A Model of Rutting Development of Asphalt Pavement in Expressway Based on Artificial Neural Network

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ABSTRACT: A method for predicting development of rut depth in asphalt pavements in expressways was developed by applying Artificial Neural Network System (ANN). We employed a three layer ANN with input units for section between interchanges, foundation type, lane type, surface type and the number of large vehicles and an output unit for rut depth. The hidden layer between the input and output layers has 20 units. In this study, we employ a backpropagation-type ANN, where the connection weight of each unit was determined from the learning process by using performance data of asphalt pavements in expressways as teacher data. The relationships between rut depth and the number of large vehicles predicted by the ANN agree well with observed ones. The model provided a reasonable relationship even for a section, of which performance data does not exist. The effects of the input parameters on rutting development were discussed based on the predicted curves. The developed ANN model is very simple and easily modified for any types of roads by using the performance data available on the roads. This paper presents the ANN structure, data preparation for training process, comparisons of predicted rutting developments with the observed ones and discussions on the effects of input parameters on rut depth.

KEY WORDS: expressway, rut depth, prediction, artificial neural network.

1 INTRODUCTION

Prediction of rutting development is a very important issue in establishing the long term maintenance strategy for expressway asphalt pavements. The Kanazawa office of Central Nippon Expressway Company operates the Hokuriku expressway with a length of 260 km located in north-west of the central Japan island as shown in Figure 1. In order to provide a high quality of road service, it is quite important to maintain road surface properly with a limited budget allocated for the maintenance of the expressway system. For that purpose, it is required to have a good performance model of pavement surface, particularly for rutting that is one of the major distress modes to be considered in the maintenance planning.

There are two methods to predict the rutting: one is based on mechanical responses of asphalt pavement system. In the method, permanent strains in pavement are calculated from stresses and strains due to traffic loads utilizing visco-plastic theory. The other is based on data regression analysis. In this method, a relationship between traffic volume and rut depth is derived from long term performance databases. Since the former method requires very complicated and time consuming structural analysis as well as determination of many visco-plastic parameters for pavement materials from laboratory tests, its implementation has been limited to research purposes (White, et al. 2002, Hossain and Wu, 2002). Although MEPDG has introduced the method in the asphalt design procedures, this difficulties are still remaining (NCHRP 1-37A, 2009). The later method, on the other hand, is able to easily provide a relationship for a particular site, which can be used to predict the rutting development there. However, the model derived for the site lacks generality and can not be applied to elsewhere.

In this study, we adopted the regression method, because we have long term performance databases of the Hokuriku expressway, which have been accumulated for years in maintenance works. Also we obtained a very useful regression tool: Artificial Neural Network (ANN) that helps us to find a relationship between input and output data without assuming specific functions (Hirano,1991). ANN has been used successfully for establishing pavement performance models from long term performance databases (Horiki and Fukuda, 1994, Saitoh and Fukuda, 1996, Baran and Hjelmstad, 1996).

Utilizing ANN, a rutting development model that is able to predict the rut depth from the amount of large vehicles, foundation type, surface type and lane type for each section between the interchanges were developed. In this paper, the structures of ANN model and performance databases are presented. Then the process of teacher data preparation from the database, which is very important to obtain a reasonable result, is described. Finally, from the rutting developments predicted by the model, the effects of the input parameters on the rut depth are discussed.

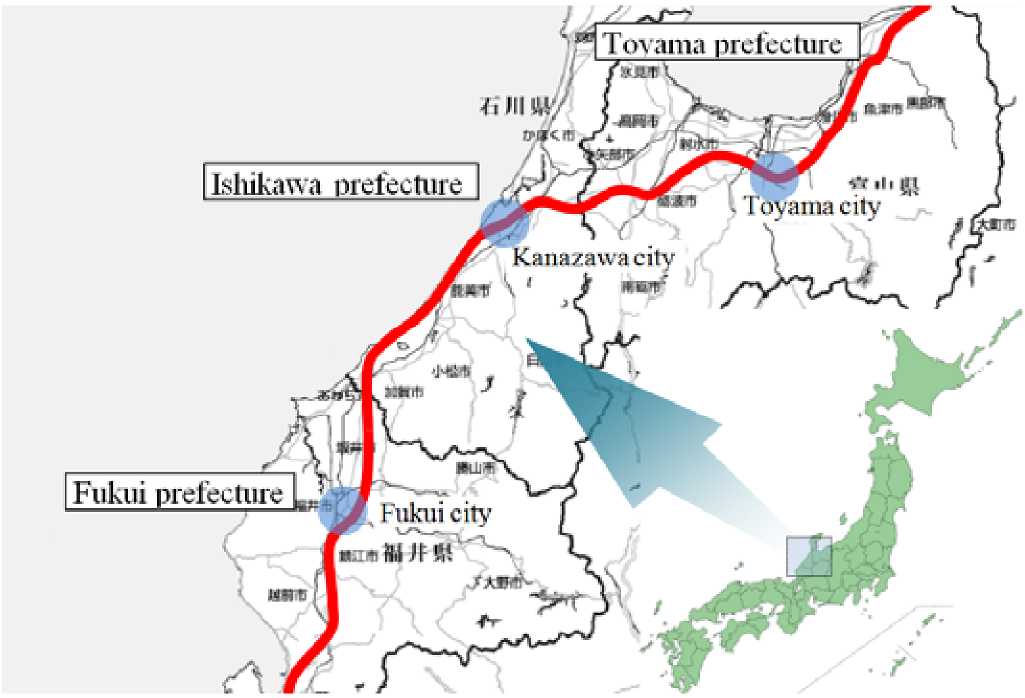
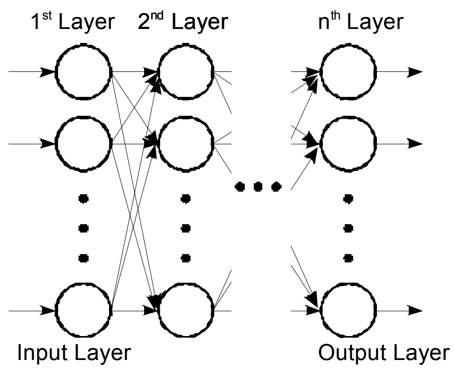


Figure 1: Location of Hokuriku Expressway



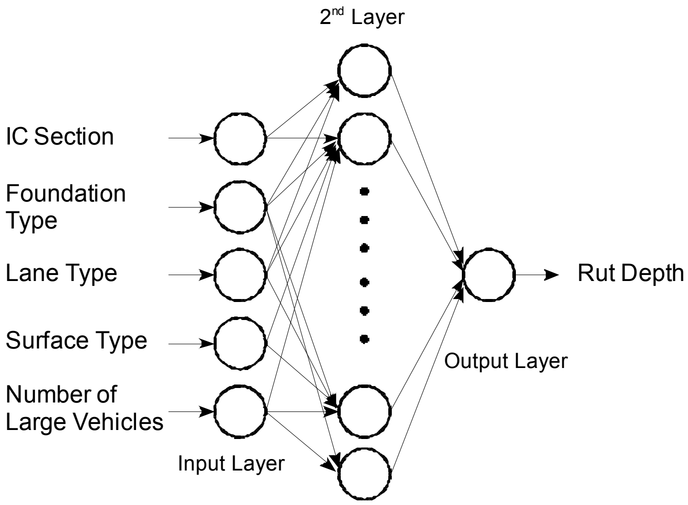


Figure 2: ANN Model

Figure 3: ANN Model for Rutting

2 ANN MODEL FOR RUTTING PREDICTION

The ANN model adopted in this study is the layered model that consists of *n* layers as shown in Figure 2. The input data at the first layer is weighted at each unit and transmitted to the next one and this process is repeated to the *n*-th layer to output the processed data. The output data is compared with the measured or actual data (teacher data), and the combined weights are modified so that the difference between the two will be reduced. If a pattern *p* is an input in the system, an input-output data at *j*-th unit in the *k*-th layer is expressed as:

$$o_{pj}^{k} = f_j^{k}(i_{pj}^{k}) \tag{1}$$

$$i_{pj}^{k} = \sum_{i=1}^{N_{k-1}} w_{i,j}^{k-1,k} o_{pi}^{k-1} + \theta_j^{k} \tag{2}$$

where, o_{pj}^{k} and i_{pj}^{k} are the output and input data, respectively at *j*-th unit in *k*-th layer for the pattern *p*; $w_{i,j}^{k-1,k}$ is the combined weight at *i*-th unit in *(k-1)*-th layer; f_j^{k}, θ_j^{k} and N_k are the input/output function, threshold and number of unit, respectively at *j*-th unit in *k*-th layer.
For the input /output function, the sigmoide function is used:

$$f(x) = \frac{1}{1+\exp(-x)} \tag{3}$$

The evaluation function is the square sum of errors between the teacher data and output data:

$$E_p = \frac{1}{2}\sum_{i=1}^{N_n}(t_{pi}^{n} - o_{pi}^{n})^2 \tag{4}$$

where, t_{pj}^{k} is teacher data at *j*-th unit in *n*-th layer for pattern *p*. To minimize E_p, $w_{i,j}^{k-1,k}$ is modified by:

$$\Delta w_{i,j}^{k-1,k} = -\eta \frac{\partial E_p}{\partial w_{i,j}^{k-1,k}} \tag{5}$$

This modification can be done in the other layers in the similar way and propagated backwardly from the output layer to the input layer to improve the accuracy of the system, which is called the backpropagation method.

In this study, a three layer ANN system was developed as shown in Figure 3. The ANN has five units in the input layer, 20 units in the hidden layer and one unit in the output layer. The units in the input layer are assigned to the design parameters: section between interchanges, foundation type, lane type, surface type and accumulated number of large vehicles, all of which will be explained later in this section. The output is simply rut depth.

3 STRUCTURE OF PERFORMANCE DATA

Two data sets were used in this study, both of which have been accumulated for the Hokuriku expressway. The one is the performance data that includes pavement structure, foundation type, design CBR, traffic volume, rut depth. The another is the maintenance data that includes type of maintenance work, location, date, route name, pavement structure, construction date, and type of distress. To utilize the data effectively, the values of input and output variables in the ANN system are discretized or normalized as presented in Table 1. The detail of each input variables are given as follows:

- IC section: Basically, the pavement structure of a road section between interchanges in the expressway is uniform. Therefore, IC section is considered to represent the pavement structure. In this study, four IC sections that seem to represent the surface condition of the Hokuriku expressway are selected from 24 IC sections: Komatsu – Mikawa, Toyamanishi – Toyama, Uozu – Kurobe and Kinomoto – Tsuruga.
- Foundation type: The road foundation is classified into two types: embankment or cut, which is supposed to represent the bearing capacity of foundation.
- Lane type: The number of large vehicles has not recorded for each lane. Generally, large vehicles tend to run on the running lane. Therefore lane type is considered to represent the traffic condition.
- Surface type: Surface layer is constructed with either dense mix asphalt mixture or porous asphalt mixture in this expressway.
- Accumulated number of large vehicles: The volume of large vehicle per day per direction has been recorded for each IC section. From the traffic data, the accumulated number of large vehicles was estimated.

The output variable is only rut depth in mm. It has been measured and recorded for every 100 m section for every year. The teacher data was prepared as follows:

1. The rut depth that developed for a period between one rehabilitation and the next one is computed.
2. The accumulated number of large vehicles is estimated for each section from traffic data. Figure 4 shows the variations of annual number of large vehicles from 1991 to 2006 for IC sections investigated.
3. The data of the section of which maintenance history is not known was excluded.
4. The case in which the rut depth significantly decreased even though the pavement was not rehabilitated or at least have no record of rehabilitation was excluded.
5. Discrete numbers were assigned to the variables of IC section, foundation type, surface type and lane type as presented in Table 1.
6. The valuables of accumulated number of large vehicles and rutting depth were normalized between 0 and 1.

Table 1: Values Assigned to Variables

Unit	Item	Value
Input Layer		
IC Section	Komatsu-Mikawa	0
	Toyamanishi-Toyama	1
	Uozu – Kurobe	2
	Kinomoto - Tsuruga	3
Founda-tion Type	Embankment	0
	Cut	1
Lane Type	Running	0
	Passing	1
Surface Type	Dense Asphalt Mix.	0
	Porous Asphalt Mix.	1
Traffic	Accumulated Number of Large Vehicles	0 to 1
Output Layer		
Rutting	Rutting Depth	0 to 1

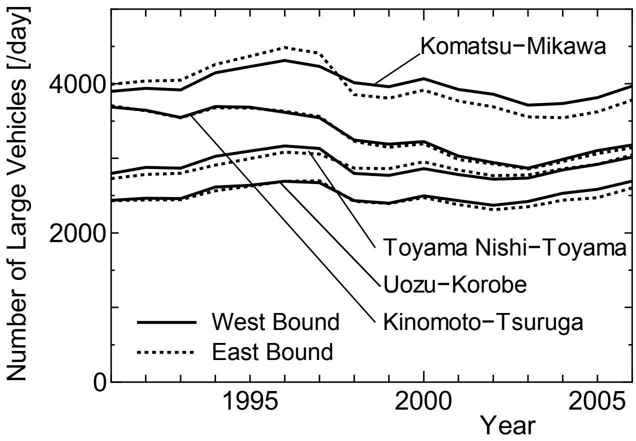


Figure 4: Variation of Annual Traffic Volume

Table 2: Overview of Teacher Data Set.

IC Section	Length (km)	Equivalent Thickness(cm)	Founda-tion Type	Surface Type	Lane Type	Number of Point
Komastu - Mikawa	11.0	29.5	0	0	0	213
			1	0	0	120
			0	1	0	30
			1	1	0	40
			0	0	1	24
			0	1	1	16
Toyamanishi - Toyama	7.4	27.6	0	0	0	154
			1	0	0	100
			0	1	0	42
			0	0	1	83
			1	0	1	55
			0	1	1	18
Uozu - Kurobe	9.6	24.3	1	0	0	139
			1	0	0	128
			0	1	0	56
			1	1	0	83
			0	0	1	22
			1	0	1	32
			0	1	1	26
			1	1	1	23
Kinomoto - Tsuruga	23.2	29.4	0	0	0	319
			1	0	0	156
			0	1	0	105
			1	1	0	51
			0	0	1	50
			1	0	1	40

This teacher data preparation is basically a filtering operation, in which improper or unreasonable data are omitted. It is the most important and the hardest work to obtain a reasonable model. The quality of model is strongly reflected by the quality of teacher data, which should be prepared very carefully with a supervision of experienced engineers.

All data used to establish the ANN system in this study are summarized in Table 2. The number of data points was 2125. The learning process was repeated about 10,000 times until the error was minimized. Figure 5 shows the accuracy of the model established in this study, comparing the predicted and measured rut depth at 2125 points. The correlation coefficient is 0.802, which is very satisfactory.

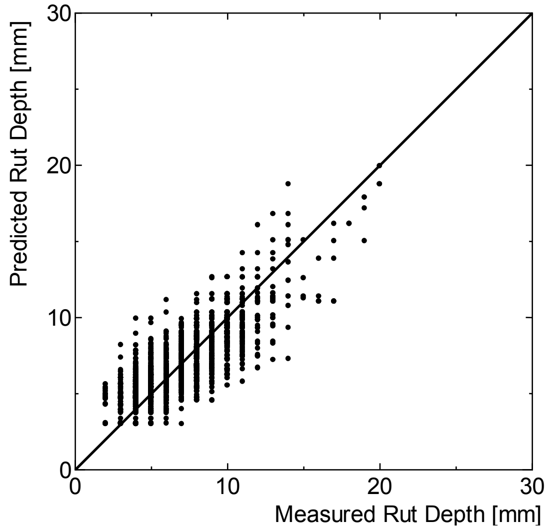


Figure 5: Accuracy of ANN Rutting Model

4 RESULTS

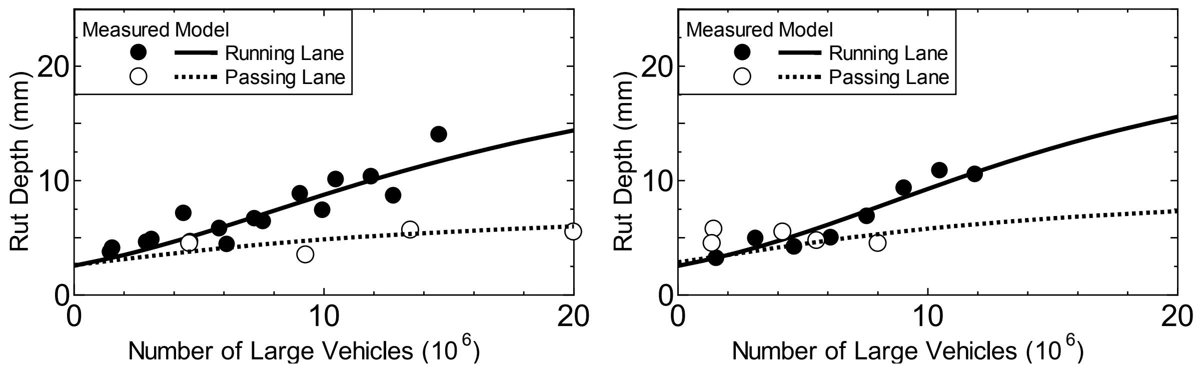
In this section, the rutting development curves predicted by the ANN model will be compared with the measured ones and discussed the effect of the input variables.

Figure 6 shows the rutting development curves for Komatsu – Mikawa section. In this figure, the measured data were plotted after those in a section with the same thickness and the same rehabilitation history were averaged to make the figure less complicated. The correspondence between the predicted and measured rutting developments is good. The rutting development is faster on running lane than on passing lane, because the actual number of large vehicle for the running lane is greater than that on the passing lane. It should be noted again that the number of large vehicle in the horizontal axis is the total number for all lanes. Therefore, the faster rutting development on running lane is understandable. There is no effects of foundation type on the rutting. In this section, rutting of porous asphalt surface develops faster than that of dense asphalt mixture.

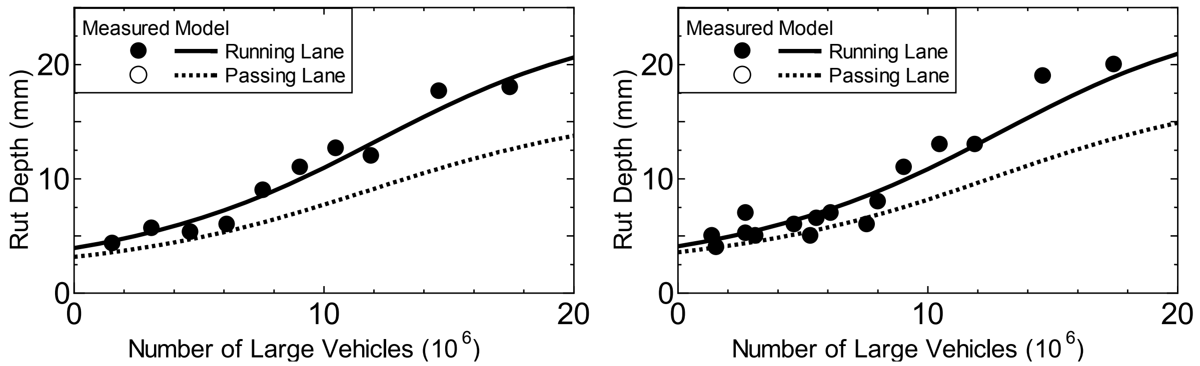
Figure 7 shows similar curves for Toyomanishi – Toyama section. Although the pavement in this section is thinner than that in Komatsu – Mikawa section, the rutting development is slower. The difference between running and passing lanes is small on porous asphalt surface. Although no measured data existed on the section of cut foundation and porous asphalt mixture, ANN generates the rutting development curves based on the data in other sections.

Figure 8 is the plots for Uozu – Kurobe section. The pavement thickness is the thinnest among the sections investigated in this study but this section exhibits the slowest rutting development. ANN predicts that the rutting on porous asphalt surface becomes greater when the number of large vehicle increases, while that on dense asphalt surface becomes stable in that stage.

Figure 9 is the plots for Kinomoto-Tsuruga section. The rutting on dense asphalt surface is nearly proportional to the accumulated traffic volume. The rutting development is faster on porous asphalt surface than on dense asphalt surface. This region is a snowy area and road users use tire chains when it snows. The raveling of asphalt surface due to the tire chains may explain the faster rutting development on porous asphalt surface.

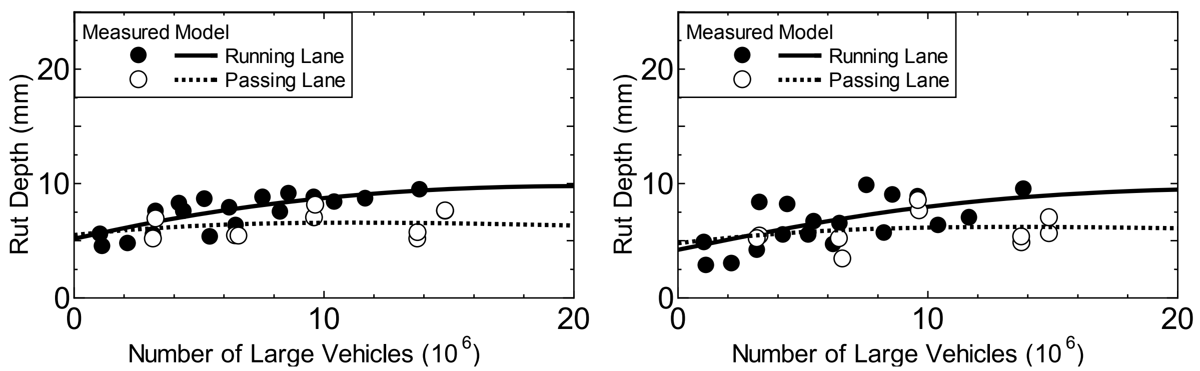


(a) Embankment, Dense Mix. (b) Cut, Dense Mix.

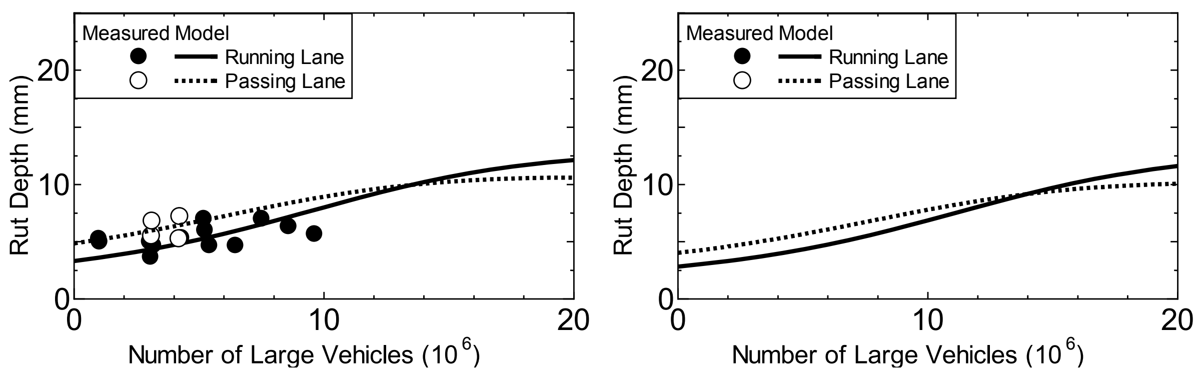


(c) Embankment, Porous Mix. (d)Cut, Porous Mix.

Figure 6: Rutting Development in Komatsu - Mikawa

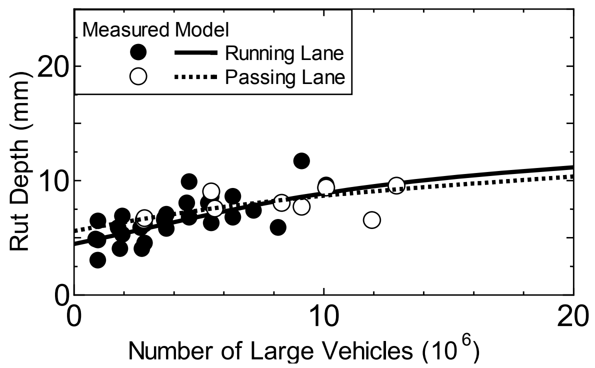


(a) Embankment, Dense Mix. (b) Cut, Dense Mix.

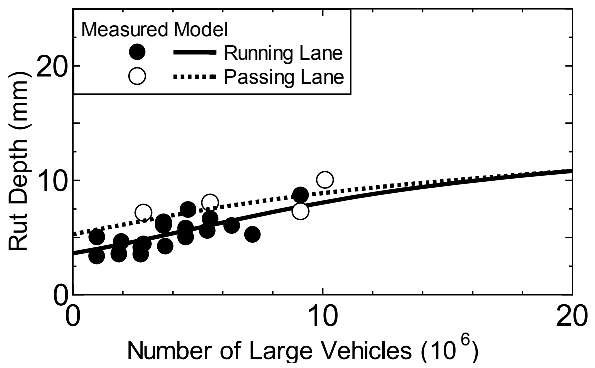


(c) Embankment, Porous Mix. (d)Cut, Porous Mix.

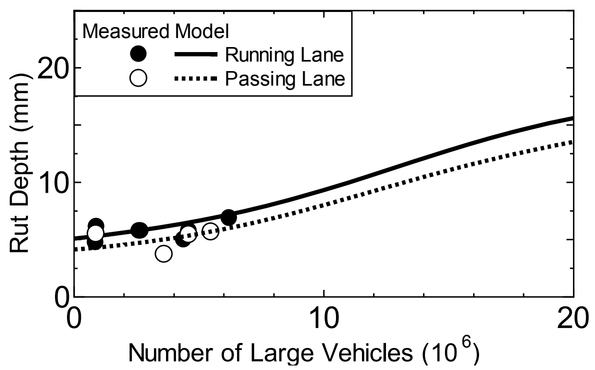
Figure 7: Rutting Development in Toyamanishi - Toyama



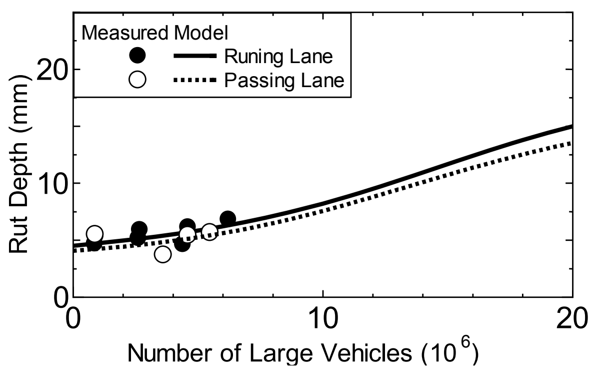
(a) Embankment, Dense Mix.



(b) Cut, Dense Mix.

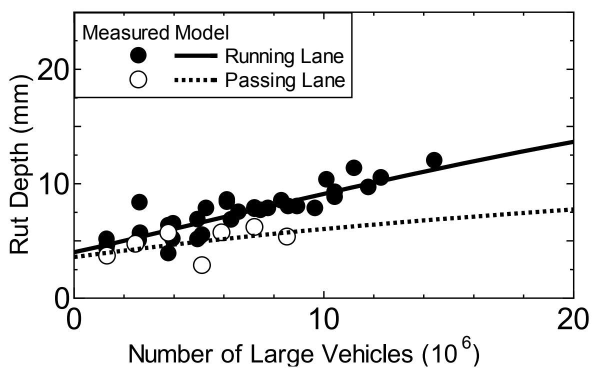


(c) Embankment, Porous Mix.

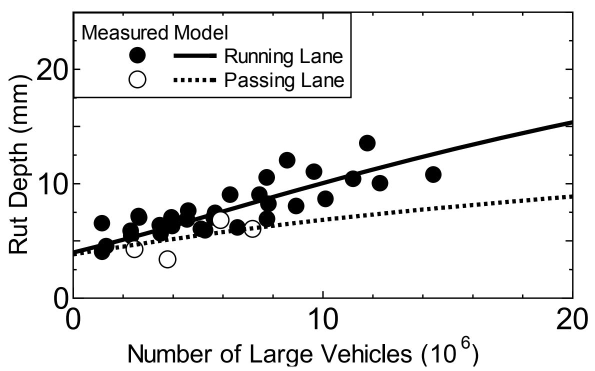


(d)Cut, Porous Mix.

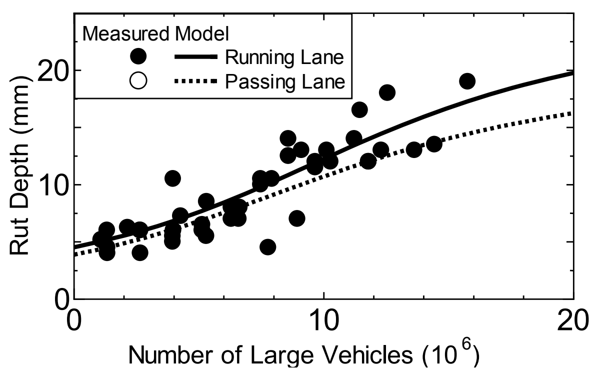
Figure 8: Rutting Development in Uozu – Kurobe



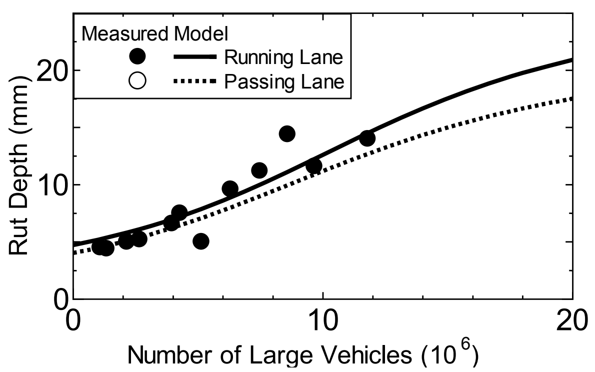
(a) Embankment, Dense Mix.



(b) Cut, Dense Mix.



(c) Embankment, Porous Mix.



(d)Cut, Porous Mix.

Figure 9: Rutting Development in Kinomoto - Tsuruga

5 CONCLUSIONS

In this study, an ANN model was established to predict the rutting development on asphalt pavement in Hokuriku expressway. The model provides the rut depth as output from inputs of IC section, foundation type, lane type, surface type and the accumulated number of vehicles. The structure of the model was determined with the back-propagation algorithm from the performance and maintenance data bases. The rutting developments were predicted by the model and compared with the measured data. The agreement of the predicted rut depth with the measured ones is very good, indicating the validity of the model.

Applicability of the ANN model developed in this study might be limited to the Hokuriku expressway, because the rutting data used were measured there. However, ANN model is very easy to handle and another model for another area can be quite easily established, if appropriate performance data base is available. It is emphasized that the teacher data should be prepared very carefully to obtain a reasonable model. The quality of the model performance is strongly reflected by that of the teacher data.

ANN performance model could be a very powerful tool for predicting various pavement performances, which is required for establishing the rational strategy of long term pavement maintenance strategy and gaining enough maintenance budget.

REFERENCES

Banan, M.R., and Hjelmstad K.D., 1996. *Neural Networks and AASHO Road Test*, Journal of Transportation Engineering, ASCE, pp.358-366.

Hirono, H., 1991. *Neural Network Programming with C Language*, Personal Media.

Horiki, K., and Fukuda, T., 1994. *Pavement Performance Forecasting Model Using Neural Network*, Proceedings of Japan Society of Civil Engineers, No.496, pp.99-102.

Hossain, M and Wu, Z., 2002. *Finite Element Simulation of Rutting on Superpave Pavements*, Proceedings of 9th International Conference on Asphalt Pavements, 5:2-3, Copenhagen, Denmark.

NCHRP 1-37A, 2009, Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, http://www.trb.org/mepdg, Accessed December 2009.

Saitoh, M., and Fukuda, T., 1996. *Neuro Performance Model Based on Pavement Design Equation*, Proceedings of Japan Society of Civil Engineers, No.550, pp.213-217.

White, T.D., et al., 2002. *Contributions of Pavement Structural Layers to Rutting of Hot Mix Asphalt Pavements*, NCHRP Report 468, Transportation Research Board, National Sconce Academies, Washington D.C.