	23.34	0.322	12	87.5	86.2	0.000

Table 2. Statistical Summary of Distress Density Models for Main Streets [Cont..]

Distress Density = a e ^{bT}								
Distress Type	Parameters		Estimated Coefficient		Overall Model Statistics			
	Pavement Condition and Traffic Level	Severity	a	b	N	R2	Adj R2	P-value
Potholes	Excellent Condition - High Traffic Level	Low	0.27	0.219	9	42.7	34.5	0.056
	Good Condition - High Traffic Level	Low	0.85	0.275	15	53.5	50.0	0.002
	Excellent Condition Low -Traffic Level	Low	1.46	0.185	15	50.1	46.2	0.003
		Medium	2.55	0.185	15	54.8	51.4	0.002
		High	3.63	0.185	15	51.2	47.5	0.003
	Good Condition -Low Traffic Level	Low	1.16	0.46	9	70.5	66.3	0.005
		Medium	1.40	0.432	9	72.1	72.1	0.001
		High	3.03	0.369	9	74.6	71.0	0.003
	Fair Condition- Low Traffic Level	Low	0.71	0.572	9	83.4	81.1	0.001
		Medium	1.45	0.348	9	81.9	79.3	0.001
		High	0.40	0.555	12	77.7	75.4	0.000
Block Cracks	Excellent Condition -High Traffic Level	Low	20.49	0.219	9	76.3	73.0	0.002
		Medium	29.08	0.219	9	78.7	75.7	0.001
		High	45.15	0.184	9	88.6	87.0	0.000
	Good Condition- High Traffic Level	Low	20.09	0.313	9	79.1	76.2	0.001
	Fair Condition- High Traffic Level	Low	21.33	0.345	9	83.0	80.5	0.001
	Poor Condition - High Traffic Level	Low	46.99	0.191	9	97.7	97.3	0.000
	Excellent Condition Low Traffic Level	Low	2.60	0.125	9	44.8	36.9	0.049
	Good Condition - Low Traffic Level	Low	20.29	0.197	9	71.1	66.9	0.004
		Medium	27.94	0.197	9	72.7	68.8	0.003
	Fair Condition Low - Traffic Level	Low	29.37	0.275	9	79.6	76.7	0.001
		Medium	34.12	0.238	9	81.9	79.3	0.001
Depression	Excellent Condition - High Traffic Level	Low	10.38	0.219	9	78.8	75.8	0.001
		Medium	11.94	0.219	9	75.2	71.6	0.002
	Fair Condition - High Traffic Level	Low	16.28	0.32	21	75.8	74.5	0.000
		Medium	18.36	0.336	21	81.5	80.5	0.000
	Excellent Condition - Low Traffic Level	Low	17.99	0.125	12	73.4	70.7	0.000
		High	19.30	0.147	12	78.7	76.6	0.000
	Good Condition - Low Traffic Level	Low	7.24	0.197	12	61.2	57.3	0.003

At excellent pavement condition and low traffic, the rate of change in distress density was 40% for low severity, and 44.29% for high severity. The rate of change in distress density at fair pavement condition and high traffic was 73.33%, and 74.29% for low and medium severity, respectively.

MODELS VALIDATION

A part of the collected data was reserved for model validation. A set of 206 data points was used to estimate densities. Estimated density values were compared with the actual measured values to validate the developed models. The percent difference between values of estimated and measured densities should be reasonable in order to accept the developed models. From the model validation process, it can be stated that the developed models could adequately predicate the distress density with reasonable accuracy. The percent difference values vary from one model to the other. Generally, the percent difference varies from 0% to 33%.

SUMMARY AND CONCLUSIONS

In this paper, model for predicting individual distress density on flexible pavement was developed. The developed model was based on data collected from the Pavement Maintenance Management System of Riyadh city. The models constructed for the most common types of distress on main streets. The model predicts distress density over time associated with each severity level, pavement condition and traffic level. A total of 61 cases were developed for main streets. All the cases for the developed model were found to be statistically significant in predicting distress density. The model was validated using reserved data points. The validation process indicated that the model could adequately predict the distress density with reasonable accuracy. Therefore, the developed model can be used to update distress data prior to each maintenance program. This will minimize the need for comprehensive visual inspection which proven to be costly and very time consuming.

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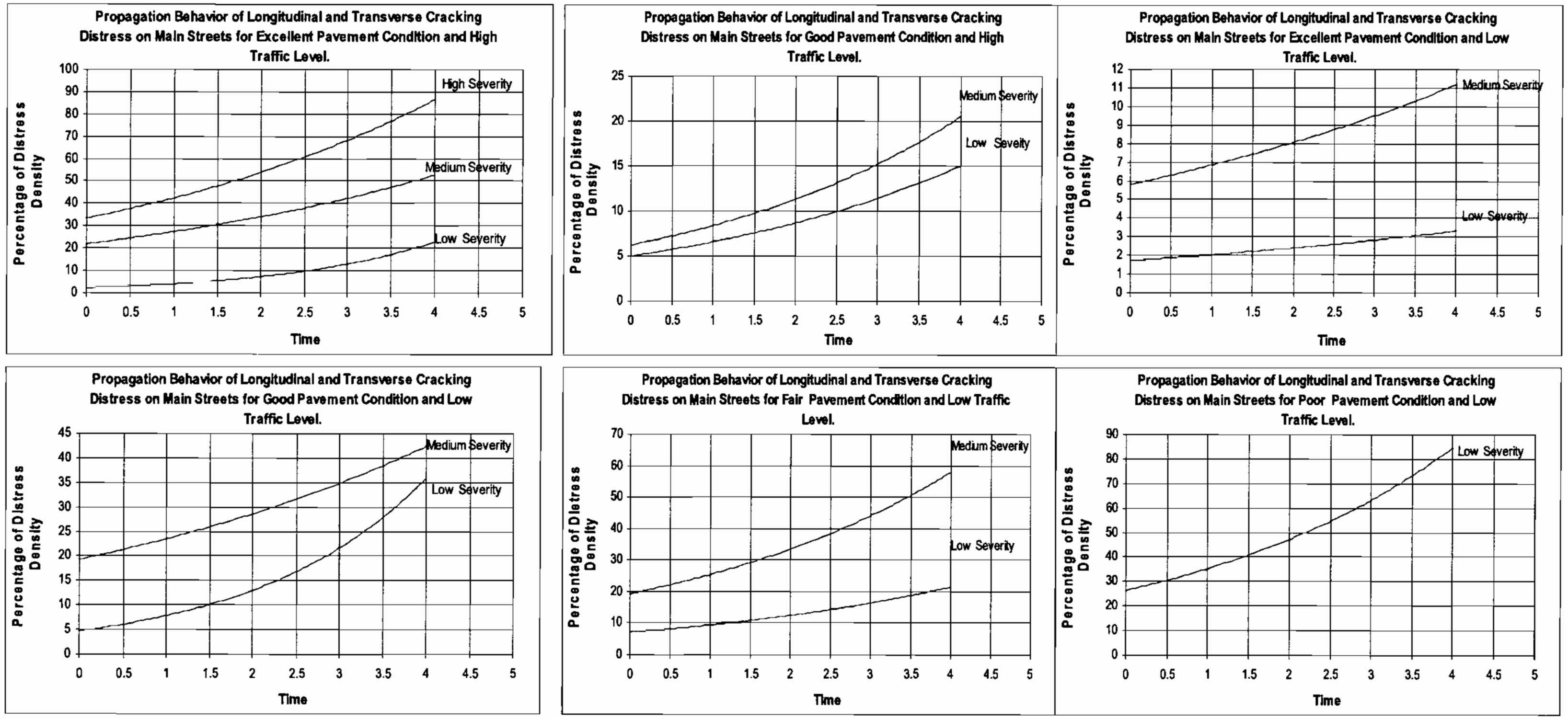

Figure 1. Distress Density Curves for Longitudinal and Transverse Cracks on Main Streets