J. Basic. Appl. Sci. Res., 3(6)187-195, 2013

ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Optimized ANN Algorithm for Estimating HMA Overlay Thickness

Gholamali Shafabakhsh[1], Reza Noroozi [2], Fazel Fasihi [3]

[1]Associate Professor, Department of Civil Engineering, Semnan University, Iran
[2, 3]Graduated in highway and transportation master of science at Semnan University

ABSTRACT

The most common method to increase the serviceability of the constructed road asphalt surface is using an asphalt overlay on the old surface to provide a safety and serviceable road for the users. So, designing and constructing the flexible overlay is very important. Nevertheless, a simple and reliable design method in which the designing engineer only focuses on the application of a common procedure has not been presented yet. In these procedures, from engineering judgment to mechanistic-empirical methods, comprehensive and reliable data collection and application of the presented analytical methods are essential to use one of the proposed methods. This process wastes a large amount of costs and time and in many cases, providing all of these data for the designing is impossible. Therefore, after study of the Hot Mix Asphalt designing methods and their effective parameters, 1638 numerical analysis based on the bed soil properties, first day traffic and the future designed traffic have been performed in this survey. The purpose of the analyses performed by the AASHTO revised method had been to reduce the time and the calculation procedure for selection of the asphalt overlay thickness (HMA) using the artificial neural network (ANN). Finally a back propagation network with 1-13-3 combination and regression of 0.99998 has been chosen as the optimum network to estimate the overlay thickness. Studies on the thickness values acquired from the model neural network and the resulted thickness values based on the relationships of AASHTO plan shows the good accordance with them that the model network could be used as an alternative for AASHTO overlay design method.
KEYWORDS: Overlay Thickness, Hot Mix Asphalt, Artificial Neural Network, Back Propagation.

1. INTRODUCTION

Roads maintenance is especially important while promoting pavement designs that usually expressed as a function of time and traffic. In 1970 a group of researchers developed the pavement design concept. So, using the hot mixed asphalt overlay (HMA) on the upper surface of the asphalt layer was known as one of the most common reconstruction methods of the deteriorating pavement [1]. Fast destruction of this reconstruction is one of the problems that the pavement engineers have [2], the cause of such destruction could name as environment effects including sunlight, air temperature and humidity which effect on the surface and deep temperature of the asphalt [3] and basically Saied the combination of the traffic loads and temperature fluctuation effects causes pavement deterioration [4].

Different methods such as an increase overlay thickness [5] have been proposed for the better function of the new overlay in last decade and some of them have been reviewing and revising. Some of these methods are AASHTO designing Guide 1993, Asphalt Institute method for new pavements and overlay, Mechanistic designing method for overlay and the nondestructive evaluation of the pavement structure.

Although, these Designing methods mentioned are common but some difficulties in their solving process such as accurate field data, make them complex. For instance, the designing engineer should have a comprehensive understanding of the type, current conditions and prospecting the future pavement function before choosing any designing method [6]. In addition, Collection and use the necessary data in the HMA overlay design process needs spending a large amount of money and time and also the reliability and comprehensive data. So, in this article to find a method with no needs of any complexity artificial intelligence is used. However, noted common methods need time, reliable and some essential data to able start designing process but artificial intelligence especially artificial neural network is a method based on learning process which can find any relation between input and output sample data. After that, it can predict the output without any time with founded relation quickly.

Artificial neural network is a type of information process pattern that inspired from inherent or natural neural systems. Artificial neural networks are dynamic systems that can transfer hidden rules and knowledge of data into network structure through experimental data processing. So, this is called intelligent system [7]. Regarding that in recent years the artificial neural network capabilities proved as the powerful identifying patterns on estimation and anticipation fields, identifying the patterns and the optimizations [8], and such tools could be used to turn complex calculation to more easier and provide a base to use that unrepeated situation and specifying the similar answer while there is not enough information. So, the results acquired from 1638 numerical analyses in this survey as a comprehensive information bank with a complete overlay of various physical and traffic conditions aiming to offer suitable ANN algorithm for summarization of the process of HMA overlay thickness determination on the roads flexible pavements. In this modeling process, the revised 1993 AASHTO overlay design procedure has been chosen as

*Corresponding Author: Gholamali Shafabakhsh, Associate Professor, Department of Civil Engineering, Semnan University, Iran, E-mail: ghshafabakhsh@semnan.ac.ir

the ANN simulation basis, and the accuracy of the acquired results and the compatibility of the actual and estimated results due to the proposed artificial neural network algorithm have been shown in the graphs.

The remainder of the paper is organized as follows: in section II introduce AASHTO overlay designing method as most common HMA overlay designing methods, in section III discuses on artificial neural network and that process on overlay, in section IV the overlay design process based on artificial neural network is investigated and finally in section *V* presented the research results.

2. HMA OVERLAY DESIGN METHODOLOGY

Performing a new asphalt layer on the old pavement is a standard method to increase the lifetime and the quality of the asphalt pavement service. The asphalt overlay is used to modify the function and remove the structural defects and could improve the deteriorating pavement and increase the skid resistance, driving quality and other functional properties. The current pavement conditions and the estimate of the future traffic are the determining parameters in the overlay thickness design [9].

The most common methodology of the overlay design which AASHTO pavement designing methods (AASHTO 1993) and the Corps Engineer Institute (Pavement Design for Roads, Streets, Walks, and Open Storage Areas, Army TM 5-822-5, Air Force AFM 88-7, Chap.1, Departments of the Army and the Air force, 1992) are on that is based on the pavement structural weakness, according to which the overlay must compensate the difference between the current pavement needed capacity for the future traffic in the design period and the actual traffic capacity of the pavement.

The second most common methodology of the overlay design according to the maximum deflection is Asphalt Institute method. In this method, the deflection of the pavement is related to the service lifetime and the overlay thickness is determined to reduce the pavement deflection for toleration the equal loads during design period.

Mechanistic design is the third design methodology which is so common and based on the fatigue failures and using the mechanistic principles [10]. In this method, stress-strain analysis of the current pavement structures is being performed and the rest service lifetime is estimated due to the fatigue fractures or rutting by experimental transfer functions. Finally the overlay thickness is determined according to limiting the fatigue fractures or rutting of the overlaid pavement to withstand the prospected traffic during the design period.

According to the statistics, among the regions that use the AASHTO 1993 method to design HMA thickness is the transportation associations of Indiana[1], Iowa[2] and Michigan[3]. Because of the comprehensive of the AASHTO overlay design plan, we have used it as a reliable and high usage methodology to express the issues of determining the HMA overlay thickness for providing the actual data bank.

3. Using the artificial neural network in the HMA overlay design process

Neural networks are composed of a series of layers that include simple parts of processor called neuron and they can act in parallel. Each input layer is related to one or more middle layer and also middle layers are connected to output layer. Since many factors like hidden layers, the number of hidden layers neurons, data normalization and learning algorithm, have an effect on neural networks function, so, the best architecture of neural network will be obtained through experiment and try and error [7]. The ability to learn the existing relationship between inputs and outputs is one of the most fundamental benefits of the neural networks. This ability has made them suitable for problems with unknown and non-linear structures such as modeling, recognition and etc. [11, 12].

The artificial neural networks are able to receive input patterns and produce the specification of these parameters and relating a given group to them. So, they can find non-linear relationship between inputs and outputs during the training process and if the process is running correctly, it could classify the patterns [13]. Finally, the applied training algorithm acts due to minimize the mean square error between the network output and the predicted output (MATLAB Neural Network Toolbox™, 2010). Figure 1 shows a sample of neural network.

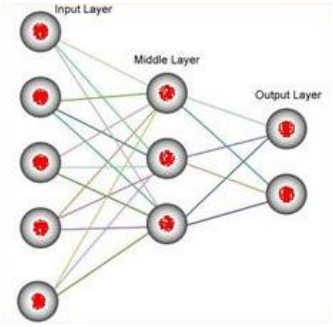

Fig. 1. An artificial neural network sample

[1] Indiana Department of Transportation
[2] Iowa Department of Transportation
[3] Michigan Department of Transportation

Classification of ANN types are described by Lippmann (1987) and Maren et al. (1990) [14]. Major applications of neural networks can be stated in 9 following classes [15]: 1-Classification, detection and recognition of pattern, 2-Signal processing, 3-Anticipating time series, 4-Modeling, 5-Optimization, 6-Wizard and fuzzy systems, 7-Finanicial issues, exchange and means of entertainment, 8-Manufacturing industrial and medical equipments, 9-Recognizing behavior in transportation models. Programming to determine probability of occurrence is the most popular usage of neural networks which they properly work for predictable issues particularly in complex systems modeling [16]. Table 1 presents the common network types and their usage ranges.

Table 1- network types and their usage [16]

Issue type	Usable networks	Description
prediction	• Back- propagation • Delta bar Delta • Extended delta bar delta • Directed random search • Higher order neural networks • Self-organizing map into back- propagation	Use input values to predict some output (e.g. pick the best stocks in the stock market, predict the weather, identify people with cancer risks)
classification	• Learning vector quantization • Counter propagation • Probabilistic neural network	Use input values to determine the classification (e.g. is the input the letter A. is the blob of video data a plane and what kind of plane is it)
Data association	• Hopfield • Boltzmann machine • Hamming network • Bidirectional associative memory • Spatio-temporal pattern recognition	Like classification but it also recognizes data that contains errors (e.g. not only identify the characters that were scanned but also identify when the scanner wasn't working properly)
Data conceptualization	• Adaptive resonance network • Self-organizing map	Analyze the inputs so that grouping relationships can be inferred (e.g. extract from a data base the names of those most likely to buy a particular product)
Data filtering	• Recirculation	Smooth an input signal (e.g. take the noise out a telephone signal)

From among the neural networks types, as mentioned in table (1), the feed forward back propagation network has been used to solve nearly all the problems and is the most suitable network to prediction, classification, speech recognition and pattern recognition problems [17, 18]. In fact, the phrase “back propagation networks” is equal to “feed forward multilayer neural network [19] that has been taught by error back propagation algorithm [20, 21, 22]. Therefore, regarding the need neural network to predict the stress and deflection in pavement analyzing to find best overly thickness, back propagation networks are the most suitable option from the introduced architectural methods which are applicable and promising the desirable results.

4. Offering the Speedy Tools to Determine the Asphalt Overlay Thickness

As above said; the overlay thickness is the minimum required thickness to modify the pavement functional problems. The pavements with structural defects require the overlay design to improve their structural capacity [9]. The most important part of the pavement reconstruction is the choosing of the suitable methodology which must be analyzed by the designers to choose the most optimal method, pavement condition parameters, destruction cause recognition, structural capacity, existing material conditions, records of construction and maintenance operations, road geometry and economic analysis [9].

AASHTO revised design methodology[4] is established due to the fact that the traffic time and loads reduce the load withstanding capability of the pavements and the overlay layer could be used to increase the pavement load withstanding capability in future. In this method, the overlay thickness is determined by using the pavement structural defects such as insufficient thickness, fractures, deformations and disintegrations that affect the load withstanding capability of the pavement structure [23].

In this method, the required structural capacity of pavement to successfully withstand the future traffic is calculated by using the design equations of AASHTO flexible pavements. In this procedure, the effective structural capacity of the flexible pavement has been introduced as effective structural number (SN_{eff}) which could be determined in three methods: visual condition survey, nondestructive deflection testing and the remaining life (AASHTO 1993). In this study, the remaining life has been used to offer the numerical analysis which is based on the past traffic analysis or the current PSI analysis (AASHTO 1993, AASHTO 1986).

4.1. ANN Training Process

The procedure of AASHTO design requires various input parameters including subgrade module, pavement structural number, final service capability and reliability [10]. In this survey, the overlay thickness required for three layers flexible pavements with inappropriate serviceability has been studied for a suburban road with 4 lanes and 20 years design period with 3% traffic growing rate. The traffic for this road is comprised of all kinds of vehicles including automobiles, buses, trucks, lorries, trailers and two trailer trucks that has been assumed 3.30 to 19.75 million equivalent axle will be passed in 20 years lifetime and road constructing time.

[4] AASHTO 1993

The passing traffic through the new overlaid pavement has been assumed in a range of 10 to 100 million equivalent axes equivalent road with a 10 years design period and 4% growing rate, during 91 positions in 1 million axles. The table 2 shows the studied range of the survey.

Table 2. Pavement studied ranges to calculate require overlay thickness and ANN simulation

Parameters	Review ranges
Subgrade Resilient Module (psi)	5500 ; 13500
First day ESAL ($\times 10^6$)	3 ;12
Future traffic based on equivalent axle (N_i) ($\times 10^6$)	10 ; 100

The simulating process and optimum network finding are steps after creating a data bank especially for the network training. Using the back propagation algorithm from among the used and introduced ANN patterns as one of the most famous, most effective and easiest models for learning and prediction has been considered within the multilayer and complicated networks. This network is capable of predicting different clusters of data with various architecture and training methods by using the non-linear solutions for problems. In fact, the phrase of the back propagation networks is equivalent to the phrase of feed forward multilayer neural networks [20]which has been taught by the error back propagation algorithm [20, 21, 22]. Regarding the operation of estimation and predicting the required asphalt overlay thickness by the neural network system analyzing the introduced numerical models, Back propagation method has been chosen as the most suitable option from among the introduced architectures in this survey.

The first step in the evaluation of the network properties is determining the number of the processing layers in the network. The network is at least 2 layers: hidden and output layer. To do so, 1638 different analyses resulted from using the AASHTO design method has done. In this survey, different modes of the subgrade properties ranging from the weak to strong soil and the passing traffic cover ranging from the light to heavy (for the pavement while service and the required coating) have been chosen to integrate the modeled network and cover all of the possible issues in the overlay design.

The purpose of the training process in such networks is the adjustment between the weights and biases nodes resulted from which a set of input could be predicted output data from the neural network [24]. So, using the inputs and related outputs, a network with a specific structure acts in such a way that the error operation function value would be minimized. The operation function in the back propagation network is usually the mean square error function. The network must be taught through different structures and the best network is one that its operation function is lower than others. In this position, network has been learned and stabled.

The number of the network inputs is always showing the number of the existing elements in the input part of the artificial neural network. Hidden layer or layers has some neurons and the number of neurons and the behavioral functions types used in each layer is affecting the prospected network behavior. The output layer of a neural network has also one or few neurons which show the number of unknowns that the network must provide an acceptable answer to them. Following the process of the survey, the subgrade resilient module, the passing traffic capacity on the servicing pavement and the passing traffic on the overlaid pavement as constituent parameters of the input layer and the required overlay thickness as constituent parameter of the output layer would be discussed.

After choosing the hidden layers properties, the used transfer function in each layer must be specified. The back propagation network which its transfer function in the outer layer and hidden layers is respectively simple linear and sigmoid tangent could be used to perform a suitable function approximation (non-linear regression).

Regarding that there is not a specified regulation to determine the number of hidden layers and its neurons and must be specified due to the minimum acceptable errors in the training and test process. Therefore, the procedure to select an appropriate geometry for the data under consideration has been used for ranging from the three layer network to choosing the optimum number of neurons for the hidden layer. In the figure 3, shows the error values acquired from the relationship 1 for three layer networks with different neurons and the regression values acquired from these networks.

$$MSE = \frac{1}{mN}\sum_{k=1}^{N}\sum_{j=1}^{m}\left(y_j^k - t_j^k\right)^2 \qquad (1)$$

In this relationship, parameters m and n are showing respectively the output neurons number and the number of the training samples.

Table 3. Neurons changes to find optimized network

Hidden layer neurons	Regression				MSE (Mean Square Error)	Epochs
	Training	Validation	Test	All		
5	0.99972	0.99938	0.99972	0.99965	0.0028492	757
6	0.99972	0.9997	0.99942	0.99965	0.0013718	1000
7	0.99976	0.9996	0.99964	0.9997	0.0018408	97
8	0.99986	0.99988	0.99988	0.99986	0.0005854	178
9	0.99993	0.99991	0.99991	0.99992	0.000409	98
10	0.99983	0.9997	0.99984	0.9998	0.0012212	118
11	0.99994	0.9999	0.9999	0.99992	0.0004355	271
12	0.99994	0.99993	0.99992	0.99994	0.0003054	264
13	0.99999	0.99998	0.99998	0.99998	0.0000962	456
14	0.99994	0.99994	0.99992	0.99994	0.0002584	133
15	0.99996	0.99995	0.99995	0.99995	0.0002347	233

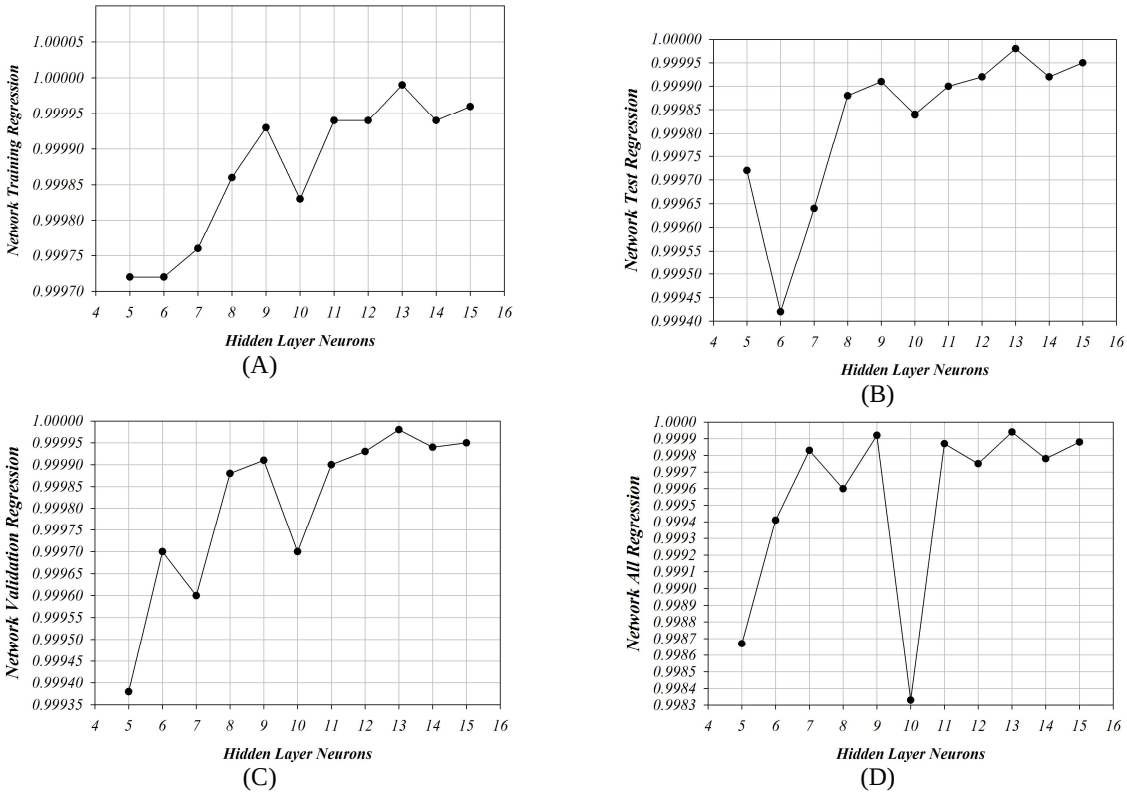

Fig. 2. Neurons changes to find optimized network base on: A) Training regression, B) Test regression, C) Validation regression, D) All regression.

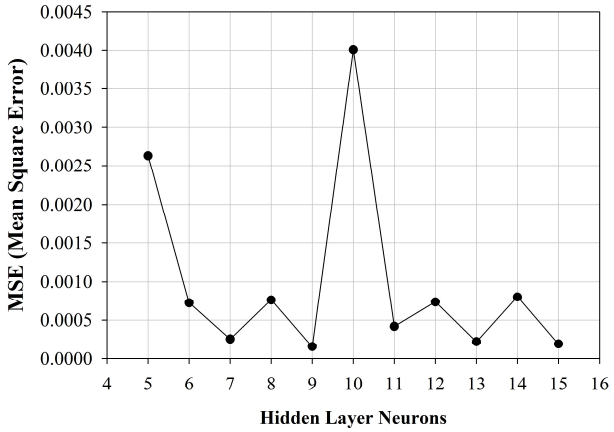

Fig.3. Neurons changes to find optimized network base on minimum MSE

According to the summary of the results presented in table 3, a network would be chosen as the optimum network that in addition to its high regression in the modeling process, its neurons and MSE are few. Therefore, the arrangement of the optimum network is 3-13-1 that is combination of 3 input, 13 neurons in a hidden layer and 1 output.

5. RESULTS AND DISCUSSION

According to the studies, the back propagation network with the 3-13-1 arrangement would be introduced as the best geometry to predict the suitable asphalt overlay thickness on the flexible pavements. In figures 4 to 6, the network regression and the method of network training and the square error values acquired through the training process have been shown.

The figure 7 compares the required overlay thickness predicted by the chosen network with the results from AASHTO design method (target values). The accordance of these two outputs shows the high accuracy of the estimated results.

According to the graphs 7and 8, the expectation from the optimum network with the 3-13-1 combination and a regression value of 0.99998 as the training result is that the values acquired by using the AASHTO design method as the required thickness of asphalt overlay have a suitable similarity with the predicted values. In addition to high accuracy in solving the planned samples, no need to provide the complicated inputs and the ability to model several pavement sections in time unit by input matrixes are some benefits of the simulated network for required overlay thickness prediction in flexible pavements.

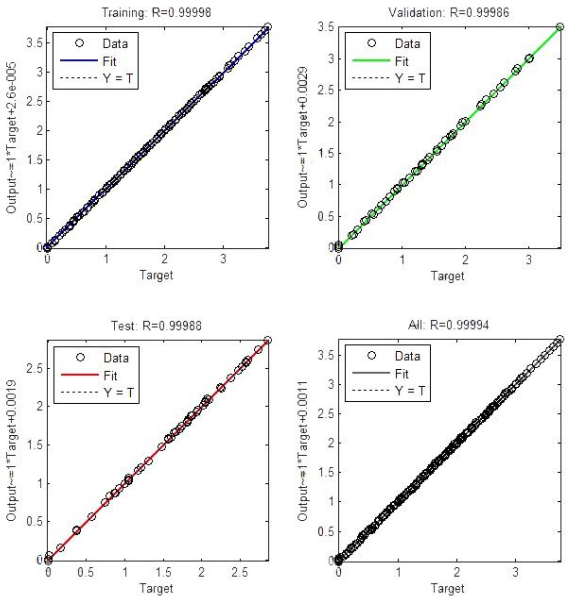

Fig.4. Chosen network regressions after training process

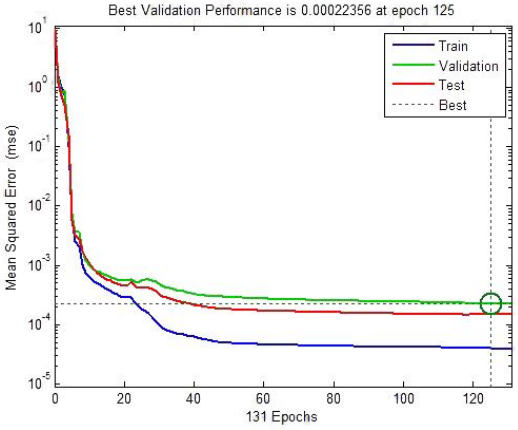

Fig.5. Chosen network MSEin training process

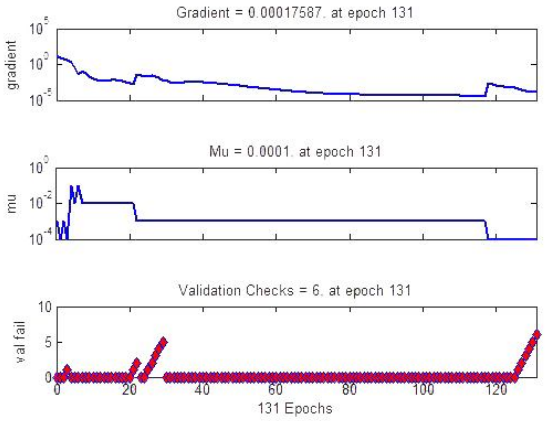

Fig. 6. Chosen network errors in training process

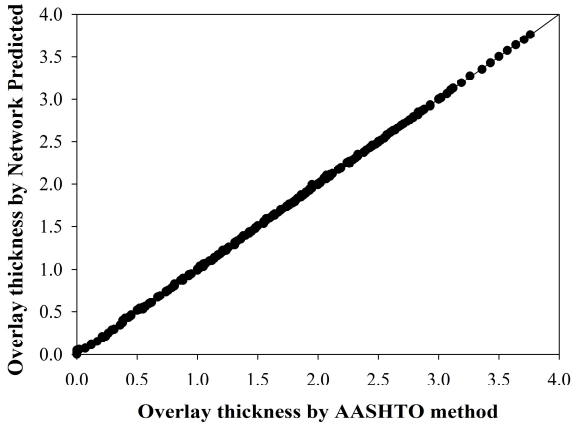

Fig.7.the predicted required overlay thickness by the chosen network versus the results from AASHTO design method

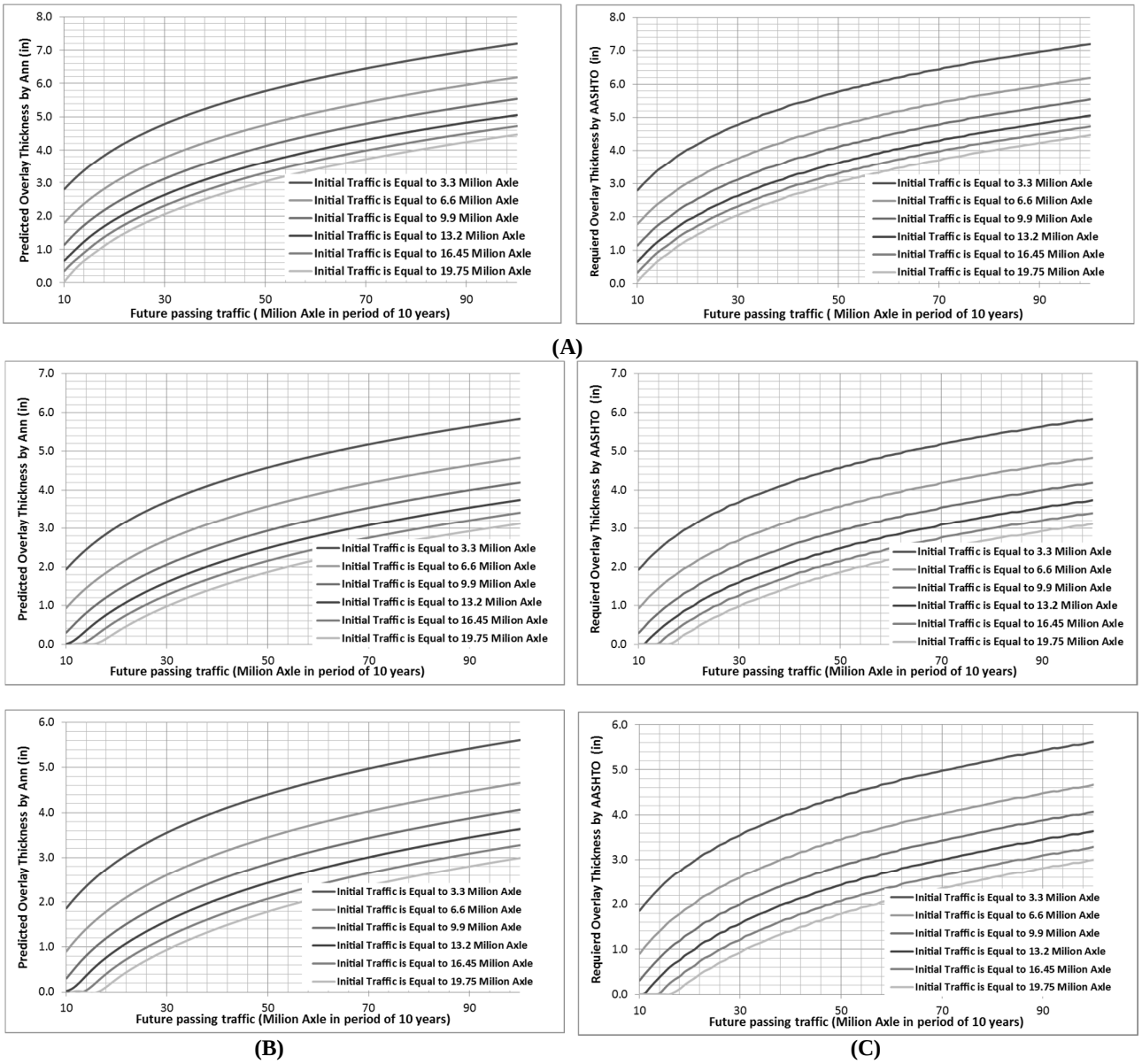

Fig. 8.review of the results acquired according to AASHTO method and the estimated results of the modeled network in the following conditions: (A: weak, B: normal, C: strong subgrade)

6. Conclusions

Since, environment effects including sunlight, air temperature, humidity, deep temperature of the asphalt and etc. causes pavement deterioration which indicates importance of Roads maintenance. Different methods such as AASHTO designing Guide 1993, Asphalt Institute and Mechanistic designing method have been offered to design the better functional overlay in last decade. Nevertheless, these designing methods have some difficulties in their solving process such as accurate field data, current conditions, outlooking the future pavement function and etc. which make them complex. In addition, Time and cost consuming to collect and use the necessary data in the design process is another fault. In this survey, introduced the overlay design methods to choose a suitable method to specify the required thickness of the asphalt overlay, and AASHTO design method was identified as an effective, common and reliable too between others. After that, 1638 three layers asphalt pavement issues have been modeled. To Achieve reduce solving steps, required input parameters and also providing the possibility of calculation and prediction of the prospected exact parameters during a short period of time, the artificial neural network especially feed forward back propagation type was considered to specify the required overlay thickness. The ability of learning the existing connection between inputs and outputs is one of the most fundamental benefits of the neural networks.

The subgrade conditions, the initial traffic and the prospected traffic after overlaid pavement have been considered as the network inputs and overlay thickness as output in the simulation process. According to the results acquired from this research and presented in the graphs, the mean squares errors reduces with increasing the network size resulted from the increase in the hidden layers neurons. Also it could be understood that the ability of the network in the function approximation and more accurate prediction of the results will not increase with the increase in the number of a back propagation network neurons.

Finally, aiming to minimum square error function, the square of back propagation network with 3-13-1 combination of internal sigmoid function and external linear function has been selected as the optimum network. According to the studies done on the results calculated through AASHTO method and the predicted results, their high accordance confirms this simulation.

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