Neural-Network-Based Procedure for Condition Assessment of Utility Cuts in Flexible Pavements

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On city streets utility companies often dig up a section of pavement to install or inspect utility services. Such locations, termed *utility cuts*, introduce discontinuities, weaken pavements, and cause localized distresses. Their condition evaluation requires a small-area investigation, for which no specific guidelines are available. A procedure for investigation of utility cuts and a rating index called the Utility Cut Condition Index (UCCI) are described. A survey of utility cuts in the city of Cincinnati was performed using the Delphi method. Field data were used to develop a neural network for predicting UCCI on the basis of the type and severity of distresses. The model was trained and tested for its accuracy. The UCCI predicted by the neural network can be used as a management tool for identifying conditions of utility cuts and for assigning priorities for their maintenance.

Periodic monitoring of highway pavement for condition evaluation is an essential aspect of a maintenance program. According to the AASHTO guidelines for pavement management systems (*1*), a condition evaluation includes four basic classes of information: (*a*) ride quality or roughness, (*b*) physical distresses, (*c*) structural capacity, and (*d*) safety.

Considerable research has been applied to the monitoring of distresses on Interstate and state road systems, on which the surface distresses are normally spread over a wider area. The distress manuals developed by the Strategic Highway Research Program (SHRP) (*2*), the U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL) (*3*), and various state agencies (*4,5*) provide specific guidelines for evaluating the severity and extent of distresses in a given highway segment on a global level. However, when the distresses are localized, engineers are required to investigate a small area of the pavement, for which no specific guidelines are available.

On city streets utility companies often dig up a section of a pavement to install or inspect utility services. After the installation or inspection, the section is restored in accordance with existing guidelines and specifications (*6*). Such a location within a pavement section is termed a *utility cut*. These cuts introduce discontinuities, weaken the pavements, and cause localized distresses.

A procedure developed for microlevel investigation of localized distresses in asphalt pavements in and around utility cuts is outlined. Then the development of a neural network that can establish a rating index for condition evaluation of utility cuts is described.

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UTILITY CUTS VERSUS PAVEMENT SECTIONS

Utility cuts differ from highway pavement sections in terms of their size and mechanical behavior. These cuts are relatively small in comparison with the surrounding pavement sections: normally the cut ranges from 15 to 50 ft^2 (1.4 to 4.6 m^2) in the horizontal plane.

Once a pavement section has been built, it experiences a decline in its condition primarily because of traffic and environmental factors. The construction and composition of a pavement section may be assumed to be fairly uniform within a given section. The life cycle of pavements has become well understood through the development of life-cycle models. A utility cut, however, normally deteriorates at an accelerated pace. Type of backfill materials used and inadequate compaction characteristics have been found to be the most important factors affecting the performance of utility cuts (*7*). Few cities have guidelines for the evaluation of utility cuts. Chong et al. (*8*) provide guidelines for municipalities to evaluate distress conditions in utility trenches and suggest alternative maintenance treatments for various severity levels. Shahin and Crovetti (*9*) adopted the techniques used for pavement evaluation and design without any modifications for utility cuts.

NEED TO DEVELOP RATING INDEX FOR UTILITY CUTS

There is considerable variety in the ways that individual agencies use pavement condition data. The two most common methods are

1. To combine attributes in a specific manner to determine a single (aggregate) index and
2. To use these data in decision trees (disaggregate them) to determine condition states or to tabulate them in the form of a pavement condition matrix.

Aggregating pavement condition data into a single rating index is a widely used concept to support project- and network-level pavement management decisions (*10*). Typical condition indicators for highway pavements referred to in the literature are the Present Serviceability Index (PSI) of AASHTO (*11*), the Pavement Condition Index (PCI) of CERL (*3*), the Pavement Condition Rating (PCR) of Ohio and Ontario (*4,12*), and the Pavement Quality Index (PQI) of Alberta (*13*). Specific guidelines are available to gather the data required to develop any of these indexes, which assist in evaluating the condition of pavements on a global level for an extended highway segment. To assemble individual distresses into a single matrix, several procedures have been used in the past, with the deduct-points method being the most common (*3,4*). However, no specific guidelines are available for condition evaluation of utility cuts or the establishment of a rating index. Engineers have so far relied on their experience to evaluate utility cuts since the condition indicators mentioned earlier have not been used for localized distress evaluation. Development of a new rating index for utility cuts is needed.

DISTRESS MANUAL

Several manuals have been developed for identification of distresses in pavements. Generally these manuals describe methods for identifying commonly observed distresses and measuring their severity. The distress manuals developed by SHRP (*2*) and CERL (*3*) encompass all categories of pavements and possible distress types. Unfortunately, the manuals currently available do not make a clear distinction between the evaluation of extended pavement sections and the evaluation of utility cuts. Hence a distress manual for utility cuts (*14*), which was a first attempt to list the most predominant distresses in utility cuts, was developed. The manual considers various types and severity of distresses but not their extent, because of the relatively small area involved. The manual lists the following nine types of distresses and their severity at low, moderate, and high levels:

1. Alligator cracking,
2. Edge cracking,
3. Transverse cracking,
4. Potholes,
5. Rutting,
6. Ravelling and weathering,
7. Pavement drop-off,
8. Edge separation, and
9. Corner breaks.

All of the foregoing distresses except 6, 8, and 9 are also applicable for evaluation of distresses in the vicinity of cuts.

FIELD STUDIES

Distress surveys were carried out to identify the type and severity of distresses in and around utility cuts. Although the distress manual provides necessary guidelines, the experience of the engineer or inspector plays a critical role in the survey because the severity of a distress must be subjectively assessed as low, moderate, or high, as described in the manual. In order to reduce variations in the evaluation of distress conditions, the collective judgment of engineers and inspectors was used. The condition data were collected on selected utility cuts in the city of Cincinnati using the Delphi method.

The Delphi method is a spin-off from defense research (*15*) in which expert opinions are extracted on items that are subjective and the variation in the responses is reduced. The Delphi technique is an iterative procedure characterized by three features: anonymity, iteration with controlled feedback, and statistical response. The opinions of the panelists, who respond to a series of questions, remain unknown to one another. After the survey is completed, feedback is provided to each participant regarding the summary results. If there are wide variations in the opinions of the panelists on any item, a new round of survey is performed based on the results of the previous round. This process is continued until an agreement or near agreement is reached on various items under consideration, or until it becomes evident that no such agreement can be reached.

The panel for the Delphi study consisted of 4 engineers from the Cincinnati Central Engineering Office and 11 inspectors from the Highway Maintenance Department. Normally the inspectors from the Maintenance Department are responsible for routine evaluation and inspection of utility cuts. Since the objective of the study was to collect opinions from a wide range of experts, engineers from the Central Engineering Office were included in the Delphi panel.

The Delphi method required asking the panelists simple questions as to the type and severity of distresses present in each utility cut. A questionnaire was prepared in the form of an evaluation form (Figure 1). This form was designed to ask the panelist about the surface profile, type and severity of the existing distresses, overall condition of the cut, and recommended action. One evaluation form was used by panelists for each cut.

In all, 75 cuts with granular base and asphalt surfacing and various levels of traffic and distresses were surveyed by the panelists. The samples were randomly drawn from a large population of utility cuts on major arterials, collectors, and residential streets. The size of the cut generally varied from 3 by 3 ft to 7 by 10 ft (0.91 by 0.91 m to 2.1 by 2.1 m).

Round 1

Initially, the research team held a series of discussions with the panelists to familiarize them with the objectives of the project. Each panelist was given a distress manual, a set of blank evaluation forms, and a list of utility cuts to be evaluated. The use of the distress manual and evaluation form was explained. Trial sessions were held on two typical cuts to ensure that the panelists understood the use of the distress manual and evaluation form.

During the first round, the panelists surveyed 75 cuts over a period of 2 months. During the distress survey, no discussion was allowed among the panelists. The first round yielded 1,125 evaluation forms.

Round 2

The information obtained during Round 1 was input into a data base and analyzed. A large deviation in the identification

City of Cincinnati

Prepared by:________ Date of Survey:________

Location:__________ Time of Survey:________

Surface Profile	very poor	poor	fair	good	excellent
(enter a number here)	0 - 20	21 - 40	41 - 60	61 - 80	81 - 100

Distresses	**Cut**			**Vicinity**			Any additional Distress?
	low	moderate	high	low	moderate	high	
Alligator Cracking							Overall Condition (UCCI)
Edge Cracking							O Very Poor(0-20)
Transverse Cracking							O Poor(21-40)
Potholes							O Fair(41-60) O Good(61-80)
Rutting							O Excellent(81-100)
Ravelling & Weathering							Recommended Action
Cut-to-Adjacent Pavement Drop-off							O Do Nothing O Surf. Treatment
Edge Separation							O Overlay O Reconstruct
Corner Breaks							
Additional Remarks:							

FIGURE 1 Evaluation form for utility cuts.

and severity of the distresses as well as in the overall condition of the utility cuts was found for most of the locations. Hence a second series of meetings was held and a statistical summary of the results for each cut was given to the panelists. They were specifically told to refer to the summary and appropriately revise their opinion only if they believed it was necessary. The panelists visited all 75 cuts.

Round 3

When the results of Round 2 were tabulated, it was found that the panelists still differed in some aspects of evaluation of the utility cuts. In particular, eight panelists seemed to disagree on some 26 cuts. Hence only these eight panelists and 26 cuts were included in Round 3 of the survey. No further rounds of survey were performed since the results indicated that there might not have been any improvement of practical significance. Table 1 shows the final distribution of the sample for different conditions of the utility cuts.

The overall condition given by the panelist for each cut is an aggregate measure of individual distresses that will be called the Utility Cut Condition Index (UCCI). The data collected by the Delphi method were used to develop a neural network for predicting the UCCI.

DEVELOPMENT OF NEURAL NETWORK MODEL

In recent years, artificial neural networks (ANNs) have been gaining wide application in business and industry. In many instances, ANNs have been found to provide better results than conventional modeling techniques, particularly if the relationships among the variables of interest are complex. There are several advantages to using a neural network to predict the UCCI on the basis of subjective views of human experts. For instance, the deduct-points method used to convert word ratings into numerical values for highway pavement sections makes several assumptions about distress weighing factors. A neural network can use word ratings to develop a rating index without the need for such assumptions. As explained in the following paragraphs, in this study the neural network derived expertise from examples of the distress survey and was trained to solve problems of a similar nature in the future. The back-propagation method (*16*) was used to develop a neural network consisting of an input layer, an output layer, and a hidden layer (Figure 2).

Data Preprocessing and Training

As mentioned before, the Delphi method was used to collect data on the conditions of utility cuts. The data base was initially prepared to contain information on the types and severity of distresses in the cut and its vicinity and overall condition. The information on surface profile and recommended action was not used in the development of the neural network.

Before a neural network could be developed, preprocessing of the data was necessary since neural networks cannot recognize categorical information such as low, moderate, or high distresses. A computer program was written to convert the categorical information into numerical codes as follows:

TABLE 1 Final Results of Distress Survey

Surface Profile					
	1-10	11-20	21-30	31-40	41-50
	17	50	60	120	180
	51-60	61-70	71-80	81-90	91-100
	173	231	197	84	13

Distresses	Cut			Vicinity		
	L	M	H	L	M	H
Alligator Cracking (A/J)	155	227	224	81	143	60
Edge Cracking (B/K)	222	270	147	96	57	23
Transverse Cracking (C/L)	147	206	95	232	415	70
Potholes (D/M)	155	105	61	32	13	4
Rutting (E/N)	319	172	93	142	61	11
Ravelling & Weathering (F)	476	297	145			
Drop off (G/O)	389	148	57	16	12	3
Edge Separation (H)	527	272	103			
Corner Breaks (I)	228	137	103			

Overall Condition					
	1-10	11-20	21-30	31-40	41-50
	28	74	101	153	132
	51-60	61-70	71-80	81-90	91-100
	159	109	172	95	9

Action	Do Nothing	Surf. Treat.	Overlay	Reconstruct
	288	249	139	356

Category	*Numerical Code*
No distress	(0,0)
Low severity	(0,1)
Moderate severity	(1,0)
High severity	(1,1)

The observations were classified into 10 groups on the basis of UCCIs ranging from 1 to 100. For example, a UCCI of 100 represents a utility cut with absolutely no distress.

To develop a neural network, training data and testing data are required. A network needs to be trained so that the application of a set of inputs can produce a desired set of outputs. The testing data are used to check the accuracy of the developed neural network. Hence, the original data, consisting of 1,032 observations, were separated into two parts: 709 observations (69 percent of the total sample) for training and the remaining 323 observations (31 percent) for testing. Observations were selected for the training and testing data sets randomly within each UCCI group.

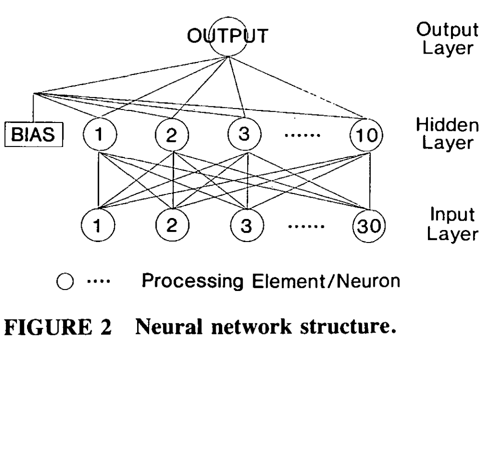

FIGURE 2 Neural network structure.

A software called NeuralWorks Professional II/Plus (*16*) was used to develop the neural network described in this paper. There were 30 processing elements in the input layer to represent nine types of distresses in the cut and six in the vicinity. The hidden layer consisted of 10 processing elements. The output layer had only one processing element, that is, one UCCI for each utility cut. In this study, the sigmoid function (*17*) was chosen to be the transfer function. Although other transfer functions such as hyperbolic tangent or sine were also tried, the sigmoid transfer function was found to allow the root-mean-square convergence most quickly.

The selection of a set of proper learning coefficients and a momentum value is important, since they are sensitive and critical to the network learning. After a few trial runs, the initial learning coefficients were set at 0.3 for the hidden layer and 0.2 for the output layer and the momentum was 0.8. These values were gradually reduced for higher numbers of training iterations as shown in Table 2.

Neural Network Testing

The neural network was tested with the testing data. A comparison of the actual UCCI with the predicted UCCI showed that the average absolute error (actual UCCI minus predicted UCCI) was 6.5 and the average relative error [(actual UCCI minus predicted UCCI)/actual UCCI] was 4.0 percent. When the output band was set to ±12, the neural network was found

TABLE 2 Learning Coefficient and Momentum Values

Number of Iterations	< 10000	< 20000	< 70000	< 150000
L_{coef} for Hidden Layer	0.30	0.1500	0.0375	0.00234
L_{coef} for Output Layer	0.15	0.0175	0.0188	0.00117
$M_{momentum}$	0.80	0.4000	0.1000	0.00625

to correctly predict 92 percent of the outputs. A graphical plot of the actual and predicted UCCIs and the output band is shown in Figure 3.

DISCUSSION OF RESULTS

The neural network technique was used to develop the relationship between observed distresses and rating index for utility cuts. Although the Delphi method was used to reduce variation in the condition evaluation of utility cuts, the data are still noisy because the inspectors and engineers did not always agree on the type and severity of distresses and the overall rating of the utility cuts. The neural network showed that a larger discrepancy between the predicted and actual outputs existed when the UCCIs were either very large or very small, for example, when UCCI was greater than 90 or lower than 10. It is believed that these errors were caused by the small sample size within these groups.

A question might arise at this time regarding the threshold value of the UCCI for practical purposes. In the case of highway pavements, many state agencies have used a value of 50 to 65, on a scale of 0 to 100, as the threshold value for maintenance management of highway pavements. When the condition of a pavement reaches the threshold value, some sort of maintenance action will be implemented. The same analogy should apply for utility cuts. In the present study, utility cuts were found to have ratings of less than 10, indicating that the existing threshold values for highway pavements will not be suitable for utility cuts. It is suggested that a threshold value for utility cuts be established in the future.

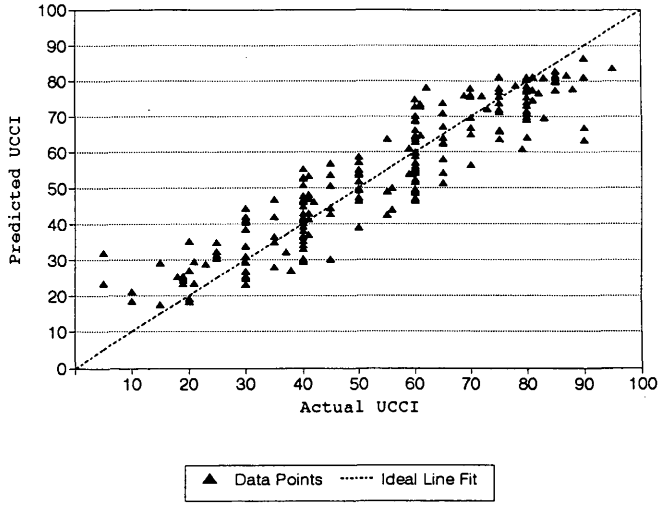

FIGURE 3 Comparison of predicted UCCI and actual UCCI.

CONCLUSIONS

The performance characteristics of utility cuts differ widely from those of highway pavement sections. A periodic evaluation of the conditions of utility cuts is essential for better management of city pavements. Once the condition evaluations are made, it is desirable to transform the individual distress data into a condition indicator or a rating index. No systematic studies have been performed for evaluating distress conditions in and around utility cuts, and none of the existing pavement condition indicators can be used for defining the condition of utility cuts. This study is a first attempt to evaluate distresses in and around utility cuts. It utilizes a rational procedure to develop a rating index for such cuts.

The distress manual for utility cuts is a valuable tool for city engineers and inspectors engaged in the evaluation of utility cuts. The Delphi method assists in narrowing the variations of opinion among panel members and provides an advantage in training city engineers and inspectors to make condition evaluations of utility cuts on a uniform basis.

The neural network for predicting the UCCI was developed by using a large amount of field data. The model was trained and tested for its accuracy. The UCCI predicted by the neural network can be used as a management tool for identifying conditions of utility cuts in a city and assigning priorities for their maintenance.

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