Artificial Neural Networks in Pavement Engineering: A Recent Review

Abhishek Kurian*, Elvin Sunildutt

Department of Civil Engineering, Saintgits College of Engineering, Kottayam, Kerala

*Corresponding author: abhishekkurian99@gmail.com

doi: https://doi.org/10.21467/proceedings.112.66

ABSTRACT

The application of Artificial Neural Networks (ANN) in civil engineering has increased drastically in the past few years. ANN tools are nowadays used commonly in developed countries over various fields of civil engineering like geotechnical, structural, traffic, pavement engineering etc. This paper deals with the review of recent advancements and utilization of ANNs in pavement engineering. The review will focus on pavement performance prediction, maintenance strategies, distress intensity detection through deep learning techniques, pavement condition index prediction etc. The use of ANNs in pavement management systems are expected to furnish a systematic schedule and economic management strategies in the field of pavement engineering. The use of ANNs combined with deep learning techniques help to address complex problems in pavement engineering and pave the way to a sustainable future.

Keywords: Artificial Neural Networks, deep learning

1 INTRODUCTION

Recent studies have shown that Artificial Neural Networks play a significant role in Pavement Management System (PMS). PMS is a pressing priority especially in developing countries like India for efficient and economic construction and maintenance of pavements. PMS was introduced as a tool to ensure proper maintenance and rehabilitation strategies for pavement construction projects with a low budget (Kirbas 2010). PMS helps to manage different stages of roads pavement such as planning, designing, construction and maintenance (S. Choi et. al. 2019). Proper execution of PMS can ensure efficient budget distribution, project prioritization and economical maintenance strategies which can maximize the service life of a pavement (Fawaz 2018). The development of technologies like "machine learning" and "deep learning" has further improved the scope of artificial intelligence in the field of pavement engineering. Deep learning is a technique which builds complex artificial neural networks based on extensive data (Hern 2016). In simple words deep learning and machine learning resemble the ability of humans to perform tasks based on knowledge and experience. These techniques are being used recently for crack detection, Pavement Condition Index (PCI) prediction and effective maintenance. According to recent studies nonlinear calculations in pavement engineering are being solved using ANN models (Ceylan et. al. 2014). Optimization by feeding adequate data to an ANN model can improve accuracy. This paper deals with applications of deep learning ANN models in pavement engineering ranging from performance prediction, pavement condition prediction, distress detection using image sensing techniques and management strategies.

1.1 ARTIFICIAL NEURAL NETWORKS

ANN work is based on the basic principle of human nervous system and consists of neurons which are interconnected. Neurons are distributed in three layers such as input layer, hidden layer and output layer. ANN models have several features such as adaptivity, non-linearity, mapping and can deal with noisy data (M.

Proceedings DOI: 10.21467/proceedings.112; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-947843-3-3

Abambres et. al. 2017). ANN models require training and validation in order to perform calculations accurately. A unique data set is used for training the model whereas another data set which has no resemblance to the initial one is used for validation purposes. However, when the data is insufficient, the accuracy level of the model suffers evidently and parameter interpretation becomes difficult. During field data measurement, factors such as climate and quality of construction are difficult to be taken into account. Hence there is a need for nonlinear models to be established in order to get accurate results.

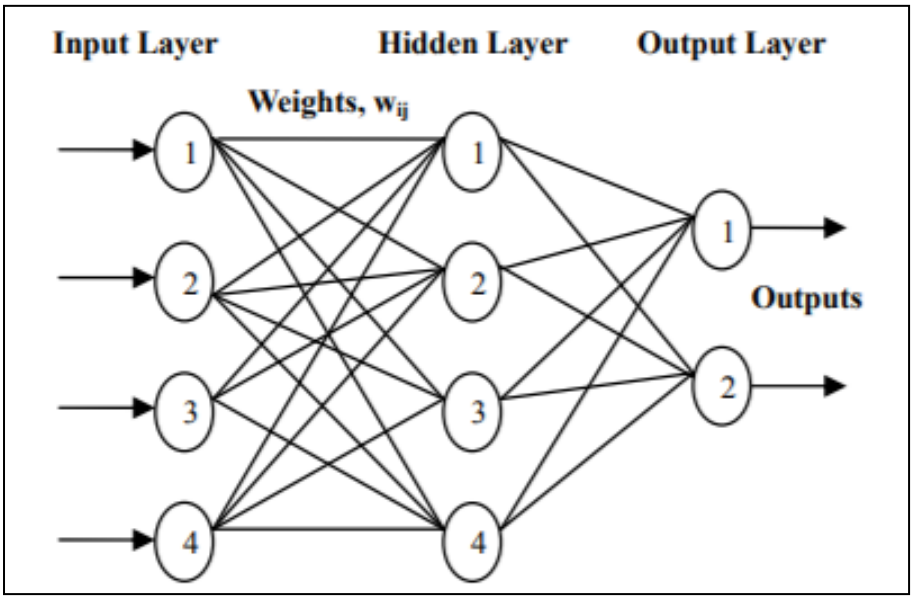

Figure. 1. ANN model (Thube 2012)

1.2 OBJECTIVE

ANNs act as an alternative technique when considering the conventional techniques. The conventional techniques are limited or restricted by linearity, normality variable independence etc. Such limitations in conventional methods along with the rising potential of artificial intelligence and deep learning had encouraged various researchers to develop ANN models for prediction, evaluation and assessment of pavement performance and condition. The objective of this study is to provide a detailed review of the recent advancements and development of ANNs in the field of pavement engineering.

2 APPLICATIONS

2.1 PREDICTION OF PAVEMENT CONDITION INDEX (PCI)

Pavement Condition Index (PCI) is a rating system ranging from 0 to 100 (0-failed, 100-good) which portrays the distress intensity of a pavement in terms of a numerical index (ASTMD 6433:18). Pavement distress assessment is necessary to establish a robust PMS to ensure cost effective practices and efficient maintenance strategies. Usually, such distress intensity assessment of pavements is carried out by a panel of experts working in the field of pavement engineering. Distress detection is performed using Network Survey Vehicles (NSV) or on foot surveys. Such human dependent assessment is time consuming and uneconomical. H. Majidifard et. al. 2020 developed a deep learning model which uses image sensing to detect the type and intensity of cracks. More than 7000 google street view images were used to train the model for crack detection. The types of distress

Proceedings DOI: 10.21467/proceedings.112
ISBN: 978-81-947843-3-3

Series: AIJR Proceedings
ISSN: 2582-3922

were divided into nine classes such as reflective crack, transverse crack, block crack, longitudinal crack, alligator crack, sealed reflective crack, lane longitudinal crack, sealed longitudinal crack and potholes. A hybrid model was developed using already existing models like YOLO and U-net. Further training was done using google street view images to make the model more human independent and accurate. The developed model was found to be effective, economical and time saving. Further study needs to be conducted in order to develop this model into a software to perform all steps like image extraction, analysis and PCI prediction as a whole.

Figure. 2. Distress detection using deep learning model (H. Majidifard et. al. 2020)

In developing countries like India, there is huge need for PCI prediction for rehabilitation and maintenance works. However, google street view function is not fully established in India due to certain restrictions put forth by the government. These restrictions are expected to be removed in the future, meanwhile manually taken images using drones or other equipment can be used to get results from such models. A. Jiminez et. al 2016 developed ANN models to predict PCI values based on data such as Equivalent Standard Axle Load (ESALs), Structural Number (SN), average annual daily traffic, age of the pavement and thickness. PCI values for both flexible and rigid pavement were calculated using this model. H. Shahnazari et. al 2012 compared the results of ANN models and genetic programming method. PCI calculation program was developed using both these techniques and was found to be a reliable prediction tool in PMS. ANN models were found to give more accurate values of PCI. M. Jalal et. al. 2017 developed an optimal ANN model to predict PCI values and input variables such as pavement type and year. The optimal model was found to have a lower value of error compared to the normal ANN models. The coefficient of determination of the entire model was found to be high.

2.2 PREDICTION OF PAVEMENT PERFORMANCE

Prediction of pavement performance adds to the effectiveness of a PMS. Predicting pavement performance helps in proper budget allocation especially in scheduling maintenance strategies and rehabilitation works throughout the service life of a pavement. Pavement performance prediction model in PMS can be defined as "a mathematical description of the expected values that a pavement attribute will take during a specified analysis period" (Hudson et. al., 1979). Such models help to schedule rehabilitation works and maintenance in time (George 2000).

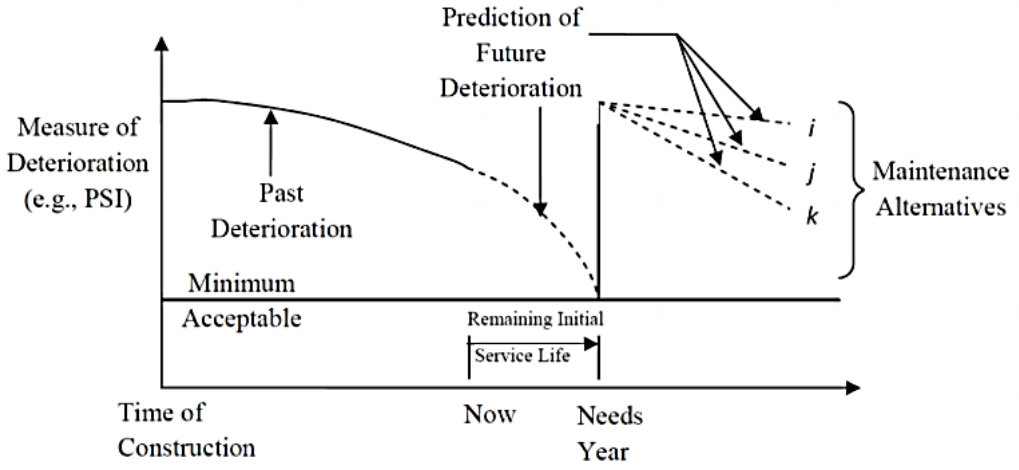

Figure. 3. Pavement performance (Haas et. al. 1994)

Pavement performance models in PMS includes deterministic, probabilistic, expert and ANN models (Wolters et. al. 2010). ANN models can be used to develop meaningful correlation between input variables (Rafiq et. al. 2001). Gencel et. al 2011 developed ANN models and linear regression models to correlate cement content, metal content and traffic loading on rigid pavements. ANN model was found to be more accurate while predicting wear of concrete. F. Alharbi 2018 developed a Multiple Linear Regression (MLR) model and ANN model to predict pavement performance. Relative contribution of input variable on distress or condition index was analyzed. A reliable correlation between structural capacity and rutting was developed using an ANN model and was found to have high R^2 values which further validates the result obtained. Influence of climate data in addition to historical data was included in this study. Weather factors such as average annual temperature, snowfall and rainfall was found to affect the performance of pavements. The study determined the influence of weather on pavement deterioration.

Ceylan et al. 2005 developed ANN models to predict strains using FWD deflection data. Tapkin et al. 2012 developed ANN models to predict stiffness, strain buildup, stability and marshall quotient. Stress, strain and deflection in rigid pavements were predicted using ANN models (Saleh 2015). Longitudinal strains in flexible pavements subjected to moving loads were predicted using ANN models by Shafabakhsh et al. 2015. I.N. Abdallah et al. 2009 developed ANN models to predict critical strains using deflection bowl obtained from Falling Weight Deflectometer. The input variables such as thickness of pavement and pavement deflection data was used in the ANN model for accurate performance prediction. Comparison of life of pavement calculated using ANN model and conventional methods like back calculation method were performed in this study.

Pavement properties such as layer moduli, thickness, poison's ratio, stress, strain, deflection etc. are taken into consideration while designing a pavement. An efficient pavement design aids the service life of a pavement. Ceylan et al. (2007) predicted moduli values for each layer using input variables such as deflection data from FWD and thickness of the layer. Bayrak et al. 2008 used ANN models to backcalculate pavement properties using FWD data. Pożarycki (2015) predicted layer thickness of bituminous pavements using input variables such as deflection data, stress applied and temperature.

Proceedings DOI: 10.21467/proceedings.112
ISBN: 978-81-947843-3-3

Series: AIJR Proceedings
ISSN: 2582-3922

2.3 PREDICTION OF PAVEMENT DISTRESS

The intensity of distress on pavements influence ride comfort, fuel consumption, frequency of accidents, fatigue etc. Solhmirzaei et al. 2012 developed an ANN model to predict pavement distress. Input variables such as vehicular acceleration and output variable such as vertical displacement was used to train the model. H. Majidifard et. al. 2020 used image sensing techniques for detecting pavement distress. Further studies need to be conducted for sensing distress such as rutting. Ceylan et al. 2011 developed ANN models to generate accurate stress intensity factor (SIF) which occurs due to changes in temperature. Thube 2012 developed ANN models to predict accumulation of pavement distress. Data including intensity of rutting, raveling and cracking area was used as model outputs. Yoo et al. 2016 developed models to differentiate noise objects and pavement distress in images. H. Majidifard et al. 2020 used a similar technique to get effective results. Saghafi et al. 2009 predicted faulting in rigid pavements by taking factors such as age of a pavement and condition of layers into account. Wu et al. 2014 detected intensity of fatigue and reflective cracking using ANN models.

3 CONCLUSION

Development of ANNs have a significant impact in the performance as well as rehabilitation aspects of pavement engineering. With its evolution, classification of pavement distress on the basis of its type and intensity are undertaken relatively with ease. Pavement parameters such as PCI can be quantified and pavement rating can be developed with minimal effort for rehabilitation purposes. Computation of pavement performance is easily one of the highlights of ANN models. ANN models can be an efficient analysis and predicting tool once they are trained and developed with appropriate datasets. The predictions made using ANNs can be utilized for enhancements subjected to improving pavement performance. Despite the advancements and applications of artificial intelligence in transportation engineering, there is a huge gap that needs to be filled in the branch of pavement engineering. Many researchers recently have introduced the concept of machine learning and deep learning into their studies related to pavement engineering. Such tools can be used to design and develop robust pavements with maximum service life. ANN models may take hours or certain months to train along with collection of immense data. However, time is a trade-off when it comes to scope and opportunity it puts forward to this field.

How to Cite this Article:

Kurian, A., & Sunildutt, E. (2021). Artificial Neural Networks in Pavement Engineering: A Recent Review. *AIJR Proceedings*, 553-558.

REFERENCES

AASHTO. (1993). AASHTO guide for design of pavement structures. 1993 (Vol. 1). AASHTO.

ASTM D6433-20, *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys*, ASTM International, West Conshohocken, PA, 2020

Amin, S. and Amador-Jiménez, L., (2016). *Backpropagation Neural Network to estimate pavement performance: dealing with measurement errors*, Road Materials and Pavement Design, 1-21, DOI: 10.1080/14680629.2016.1202129

Ceylan, H., Bayrak, M. and Gopalakrishnan, K. (2014). *Neural Networks Applications in Pavement Engineering: A Recent Survey*, International Journal of Pavement Research and Technology, 7(6), 434-444.

Ceylan, H., Gopalakrishnan, K., and Kim, S. (2014). I-BACK: *Iowa's Intelligent Pavement Backcalculation Software.* Geo-Congress 2014 Technical Papers, Geo-Technical Special Publication (GSP), No. 234, pp. 2952-2959.

Choi, S. and Do, M. (2019) *Prediction of Asphalt Pavement Service Life using a Deep Learning Method*. International Journal of Highway Engineering, 20, 57–65.

Eldin, N.N. and Senouci, A.B. (1995). *Use of neural networks for condition rating of jointed concrete pavements.* Advances in Engineering Software, 23(3), pp. 133-141.

Gopalakrishnan, Ceylan, H., and Attoh-Okine. (2009) *Intelligent and Soft Computing in Infrastructure Systems Engineering: Recent Advances.* Studies in Computational Intelligence. Springer, pp. 47–66, Heidelberg, Berlin, Germany.

Gajewski, J. and Sadowski, T. (2014). *Sensitivity analysis of crack propagation in pavement bituminous layered structures using a hybrid system integrating Artificial Neural Networks and Finite Element Method*. Computational Materials Science, 82, pp. 114-117.

Haas, R., W. R. Hudson, & J. Zaniewaski. (1994). Modern pavement management. Malabar, FL: Krieger.

Kirbas, U. and Karasahin, M. (2016) *Performance models for hot mix asphalt pavements in urban roads.* Construction and Building Materials 116, 281–288.

Kirbas, U. and M. Gursoy. (2010). *Developing the basics of pavement management system in Besiktas district and evaluation of the selected sections*. Scientific Research and Essays, 5(8), 806-812.

Kim, S., Gopalakrishnan, K., and Ceylan, H. (2009). *Neural Networks Application in Pavement Infrastructure Materials.* Studies in Computational Intelligence. Springer, pp. 47–66, Heidelberg, Berlin, Germany.

Majidifard, H., Adu-Gyamfi, Y. and Buttlar, W (2020). *Deep Machine Learning Approach to Develop a New Asphalt Pavement Condition Index,* Construction and Building Materials 247 (2020) 118513

Shahnazari, H., Tutunchian, M. A., Mashayeki, M. and Amini, A. A, *Application of soft computing for prediction of pavement condition index* (2012). Journal of Transportation Engineering 138(12):1495-1506

Sharma, S. and Das A (2008). *Backcalculation of pavement layer moduli from falling weight deflectometer data using an artificial neural network*, Canadian Journal of Civil Engineering, 35(1), 57–66.

Saghafi, B., Hassani A, Noori, R. and Bustos MG (2009). *Artificial neural networks and regression analysis for predicting faulting in jointed concrete pavements considering base condition*, International Journal of Pavement Research and Technology, 2(1), 20-25.

Saleh, M., (2015). *Prediction of Rigid Pavement Responses under Axle Loads Using Artificial Neural Network*, International Journal of Pavement Research and Technology, 8(1), 10-16.

Santos, J., Ferreira, A. and Flintsch G (2017). *An adaptive hybrid genetic algorithm for pavement management*, International journal of pavement Engineering

Tapkın, Çevik, A., and Özcan Ş (2012). Utilizing Neural Networks and Closed Form Solutions to Determine Static Creep Behaviour and Optimal Polypropylene Amount in Bituminous Mixtures, Materials Research, 15(6), 865-883.

Thube, D. T., (2012). *Artificial Neural Network (ANN) Based Pavement Deterioration Models for Low Volume Roads in India*. International Journal of Pavement Research and Technology, 5(2), pp. 115-120.