Interdependence between Structural Engineering and Construction Management
*Edited by*Ozevin, D., Ataei, H., Modares, M., Gurgun, A., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-6-2

DEVELOPMENT OF PAVEMENT PERFORMANCE MODEL FOR PROPER REHABILITATION AND MAINTENANCE USING FIRST ORDER MARKOV CHAIN

AMJAD ISSA and SAMEER ABU EISHEH

Dept of Civil Engineering, An-Najah National University, Nablus, Palestine

The development of pavement performance model is an important step in prediction the future condition of pavement section and accordingly identifying the right road rehabilitation and maintenance in the right time for the right section. The first order Markov chain probabilistic model is used to predict the degradation of flexible pavement in Palestine. A pilot study is conducted on part of the road network in Nablus City. Visual road condition assessment is performed, and the Pavement Condition Index (PCI) is used in rating pavement sections by dividing the roads each 100 m length. The prediction of the pavement condition rating for each section in the first five to ten years of section age will enhance the applying of preventive maintenance strategy and consequently urges the Local Governmental Units to use the limited allocated budgets specified for pavement maintenance in a cost-effective manner by applying maintenance actions such as crack sealing, surface patching, micro-surfacing, milling and overlay, etc.

Keywords: Flexible pavement, Degradation model, Pavement condition index, Preventive maintenance, Maintenance proper time.

1 INTRODUCTION

1.1 Pavement Rehabilitation and Maintenance Status in Palestine

The foundation and alignment of some existing roads in Palestine were established during the British mandate of Palestine. A considerable portion of those roads was constructed as Macadam roads following old footpaths with relatively tortured alignment due to the prevailing mountainous terrain and limited resources. During the last three decades most of the roads have been in a deteriorated condition, while some of the urban streets have received some maintenance activities, but not in an organized or prioritized manner. Considering the evaluation of existing pavement evaluation, most of the types are of structural capacity evaluation, functional evaluation, safety evaluation, and distress evaluation. The current road maintenance practices in Palestine are not based on scientific systematic methods. Most of the municipalities use the "worst-first" criterion. Therefore, the current practices are not applying road inventories, road pavement condition surveys, overall evaluation of pavement conditions, identification of the proper maintenance and rehabilitation measures, and setting priorities.

1.2 Importance of Developing Pavement Performance Model

The development of pavement performance model is an important step in predicting the future conditions of pavement sections, and accordingly, in identifying the right road preventive rehabilitation and maintenance measures at the right time for the right section. The lack of systematic maintenance procedures in Palestine requires proposing a new cost-effective system, which will be part of the future Pavement Management System (PMS). Accordingly, it is essential to model the deterioration process of the pavement sections using an applicable and practical model. The first order Markov chain (MC) probabilistic model is used to predict the degradation of flexible pavement in Palestine.

1.3 Literature Review

The future conditions of pavement sections are usually predicted for the purpose of maintaining road networks. Pavement performance has been traditionally presented using a performance curve, which shows how the pavement condition declines over time in the absence of maintenance and rehabilitation (M&R) works (Huang 2004, Shahin 1994). The pavement condition has been historically presented by indicators, such as Pavement Condition Index (PCI), Present Serviceability Index (PSI), and Distress Rating (DR) (AASHTO 1993, ASTM 2007, Shah *et al.* 2013). The emphasis on developing effective models for predicting pavement performance had become of great importance with the emergence of pavement management science over three decades ago. Therefore, an effective pavement prediction model is a significant component of any advanced PMS (Abaza *et al.* 2004, Jorge and Ferreira 2012, Khan *et al.* 2014). Generally, there are two types of models used in predicting future pavement conditions: deterministic and stochastic models (Amin 2015, Li *et al.* 1997). Both types of models can predict future pavement conditions; however, the stochastic-based models have gained wider use in pavement management applications, because they make possible the consideration of risk assessment. This can be attributed to the fact that pavement performance has been identified as probabilistic, which requires assigning different levels of uncertainty (i.e., probability) to different pavement condition outcomes (Abaza 2015). The stochastic model that was used by several researchers over the last three decades had mainly relied on deploying different forms of the discrete-time Markov model (Butt *et al.* 1987, Li *et al.* 1996). The homogenous and non-homogenous chains are the two most popular forms of the deployed discrete-time Markov model (Abaza 2015). In this paper, the homogeneous MC is used, considering the traffic is similar on all roads.

1.4 Research Hypotheses

Homogenous MC is one of several methods devoted to the prediction of future pavement conditions. It is used in several PMSs in many countries around the world. The use of MC requires calculating the transition probability matrix (TPM) from the available historical data of pavement. The indicated research illustrated that the MC theory relies on a discrete probabilistic approach that is widely used in developing probabilistic models for predicting pavement deterioration. MC has been used by many researchers (Butt *et al.* 1999, Abaza and Shahein 2007). Accordingly, there is an agreement that the principles and conditions of the MC theory (the stochastic process is discrete in time and a finite state space) are applicable to pavement deterioration modeling. Additionally, the first order Markov property that future state of the process depends on its current state and not past state holds in pavement deterioration (i.e., future network condition depends on its present condition but not past condition). This means that the present condition contains implicitly a given history (load and resistance) or that whatever the history, a given present distribution turns always to a given future distribution.

2 RESEARCH METHODOLOGY

To establish an appropriate pavement deterioration model, information regarding the road pavement conditions was collected considering visual inspection. After that, the pavement deterioration model using MC is then estimated. All the indicated studies considered using 1st order MC from two consecutive inspection years without considering uncertainty. However, this research deals with the transition probabilities (TP) calculation from age of pavement sections, which leads to providing an uncertainty modeling of the TP. The form of the TPM used in the paper is composed of the diagonal probabilities in addition to extra probabilities concerning the first row of the TP matrixes follows:

$$TPM = \begin{bmatrix} P_{11} & P_{12} & 0 & 0 & 0 \\ 0 & P_{22} & P_{23} & 0 & 0 \\ 0 & 0 & P_{33} & P_{34} & 0 \\ 0 & 0 & 0 & P_{44} & P_{45} \\ 0 & 0 & 0 & 0 & P_{55} \end{bmatrix}$$

Figure 1. TPM matrix.

Where p_{12}, is the probability of the pavement section condition to deteriorate from very good to good condition. The methodology followed in this research can be highlighted to include the interesting issue of using the homogenous first order MC as a stochastic model in the prediction of the performance of flexible pavements through the consideration of the calculated TPM.

3 DATA COLLECTION

The database was categorized by roadway length, sections, uniformity of cross-section, and thickness of pavement structure. The length of road sections was taken to be 100m. The selected pilot roads and related lengths are presented in Table 1. These include three arterial and one collector roads. Figure 1 shows a typical division of an arterial road into sections in each direction. The data collected were based on 2 years of inspection: 2012 and 2016, respectively. Percentage rating of the Road Condition Survey for all the surveyed sections of 138 showed that 60 percent of the sections were in very good and good conditions while 29 percent were in fair condition. The rest of the sections were approximately in poor or very poor condition.

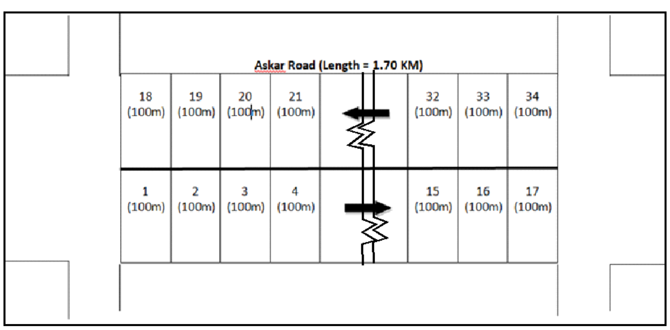

Figure 2. Section identification example.

Table 1. Selected roads in the pilot case study.

Road Name	***Length (KM)***	***Classification***
Yaser Arafat	1.50	Arterial
Tunis	1.20	Arterial
Askar	1.70	Arterial
Mohammad Bin Rashid	2.50	Collector
Total	**6.90**	

4 MODEL FORMATION

The model in this research is developed based on statistical analysis correlating pavement performance as indicated by PCI with pavement age and/or design service life. For each treatment, representative in-service projects were selected and their corresponding needed data were used to develop pavement performance models. The pavement condition rating and the corresponding number of sections are illustrated in Table 2. The resulting Markov model output, considering the collected data for the surveyed selected road sections in this research, is shown in Table 3. After the data was filtered, all the surveyed pavement segments wereused in the development of the TPM. The formations of TM and the TPM are shown in Tables 4 and 5. The calculations required for the Markov model were conducted using Eq. (1):

$$p_{ij} = \frac{n_{ij}}{n_i} \quad (1)$$

Where p_{ij} is the probability of the pavement section to deteriorate from the current condition to the next condition,n_{ij} is the number of the pavement sections deteriorated from i to j condition state, and n_i is the total number of pavement sections in condition state i.

Table 2. Pavement condition rating and corresponding no. of sections.

PCI	**No. of Sections**
Very Good (VG): [5]	58
Good (G): [4]	44
Fair (F): [3]	20
Poor (P): [2]	12
Very Poor (VP): [1]	4
Total	**138**

Table 3. Data on pavement conditions for the selected roads.

PCI	**No. of Sections**
VG to VG	45
VG to G	13
G to G	30
G to F	14
F to F	15
F to P	5
P to P	9
P to VP	3
VP to VP	4
Total	**138**

Table 4. Transition matrix for the selected roads.

Rating Value	**VG**	**G**	**F**	**P**	**VP**	**No. of Sections**
VG	45	13	0	0	0	58
G	0	30	14	0	0	44
F	0	0	15	5	0	20
P	0	0	0	9	3	12
VP	0	0	0	0	4	4
Total						**138**

Table 5. TPM for selected roads.

Rating Value	**VG**	**G**	**F**	**P**	**VP**	**Total**
VG	0.78	0.22	0	0	0	1
G	0	0.68	0.32	0	0	1
F	0	0	0.75	0.25	0	1
P	0	0	0	0.75	0.25	1
VP	0	0	0	0	1	1

5 RESULTS AND DISCUSSION

Table 6 presents the Markov probability distribution for the first six years, which are calculated based on the TPM given in Table 5. The probability distribution within each state vector is the main characteristic that makes the Markov model more attractive than the deterministic models. In Table 6, the state of maximum probability is shown in bold face. This path is the most likely deterioration path that the sections will follow. For example, at year four, there is a probability of 0.370 for the sections to stay at PCI value of 5, but the highest probability value of 0.486 for that year is at PCI value of 4. Figure 2 shows the plot of the Markov model for selected roads pavement sections. In the Markov model, the predicted future determination trend starts at the last rating, which the sections had received. The line represents the average states of the pavement determined from a probability distribution based on the TPM established from the entire data set. This figure also shows that the prediction of performance trend of pavement sections indicates the pavement reaches the minimum accepted performance level of value 2at age of approximately eight years, which is unacceptable value for twenty years pavement design service life, and accordingly, the rate of deterioration is high. The Markov probabilistic model for the selected roads gave approximately the expected deterioration behavior. The pavement reached the minimum acceptable performance level at age of eight years which means that the sections with poor or very poor conditions must have major rehabilitation, while the remaining sections from fair to very good sections may have preventive maintenance or localized repair actions.

Table 6. Probability distribution values for MC for selected roads.

Rating Value	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
VG (5)	**0.780**	**0.608**	**0.475**	0.370	0.289	0.225
G (4)	0.220	0.361	0.444	**0.486**	**0.500**	**0.493**
F (3)	0.000	0.070	0.168	0.268	0.357	0.428
P(2)	0.000	0.000	0.018	0.055	0.109	0.171
VP (1)	0.000	0.000	0.000	0.004	0.018	0.045

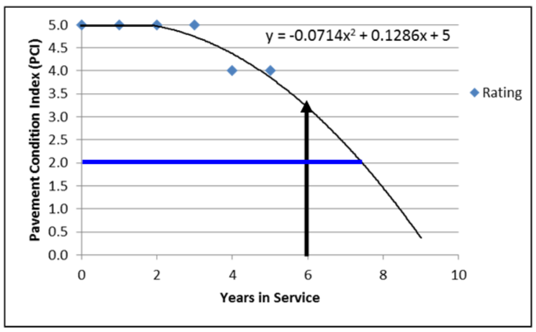

Figure 3. A graphical presentation of the estimated pavement performance model.

6 CONCLUSIONS AND RECOMMENDATIONS

The PMS includes different modules such as inspection and inventory, performance model, and prioritization. The use of first order MC as part of the PMS in Palestine will assist in developing a systematic process of defining the right treatments for the right sections at the right time. The

1st order MC is used to estimate the performance of urban arterial and collector roads in Nablus City. The results indicate that it is possible to model the performance of the existing roads using MC up to eight years, which means that this model is appropriate in case of applying preventive maintenance measures such as seal coating, surface patching, milling and overlay, etc. The newly proposed estimate is suitable for applying preventive maintenance treatments, which is usually of limited cost, and do not need much more finance to compare with preventive and other maintenance strategies. The main recommendations are:

- To adopt and apply the new estimated model in other Palestinian municipalities;
- To collect data and perform the inspection process bi-annually;
- To estimate the new model for rural roads using the first order MC.

Acknowledgments

The authors would like to thank the Department of Public Works in Nablus Municipality, and students of GP (CED, An Najah National University) for providing the pavement database used in the paper.

References

Abaza K. A., Simplified Staged-Homogenous Markov Model for Flexible Pavement Performance Prediction, *Journal of Road Materials and Pavement Design,*17(2), 365-381,2015.

Abaza, K. A., Ashur, S. A., and Al-Khatib, I. A., Integrated Pavement Management System with A Markovian Prediction Model, *Journal of Transportation Engineering*, 130(1), 24–33, 2004.

Abaza, O., and Shahein, L., Developing Pavement Performance Functions for Palestinian Roadway Network, *An-Najah University Journal of Research*,21, 23-51, 2007.

AASHTO (American Association of State Highway and Transportation Officials), *AASHTO Guide For The Design Of Pavement Structures*, Washington, DC: AASHTO, 1993.

ASTM (American Standard Testing Manual), *Standard Practice for Roads and Parking Lot Pavement Condition Index Surveys*, D6433-07, Philadelphia. Retrieved from http://www.astm.org/Standards/D6433.htm, 2007.

Amin, X. and Reza, XX, *The Pavement Performance Modeling: Deterministic vs. Stochastic Approaches*, S. Kadry & A. El Hami (Eds.), Numerical Methods for Reliability and Safety Assessment, Switzerland: Springer International, 179–196, 2015.

Butt, A., Shahin, M., Feighan, K., and Carpenter, S., Pavement Performance Prediction Model Using The Markov Process, *Transportation Research Record*, 1123, 12–19, 1987.

Huang, Y., *Pavement Analysis and Design*. 2nd ed., Upper Saddle River, NJ: Pearson/Prentice Hall, 2004.

Jorge, D., and Ferreira, A., Road Network Pavement Maintenance Optimization Using The HDM-4 Pavement Performance Prediction Models, *International Journal of Pavement Engineering*, 13(1),39–51, 2012.

Khan, M. U., Mesbah, M., Ferreira, L., and Williams, D. J., Development of Road Deterioration Models Incorporating Flooding for Optimum Maintenance and Rehabilitation Strategies, *Road and Transport Research: A Journal of Australian and New Zealand Research and Practice*, 23(1), 3–24, 2014.

Li, N., Haas, R., and Xie, W.-C., Investigation of The Relationship Between Deterministic and Probabilistic Prediction Models in Pavement Management, *Transportation Research Record*, 1592, 70–79, 1997.

Li, N., Xie, W.-C., and Haas, R., *Reliability-Based Processing of Markov Chains for Modeling Pavement Network Deterioration*, *Transportation Research Record*, 1524, 203–213, 1996.

Shah, Y., Jain, S., Tiwari, D., and Jain, M., *Modeling The Pavement Serviceability Index for Urban Roads in Noida*, *International Journal of Pavement Research and Technology*, 6(1), 66–72, 2013.

Shahin, M., *Pavement Management for Airports, Roads, And Parking Lots*, New York, NY: Chapman and Hall, 1994.