CETRA 2014

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

Stjepan Lakušić – **EDITOR**

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA 2014
3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

TITLE
Road and Rail Infrastructure III, Proceedings of the Conference CETRA 2014

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, April 2014

COPIES
400

Zagreb, April 2014.

Proceedings of the
3rd International Conference on Road and Rail Infrastructures – CETRA 2014
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EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

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APPLICATION OF AN ARTIFICIAL NEURAL NETWORK IN A PAVEMENT MANAGEMENT SYSTEM

Hrvoje Dragovan[1], Tatjana Rukavina[2], Josipa Domitrović[2]
1 Institute IGH d.d., Road Planning Department, Osijek, Croatia
2 Faculty of Civil Engineering, University of Zagreb, Zagreb, Croatia

Abstract

The era of intensive construction of new roads is behind us, and now road agencies are focused on maintaining and preserving existing pavement surfaces. As they are faced with limited funds for maintenance, it is important to best utilize resources by selecting the best maintenance strategy. Selection of an appropriate maintenance strategy is a complex task which includes factors such as current condition of the pavement, road classification, traffic volume and type of pavement distress. These factors can be automated and implemented in pavement management systems to achieve a standardised approach to road pavement assessment and management. One of the key components of pavement management systems are pavement performance prediction models, which simulate the pavement deterioration process and forecast its condition over time. One such model is the artificial neural network. This paper analyzes the possibility of using artificial neural networks in pavement management systems to evaluate existing pavement condition, and its possible application for defining the maintenance strategy of state roads. A backpropagation algorithm was applied on 481.3 km of state roads in Osijek-Baranja County, which represents 7% of total length of the national road network in Croatia. The obtained results indicated that artificial neural networks can be used for optimization of maintenance or rehabilitation strategies, and for assessment of pavement condition at the project and network level.

Keywords: artificial neural network, pavement management system, backpropagation algorithm, pavement maintenance

1 Introduction

Every pavement no matter how well designed and/or constructed will deteriorate over time [1]. Pavement deterioration is influenced by the traffic load, climate conditions, quality of construction, layer thicknesses and quality of previous maintenance and rehabilitation activities. In general, it can be said that the rate of pavement degradation increases proportionately with the intensity of its use and age. Appropriate maintenance or rehabilitation activities, if applied in timely manner, can slow down or reset degradation processes. Over the past twenty years, it has been observed that the existing, classical experience in road maintenance is insufficient, and new methods of data collection and processing are being introduced in the pavement management system. Through accelerated development of information technology and artificial intelligence, unlimited opportunities are opening for their implementation in the pavement management system. A neural network is a form of artificial intelligence that is applied in pavement management systems as pavement behaviour prediction and maintenance optimisation models. This paper analyses the possibilities of using artificial neural networks to evaluate existing pavement condition, and to define the optimal pavement maintenance strategy.

2 Artificial neural network (ANN)

A neural network is an interconnected assembly of simple processing elements, units or nodes, whose functionality is based on neuron function in living creatures. The processing ability of the network is stored in the interunit connection strengths, or weights, obtained by a process of adaptation to, or learning from, a set of training patterns [2].

2.1 Processing information in the neural network

Processing information in the neural network is carried out in units called neurons (Fig. 1). Artificial neurons have multiple entry points from which they receive information, input values, x_i. Each input value is multiplied by the assigned weight, w_i. The sum of all the weighted values, x_i*w_i represents the internal activation of the neuron, I. The transfer function f(I), applied to this sum, changes the sum of the inputs into the output value, y [3].

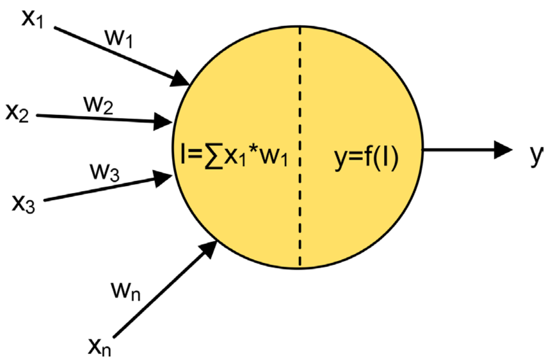

Figure 1 An artificial neuron

Neurons are connected in the network in the way that the output of each neuron represents the input into one or more other neurons. In the artificial neural network, neurons are organised in groups or layers in which the information is processed.
One of the most commonly applied neural networks, which found its place in the framework of the pavement management system, is the 'backpropagation' network. The functioning of the neural network that uses the backpropagation algorithm is described below.

2.2 Backpropagation neural network

The structure of the neural network consists of two external layers (input and output) and one or more hidden layers (Fig. 2). The network receives data by neurons in the input layer and the result of the network is given by neurons on an output layer. The hidden layers examine the interdependencies in the model and process the information of neurons, which are then forwarded to the neurons of the output layer.
The neural network is defined through two phases, the learning or training phase, and the testing phase. Prior to learning, it is necessary to define the input and output variables, and to collect data on which the backpropagation algorithm will be applied.
The backpropagation algorithm uses supervised learning, which means that we provide the algorithm with examples of the inputs and outputs we want the network to compute, and then the error (difference between actual and expected results) is calculated. The idea of the backpropagation algorithm is to reduce this error until the artificial neural network learns the training data. The training begins with random weights, and the goal is to adjust them so that the error will be minimal. In backpropagation, the scaling of local error and the increase or

decrease of weight is calculated backwards for each layer, beginning from the layer directly under the output layer, back to the first hidden layer, and the weights are then adjusted [3]. The described learning process is repeated in multiple iterations, and new weights and new errors are calculated in each iteration.

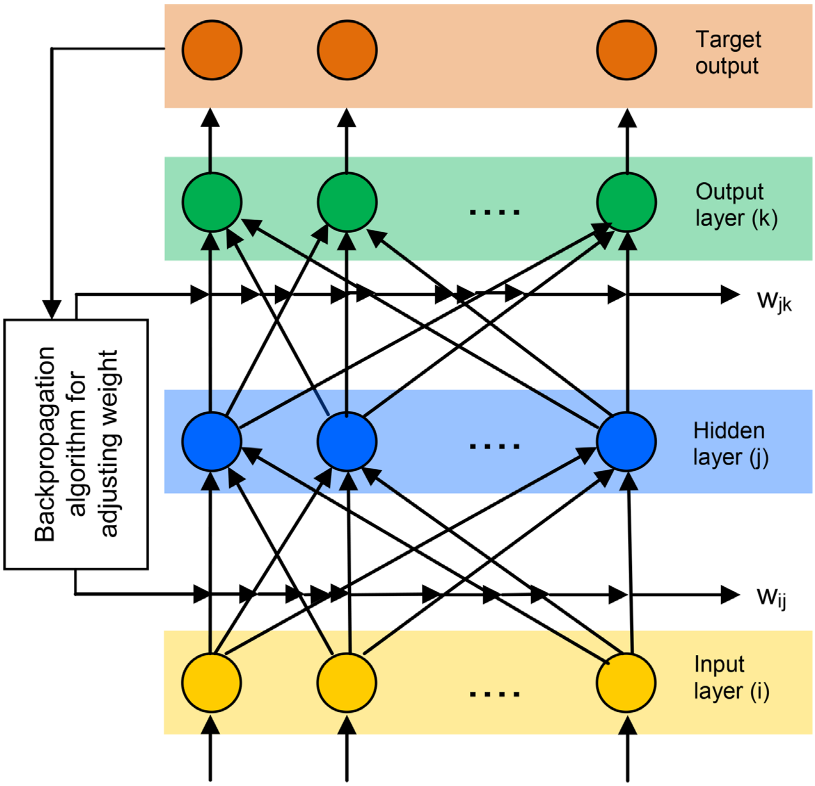

Figure 2 Structure of the backpropagation network in the learning phase

In the testing phase, the weights are fixed to the values obtained as a result of the learning phase. The network represents new input data that have not participated in the learning process. The output from the network is compared with the desired output to calculate error. Depending on the size of calculated error an assessment is given regarding the possible application of the neural network.

3 Application of ANN within PMS

As part of the pavement management system (PMS), the neural network is applicable for the purpose of assessing pavement condition, and selecting optimum pavement maintenance strategy. In this paper, pavement condition is determined with the application of the general performance indicator (GPI) as defined by the COST project 354 [4]. The maintenance strategy (MS) is defined depending on the type of required pavement rehabilitation in order to increasing pavement bearing capacity as well as driving comfort and safety [5].
The neural network input database includes data on field measurements of various types of pavement distresses (longitudinal evenness, rut depth, texture depth, surface cracks and patches). Measurements were conducted on the network of state roads in Osijek-Baranja County, over a total length of 481.3 km [5].

3.1 Preparation of the database

The road database consists of three bases, whose mutual relations are shown in Figure 3. The initial calculation database (ICD) is intended to unite the input data on the current pavement condition. The collected data are divided into segments of 1 km length, forming a database with a total of 471 samples. In this base, the mean values of input parameters were calculated, and the procedure to calculate the general performance indicator was carried out. The strategy determination database (SDD) contains the implemented initial calculation database, in such a way that the decision on the selection of individual strategies is based on the assessment of the technical parameters on the basis of the adopted criteria.
The neural network input database (NNID) consists of sets of input data (data from the initial calculation database tied to the technical parameters that describe pavement condition) and the set of output data (general performance indicator from the initial calculation database and maintenance strategy from the strategy determination database).

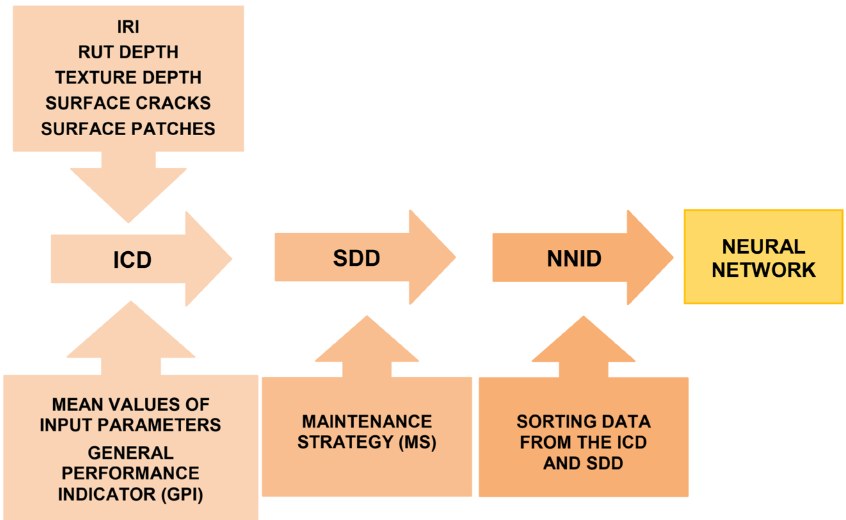

Figure 3 Schematic overview of databases

3.2 Learning and testing in the neural network

Neural network database is reduced by a random selection of 10% of samples that are used to evaluate the output results, i.e. a total of 421 samples were presented to the neural network. The data from the reduced neural network database were divided into two groups: a series of data in which the neural network conducts learning on 80% of the randomly selected data, while the remaining 20% form the control group on which network testing is performed. The configuration of the selected neural networks is shown in Figure 4. A neural network with backpropagation algorithm was applied in the software package NeuroShell2.0 [6].
The inputs and outputs of the neural network are connected by two hidden layers. The input layer (slab 1) contains five neurons, each of which represents one input parameter. In the first hidden layer, there are two elements (slab 2 and slab 3) with eight neurons each, while the second hidden layer contains slab 4, which also has eight neurons. The output layer (slab 5) contains two neurons, which corresponds to the number of output data. Each of the input data are connected to each of the total 24 neurons in both hidden layers, and all neurons of the output layer are connected to the final output data of the neural network.

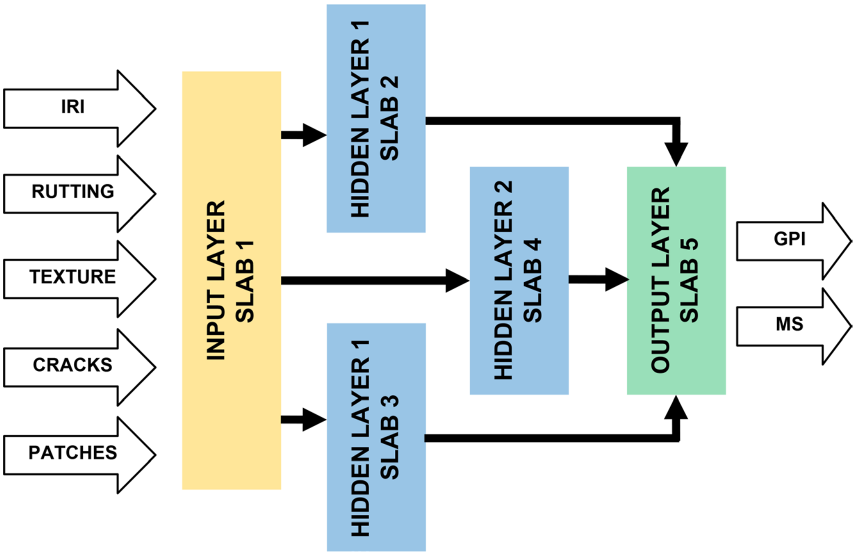

Figure 4 Schematic overview of the applied neural network

The function that results in the transfer of processed data for slabs 2 and 4 is a Gauss function, for slab 3 this is the tangent-hyperbolic function, while for the output layer this is a logical function. For all input data, a weight of 0.3 was assigned. After the learning phase, the neural network was subjected to testing. The results of statistical analysis of output data are shown in Table 1.

Table 1 Results of statistical analysis

Statistical comparison criteria	Pavement maintenance strategy (MS)	General Performance Indicator (GPI)
Coefficient of determination	0.9547	0.9678
Mean square of error	0.023	0.031
Mean absolute error	0.099	0.066
Lowest absolute error	0	0
Highest absolute error	0.900	1.759
Coefficient of correlation	0.9796	0.9851

On the basis of the obtained results, it is evident that there is a high coefficient of correlation between the results obtained in the calculation of the neural network and the known outputs.

3.3 Assessment of output results

After learning and testing of the network, a new dataset was applied (the 47 remaining samples). Only the input data, i.e. the calculated values of the technical parameters (IRI, rutting, texture, cracks and patches) were presented to the neural network. On the basis of previous 'experience', the network assessed the value of the general performance indicator and selected the management strategy. Figures 5 and 6 show the relationships between the assessed output results calculated by the neural network and the known output results.

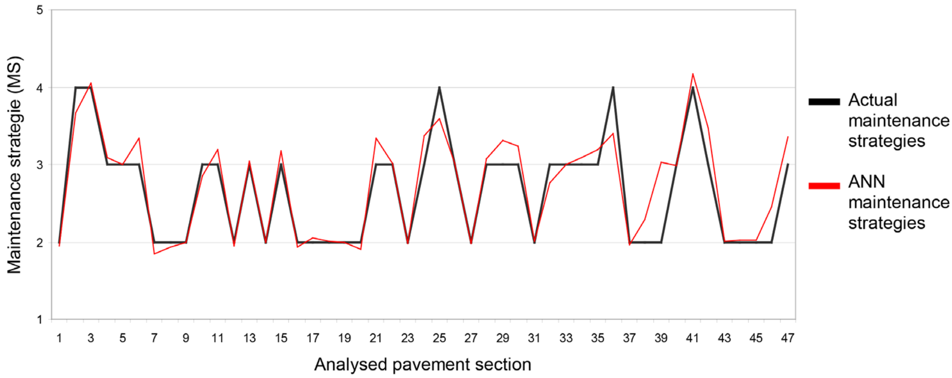

Figure 5 Selected maintenance strategies

The comparison of the actual selected maintenance strategies and strategies proposed by the neural network showed that the neural network incorrectly assessed the type of strategy on two samples, i.e. that the percentage success rate of assessment by the neural network was 95%.

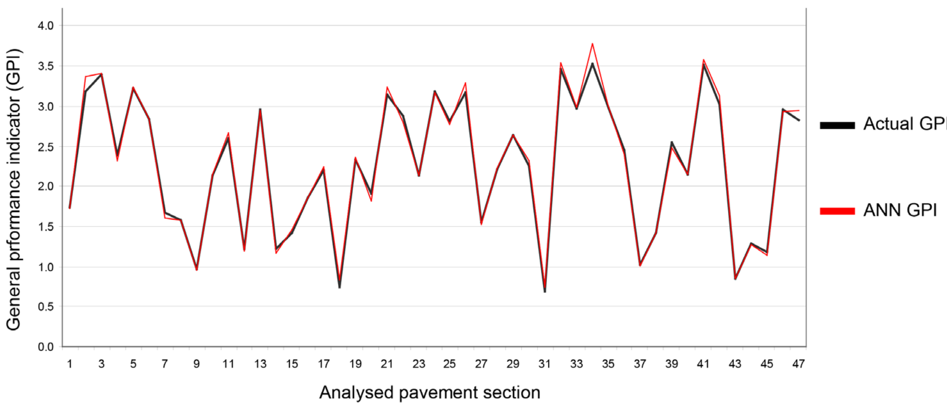

Figure 6 Calculated general performance indicator

A comparison of the assessed value of the general performance indicator with the real values ascertained that the neural network did not determine an accurate value of the GPI on six samples, and that its accuracy rate was 87%.

4 Conclusions

The primary tasks of the pavement management system are pavement distress data collection, assessment of pavement condition through an analysis of collected data, and selection of the most optimal maintenance strategy. This paper examines the possibilities of using artificial neural networks in determining the general performance indicator and selecting the appropriate pavement management strategy.

A neural network with backpropagation algorithm was selected as part of the software package NeuroShell2.0. The neural network was applied to a group of data obtained in the measurement of different pavement distresses in the state road network in Osijek-Baranja County. Statistical analysis of the output results confirmed a high coefficient of determination and correlation between the actual data and the data assessed by the neural network. In 95% of

cases, the neural network correctly determined the maintenance strategy, while the percentage of forecasting accurate values of the general performance indicator was 87%.
From the above analysis, it can be concluded that the considered neural network is appropriate for the classification of data on pavement condition for the purpose of determining the general performance indicator and optimal maintenance strategy. Its implementation in pavement management system provides a high quality tool that should facilitate decision-making in selecting maintenance procedures and rehabilitation of pavement for individual sections, sub-segments or segments of the state road network in the Republic of Croatia.

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