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Development of Pavement Prediction Models Using Markov Chain Theory for Egyptian Highway Network

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Abstract— ***Typically, available funds are not adequate to satisfy all the required improvement, repair and/or maintenance projects for the highways and roads networks in most countries, including Egypt. Under current policies and funding levels, further deterioration in the highways can be expected, since the budget needed for highway maintenance is greater that the funding levels available. As a result, highway agencies must seek more cost-effective methods for highway network preservation.***

Pavement performance prediction models are generally used to forecast changes in condition over some future time period. Predicted conditions are used in several pavement management activities. Markov chain theory has been used in this paper to develop future pavement deterioration prediction model for highways in Egypt, and to forecast the future pavement performance. Transition Probability Matrices (TPM) were generated for two highways in Egypt as a case study; namely, the Alexandria-Cairo Agricultural R and the Alexandria-Matrouh North Coast Highway. TPMs were developed based on data made available through the Central Administration for Road Maintenance, at the General Authority for Roads and Bridges and Land Transport (GARBLT).

The Pavement Condition Index (PCI) was used as pavement performance indicator. The pavement deterioration prediction model were developed for the two highways consider in the case study for a planning horizon of five years. The results of the models were then validated using actual data outside the planning horizon and the difference between the predicted data and validation data was insignificant at a 95% confidence level.

Keywords— Pavement Management, Markov Chains, Transition Probability Matrix, Pavement Condition, Probabilistic Deterioration Models

I. Introduction

Highways are considered to be one of the major capital investments in any country, with the presence of a good highway network considered to be one of the most important aspects of the development of any country. Socio-economic development cannot be made without the presence of good and integrated roads and highways networks (Khamis 2005). Roads networks are considered to be a very important asset, which large amount of money are invested in it either at the phase of construction or during the highways maintenances (GAO 2011).

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The land transport system is the main system of transportations in Egypt, with the highways and road network representing in the main means of land transportation. Its play the main role in passengers and goods transportation in Egypt, where the highway and road network share by about 50% of the passengers' transportation in Egypt (GARBILT 2014). In addition, there is tremendous growth in constructing new highways and roads networks in Egypt to meet the increase in demand on the land transportation system, due to the increase in numbers of population and the extension in building the new developmental towns. As a result, the highway and road network of passenger and freight transportation is expected to increase. (GARBILT 2014).

The total length the highways and roads network in Egypt about 60,000 km. The total length of roads under jurisdiction of GARBLT is 24,000 km, while the remaining road network is under jurisdiction of the local authorities in the governorates. (GARBILT 2015).

Pavement Management System is very essential in Egypt to maximize the benefits and minimize the overall costs of maintaining or preserving the Egyptian highways and roads network .Pavement Management System can be define as systematic approach that provides the engineering and economic analysis tools required by decision makers in making cost-effective selections of Maintenance, Rehabilitation, and Reconstruction (MR&R) strategies on a network basis.

Pavement prediction deterioration modeling is one of the main components of Pavement Management system frame work which also contain the pavement condition assessment ,repair alternatives and strategies ,improve after repair , asset prioritization and repair fund allocation .

The objective of this research is to develop a future pavement Deterioration Prediction model for highways in Egypt using one of the most important probabilistic approaches which is the Markov chain theory to determine and forecast the future pavement performance on the prediction of deterioration.

The research methodology can be summarize in the following :

- Gathering the data that will be used in generate the pavement prediction deterioration model.
- Identify the current pavement condition state vector.
- Generating the Transition Probability Matrix (TPM) using Markov chain theory for highways pavement prediction deterioration model for Alexandria-Cairo agricultural highway and Alexandria-Matrouh North Coast highway .
- Generating the pavement prediction deterioration model.

II. Methodology

A. *Markov Chain Theory*

Markovian models are the most common stochastic techniques that have been used extensively in modeling the deterioration of infrastructure facilities (Butt et al 1987; Jiang et al. 1988). The Markovian technique is a probabilistic model that accounts for the uncertainty associated with the future pavement condition. These models use the Markov Decision Process (MDP) that predicts the deterioration of a component by defining discrete condition states and accumulating the probability of transition from one condition state to another over multiple discrete time intervals (Lounis et al. 1998). Transition probabilities are represented by a matrix of order (n x n) called the Transition Probability Matrix (TPM), where (n) is the number of possible condition state. The key elements of any TPM are states and transitions. (Kostuk 2003).

The Markov method considers the pavement to belong to one out of a number of mutually-exclusive conditions (states) and requires that the probability of transition to a particular future state j from a current state i be independent of the history of states occupied before the current state. The conditional probability for the pavement condition to shift from a given state to another is termed the transition probability. If a given pavement section does not deteriorate beyond one state during one duty cycle, the transition probabilities can be expressed as the equations (1),(2),(3) (Bandra and Guarantee 2001):

$$p_j = prob[X(t+1) = j/X(t) = j] \quad (1)$$

$$q_j = prob[X(t+1) = j-1/X(t) = j] \quad (2)$$

$$q_j = 1 - p_j \quad (3)$$

Where p_j= probability of remaining in state j after one cycle;q_j= probability of shifting to next lower state (j_{21}); and X = pavement condition. These transition probabilities can be arranged in a matrix known as the one-step TPM, **P**, as shown in Figure (1).

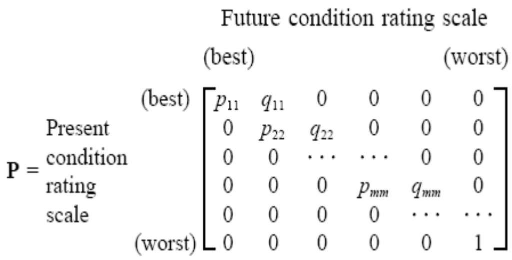

Fig. 1: Arrangement of Transition Probability Matrix

Thus, if the current condition of a pavement section is expressed by the probability vector p(0) defined on the discretized condition rating scale [0 –100], the condition of the pavement in the next duty cycle (t = 1) can be expressed as Equation (4).

$$p(1) = p(0) \times p \quad (4)$$

B. *Pavement Condition Data*

GARBLT is the governmental body in the Ministry of Transport responsible for construction, upgrading, managing and maintaining the roads and highways network in Egypt. The central administration for road maintenance management in GARBLT collects biannual pavement surface distress condition data for all the roads under GARBLT jurisdiction. GARBLT uses the Pavement Condition Index (PCI), as per ASTM standard D 6344, as the main performance indicators for the performance and pavement condition of the roads and highways in Egypt.

The surface distress data is collected in 19 different surface distress types, as per the requirements of the Volume 10 of the Egyptian Code for Practice for Urban and Rural Roads. It should be noted that the pavement condition data are visually collected, which should be done by qualified and skilled inspectors. These inspectors are trained through technical courses provided by GARBLT to ensure the accuracy and homogeneity of the collected data.

The surface condition data is then used to calculate the overall PCI for each pavement section. PCI is a numerical indicator that rates the surface condition of the pavement. It provides a measure of the present condition of the pavement based on the distress observed on the surface of the pavement, which also indicates the structural integrity and surface operational condition of the pavement. (ASTM, D6433-03). The data is collected by dividing each highway into 2.0-km long pavement sections. The inspector collects the pavement condition data using the walking survey technique, he walks along the sidewalk/shoulder of the sections being surveyed and records all distress existing in the section with their severity level. Each distress type and severity must corresponding with that described and defined in the Egyptian Code (ECP-104-2008, tenth part). The distress types, their severity levels and the highway information, section ID, all the data are registered in datasheet template for visual pavement distresses evaluation. The Egyptian code divided the PCI states into different seven states and ranges with ratings ranging from 0 to 100. The condition states used by the Egyptian Code is shown in Table (1).

C. *Development of Transition Probability Matrix (TPM)*

The Count Proportions Method (CPM) is used to generate the Transition Probability Matrix (TPM). In this method, the probability $P_{i,j}$ of the pavement condition transitioning from state i to state j can be estimated using in equation (5) (Jiang et al. (1988); Morcous et al. (2002); Garcia et al. (2006)):

$$P_{ij} = {n_{ij}}/{n_i} \quad (5)$$

TABLE (1): CLASSIFICATION FOR CONDITION STATE AND PAVEMENT CONDITION INDEX RANGES

Condition State	Pavement Condition Index(PCI) Ranges
Excellent	100-86
Very Good	85-71
Good	70-56
Fair	55-41
Poor	40-26
Very Poor	25-10
Failed	9-0

Where, $n_{i,j}$ is the number of road sections transitioning from state i to state j within a given time period, n_i is the total number of road sections in state i before the transition. Estimating a transition probability can be carried out if one is able to observe the sequence of states for each individual unit of observation. For instance, if we observe the condition ratings of a number of pavement sections at the beginning of any given year and then again at the end of the year, then we can estimate the probability of pavement condition moving from one state to another. The probability of a section having a particular condition rating at the end of the year (e.g., Good) given their condition states at the beginning of the year (e.g. Very Good) is given by the ratio of the number of sections that began the year with the same rating (Very Good) and ended with a Good rating to the total number of sections that began with a Very Good rating.

There were certain assumptions made in generating transition probability matrix for the pavements, which are as follows (Kamalesh 2009):

- Pavement conditions are expressed in a finite number of states, i.e., distress rating is discretized into seven different states.
- The transition probabilities depend only on the present condition state.
- The transition process is stationary, that is, the probability of transition from one condition state to another is independent of time.
- Condition ratings will always remain constant or decrease with time. Increase in condition rating is not taken into account for pavement that is left to deteriorate on its own.
- The pavement condition cannot deteriorate by more than a single state in one year.
- Transition probability matrix assumed here is homogenous meaning that the transition probability for deterioration from one year to the next is always the same.

D. Development of Pavement Deterioration Prediction Model

The development of the pavement deterioration prediction models is carried out using a number of analysis steps as described in the following subsections

1. *Generating of TPM for Pavement Deterioration Prediction Model*

Markov chains approach uses the TPMs, which shows the probabilities of moving from one condition state to another to estimate the future condition. At this time, no previous research work has been carried out to generate TPMs for highways based on general road conditions in Egypt. As a result, it is important to generate these matrices for highways conditions in Egypt.

The Alexandria-Cairo agricultural highway (with a length of 220 km) and the Alexandria-Matrouh North Coast highway (with a length of 300 km) are considered from the most important highways in Egypt, serving a large number of passenger and freight transportation in north western Egypt. PCI data for Alexandria-Cairo agricultural highway was available for the years 2006, 2008, and 2010, while the data Alexandria-Matrouh North Coast highway was available for years 2008, 2010, and 2012. This data was collected and made available through the central administration for Road Maintenance in GARBLT.

Two individual TPMs were generated based on the available data, where one TPM was generated using the data for the Alexandria-Cairo agricultural highway, representing the agricultural roads conditions in Egypt. The other TPM was generated based on the data for the Alexandria-Matrouh North Coast highway, representing the coastal highways conditions in Egypt.

The total numbers of sections are 133 sections considered for generating the TPM, for the Alexandria-Cairo agricultural highway. These sections were the final set of data after filtering out the all highway sections that have undergone maintenance work. These sections were identified based on available records and/or data observations of sections exhibiting significant condition improvement in any given data collection cycle. The final TPM for agricultural roads conditions in Egypt is shown Table (2).

TABLE (2): TPM FOR THE AGRICULTURAL ROADS CONDITIONS

PCI State in Year t	PCI State in Year t+1						
	Excellent	Very Good	Good	Fair	Poor	Very Poor	Failed
Excellent	0.61	0.39	0.0	0.0	0.0	0.0	0.0
V. Good	0.0	0.36	0.64	0.0	0.0	0.0	0.0
Good	0.0	0.0	0.29	0.71	0.0	0.0	0.0
Fair	0.0	0.0	0.0	0.17	0.83	0.0	0.0
Poor	0.0	0.0	0.0	0.0	0.24	0.76	0.0
V. Poor	0.0	0.0	0.0	0.0	0.0	0.19	0.81
Failed	0.0	0.0	0.0	0.0	0.0	0.0	1.0

As can be noted from Table 2, the sum of each raw is 1.0 (100%). As an example, the probability that the pavement section in an Excellent condition deteriorates to a Very Good condition is 39%, while the probability that is stays in an Excellent condition is 61%.

The same analysis approach was carried out using the data available for Alexandria-Matrouh North Coast highway. The total numbers of sections used to generate the TPM representing the roads of Coastal conditions in Egypt were 157 sections after applying the Markov chains approach criteria and also after excluding all the highway sections that under maintenance work. Table (3) shows the final transition probability matrix representing the roads of Coastal conditions in Egypt.

Similar to Table 2, the sum of each raw in Table 3 is 1.0 (100%). As an example, the probability that the pavement section in a Good condition deteriorates to a Fair condition is 86%, while the probability that is stays in a Good condition is 14%.

E. Current Pavement Condition State Vector

In order to determine the future pavement condition after n number of years, it is essential to determine the present pavement condition, having determined the range for different states of pavement condition.

The derivation of current condition state vector (2014) was carried out by using the last available condition data for each of the two roads considered in the analysis, which are the year 2010 data for Alexandria-Cairo agricultural highway and the year 2012 data for Alexandria-Matrouh North Coast highway. The initial condition probability for the Alexandria-Cairo agricultural highway for the year 2010 can be represented by a condition state vector

IP_o= [0.236, 0.040, 0.302, 0.210, 0.171, 0.026, 0.013]

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This vector of probabilities represents the probabilities of each of the seven condition states of any given pavement sections at the beginning of year 2010. Based on this vector, the overall PCI for the entire road in the year 2010 was 67.4, which is corresponding to good condition state. This value was evaluated by multiply the condition state vector by the

TABLE (3): TPM FOR COASTAL ROADS CONDITIONS

PCI State in Year t	PCI State in Year t+1						
	Excellent	Very Good	Good	Fair	Poor	Very Poor	Failed
Excellent	0.62	0.38	0.0	0.0	0.0	0.0	0.0
V. Good	0.0	0.24	0.76	0.0	0.0	0.0	0.0
Good	0.0	0.0	0.14	0.86	0.0	0.0	0.0
Fair	0.0	0.0	0.0	0.24	0.76	0.0	0.0
Poor	0.0	0.0	0.0	0.0	0.23	0.77	0.0
V. Poor	0.0	0.0	0.0	0.0	0.0	0.17	0.83
Failed	0.0	0.0	0.0	0.0	0.0	0.0	1.0

possible states column vector [PS] (PCI Ranges), which is expressed by the following:

$$\text{PCI for initial state } (FS_0) = [IP_o]* \begin{bmatrix} 100 \\ 85 \\ 70 \\ 55 \\ 40 \\ 25 \\ 9 \end{bmatrix} = 67.4$$

Similarly, the initial condition probability vector for the Alexandria-Matrouh North Coast highway at the year 2012 can be represented by a condition state vector:

IP_o = [0.285, 0.085, 0.195, 0.070, 0.060, 0.110, 0.200]

This vector of probabilities represents the probabilities of each of the seven condition states of any given pavement sections at the beginning of year 2012. Based on this vector, the overall PCI for the entire road in the year 2010 was 60.0, which is corresponding to good condition state.

2. ***Generation of Future Pavement Deterioration Prediction Model***

Prediction of future pavement condition is not only essential for maintenance budget forecasting at the network level, but also for determining the most cost-effective rehabilitation strategy at the project level. Rehabilitation project selection, in any given pavement management system, is based on the evaluation of each individual pavement section. If the highway agency is unable to perform pavement condition surveys every year, an appropriate pavement condition prediction model can be used to predict the expected condition of each pavement section (Bandra and Guarantee 2001).

To calculate the future performance condition of the pavement, the future probability row vector at any time (FP_t) after (t) years should be determined using the initial row vector (IP_o). FP_t can be calculated by multiplying the condition vector at the known condition by the [TPM] raised to the power (t), as shown in Equation (6) (ElHakeem 2005):

$$[FP_t]_{1\times n} = [IP_o]_{1\times n} * [TPM]^t_{n\times n} \quad (6)$$

Where FP_t is the future probability row vector at any time after (t) years, IP_o is the initial row vector. As an example, at (t = 2), the expected [FP_2] vector for the Alexandria-Cairo agricultural highway can be determined as follows:

$$FP_2 = [0.236 \quad 0.040 \quad 0.30 \quad 0.21 \quad 0.171 \quad 0.026 \quad 0.013] * \begin{bmatrix} 0.61 & 0.39 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.36 & 0.64 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.29 & 0.71 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.17 & 0.83 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.24 & 0.76 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.19 & 0.81 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1.0 \end{bmatrix}^2$$

= [0.09, 0.09, 0.10, 0.12, 0.26, 0.19, 0.14]

The results indicates that after two years from the known condition, the condition vector has the following probabilities; 9% for state 1 (Excellent), 9% for state 2 (Very good), 10% for state 3 (Good), 12% for state 4 (Fair), 26 % for state 5 (Poor), 19% for state 6 (Very Poor), and 14% for State 7 (Failed). The overall PCI for the Alexandria-Cairo agricultural highway at (t=2) is 47.07, which is corresponding to Fair condition state, and it is calculated by multiply the condition state vector by the possible states column vector [PS] (PCI Ranges).

The final step is to come up with one value to describe future condition of the pavement (i.e., the future state value FS_t), which is expressed as the PCI value at any time. This value can be calculated by multiply the future probability row vector at any time (FP_t) by the possible states column vector [PS] (PCI Ranges). Since this process predicts the condition state at any time (t), it can be repeated with various (t) values (1 to 5, for example) to draw a deterioration behavior for 5 years planning horizon.

Table (4) shows the future probability row vector (FPt) and the future PCI state value (FSt) for the pavement Deterioration Prediction model for the Alexandria-Cairo agricultural highway for 5 years period with initial known condition at year 2010

As can be noted from Table 4, the PCI state at the initial condition (at year 2010) was 67.42, and then it decrease at the next year to be 57.49 and then it continues to decrease over time to reach 23.77 at year 5. This is an expected behavior, where pavement condition would deteriorate over time in absence of any maintenance to the road.

Similarly, Table (5) shows the future probability row vector (FP_t) and the future PCI state value (FS_t) for the pavement deterioration model for the Alexandria-Matrouh North Coast highway for time period 5 years with initial known condition at year 2012.

Figure (2) and Figure (3) show the future pavement deterioration with time for the Alexandria-Cairo agricultural highway and the Alexandria-Matrouh North Coast highway respectively.

E. Pavement Deterioration Prediction Model Validation

The Pavement Deterioration Prediction Model Validation was carried out to ensure that the future pavement performance predicted from the model at certain year is accurate compared to the pavement performance measured from the actual data for the same year.

TABLE (4): THE FUTURE PROBABILITY ROW VECTOR AND THE FUTURE PCI FOR ALEXANDRIA-CAIRO AGRICULTURAL HIGHWAY

Year (t)	Future Probability row Vector (FP_t) at time t	the future PCI state value (FS_t)
Year 0	[0.24, 0.04, 0.30, 0.21, 0.17, 0.03, 0.01]	67.42
Year 1	[0.14, 0.11, 0.11, 0.25, 0.22, 0.14, 0.03]	57.49
Year 2	[0.09, 0.09, 0.10, 0.12, 0.26, 0.19, 0.14]	47.07
Year 3	[0.05, 0.07, 0.09, 0.09, 0.16, 0.24, 0.30]	37.61
Year 4	[0.03, 0.05, 0.07, 0.08, 0.12, 0.17, 0.49]	29.63
Year 5	[0.02, 0.03, 0.05, 0.06, 0.09, 0.12, 0.63]	23.77

TABLE (5): FUTURE PROBABILITY ROW VECTOR AND FUTURE PCI FOR ALEXANDRIA-MATROUH NORTH COAST HIGHWAY

Year (t)	Future Probability row Vector (FP_t) at time t	the future PCI state value (FS_t)
Year 0	[0.29, 0.09, 0.20, 0.07, 0.06, 0.11, 0.20]	60.05
Year 1	[0.18, 0.13, 0.09, 0.18, 0.07, 0.06, 0.29]	52.06
Year 2	[0.11, 0.10, 0.11, 0.12, 0.16, 0.06, 0.34]	44.69
Year 3	[0.07, 0.06, 0.09, 0.12, 0.13, 0.13, 0.39]	37.50
Year 4	[0.04, 0.04, 0.06, 0.11, 0.13, 0.12, 0.50]	30.57
Year 5	[0.03, 0.03, 0.04, 0.08, 0.11, 0.12, 0.60]	24.77

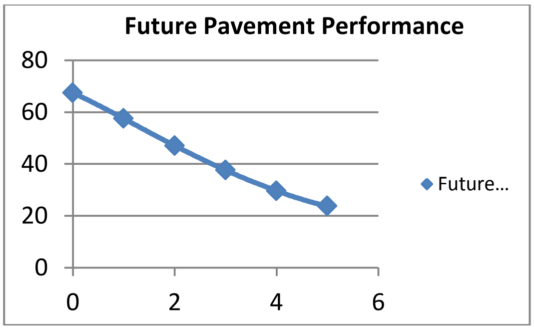

Fig. 2: Pavement Deterioration Prediction for Alexandria-Cairo agricultural Highway

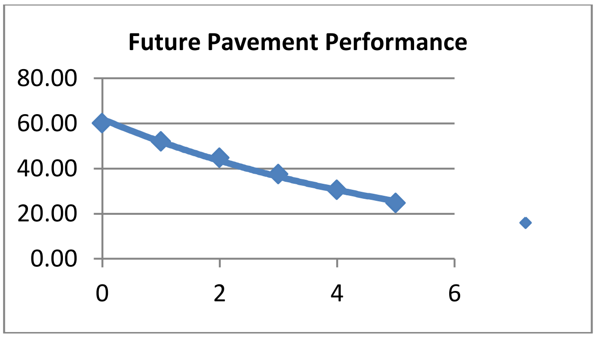

Fig. 3: Pavement Deterioration Prediction for Alexandria-Matrouh North Coast Highway

By accurately predicting the future pavement performances, pavement maintenance strategies can be reliably planned in advance. To validate the future Pavement Deterioration Prediction model that had been developed, the measured PCI from the actual data that collected from the GARBLT for Alexandria-Cairo agricultural Highway for year 2012 was 59.67. The pavement deterioration prediction model predicted that this value was expected to be 57.49. For this particular highway, no data was available beyond the year 2012.

Similarly, for Alexandria-Matrouh North Coast highway, the pavement condition as evaluated by GARBLT in 2014 was 54.56, while the PCI as predicted by the pavement deterioration prediction model 52.06.

To examine the statistical significance of the difference between the actual measure field condition and the predicted condition expected condition using the pavement deterioration model, the states of pavement segments were treated as two groups of data (the data is collected for each 2.0 km sections), and the chi-squared significance test for comparing two sets of data was used. The chi-squared test statistic is computed using the following formula in Equation (7) (Montgomery and Runger 2006):

$$X_0^2 = \sum_{i=1}^{k} \frac{(Oi-Ei)^2}{Ei} \qquad (7)$$

Where O_i is the observed value from future pavement prediction model; and E_i is the expected value or actual value describing pavement performance behavior. To determine if the models are a good fit, the following hypotheses were considered

H_0: predicted values reflect actual pavement behavior

H_1: predicted values do not reflect actual pavement behavior

The Minitab statistical analysis program was used to identify the chi-squared test and others statistics values to determine test the hypotheses at $\alpha = 0.05$. Table (6) and Table (7) show the proportions of seven different condition states for the probability row vector of the actual performance and the predicted performance from the model at year 2012 for the Alexandria-Cairo agricultural highway and at year 2014 for the Alexandria-Matrouh North Coast highway, respectively.

The Minitab software program analysis outputs for the Alexandria-Cairo agricultural highway showed that the total chi-squared is 0.023 and p-value is 0.978 with coefficient of determination (R^2) 0.911. Also, the analysis results for the Alexandria-Matrouh North Coast highway showed that the total chi-squared is 0.016 and p-value is 0.986 with and R^2 value of 0.962. Since the chi-squared for the two mentioned highways was less than 0.05, the null hypothesis (H_0) cannot be rejected and the predicted value can be assumed to reflect the actual conditions, and that the data sets are comparable at 95% level of significance.

TABLE (6): CHI-SQUARED TEST FOR ALEXANDRIA-CAIRO AGRICULTURAL HIGHWAY (MINITAB,V15)

Condition State	Actual Probability row Vector in 2012	Predicted Probability row Vector in 2012	chi-squared Values
Excellent	0.1818182	0.1447368	0.00758
Very Good	0.0909091	0.1064593	0.00267
Good	0.0991736	0.1115858	0.00155
Fair	0.2396694	0.2512531	0.00056
Poor	0.2396694	0.2161654	0.00230
Very Poor	0.1074380	0.1353383	0.00722
Failed	0.0413223	0.0344612	0.00114
PCI Value	59.67768595	57.49287993	

TABLE (7): CHI-SQUARED VALUES FOR ALEXANDRIA-MATROUH NORTH COAST HIGHWAY (MINITAB,V15)

Condition State	Actual Probability row Vector in 2012	Predicted Probability row Vector in 2012	chi-squared Values
Excellent	0.15873	0.17670	0.002
Very Good	0.15079	0.12854	0.0032
Good	0.10317	0.09262	0.0017
Fair	0.19048	0.18394	0.0002
Poor	0.07937	0.06749	0.0017
Very Poor	0.07143	0.06321	0.0009
Failed	0.24603	0.28750	0.0069
PCI Value	54.56349206	52.06321429	

F. *Conclusion*

This paper presents an approach in which historical pavement conditions were used to develop a future pavement Deterioration Prediction model using the Markov chain theory that is applicable in predicting and forecasting the highway pavement performance. A future Pavement Deterioration Prediction models was developed based on the available data at the GARBLT for the Alexandria-Cairo agricultural highway and the Alexandria-Matrouh North Coast highway, which represent the agricultural highway conditions and the coastal highway conditions in Egypt, respectively.

The Pavement Deterioration Prediction model results shows decreasing pavement condition (PCI) trends with time for planning horizon five years in the two mentioned highways, which is expected due to many factors including high traffic load, environmental conditions, construction quality, and the absence of any maintenance action over the analysis period.

For the Alexandria-Cairo agricultural highway the pavement performance (PCI) PCI state at the initial condition at the base year (2010) is 67.42 and predicted to reach 52.98 after 5 years. On the other hand for the Alexandria-Matrouh North Coast highway PCI was 60.05 at the analysis base year (2012) and predicted to reach to 45.06 at the end of the planning horizon 5 years.

The pavement Deterioration Prediction model results are validated by comparing the models output for certain year by an actual measured results of pavement performance (PCI) data at the same year which had been gathered from the GARBLT. The model results were compared against actual measured PCI values from data collected by GARBLT for both highways. Chi-squared statistical test showed that the prediction model are good fits and able to predict future pavement condition state with a reasonable accuracy at a 95% confidence level.

The future Pavement Deterioration Prediction model that had been developed in this paper helps any pavement or highways agencies to identify and predict the future pavement performance for any planning horizon. It should be noted that the deterioration model only represents a part of a pavement management system. Therefore, future work will involve integrating the Markov deterioration model with a cost-effectiveness model for maintenance, repair, and rehabilitation for various alternatives to obtain a Pavement Maintenance Management Optimization Model that can be used in the highways and road networks for setting out the optimum network maintenances strategy for pavement maintenance under constraints of funds, time, cost, and pavement performance.

References

[1] [1] Ahmed A. M. Elhakeem." An Asset Management Framework for Educational Buildings with Life-Cycle Cost Analysis ".Ph.D., Thesis, The University o f Waterloo,Canada.(2005).

[2] ASTM International, Designation: D 6433 – 99. " Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys". Website (www.astm.org).

[3] Bandera and Guarantee."Current and Future Pavement Maintenance Prioritization Based on Rapid Visual Condition Evaluation ". ASCE Journal of Transportation Engineering, March. (2001).

[4] Butt, A.A., Shahin, M.Y., Feighan, K.J., and Carpenter, S.FI. "Pavement Performance Prediction Model Using the Markov Process." Transportation Research Record: Journal of the Transportation Research Board, No. 1123, TRB, Washington, D.C., (1987).

[5] Garcia, J.J., Costello S.B., and Snaith, M.S.. "Derivation of Transition ProbabilityMatrices for Pavement Deterioration Modeling." ASCE Journal of Transportation Engineering.March, (2006).

[6] GAO, Hui ." Performance-Based Road Asset Management and Optimization System" .Ph.D., Thesis.Department of Civil and Environmental Engineering,The Hong Kong University of Science and Technology.(2011).

[7] Jiang, Y., Saito, M. and Sinha, K.C. "Bridge Performance Model Using the Markov Chain." T ransportation Research Record 1180, Transportation Research Board, National Research Council.(1988).

[8] Kamalesh Panthi."A Methodological Framework for Modeling Pavement Maintenance Costs for Projects with Performance-Based Contracts". Ph.D., Thesis, Florida International University.(2009).

[9] Khamis,Mahmoud."Predication of the Effectiveness of Pavement Preventive Maintenance in Egypt ". Ph.D., Thesis ,Faculty of Engineering, Zagazig Universty .(2005).

[10] Kostuk, K.J." Quantifying the Uncertainty Associated with Long Term Maintenance Contracts". Ph.D. Dissertation, University of Saskatchewan, Saskatoon,Canada. (2003).

[11] Lounis, Z., Vanier, D. J., and Lacasse, M. A. "A Discrete Stochastic Model for Performance Prediction of Roofing Systems." Proceedings CIB World Building Congress, Gavle,Sweden, June. (1998).

[12] Minitab statistical software program , version 15 .

[13] Montgomery, D. C., and Runger, G. C. "Applied Statistics and Probability for Engineers", 4th Ed., Wiley, Hoboken, NJ. (2006).

[14] Morcous,G., Lounis Z., and Mirza, M.S. "Life-Cycle Assessment of Highway Bridges" .Proceedings of the Taiwan-Canada Workshop on Bridges, April. (2002).

[15] The Egyptian Code for Highways work, The Tenth Part for Highways Maintenance (2008).

[16] The General Authority for Roads &Bridges and Land Transport in Egypt (GARBLT).Website (www.garblt@gov.eg)

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