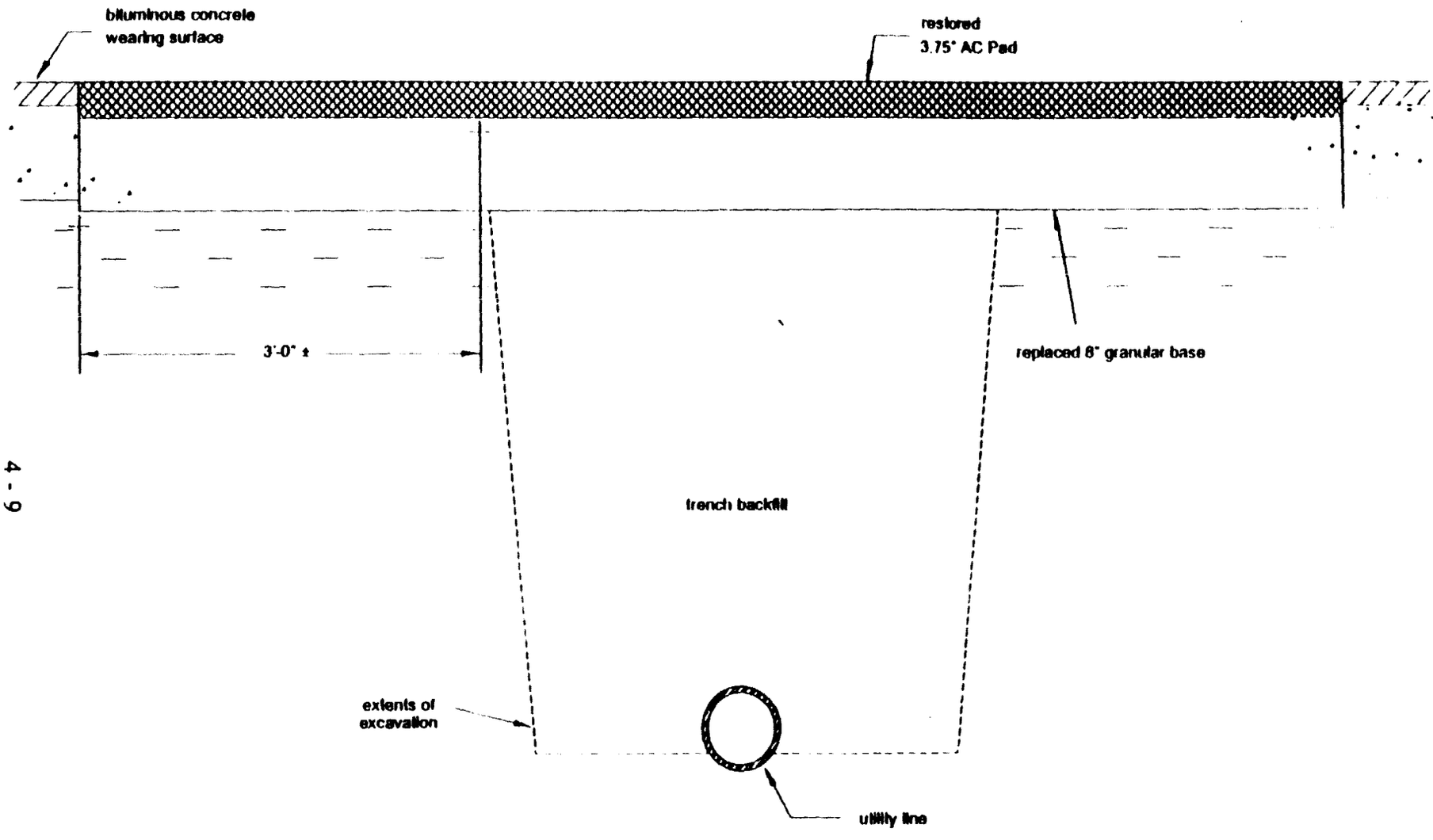

FIG. 4.5. Pavement Strengthening by a Deeper 8 in. Thick Granular Base and 3.75 in. Thick AC Pad - Scheme 4

CHAPTER 5

CONDITION EVALUATION

USING DISTRESS SURVEY

A periodic monitoring of highway pavement for condition evaluation is an essential aspect of a maintenance program. The components of a monitoring program, include (i) specific guidelines to evaluate distresses (in the form of a Distress Manual), and (ii) a procedure to assemble individual distresses into an aggregate index.

The distress manuals developed by the National Research Council's Strategic Highway Research Program (SHRP) (5.1), the U.S. Army Corps of Engineers' Construction Engineering Research Laboratory (CERL) (5.2), and various state agencies (5 3, 5 4) provide specific guidelines for evaluating the severity and extent of distresses on a global level for our Interstate and State Highways. However, when the distresses are localized, as in the case of utility cuts, engineers are required to investigate a small area of the pavement for which no specific guidelines are available.

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

(1) Combine attributes in a specific manner to determine a single (aggregate) index.

(2) Use the data in decision trees (disaggregate), to determine condition states, or tabulate the data in the form of a pavement condition matrix.

The first method, aggregating pavement condition data into a single rating index, is a widely used concept to support project and network level decisions in pavement management (5.5).

Typical condition indicators for highway pavements referred to in the literature are Present Serviceability Index (PSI) of AASHTO (5.6), Pavement Condition Index (PCI) of CERL (5.7), Pavement Condition Rating (PCR) of Ohio and Ontario (5.8, 5.9) and Pavement Quality Index (PQI)

of Alberta (5.10). Specific guidelines are available to gather the data required for developing any of these indices. These indices assist in evaluating the condition of pavements on a global level for an extended highway segment. In order to assemble individual distresses into a single matrix, several procedures have been used in the past with the deduct points method being the most widely used (5.2, 5.3). However, there are no specific guidelines available for condition evaluation of utility cuts or establishment of a rating index. Engineers have so far relied on their experience for evaluating utility cuts since the condition indicators mentioned above have not been used for localized distress evaluation.

The above discussions call for the development of a Distress Manual and a new rating index for utility cuts.

Distress Manual

The distress manuals developed by SHRP (5.1) and CERL (5.2) 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 utility cuts. Hence a distress manual for utility cuts (5.11), which was a first attempt to list the most predominant distresses in utility cuts, was developed (See Appendix C). The manual considers various types and severity of distresses, but does not consider the extent due to the relatively small area of utility cuts. The manual lists nine types of distresses with their level of severity at (a) low, (b) moderate or (c) high. The distresses listed are:

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

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

Field Studies

Distress surveys were carried out to identify the type and severity of distresses present 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. This is because the severity of a distress is subjectively assessed as low, moderate or high, as described in the manual. In order to reduce variations in the evaluation of distress conditions, collective judgments of engineers and inspectors were used. The condition data were collected on selected utility cuts in the City of Cincinnati using the Delphi Method.

Data Collection by Delphi Method

The Delphi Method is a spin-off of defense research (5.12). This method extracts expert opinions on items that are subjective and reduces the variation in their responses. The Delphi Method is an iterative procedure characterized by three features: (i) anonymity, (ii) iteration with controlled feedback, and (iii) statistical response. The opinions of the panelists, who respond to a series of questions, remain unknown to one other. 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 Delphi study consisted of four engineers from the Highway Engineering Office

and 11 inspectors from the Highway Maintenance Department of the City of Cincinnati. 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 Highway 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 as shown in Figure 5.1. 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 a panelist for each cut.

In all, 75 cuts in asphaltic concrete and macadam pavements with granular base were surveyed by the panelists. The samples were randomly drawn from a large population of utility cuts on major arterials, collectors, and residential streets, all of which exhibited various levels of distress. The cuts varied in size generally from 3 feet x 3 feet to 7 feet x 10 feet.

Round 1: Initially, the research team held a series of discussions with the panelists. The panelists were familiarized 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 two months. During the distress survey, no discussion was allowed among the panelists. The first round yielded 1125 evaluation forms.

Round 2: The information obtained during Round 1 was inputed into a database and analyzed. A large deviation in the identification and severity of the distresses as well as in the overall

condition of the utility cuts was found at most of the locations. A second series of meetings was held and a statistical summary of the results for each cut was handed to the panelists. They were specifically told to refer to the summary and appropriately revise their opinion only if they felt it was necessary. The panelists re-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, there were 26 cuts on which there seemed to be some difference of opinion among eight panelists. Only these eight panelists and 26 cuts were included in Round 3 of the survey. No further round of survey was performed since the results indicated that there may not be any improvement to be of practical significance. Table 5.1 shows the final distribution of 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 which will be called the Utility Cut Condition Index (UCCI) in the following discussions. The data collected by the Delphi Method was used to develop a neural network for predicting UCCI.

Development of Neural Network Model

In recent years, artificial neural networks (ANNs) have been gaining wide applications in business and industry. In many instances, ANNs have been found to provide better results than the conventional modeling techniques, particularly if the relationships among the variables of interest are complex. There are several advantages in using a neural network for predicting UCCI based on the subjective views of human experts. For instance, the deduct point method used for highway pavement sections to convert word ratings into numerical values makes several assumptions on distress weighing factors. A neural network can use word ratings to develop a rating index without the need for such assumptions. In this study, as explained in the following paragraphs, the neural network derived expertise from examples of the distress survey and was trained to solve problems of similar nature in the future. The back-propagation method (5.12) was used to develop the neural network consisting of an input layer, an output layer and a hidden layer (Figure 5.2).

Data Pre-processing and Training the Neural Network

As mentioned before, the Delphi Method was used to collect data on the conditions of utility cuts. The database was initially prepared to contain information on the types and severity of distresses in each cut and its vicinity, and the overall condition of the cut. 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, pre-processing of the data was necessary since neural networks can not recognize categorical information such as low, moderate or high distresses. A computer program was written to convert the categorical information on distress into numerical codes as follows:

No distress	(0,0)
Low severity	(0,1)

Moderate severity	(1,0)
High severity	(1,1)

The observations were classified into ten groups, based on UCCI ranging between 1 and 100 For example, an UCCI of 100 represents an utility cut with absolutely no distress.

To develop a neural network, two kinds of data are required: training data and testing data. A network needs to be trained so that an 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. The original data, consisting of 1032 observations, was separated into two parts: 709 observations or 69 percent of the total sample for training, and the remaining 323 observations or 31 percent for testing. The selection of the observations for the training and testing data sets were done randomly within each UCCI group.

A software called NeuralWorks Professional II/Plus (5.12) was used to develop the neural network described in this paper. There were 30 processing elements (PEs) in the input layer to represent nine types of distresses in the cut and six in the vicinity The hidden layer consisted of ten processing elements. The output layer had only one processing element, that is, one UCCI for each utility cut. In this study, the sigmoid function (5.13) was chosen to be the transfer function. Although other transfer functions such as hyperbolic tangent or sine were also tried, sigmoid transfer function was found to allow the Root Mean Square (RMS) converge most quickly.

The selection of a set of proper learning coefficients and 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 as 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 number of training iterations as shown in

Table 5.2.

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 plus or minus 12, the neural network was found 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 5.3.

Discussion

This study utilized the neural network technique 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, there are still "noises" in the data since 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 due to the small sample size within these groups.

A question might arise regarding what threshold value of UCCI one should use to determine when some maintenance action must be taken on a utility cut. 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. When the pavement condition reaches the chosen value, maintenance action is taken. The same reasoning also should apply for utility cuts. In the present study, utility cuts have been found to have ratings that were less than 10, indicating that the existing threshold values for highway pavements may not be suitable for utility cuts. It is suggested that a threshold value for utility cuts be established in the future.

Conclusions

A periodic evaluation of the conditions of utility cuts is essential for better management of city street pavements. However, none of the existing pavement condition indicators are suitable for defining conditions of utility cuts, as the performance characteristics of utility cuts differ widely from those of longer highway pavement sections. 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 utility 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 opinions 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 Utility Cut Condition Index (UCCI) was developed by using a large amount of field data. The model has been 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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TABLE 5.1. 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

TABLE 5.2. 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

City of Cincinnati

Prepared by: _____ Date of Survey: _____

Location: _____ Time of Survey: _____

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

Distresses (Rate by severity. If different levels exist, rate by highest severity)	Cut			Vicinity			Any additional distress?
	low	moderate	high	low	moderate	high	
Alligator Cracking							
Edge Cracking							
Transverse Cracking							Overall condition
Potholes							
Rutting							
Ravelling & Weathering							
Cut-to-Adjacent Pavement Drop-off							Recommended action
Edge Separation							
Corner Breaks							

Overall condition: very poor (0-20); poor (21-40); fair (41-60); good (61-80); excellent (81-100)

Recommended action: do nothing; surface treatment; overlay; reconstruct

Additional Remarks:

FIG. 5.1. Evaluation forms for utility cuts

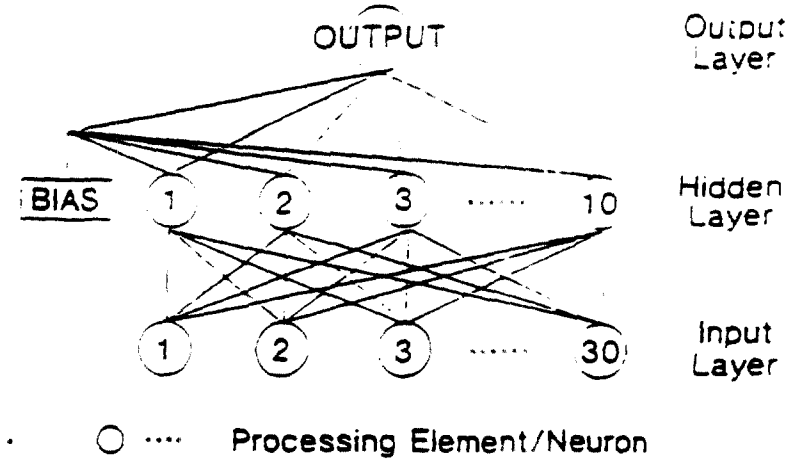


FIG. 5.2. Neural Network Structure

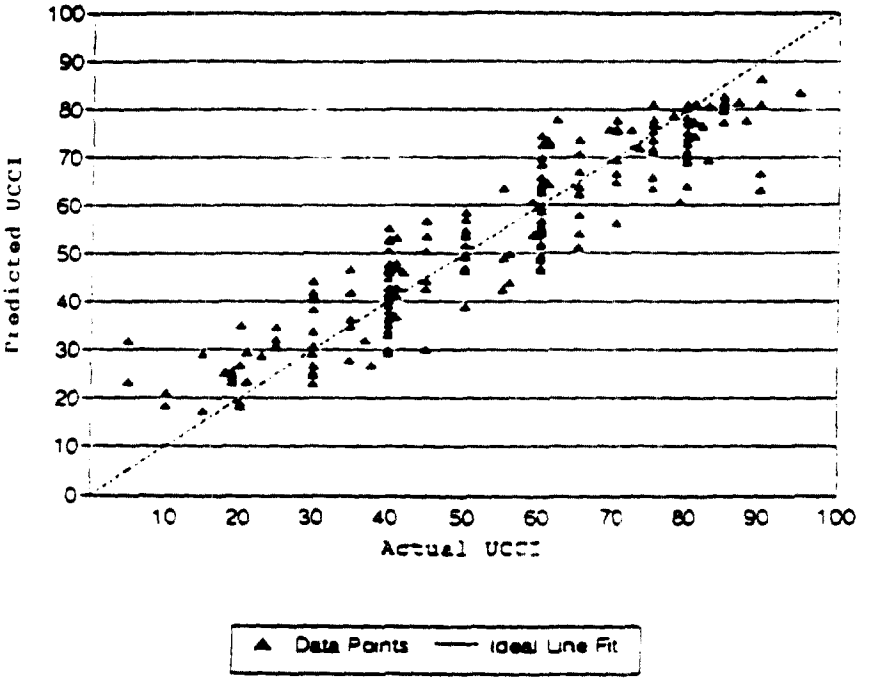


FIG. 5.3. Comparison of Predicted UCCI with Actual UCCI

CHAPTER 6

UTILITY CUT MANAGEMENT SYSTEM

Introduction

With the large number of utility cuts being made every year in every city, either for installing new services or inspection and maintenance of existing ones, controlling the quality of opening and restoration becomes an uphill task. Although guidelines have been developed by certain cities for opening and restoration of pavements, most cities have experienced additional maintenance costs due to poor restoration. Officials concerned with management of road networks with utility cuts are in need of practical methods that would address the impact of cuts on pavement performance, the economic evaluation of life cycle costs, and provide the basis for a realistic cost recovery policy. A structured maintenance management program can answer these needs. As the existing pavement management systems do not consider the effect of utility cuts, municipalities, like the City of Cincinnati, are currently seeking specific guidelines in the form of a Utility Cut Management System (UCMS).

UCMS is a subjective system based on gathering and assimilation of information, including visual observation. It synthesizes field evaluation procedures, cost management and policy issues related to street pavement sections affected by utility cuts. The goals of UCMS are to: 1) Identify the product most useful for evaluating performance of utility cuts; 2) Differentiate between the quality of restoration by different utilities/sub-contractors; 3) Generate a comprehensive database; 4) Develop statistically calibrated models to predict future performance, life cycle cost and monetary impact; and 5) Address issues related to planning, investments and maintenance activities.

Evaluating Performance

Two functions available for evaluating performance are deflection and Utility Cut Condition Index (UCCI). Deflection is an objective measurement resulting in a realistic evaluation of the structural condition, however, it requires physical measurement. UCCI, a subjective index, is simple and quick to measure.

In the present system, deflection values at critical locations, at or near the cut, will be used as the criteria for estimating the extent of damage and the cost to be recovered. The UCCI serves as a management tool to identify the time at which remedial action is to be implemented and the potential consequences of a decision.

Performance Models and Life Prediction

The performance prediction models require a variety of factors that affect the rate of deterioration. These factors include age of cut, restoration, traffic, backfill characteristics, pavement composition and construction quality. A cursory look at the City of Cincinnati's database indicated that information generally is limited to location, age, traffic, and name of the utility restoring the cut.

A list of 600 cuts in asphaltic concrete and macadam pavements was prepared by referring to permits. A team of trained personnel was assigned the task of conducting a Distress Survey. However, the team was able to locate only 94 cuts, many of the others having been resurfaced. The Distress Survey was performed using the Distress Manual. The distress data were used in conjunction with the neural network model and the UCCI for each cut was computed. Statistical regression models, with UCCI as a function of age, were developed for cuts in six groups as follows:

Group No.	Contractor	Traffic Level
1	CG&E	Low
2	CG&E	Medium
3	CG&E	High
4	WW	Low
5	WW	Medium
6	WW	High

Note: CG&E - Cincinnati Gas & Electric Company;
WW - Cincinnati Water Works

Since generally the effect of the traffic level was not pronounced on UCCI, it was decided to combine groups with various traffic levels. Thus only two sets of models are reported, one for cut restored by CG&E and the other for cuts restored by WW. The general form of these two models is:

$$UCCI = A + B * age + C * age^2 + D * age^3$$

The constants, sample size and other statistics are shown in Table 6.1.

Table 6.1 Summary Statistics of Performance Models

Group	A	B	C	D	Sample Size	r^2	Life, Years
CG &E	86.1	-0.2	-0.4	2.2E-02	58	0.71	9.0
WW	88.9	-6.7	0.87	-5.1E-02	36	0.83	7.0

The shape of the models is shown in Figure 6.1. As seen in the figure, for a given threshold value of UCCI (chosen to equal 65), cuts have an average life of 9 years when restored by CG&E and 7 years when restored by WW. This may be contrasted with the 15 to 20 years of life for a newly resurfaced pavement.

Implementation on a Micro-Computer

A comprehensive MS-Windows based software (UCMS Ver 1.0) has been developed in Foxpro 2.5 in order to: 1) aid in the development of a comprehensive database, 2) select a prioritized listing of cuts to be maintained, 3) select the appropriate Maintenance and Rehabilitation (M&R) action, and 4) determine its cost impact. The basic context diagram and system data flows are shown in Figures 6.2.a through 6.2.e. A detailed discussion on the software and the procedure adopted for managing cuts follows.

Input To The System

As shown in the context diagram the inputs to this software are Cut Information, Distress Data (collected using the Distress Manual), Deflection Data, Traffic Data and Cost Data. UCMS contains one comprehensive screen, divided into three modules, for the entry of all the input data.

Cut Information This module of the input to the system asks the user for the historical information on the cut. This information primarily consists of the location of cut, date of survey, date of restoration, contractor's name (limited to CG&E and WW), area of the cut, and type of pavement.

Distress Data The distress data are primarily based on the visual inspection of the cuts. This is done using the Distress Manual developed by the University of Cincinnati researchers. It is expected that every cut made in the city is surveyed using this manual and the data obtained is input into the system. User friendly screen has been designed to enable the user to enter this data. Validation checks have been incorporated into the system to ensure that the user enters the appropriate data and error

messages are displayed whenever a invalid entry is made into the system. Online help is available in the form of text as well as pictorial information to help the user to enter the data.

Deflection Data The deflection data is collected using the Benkelman Beam at selected locations at the cut as shown in Figure 6.3. The layout of the module for entry of deflection information is shown in Figure 6.4. As in the case of distress data, online help is available which explains in detail the information expected from the user. This deflection data is primarily used to compute the overlay thickness required.

Traffic Data The user is prompted for traffic information in terms of Average Daily Traffic (ADT), percent trucks and percent growth.

Processing Within the System

Computation of Overlay Thickness Deflection information is used in the computation of the overlay thickness. If the deflection at any point within or near the cut is greater than the deflection at the control point, an overlay is recommended and the overlay thickness required for the excess deflection is computed using the Asphalt Institute Manual (6.1). Since deflection is an objective measurement, the recommendation obtained through the use of deflection data overrides the recommendation based on the distress data.

Computation of UCCI The distress data is used as an input to the neural model for the computation of UCCI. The UCCI values are added to the database for further processing.

Selection of M&R Action Initially, distress surveys were performed on 75 cuts by four engineers and eleven inspectors from the City of Cincinnati. This data was used

to develop the neural model for the computation of UCCI. Simultaneously, the surveyors were asked to give their recommendation on the required maintenance and rehabilitation action for each cut, based on the overall condition index (UCCI). The data was analyzed and the appropriate maintenance actions for various levels of UCCI, as recommended, are presented in Table 6.2.

Table 6.2 - Rehabilitation Activities vs. UCCI

UCCI Range	M&R Action
80 - 100	Do Nothing
60 - 80	Surface Treatment
40 - 60	Overlay
0 - 40	Reconstruct

This information is used in the UCMS model to generate M&R actions based on the UCCI values.

Cost Computation The model takes into account the labor, material and equipment costs involved in every M & R action for the cost computation. A facility has been provided to update the costs with the changing market prices. The program computes cost for maintenance action over the entire area of the cut plus an area extending 3 feet beyond the cut in all directions.

Output from fhe System

The output from the system can be in threee forms: 1) Individual Report; 2) Group Report; 3) Custom Report.

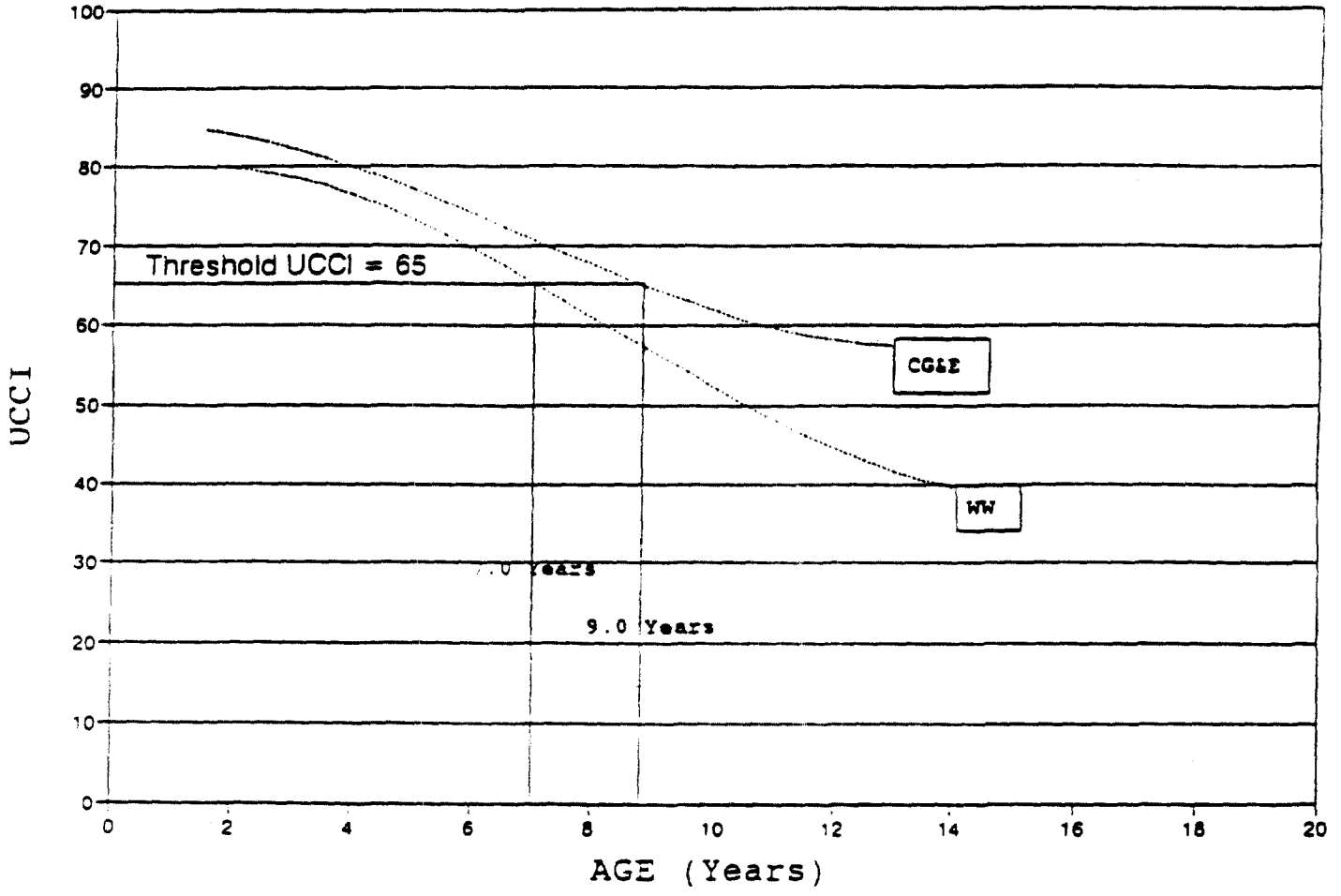
Individual Report This report contains all of the information available in the

database on any specific cut. This information includes cut information, distress data, deflection data (if available), computed UCCI, computed overlay thickness, recommended M&R action and the cost implication. The software user asks to select a cut based on the cut location. This is done by presenting the user a list of all cut locations available in the database. After this selection the user can obtain this report either on the screen or on the printer. A sample copy of this report is shown in Figure 6.5.

Group Report This report is primarily aimed at assisting the engineer in policy decisions. It presents a histogram which consists of information on the number of cuts in each of the four UCCI ranges (0 - 40, 40 - 60, 60 - 80, 80 - 100). It also gives the total amount of money required to rehabilitate the cuts. In addition, there is an option provided for analyzing various budget scenarios. In case of a budget limitation, the user can input the available budget and the software comes up with a revised histogram and an annual prioritized listing of the cuts to be rehabilitated based on their UCCI and the available budget. It is assumed in the preparation of this report that any cut which has been rehabilitated attains a UCCI in the range of 80 to 100. A sample copy of this report is shown in Figure 6.6.

Custom Report This is a customized report in which the software user can select a list of cuts and obtain relevant information on this selected group of cuts like cut location, UCCI, recommended action and cost. In addition to this the total cost for rehabilitating this group of selected cuts is reported. A sample copy of this report is shown in Figure 6.7.

FIG. 6.1. Performance Prediction Models
(For CG&E and WW Cuts)



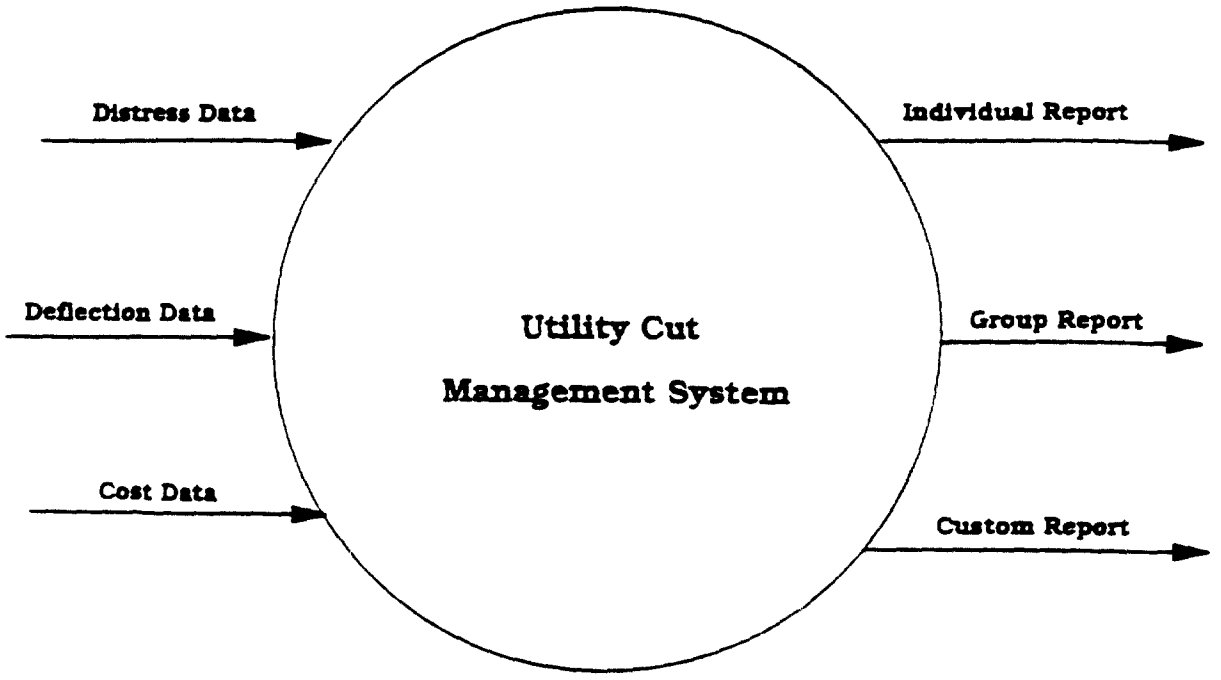


FIG. 6.2.a. Overview of Utility Cut Management System