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USING ARTIFICIAL NEURAL NETWORKS TO PREDICT THE DISTRESSES OF FLEXIBLE PAVEMENT

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Abstract

Road networks have a very important role in the economic development of any country. Therefore, Pavement Management Systems (PMS) are considered significant in managing the condition of highway networks efficiently to determine the required maintenance in a timely manner at the lowest cost.

This research aims to use Artificial Neural Networks (ANNs) in the possibility of predicting the pavement condition index of the flexible pavement using the LTPP database. This research included the use of many inputs and data of flexible asphalt pavement containing thickness of the layers (A.C- Base-Subbase-Subgrade), temperature, humidity, precipitation, freezing, age, traffic volumes, and distress. The total number of sections that were used in the Artificial Neural Network model was 862 sections for nine states of the United States of America. All sections were divided into two categories; the first, overlay was not used to treat the distress. These sections take symbols (SPS-1&3&8) according to LTPP. The second sections were subjected to overlay layer as a result of the maintenance that was performed on it and was of the type (SPS-5) and in this type two cases were monitored; In the first case; the distresses before and after the maintenance operation using an overlay layer, the second case; the distresses were monitored after the maintenance process using an overlay layer was increased due to distresses. The Matlab program was used to build the ANN model based on the collected data to predict the Pavement Condition Index (PCI).

The results indicated that the model showed an excellent prediction for the Pavement Condition Index. The correlation coefficient (R^2) was more than 80% approximately for all sections. This result indicated that the ANN models can be used efficiently to predict the pavement condition and contribute to building an effective plan for future road maintenance work.

KEYWORDS: Artificial Neural Networks; Pavement Condition Index; predict; flexible pavement.

استخدام شبكات الخلايا الإصطناعية للتنبؤ بعيوب الرصف الأسفلتى المرن

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الملخص

إن شبكات الطرق لها دور فى غاية الأهمية للتنمية الإقتصادية لأى وطن. لذلك، تعتبر أنظمة إدارة الرصف (PMS) مهمة فى إدارة شبكة الطرق السريعة بكفاءة لتحديد الصيانة المطلوبة فى الوقت المناسب وبأقل تكلفة.
إن هذا البحث يهدف إلى استخدام شبكات الخلايا الاصطناعية (ANNs) فى إمكانية التنبؤ بمعامل حالة الرصف الأسفلتى المرن مستخدماً قاعدة البيانات (LTPP). وقد تضمن هذا البحث استخدام العديد من المدخلات والبيانات الخاصة بالرصف الأسفلتى المرن محتويا على سمك الطبقات (طبقة الأسفلت – طبقة الأساس – طبقة الأساس المساعد – الأرض الطبيعية)، درجة الحرارة، الرطوبة، هطول الأمطار، التجمد، العمر، حجم المرور والعيوب. وكان العدد الكلى للقطاعات التى تم استخدامها فى نموذج الشبكة العصبية الإصطناعية 862 قطاعاً لتسع ولايات أمريكية.
تم تقسيم القطاعات إلى مجموعتين: الأولى، بدون استخدام طبقة تقوية لمعالجة العيوب وتأخذ الرموز (SPS-1&3&8) وفقاً للـ LTPP . وأخضعت القطاعات الثانية لطبقة تقوية نتيجة للصيانة التى أجريت عليها وكانت من نوع (SPS-5) وفى هذا النوع تم رصد حالتين: فى الحالة الأولى، العيوب قبل وبعد عملية الصيانة وطبقة التقوية، وفي الحالة الثانية، تم رصد العيوب بعد عملية الصيانة وزيادة طبقة التقوية نتيجة للعيوب.
تم استخدام برنامج Matlab لبناء نموذج شبكات الخلايا الإصطناعية ANNs بناءً على البيانات التى تم جمعها للتنبؤ بمعامل حالة الرصف (PCI).
أشارت النتائج إلى أن النماذج متميزة فى التنبؤ بمعامل حالة الرصف (PCI)، وكان معامل الإرتباط (R^2) أكثر من 80% تقريباً لجميع القطاعات. كما أشارت هذه النتيجة إلى أنه يمكن استخدام نماذج شبكات الخلايا الإصطناعية بكفاءة للتنبؤ بحالة الرصف والمساهمة فى بناء خطة فعالة لأعمال صيانة الطرق المستقبلية.
الكلمات المفتاحية : شبكات الخلايا الاصطناعية، معامل حالة الرصف ، التنبؤ، الرصف المرن

1. Introduction

In recent years, the importance of the highway is increased because it is considered a measure of the civilization of any homeland and due to the increase of motorization. The policy of improving the highway system depends on two methods techniques. The first, for new highways, is the selection of a design method that suits conditions to decrease the cost of maintenance. Secondly, for existing highways, is the suggestion of the most rapid and economic strategy of maintenance. However, rehabilitation, maintenance, and the prediction of the distress for the pavements to the desired level of serviceability are problems faced by the pavement engineers and administration in the section of the highway.

2. Artificial Neural Networks Principles:

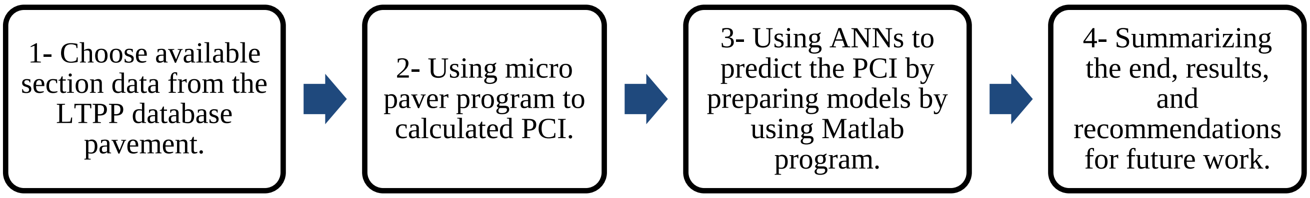
ANNS can be known as a machine learning approach that models the human brain and consists of several artificial neurons. Every neuron in ANN receives a number of inputs, and an activation function is applied to these inputs which results in the activation level of a neuron[1, 2]. The Neural networks are adaptive; they can infer solutions from the data provided to them, often capturing quite subtle relationships. ANNs capable to generalize correctly process data that only broadly resembles the data they were trained on originally. As well, they can handle imperfect or incomplete data, providing a measure of fault tolerance. Among the helpful features of ANNs depicted by *Hewitson and Crane*, sundry is favorable for pavement prediction modeling. The primary feature is its capability to represent any arbitrary nonlinear function. ANNs have utility in a wide area of applications in Highway and Traffic engineering and come in many different forms and structures [3]. Generally, A number of applications of neural networks in complex problems related to pavement engineering have been reported and can work on solving it. Neural networks are now readily available and can be used for solving many of the problems in pavement performance modeling [1].

3. Objective of the Study

The main objective of this study is the prediction of the (PCI) values when occurring in the future of the flexible pavement based on analyzing the database of the Long Term Pavement Performance (LTPP) by using Artificial Neural Networks models.

4. Literature review:

In the past studies *(Attoh-Okine 1994 [4], Jidong Yang et al. 2006 [5], Alessandra Bianchini and Paola Bandini 2010 [6] and Sanja DIMTER et al. 2018 [7])* ANNs used one of the applications in pavement deterioration modeling when a lot of databases on pavement condition is obtainable. Many models have been developed for predicting the deterioration of the crack condition. Pavement rutting and cracking are two of the most critical distress types that appear on flexible pavements. Predicting pavement performance by the hybrid model was described by the multilayer and feedforward neural networks. The results showed the model performance satisfactory results, pretending the efficiency and possibility of these advanced



mathematical modeling techniques. Most studies demonstrated that achieved results due to ANNs could be used for the improvement of maintenance or rehabilitation strategies.

5. Methodology:

The main zones included in this research methodology are used in pavement data from the United States. After Collecting data required from LTPP. In this study, Artificial Neural Networks (ANNs) were used to predict pavement performance. The steps of work can be listed as follow:

6. Data Collection:

This study will be on the sections of the SPS experiments in the LTPP program. The SPS sections include monitoring newly constructed sections or existing pavement sections subjected to rehabilitation or maintenance. More Specifically, sections were chosen having symbols SPS-1, SPS-3, SPS-8, and SPS-5. This research relied on a number of sections and awareness of the converging temperature from Egypt. **Table 1** shows in detail the number of sections and locations in the LTPP that will be used in this study.

Table 1. Sections and locations in the LTPP used in this Research.

The section selected from SPS according to the selection factors					
STATE \ SPS	SPS-1	SPS-3	SPS-5	SPS-8	**Total according to State**
	No. of Sections	**No. of Sections**	**No. of Sections**	**No. of Sections**	
North Carolina	-	-	-	9	**9**
Mississippi	-	-	-	10	**10**
Arkansas	-	-	-	4	**4**
Alabama	-	-	138	-	**138**
Arizona	-	-	58	-	**58**
California	-	-	86	-	**86**
Florida	68	-	151	-	**219**
Louisiana	59	-	-	-	**59**
Texas	91	72	104	12	279
Total according to SPS	**218**	**72**	**537**	**35**	**862**

7. Training Set Generation:

In this study, the reliance was on the database of LTPP, the use of flexible pavement sections, and a general form was adopted to extract the required data from LTPP. First, a unified table was set to collect distresses data for the sections monitored from the site. As shown in **Table 2,** the standard table contains all the elements used in the study. These elements are including the sections code, the thickness of each of the pavement layers (A.C- Base - Subbase) as well as temperature, humidity, precipitation, freezing, age and traffic volumes. Also, all distress on the section with it's three severity levels (low- medium-high), and the age of the section included. The value of the Pavement Condition Index was calculated by the micro-paver program. In this research, 862 sections were collected from LTPP as shown in **Table 1**, where many inputs for each section were used to develop a pavement condition index model which includes the thickness of each of the pavement layers as well as temperature, humidity, freezing, and precipitation.

Table .2 Sample of LTPP Data

STATE	Florida	Florida	Florida	Florida	Florida	Florida	Florida	Florida
SHRP_ID	12-101	12-101	12-101	12-101	12-101	12-101	12-101	12-101
Experiment Number	1	1	1	1	1	1	1	1
A.C layer 3 (in)	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
A.C layer 2 (in)	2	2	2	2	2	2	2	2
A.C layer 1 (in)	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Bound (treated) base (in)	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1
Unbound (granular) base (in)	0	0	0	0	0	0	0	0
Engineering Fabric (in)	0	0	0	0	0	0	0	0
Bound (treated) subbase (in)	0	0	0	0	0	0	0	0
Unbound (granular) subbase (in)	0	0	0	0	0	0	0	0
Engineering Fabric (in)	0	0	0	0	0	0	0	0
Subgrade (untreated) (in)	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4
Time(year)	2001	2002	2003	2004	2005	2006	2009	2011
Annual Average Precipitation (mm)	1463.5	1584.4	1403.2	1621.3	1547.5	1129.2	1222.7	1249.3
Annual Average Temperature (deg C)	23.4	23.7	23.1	22.6	22.6	22.8	23	23
Annual Average Freeze Index (deg C deg days)	0	0	0	0	0	0	0	0
Annual Average Humidity Min-Max (%)	74	76	76	74	72.5	71.5	68.5	69.5
18-Kip ESAL (KESAL)	328	480	544	707	765	723	750	780
Age (years)	5.52	6.23	7.23	8.47	9.22	11.01	13.52	15.42

GATOR_CRACK_A_L	0	0	0	0.1	0.2	0.9	4.4	14
GATOR_CRACK_A_M	0	0	0	0	0	0	0	0
GATOR_CRACK_A_H	0	0	0	0	0	0	0	0
BLK_CRACK_A_L	0	0	0	0	0	0	0	0
BLK_CRACK_A_M	0	0	0	0	0	0	0	0
BLK_CRACK_A_H	0	0	0	0	0	0	0	0
EDGE_CRACK_L_L	0	0	0	0	0	0	0	0
EDGE_CRACK_L_M	0	0	0	0	0	0	0	0
EDGE_CRACK_L_H	0	0	0	0	0	0	0	0
LONG_CRACK_WP_L_L	0	0	0	0	0	0	5.4	23
LONG_CRACK_WP_L_M	0	0	0	0	0	0	0	0
LONG_CRACK_WP_L_H	0	0	0	0	0	0	0	0
LONG_CRACK_NWP_L_L	5.3	20.5	49.7	138.4	146.2	226.6	133.4	131.7
LONG_CRACK_NWP_L_M	0	0	0	0	0	0	109.8	133.8
LONG_CRACK_NWP_L_H	0	0	0	0	0	0	0	0
TRANS_CRACK_L_L	0	0	0	0.3	0.8	2.1	8	30.1
TRANS_CRACK_L_M	0	0	0	0	0	0	0	0
TRANS_CRACK_L_H	0	0	0	0	0	0	0	0
PATCH_A_L	0	0	0	0	0	0	0	0
PATCH_A_M	0	0	0	0	0	0	0	0
PATCH_A_H	0	0	0	0	0	0	0	0
POTHOLES_A_L	0	0	0	0	0	0	0	0
POTHOLES_A_M	0	0	0	0	0	0	0	0
POTHOLES_A_H	0	0	0	0	0	0	0	0
SHOVING_A	0	0	0	0	0	0	0	0
BLEEDING	0	0	0	0	0	0	0	0
RAVELING	0	0	0	0	0	0	0	0
PUMPING_L	0	0	0	0	0	0	0	0
PCI	100	100	98	93	92	89	82	81

8.Analysis of Models for ANNs and Discussions for Flexible Pavement:

When building the models we concentrated on potential factors affecting the performance of the pavement and summarized them as: (service life, traffic, pavement layers thickness, environmental, climate data, and distresses). These factors will improve the inclusive database with information on construction, traffic, materials, performance, and environment to the test sections.

Several inputs were used in developing of ANNs model as the road code, thickness layers (A.C- Base-Subbase-Subgrade), temperature, humidity, precipitation, freezing, age, traffic volumes and all distress by three severity levels (high- medium-low) as shown in the figure (1). These input data were used when creating the ANNs models. When building a model for Artificial Neural Networks (ANNs) in the Matlab program, the sections must be divided into two parts, 70% for the training process and 30% for the testing process[8]. **Figure 1** shows the number of layers used in the model in that study. Training, testing data sets were randomly selected from the flexible pavement database.

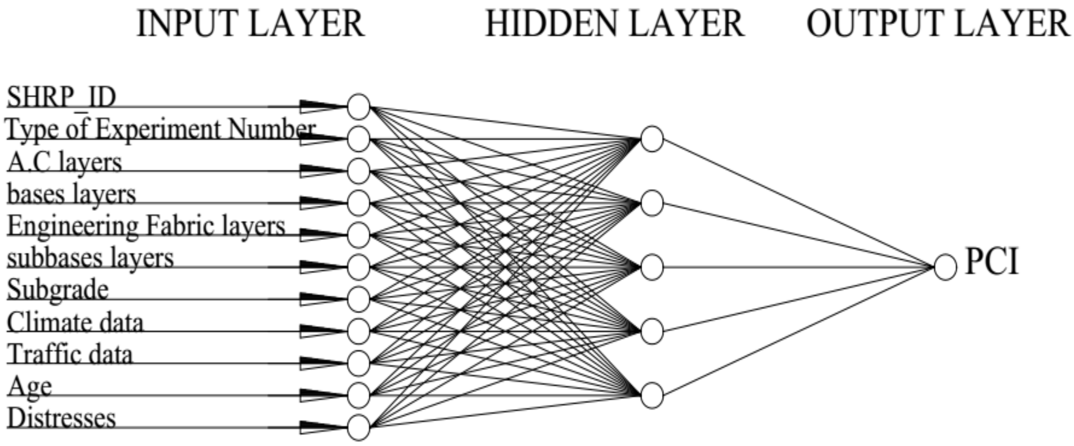


Figure 1: ANN Prediction model of PCI.

In this study, three models were made for two categories; in the first one, overlay was not used to treat the distress, it's from SPS-1&3&8 (MODEL 1). Whereas, the second category was from SPS-5 and, we divided them into two models. The first case is for sections that have distresses before and after the maintenance operation using the overlay (MODEL 2). The second case was for sections that have distresses after the maintenance operation using the overlay (MODEL 3).

The results showed excellence in predicting the PCI, as shown in **Figures 2, 3 and 4.** Where the results were excellent and the correlation coefficient (R^2) was 83% for the first model and 90% for the second model and 91% for the third model.
ANNs have been established to be useful for modeling the complex relationship between the number of a large of the pavement parameters and the Pavement Condition Index (PCI). The next show that the relation between tested PCI and actual PCI and the relation between trained PCI and actual PCI. The values indicate a strong linear dependence in these models for all categories. Therefore, shows the relationship between the predicted PCI and actual PCI has an R^2 of more than 80%. In all models for categories within the range of input parameters of the pavement layers thickness, temperature, humidity, precipitation, freezing, age, traffic volumes, and actual PCI. The only output parameter was the predicted PCI value.

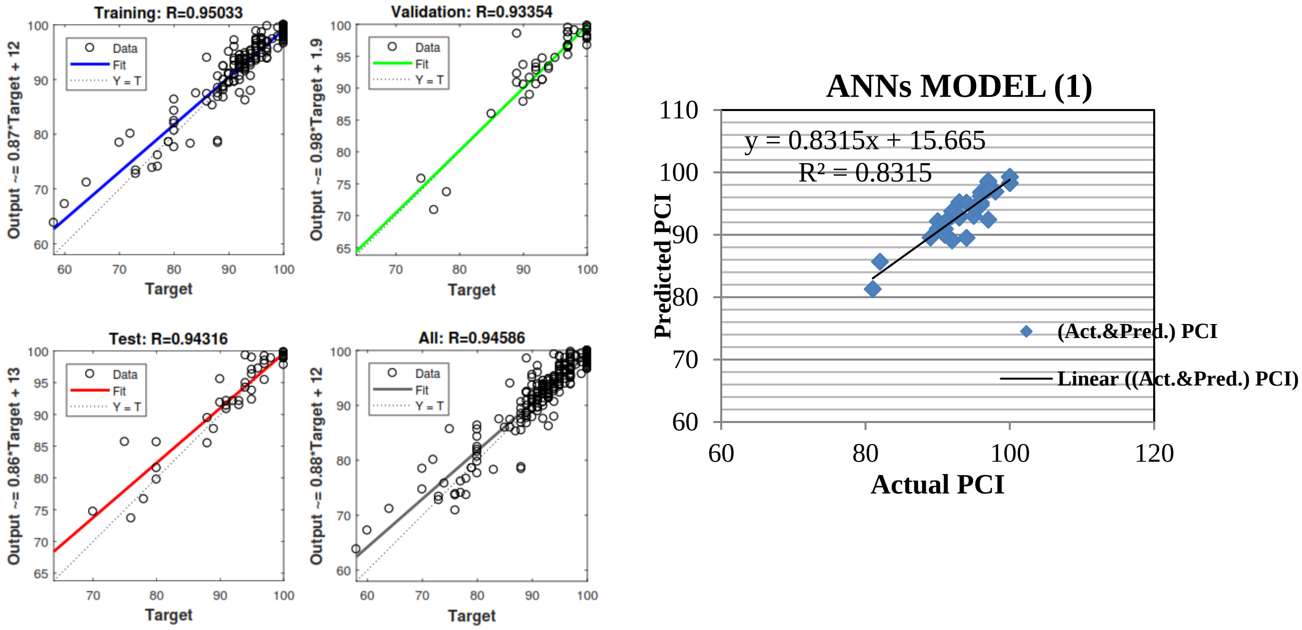


Figure 2: The relation between actual PCI and predicted PCI using Matlab program (The first category of sections).

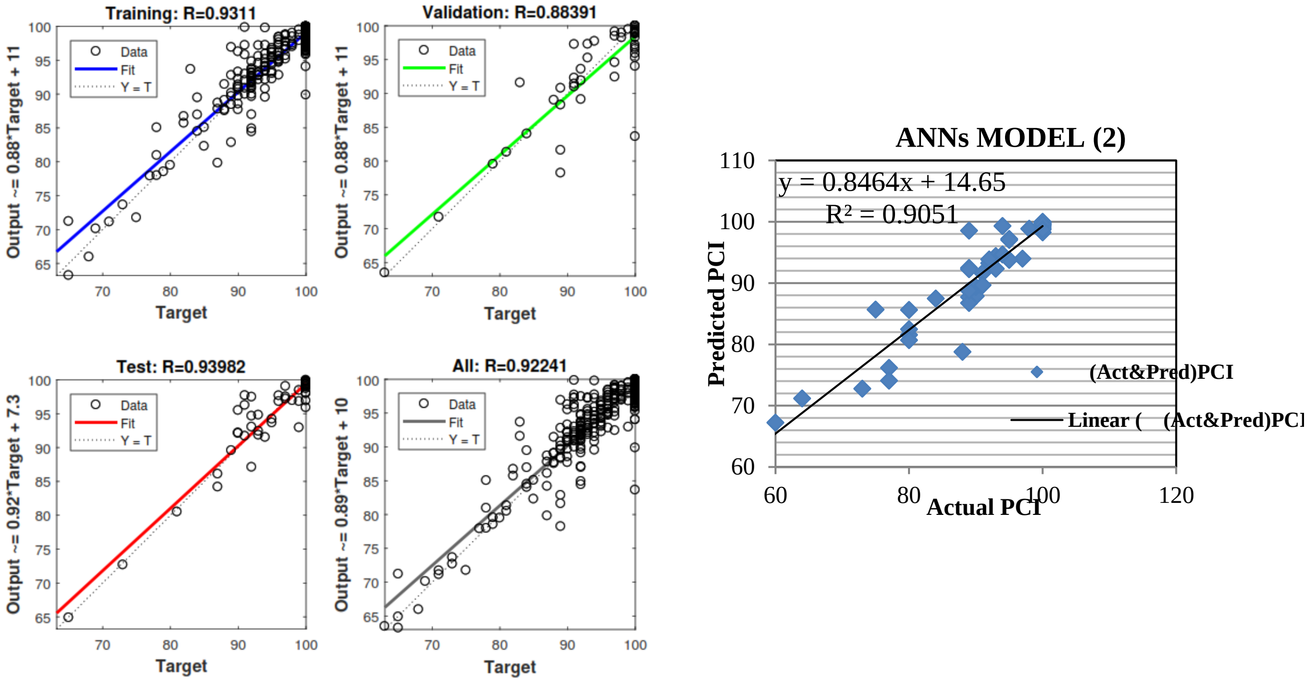


Figure 3: The relation between actual PCI and predicted PCI using Matlab program (The second category of sections- CASE one).

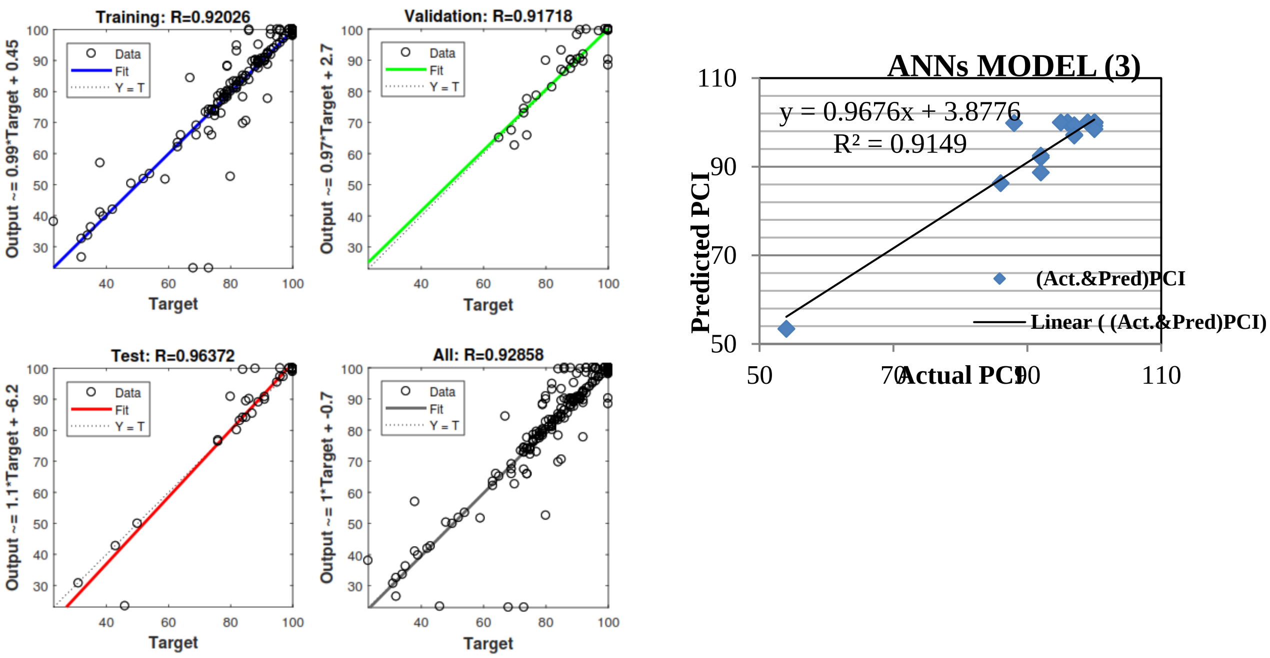


Figure 4: The relation between actual PCI and predicted PCI using Matlab program (The second category of sections- CASE two).

9. Summary and Conclusions:

This paper has been placed to prove the appropriateness of ANNs in predicting Pavement Condition Index(PCI). Artificial Neural Networks (ANNs) are able to deal with a large amount of data for huge pavement networks. The results indicated that ANN models were capable to successfully predict the Pavement Condition Index (PCI) values using the Matlab program.
The results showed in the first category of sections, the value of the correlation coefficient (R^2) is 83% for the predicted data. However, in the second category of sections; in the first case, the value of the correlation coefficient (R^2) is 90% of the predicted data. And the second case, the value of the correlation coefficient (R^2) is 91% for the predicted data for the flexible pavement model. However, the results indicate that the proposed model has a good capability that may be used for planning maintenance.

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