UTILIZATION OF ANN AND MARKOV CHAIN-BASED PAVEMENT PERFORMANCE MODELS FOR NETWORK-LEVEL MAINTENANCE MANAGEMENT

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1. INTRODUCTION

Pavement Performance Modeling (PPM) is essential to the Pavement Management System (PMS). With the evolution of data analytics, pavement deterioration prediction models become more popular among road engineers and researchers for forecasting pavement conditions based on various factors such as traffic loading, road characteristics, and maintenance history and prioritizing the road sections for maintenance treatment for network-level maintenance management. There are different data analytics techniques that can be used for PPM. The commonly used are Markov Chain (MC) modeling (Abbas A. Butt et al.) and Artificial Neural Networks (ANN) (Attoh-Okine et al. 1994). In this research, results from two different analyses applying these models to the provincial road data of Pakistan are reviewed, and the applications of the two models are discussed from the network-level maintenance management perspectives.

2. METHODOLOGY

2.1. Data

Provincial highway network data of Khyber Pakhtunkhwa province, Pakistan consisted of 105 road sections of different lengths with 10 road characteristics that included divisions (highway network is divided into four divisions based on topography for monitoring purposes), pavement terrain, road importance, road purpose (mines, minerals, industrial, tourism road), condition of side drain, culvert, traffic load, time since last rehabilitation, strategic importance along with pavement condition (categorized based on IRI as good, fair, and bad) were utilized for both the methods.

2.2. Pavement Performance Models (PPM)

The data was analyzed using the MC approach to develop the PPM. The states were defined as good, fair, and bad. However, in the Markov chain, it is essential to select pavement sections with similar characteristics, particularly, for the transition matrix to best reflect the behavior of the pavement with time, the factors must be constant or be similar throughout the modeling period. However, the network-level data consists of road sections with varying characteristics. Agglomerative Hierarchical Cluster (AHC) analysis was first performed to identify the different families of pavement sections with similar road characteristics. Five clusters were obtained in total, but Markov PPM was developed for three clusters (pavement families) to find the deterioration progress for the next 10 years (Figure 1) because they contained enough pavement age data for finding the probability of pavement conditions in different years for the transition matrix.
A back-propagation ANN PPM was then developed by utilizing the same data with 10 input variables for four divisions. The structure of the ANN model is shown in Figure 2. To find the relative importance of the input variables with respect to pavement condition and for enhancing the performance of the model, the Garson algorithm was applied, and the ANN model was regenerated by removing the two least important variables (obtained through Garson's algorithm).

3. RESULTS AND DISCUSSIONS

3.1. Markov chain and ANN analysis results

Figure 1 shows PPMs for three families of roads (clusters 1, 2, 3) developed by MC analysis, in which the transition probabilities of three states (good, fair, bad) were used to predict future conditions. As in MC modeling, pavement's future condition is assumed to depend only on its current condition irrespective of the factors that affect it, hence, by applying AHC before MC, road sections were separated based on similar characteristics but the impact of these factors on pavement conditions was not possible to determine. It was observed that rate of deterioration of roads in Cluster 1 (hilly areas with medium traffic load) is more than in Cluster 2 (plane areas with high traffic load). However, rate of deterioration for the road sections in Cluster 3 (mines and minerals areas roads) was found to be very high as compared to the other two families.
Figure 3 shows the relative importance of 10 input variables with respect to pavement condition by applying ANN with Garson's algorithm. It was observed that drainage condition and traffic loading were the most important variables associated with the pavement condition indicating that pavement deterioration is highly related to these factors. Table 3 shows the result of ANN models for 4 divisions. It was observed that the road sections in the Center and East divisions will completely deteriorate in 5 and 4 years respectively if no maintenance activity is performed. However, the rate of deterioration of the road networks of the North and South divisions was found on the higher side than other two divisions.

3.2. Utilization of models for network-level maintenance management

For the provincial road network, at the division level, the MC model can be utilized for long-term planning (5-10 years) or to perform life cycle cost analysis for the specific highways in the same region with similar characteristics. Such kind of MC models can also be utilized for identifying the critical pavement sections family that requires immediate attention from a maintenance perspective. The current study revealed that the road sections that lead to mines and mineral areas are

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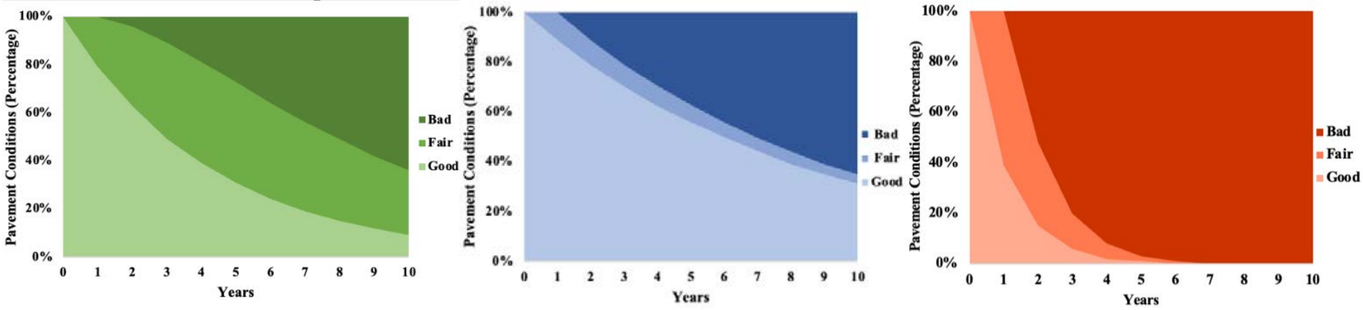
more critical and should be prioritized for maintenance.



a) Cluster 1(Hilly areas, tourism roads, medium traffic, good drainage). b) Cluster 2 (Plain areas, high traffic, good drainage condition). c) Cluster 3 (Mines and minerals, medium traffic, fair drainage).

Fig. 1 Pavement conditions prediction models for three clusters

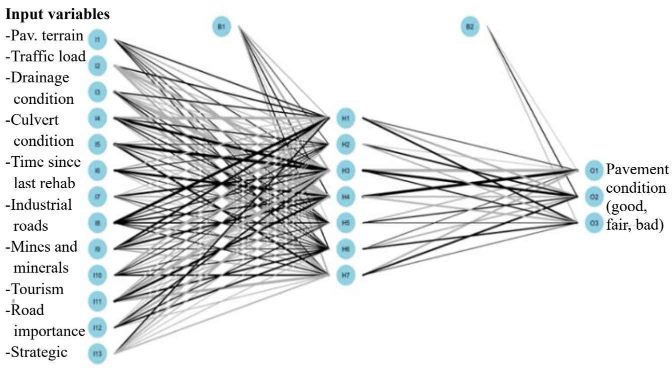


Fig. 2 ANN model (9-7-3) with all input variables Training, testing ratio (75%, 25%)

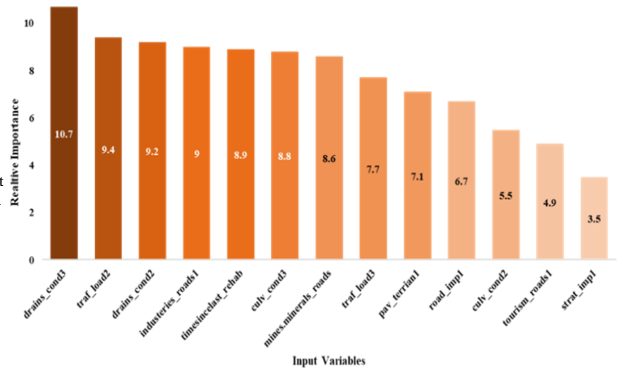


Fig. 3 Relative importance of the input variables by

Table 1. Pavement condition prediction for 4 divisions network by ANN model

Divisions	Predictions of the Pavement Performance with time.				
	Year1	Year 2	Year 3	Year 4	Year 5
Centre	3	3	2	2	1
North	3	2	1	1	-
East	3	3	2	1	-
South	3	2	1	1	1
Accuracy with 11 Variables=81%			Accuracy with 9 Variables=83%		
Pavement Condition: Good=3, Fair=2, Bad=1					

The ANN models are more complex than the MC model and can provide more robust predictions no matter how complex the relationship between pavement conditions and other factors is. As the model is trained on a wide range of input variables (10 road characteristics), it is more flexible than MC and can be utilized for predicting road conditions with different combinations of road characteristics. The other important aspect of ANN is its explanation of the relative importance of input variables (road characteristics) with respect to pavement conditions (Figure 3). In the study, it was observed that pavement managers need to improve the drainage conditions and address the factor of traffic loading to minimize the deterioration rate.

3.3. Limitations of models

In the case of MC PPM, the pavement age data should be comprehensive, and it must cover a wide range of pavement ages with respect to pavement conditions for constructing a transition matrix to represent the probability of moving from one pavement state to another over time. In this study, due to limited data, a few of the road sections in two clusters were not considered for Markov modeling which may limit the ability of the model to apply to the entire network. Furthermore, Markov models assume that the probability of transitioning from one state to another is constant over time, but it not may always be the case especially if there are external factors that can affect the pavement performance. However, in ANN modeling, the number of input features (road characteristics) requiring training the model can impact the amount of data needed or conversely it can affect accuracy. It was observed in the study that by deleting the last two important variables from the ANN model, the accuracy of the model increased but for more robust modeling, maximum road characteristics are essential for making it applicable in different scenarios.

4. CONCLUSION

Both the MC and ANN-based approaches have their strengths and limitations, and the choice between them may depend on the availability of data, the level of complexity of the pavement deterioration process, and the specific goals of the analysis. Markov models are based on a simple probabilistic approach and are comparatively easy to implement for capturing long-term pavement performance. However, the ANN models are comparatively complex and computationally intensive, but they can provide more accurate predictions and the modeling can be done at any desired level.

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