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WHAT IS THE RELATIONSHIP BETWEEN PAVEMENT STRUCTURAL AND FUNCTIONAL PERFORMANCE?

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Abstract: *Nondestructive testing (NDT), such as the falling weight deflectometer (FWD) test, is generally used to evaluate the structural performance of pavements. Serviceability and roughness are used as indicators to obtain information about the functional performance of pavements.*
In this study, the relationship between the FWD and panel rating measurements in the same highway pavement sections was investigated. The Artificial Neural Networks (ANN) method was used to determine this relationship, and as a result, the structural and functional performance of pavement could be observed, though not at a very high rate.
Keywords: *pavement, Artificial Neural Networks, serviceability, roughness*

1. Introduction

Flexible pavements are layered systems with better quality materials on top and inferior materials at the bottom. Starting from the top, the pavement consists of wearing course, and base and sub-base layers. The base material may be a bituminous mix or a granular material, depending on the number of heavy vehicles on the considered section of the road (Huang, 1993). Repeated applications of vehicle loads, weather conditions, and other factors decrease the serviceability of the pavement. For this reason, a maintenance program should be set up to decide when and where to carry out maintenance works. The most difficult aspect is to determine the remaining life of the pavement. In order to determine the remaining life, the pavement should be analyzed structurally with material properties for each layer being elastic modulus, Poisson's ratio, and thickness of layer (Saltan and Terzi, 2009).
Highway maintenance engineers preferably need to determine the structural integrity of a road pavement by nondestructive means (McMullen et al., 1986). It is essential not only to evaluate the structural integrity of existing pavement, but also to have accurate information on pavement surface conditions in order to establish a reasonable pavement rehabilitation design system (Inoue and Matsui, 1990). Nondestructive Testing (NDT) of asphalt concrete pavements is one of the most useful and cost-effective methods developed by engineers to assist in the management of pavements (Zhou et al., 1990).
The term "present serviceability" was adopted to represent the momentary ability of pavement to serve traffic, and the performance of the pavement was represented by its serviceability history in conjunction with its load application history. Serviceability was found to be influenced by longitudinal and transverse profile as well as the extent of cracking and patching. The amount of weight that must

be assigned to each element in the determination of the over-all serviceability is a matter of subjective opinion (Terzi, 2007).

The condition of a pavement section has traditionally been assessed by several condition indexes. The present serviceability index (PSI) is one common evaluator used to describe the functional condition with respect to ride quality. Pavement condition index (PCI) is another index commonly used to describe the extent of distress on a pavement section (Shoukry et al., 1997).
In recent years, one of the most important and promising research fields has been "Heuristics from Nature", an area utilizing some analogies with natural or social systems and using them to derive non-deterministic heuristic methods and to obtain useful results. The Artificial Neural Network (ANN) and Fuzzy Logic Approach (FLA) methods are among the heuristic methods.
The main purpose of this paper is to develop an ANN methodology for estimating the relationship between pavement structural and functional performance.

2. Nondestructive Testing

The calculation of load-related pavement surface deflections of specific points using material properties of pavement layers (modulus, Poisson's ratio, and thickness) is well established (Noureldin, 1993). Of the different load responses (stress, strain and deflection), only surface deflections are measured easily. Pavement deflection is the basic response of the structural system (surface-base-subgrade) to the applied load. It is used frequently as an indicator of pavement structural capability and performance potential. Surface deflection measurements are rapid, relatively cheap, and nondestructive (Garg and Thompson, 1999). Pavement deflection is measured through a series of velocity transducers at various distances from the baseplate, and the data can be used to back calculate *in situ* pavement layer properties. This information can in turn be used in pavement structural analysis to determine the bearing capacity, estimate the remaining life, and calculate an overlay requirement over a desired design life (Wang and Lytton, 1993). The Falling Weight Deflectometer (FWD) was first introduced in France in the 1970s to test flexible road networks. It has since gained increasing acceptance as one of the most effective methods for evaluating flexible roads (Karadelis, 2000). In order to simulate the truck loading on the pavement, a circular mass is dropped from a certain height onto the pavement. The height is adjusted according to the desired load level. Underneath the circular plate a rubber pad is mounted to prevent shock loading. Seven geophones are generally mounted on the trailer (the number of geophones can change). When the vertical load is applied on the pavement, the geophones collect the deflection data. The duration and magnitude of the force applied is representative of the load pulse induced by a truck moving at moderate speeds (Garg and Thompson, 1999).
FWD (Figure 1) gives information about the other six points (or more) which are away from the circular plate. Therefore, the effect of the wheel loading can also be seen in other points.

Figure 1. FWD Application (http://training.ce.washington.edu/wsdot/)

There are many types of FWDs which can apply similar loading. The time of loading varies between 0.025 and 0.030 sec; the applied loads vary between 6.7-156 kN. The loading time of 0.030 sec represents duration of a load pulse produced by a wheel moving at a speed of 30 km/h, and ± 0.023 mm deviations can be seen from the FWD measurements (Moreland, 1983). Typically, 200-300 FWD measurements can be made in a day.

3. Pavement Serviceability

Performance is the general term for how pavements change their condition or serve their intended function with accumulating use (Lytton, 1987). The evaluation of pavement performance involves a study of the functional behavior of a section or length of pavement. For a functional or performance analysis, information is needed on the history of the riding quality of the pavement section for the time period chosen and the traffic during that time. This can be determined by periodic observations or measurements of the pavement riding quality coupled with records of traffic history and time. It is this history of deterioration of the ride quality or serviceability provided for the user which defines pavement performance, as shown in Figure 2 (Haas et al., 1994).

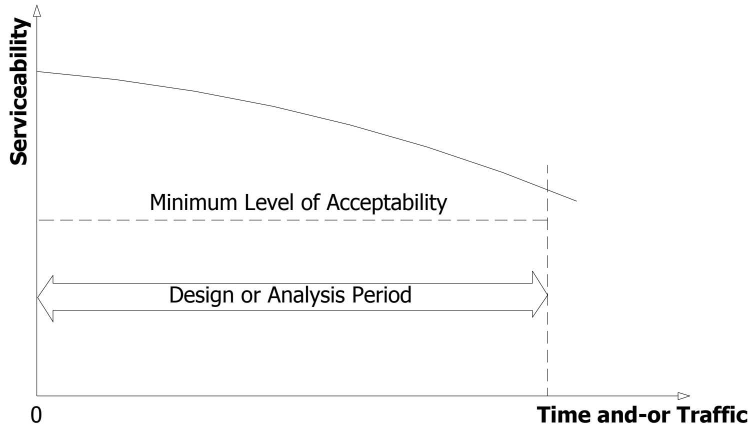

Figure 2. Deterioration of ride quality or serviceability (Haas et al., 1994).

In order to define performance, a new concept was evolved founded on the principle that the prime function of a pavement is to serve the traveling public. The term "present serviceability" was adopted to represent the momentary ability of pavement to serve traffic, and the performance of the pavement was represented by its serviceability history in conjunction with its load application history. Though the serviceability of a pavement is patently a matter to be determined subjectively, a method for converting it to a quantity based on objective measurements is given in the next two sections (AASHO, 1962).

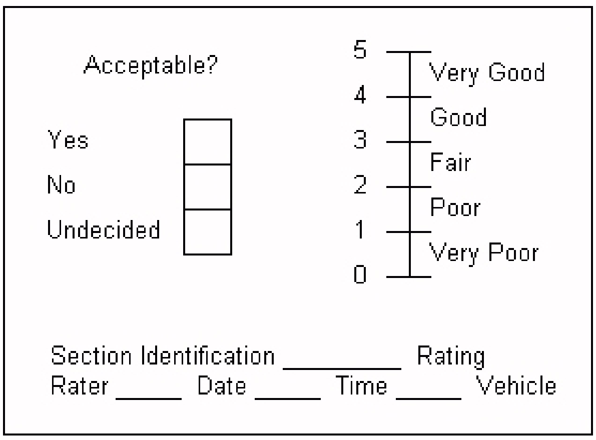
Acceptable?
Yes
No
Undecided
5
Very Good
4
Good
3
Fair
2
Poor
1
Very Poor
0
Section Identification _________ Rating
Rater _____ Date _____ Time _____ Vehicle

Figure 3. Individual Present Serviceability Rating Form (AASHO, 1962).

It is believed that the general public perceives a good road as one that provides a smooth ride. Studies in road tests sponsored by the American Association of State Highway and Transportation Officials (AASHTO) showed that the subjective evaluation of the pavement is based on mean panel rating (Perera, et al., 1998).

4. ARTIFICIAL NEURAL NETWORKS (ANN) METHOD

Neural networks are composed of simple elements operating in parallel. These elements are inspired by biological nervous systems. As in nature, the network function is determined largely by the connections between elements. A neural network can be trained to perform a particular function by adjusting the values of the connections (weights) between the elements. Commonly, neural networks are adjusted, or trained, so that a particular input leads to a specific target output. Such a situation is shown in Figure 4. Here, the network is adjusted based on a comparison of the output and the target, until the network output matches the target. Typically, many such input/target output pairs are used to train a network. Batch training of a network proceeds by making weight and bias changes based on an entire set (batch) of input vectors. Incremental training changes the weights and biases of a network as needed after presentation of each individual input vector. Incremental training is sometimes referred to as "on line" or "adaptive" training. Neural networks have been trained to perform complex functions in various fields of application, including pattern recognition, identification, classification, speech, vision and control systems. Today neural networks can be trained to solve problems that are difficult for conventional computers or human beings (Demuth and Beale, 2001).

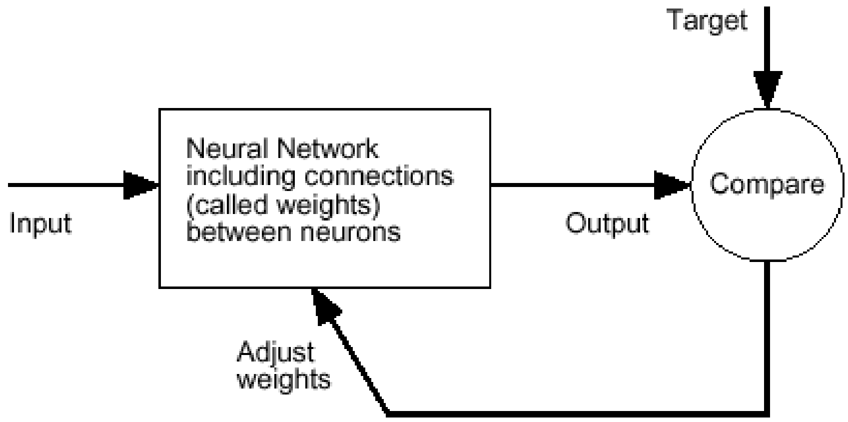

Figure. 4. Basic Principles of Artificial Neural Networks (Demuth and Beale, 2001).

4.1. Model Results

The ANN modeling consists of two steps: The first step is to train the network; the second step is to test the network with data which were not used in training step (Kaseko and Ritchie, 1994). During the training stage, the network uses the inductive-learning principle to learn from a set of examples called the training set (Lingras, 1995).

Input variables of the ANN model include five deflection values and elastic modulus while output is panel data. In this study, the data set taken from General Directorate of Highways of Turkey includes 88 samples. For the training set, 70 samples (approximately 80 %) were randomly selected and the residual data (18 samples) (approximately 20 %) were selected as the test set. The values of the training and test data were normalized between 0 and 1.

Levenberg-Marquardt Back-propagation training was repeatedly applied until the evaluation standard was reached (Demuth and Beale, 2001). Logarithmic sigmoid transfer function was used as the activation function for hidden layers and output layers. The learning rate and momentum were the parameters that affected the speed of the convergence of the back-propagation algorithm. The stopping criteria employed were 10000 for training. A learning rate of 0.001 and momentum of 0.1 were fixed for a selected network after training and model selection was completed for the training set. The trained networks were used to run a set of test data.

Various combinations of network architecture to develop the optimum ANN model were examined. ANN (i, j, k) indicates a network architecture with i, j and k neurons in input, hidden and output layers, respectively. The ANN (6, 10, 1) appeared to be the most optimal topology. The configuration is shown in Fig. 5. A comparison of panel data between PSI and the ANN model are given in Fig. 6 and 7 for training and testing sets, respectively.

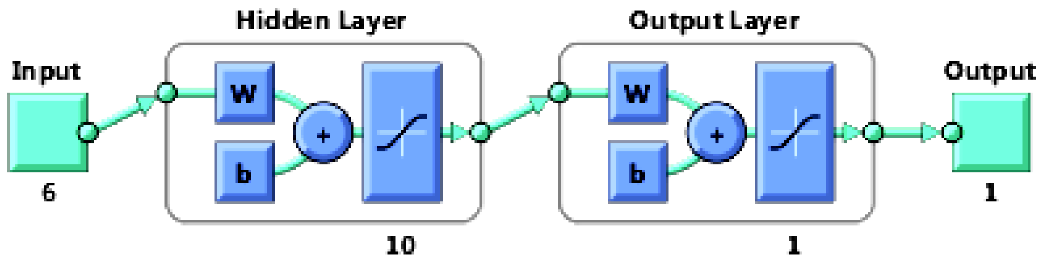

Figure 5. ANN model based on 6-10-1 configuration

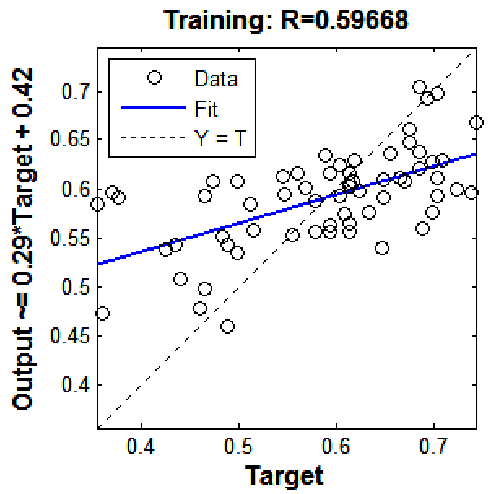

Figure 6. Comparison of the ANN and PSI for training set

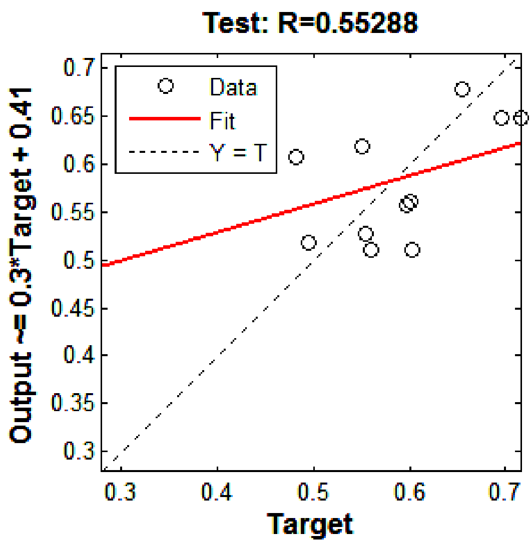

Figure 6. Comparison of the ANN and PSI for testing set

Regression values of PSI and the ANN model were obtained as 0.59 for the training set and 0.55 for the testing set.

5. CONCLUSION

Modeling the present serviceability index is very important in pavement management systems. In this work, an ANN model was developed for pavement serviceability ratio (PSR) determined on the surface of the flexible pavements. For this estimation, deflection and elastic modulus obtained from FWD measurement values were used.

ANN is especially appropriate for investigating the complex PSR forms in evaluating the functional capacity of the flexible pavements. These forms are filled by several experts as subjective evaluation.

This new methodology can help the highway agency in estimating PSR for pavement management systems.

REFERENCES

[1] AASHO. The AASHO Road Test Report 5, Pavement Research, Highway Research Board, National Academy of Sciences-National Research Council, Washington D.C. USA: 1962.

[2] Backcalculation, http://training.ce.washington.edu/wsdot/, Last Access in 17 Agust, 2011.

[3] Demuth H, Beale M. Neural Network Toolbox, User Guide, Version 4, The MathWorks, Inc., 2001.

[4] Garg, N. and Thompson, M.R., 1998. Structural Response of LVR Flexible Pavements at Mn/Road Project, Journal of Transportation Engineering, ASCE, 125 (3), 238-244.

[5] Haas R, Hudson WR, Zaniewski J. Modern Pavement Management Systems. Krieger Publishing Company, USA: 1994.

[6] Huang, Y.H., 1993. Pavement Analysis and Design, Prentice Hall, New Jersey, USA.

[7] Inoue, T. and Matsui, K., 1990. Structural Analysis of asphalt Pavement by FWD and Backcalculation of Elastic Layered Model, 3rd Int.Conf. on Bearing Capacity of Roads and Airfields, 425-434, Trondheim, Norway.

[8] Karadelis, J.N., 2000. A Numerical Model for the Computation of Concrete Pavement Moduli: A Nondestructive and Assessment Method, NDT&E International, 33, 77-84.

[9] Kaseko MS, Lo Z-P, Ritchie SG. Comparison of traditional and neural classifiers for pavement-crack detection. Journal of Transportation Engineering 1994;120(4):552-569.

[10] Lingras P. Classifying highways: hierarchical grouping versus kohonen neural networks. Journal of Transportation Engineering 1995;121(4):364-368.

[11] Lytton RL. Concepts of pavement performance prediction and modeling. Proc. of Second North American Conf. on Managing Pavements. Canada: 1987;2:4-19.

[12] McMullen, D., Snaith, M.S. and Burrow, J.C., 1986. Back Analysis Techniques for Pavement Condition Determination, the 1986 Int.Conf. on Bearing Capacity of Roads and Airfields, 335-344, Plymouth, England.

[13] Moreland, P.B., 1983. Calibration Services for Pavement Survey Equipment, FHWA-RD-82-135 Final Report.

[14] Noureldin, A.S., 1993. New Scenario for Backcalculation of Layer Moduli of Flexible Pavements, TRR 1384, 23-28.

[15] Perera, R.W., Byrum, C., and Kohn, S.D. 1998, Investigation of Development of Pavement Roughness, Final Report, FHWA-RD-97-147

[16] Saltan, M., Terzi, S., 2009, Backcalculation of Pavement Layer Thickness and Moduli Using Adaptive Neuro-fuzzy Inference System, Intelligent and Soft Computing in Infrastructure Systems Engineering, Studies in Computational Intelligence, Volume 259/2009, pp 177-204, Springer Berlin / Heidelberg

[17] Shoukry S, Martinelli DR, Reigle JA. Universal pavement distress evaluator based on fuzzy sets. Transportation Research Record 1997;1592. 180-186

[18] Terzi, S., Modeling the pavement serviceability ratio of flexible highway pavements by artificial neural networks, Construction & Building Materials, 2007, V. 21, pp 590-593

[19] Wang, F. and Lytton, R.L., 1993. System Identification Method for Backcalculating Pavement Layer Properties, TRR 1384, 1-7.

[20] Zhou, H., Hicks, R.g. and Bell, C.a., 1990. Development of A Backcalculation Program and Its Verification, 3rd Int.Conf. on Bearing Capacity of Roads and Airfields, 391-400, Trondheim, Norway.

КАКВА Е ВРЪЗКАТА МЕЖДУ СТРУКТУРНАТА ЕФЕКТИВНОСТ И ФУНКЦИОНАЛНОТО ДЕЙСТВИЕ НА НАСТИЛКАТА?

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Ключови думи: *настилка, невронни мрежи, експлоатационна надеждност*

Резюме*: За оценка на структурните характеристики на настилки обикновено се използва безразрушителен контрол (БР), като например тест за измервате на намаляване на теглото (FWD). Експлоатационната надеждност и грапавостта се използват като показатели за получаване на информация за функционалните характеристики на настилките.*
В това проучване е изследвана връзката между FWD и панелно-оценъчните измервания в едни и същи участъци на магистрална настилка. За да се определи тази връзка, е използван методът на изкуствените невронни мрежи (ANN), като в резултат може да се наблюдават, макар и в не много голяма степен, структурните и функционални характеристики на настилката.