Environmental Classification Scheme for Pontis

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In efforts to comply with the federal mandate for bridge management systems, many states are implementing Pontis. Pontis is the network-level bridge management system developed through FHWA's Demonstration Project 71. One component of the Pontis implementation process involves assigning the bridge elements to one of four environments. The environments used in Pontis—benign, low, moderate, and severe—represent relative distinctions among rates of deterioration resulting from operating practices and climatic exposure. Because of this, each agency should develop its own criteria for assigning elements to environments. A systematic strategy for developing a definition of these environments suitable to the needs of individual states is presented, and a step-by-step procedure for collecting data is explained. Regression analysis can then be used to analyze the data, thereby providing a way of defining the environments. To illustrate the method, an application is described for concrete bridge decks that uses operating practices and climatic exposures specific to Virginia.

The 1991 Intermodal Surface Transportation Efficiency Act mandated the use of bridge management systems. These systems predict the future condition of bridges within a network both with and without intervening actions (*1*). To make this prediction, it is necessary to model the deterioration of the bridges. The Markov process is one method that captures the stochastic nature of this deterioration. Through use of only the current state of the bridge system, the future conditions are predicted through a probabilistic mechanism. One-step transition probabilities depict the probability of the system deteriorating from its current state, or condition, to its next (future) state in a given interval. When all of the one-step transition probabilities for a specific time are grouped, the result is a transition probability matrix.

Because some parts of a bridge deteriorate more rapidly than other parts, transition matrices are needed to predict the rate of deterioration of each part. Modeling at this level of detail provides the information needed to specify corrective actions that should be taken. This method of modeling deterioration is used by Pontis, the network-level optimization and planning program developed through FHWA Demonstration Project 71 (*2*).

During the development of Pontis, it was recognized that the component condition ratings required as part of the National Bridge Inspection Standards program were inadequate. This inadequacy is because these components are a collection of various elements, each of which has a distinct deterioration pattern. To enable better predictive modeling and more representative feasible actions, Pontis uses individual elements of the bridge with clearly defined condition states and costs of actions.

To refine this predictive model further, it is helpful to examine a single bridge element. Consider, for example, two identically constructed concrete bridge decks, one of which is on a seldom traveled secondary road and the other on a heavily traveled interstate highway. To allow for the difference in deterioration rates because of climatic exposure and operating practices (e.g., average daily traffic or annual chloride applications), Pontis requires the elements to be classified in one of four environments. Essentially, these are deterioration classes. These four environments—benign, low, moderate, and severe—must be defined by individual agencies.

Purpose and Scope

The purpose of this research was to develop a method to be used to determine how to assign bridge elements to one of the four environments—benign, low, moderate, or severe—within Pontis. [A more detailed explanation of the development and results appears in Wells (*3*).] Such a method would allow an agency to develop quantitative definitions of the environments on the basis of the appropriate operating practices and climatic exposure for every element in the agency's bridge population. To illustrate the method, an application is described for concrete bridge decks using operating practices and climatic exposures specific to Virginia.

Approach

The problem posed by Pontis is that every element of a bridge must be assigned to an environment. Because most previous studies addressed the deterioration of individual bridges, the results cannot be used to generate environmental categories at this level. Because the definition of the environments should be tied to realistic situations anticipated within an agency's bridge population, the definition of the environments needs to be tailored to each state agency. For these reasons, a survey was created to collect the data for the initial environmental classification. The result of using the surveys is an easily implemented methodology that allows quick assignment of the elements to the appropriate environments. A review of the classification after several cycles of use will determine the method's effectiveness. If the method performs unsatisfactorily, the historical data collected in the intervening time can be used to reformulate the model.

Using the results from the surveys, a process was devised for creating the definitions of the four environments from the collected data. Steps include the organization of the data, the selection of the appropriate sample of the data, and the classification method to be used to develop the definitions. The method that emerged from a process of trial and error is discussed in the following section.

Findings and Interpretation

The methodology developed to quantify the definitions for the environments is a 10-step procedure:

1. Determine the element or group of elements of a structure for which the survey is to be developed.
2. Gather information about climatic conditions and operating practices that may affect the deterioration of the specified element or elements.
3. Determine the applicable, state-specific, quantitative ranges over which the selected factors may vary.
4. Create a survey for the element selected.
5. Distribute the survey.
6. Collect the survey and review the responses.
7. Create a data base of the responses and classify the elements into environmental categories.
8. Analyze the results of the environmental assignments on the basis of the definitions developed.
9. Distribute the results to survey respondents for verification.
10. Use the results to assign defined elements to the appropriate environment.

An application to concrete bridge decks in Virginia illustrates the method.

Selection of Elements

Elements affected by the same operating practices and climatic conditions may be grouped. For example, all decks and slabs can be covered in one survey for the purpose of environmental classification, but the deck and the substructure elements should not be grouped together. Expert elicitation and historical records can be used to distinguish between the deterioration behaviors resulting from the use of different materials or structural properties.

Information About Deterioration

One source of information is previous research studies. A second source is what experts in the field believe affects deterioration rates. For example, in the application of this method to concrete bridge decks, the type of span (e.g., simple versus continuous), age of the deck, average daily traffic, number of chloride applications per year, average daily truck traffic, and construction and maintenance procedures were found to be significant factors that influence the deterioration rates of concrete decks (*4–7*). In addition to the factors identified through the literature search, various experts at the Virginia Transportation Research Council mentioned freeze/thaw cycles. For this application, average daily truck traffic, freeze/thaw cycles, and chloride applications were selected.

It is important to ensure that the factors determined to affect the rate of deterioration are not used to differentiate between Pontis elements. For example, the presence of epoxy-coated reinforcing steel is generally considered to affect the rate of deterioration of concrete decks. However, a concrete deck with epoxy-coated reinforcing steel is a separate Pontis element; thus, it should not be incorporated into the definition of the environment.

Another caution is that the surveys should focus on information that is easily available for the bridge elements. For example, in the case described, average daily truck traffic is measured easily, and the information generally can be found on record. However, the state of Virginia does not track the number of chloride applications. Because it is uncertain where and how frequently chloride is applied, the inspector must estimate the number of chloride applications, which adds inaccuracy and complexity. Freeze/thaw data can be derived from historical climatological information since most states are divided into climatological regions. However, this information is not recorded on bridge records.

Determination of Applicable Ranges

For general survey construction, the ranges of the variables should include all of the possible responses for bridges in the agency's Pontis data base. In the example, a range of 0 to 800 was selected for average daily truck traffic, 0 to 75 for chloride applications, and 0 to 60 for freeze/thaw cycles. These ranges suggest that no bridge included in the state's Pontis data base is expected to have less than the minimum or more than the maximum value.

Creation of Survey

The purpose of the survey is to relate the factors found to affect the deterioration of an element and their impact on the rate of deterioration. A graph like the one shown in Figure 1 is easily adapted to various elements and is an easy format for the respondent to understand. In this figure, an example was taken from the application to bridge decks in Virginia. The climatic and operating practices were average daily truck traffic (ADTT), annual freeze/thaw cycles (F/T), and annual chloride applications (C1).

The heavy line represents the particular characteristics of the deck the respondent is being asked to consider. In the graph in the top left corner, the respondent is asked to evaluate the rate of deterioration of the concrete bridge deck with high values of the three factors, as compared with all the other concrete bridge decks in the agency. Enough graphs should be depicted to allow subsequent analysis. One suggestion is that the user be given 3^f graphs, where f is the number of factors that will be used. This allows a high, medium, and low range for each variable. In the example shown in Figure 1, there are three factors; therefore, there should be a total of $3^3 = 27$ graphs. Using the various combinations in the survey, many different combinations of variables can be surveyed. Other methods that can survey this wide range of possible responses were found to take much longer to answer.

Distribution of Surveys

The information used to develop the definition of the environments will be based on the survey results. Because the responses from the survey will be used to determine to which environment the elements are assigned, it is important that careful consideration be given to the selection of the people to be surveyed. In Virginia, the survey was distributed to district bridge engineers.

Review of Returned Surveys

If enough responses state that a particular relevant factor was initially disregarded, the survey should be reformulated so that the factors determined originally to influence the rate of deterioration and the other factors can be included. For example, respondents in Virginia noted that the type of span and the class of road or the speed of the traffic on the road should be considered in subsequent deck surveys.

Classification into Environments

The classification will use the data collected from the surveys to create a definition of the four environments for a particular element for the bridges in the agency. If the data set is split, then part of the data can be used to "train" the model and the other part can be reserved to "test" the model. One way of estimating the error of the various approaches is to divide the sample data ($\mathcal{L}$) into two sets ($\mathcal{L}_1$, $\mathcal{L}_2$). The data in $\mathcal{L}_1$ are used to train or build the model. The data in $\mathcal{L}_2$ are then used to test, or validate, the model for its ability to assign the described cases to the appropriate environment (*8*). In this case, the appropriate environment is the one to which the experts in the survey assigned the described element.

Because the Pontis environments are categorical variables, the environments were mathematically manipulated into real, ordered variables. In this manipulation, the set of environments {benign, low, moderate, severe} was translated into {1, 2, 3, 4}, where 1 represents the

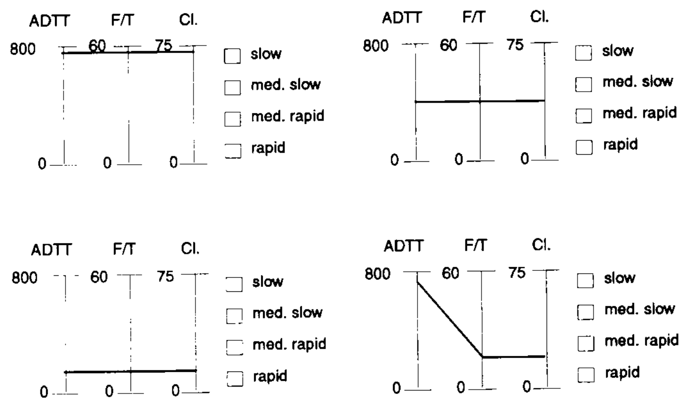

FIGURE 1 Suggested format for the survey.

class with the slowest deterioration rate for the area of use. This manipulation was possible because the environmental classes represent increasingly greater rates of deterioration, and it allowed a broad selection of modeling approaches.

One method used to quantify the environments was regression analysis. In this case, an equation is generated that can be used to estimate the output for future variable sets. The value produced using the equation is rounded to the nearest integer to find the appropriate environmental assignment (where 1 is benign and 4 is severe). In this application, the following equation is given:

$$En = 0.001347\,(ADTT) + 0.005533\,(F/T) + 0.024999(Cl) + 0.677581$$

where

En = the environment,
$ADTT$ = average daily truck traffic
F/T = freeze/thaw cycles, and
Cl = the number of chloride applications per year.

Analysis of Results

In general, the model should provide accurate and realistic classification, be easy to use, and be familiar to agency staff. When several classification methods were compared, multiple regression was found to provide a good model of the data (*3*). In addition, it is a common statistical method, and most agencies have software available for regression analysis. Regression analysis did not predict any class that was more than 1 off the actual class predicted by the respondents.

A weakness of the type of regression analysis used is that all of the input variables will appear in the output equation with some weight. If a variable is found to have no impact on the environmental classification, some other methods do not use it in the model. The inclusion of all of the variables in the resulting model is tolerable if all of the factors influence the deterioration to some degree. If sufficient previous research exists, as was the case with bridge decks, then the factors can be verified.

As the survey method is developed and later used, there are two major sources of error. The first is the classification method itself. The second is that the information used to train and then evaluate the model was gathered from a survey of people who may have different frames of reference, experience, and exposure. Because the responses from the survey will be used to determine the assignments of the environments, it is important that careful consideration be given to the selection of the people to be surveyed. It is important that these people have experience in the field. It is also important that they be willing to spend the time to complete the survey as accurately as possible.

If an element is assigned to an environment that is not a true representation, the predictions of the future condition of the element will be off because the element will deteriorate either slower or faster than was anticipated. Any critical deterioration should be noticed on the 2-year inspection cycles, and the problem should be flagged. If the element is deteriorating at a slower rate than is expected, the condition assigned during the bridge inspection will reflect this, and no action will be taken.

In addition, as the bridge management system is used, the deterioration of the elements of particular bridges can be tracked using the historical data base. If the rate of deterioration is not consistent with the class assignment, the element can be reassigned. If this occurs often, then the deterioration rates tracked historically can be used to redefine the environments.

TABLE 1 Matrix of Actual Responses Versus Predicted Responses

	True Class			
Predicted Class	Benign	Low	Moderate	Severe
Benign	36	12	0	0
Low	0	29	14	1
Moderate	0	6	37	5
Severe	0	1	6	29

Verification of Results

The construction of a matrix is one way to evaluate how well the method classifies the data (see Table 1). The values in the matrix display the results predicted from the model versus the respondents' answers from the survey. A strong diagonal with 0's in the upper and lower diagonals is desirable. Ideally, 100 percent of the values would be along the diagonal, but in most cases, since the opinions of experts vary, the "true" classes are not uniform. In general, the values along the diagonal should be maximized, whereas those values outside the diagonal should be minimized. Preferably, the more extreme triangular regions are equal to 0. However, the results must be examined outside of these restrictions. For example, if nine experts predict severe and one expert predicts benign, it is preferable for the model to predict severe and have one prediction three classes off than for it to predict moderate and have nine predictions one class off and one prediction two classes off.

Various classification methods can be compared by developing matrices for each method and comparing the diagonals. Review of the assignments by experienced field staff is also beneficial.

Implementation of Classification

The results are used to assign defined elements to the appropriate environment.

CONCLUSIONS AND RECOMMENDATIONS

The classification of the elements of the bridge population into the four environments helps improve the accuracy of the model used by Pontis. The result is a more realistic representation of the actual behavior of the bridge network. As the model of the behavior becomes more refined, the projections of where resources are best expended become more accurate. Whether this method for developing environment definitions or another is used, the development of objective criteria for assignments of the elements to the environments should not be sacrificed for a slight initial savings in time. The method presented in this report is easily adaptable to any Pontis element or group of elements, and it was found in the application to yield reasonable results.

Once Pontis has been in use for four cycles (8 years), it is recommended that the environments be evaluated. At that time, it may be found that the transition matrices for the different environments are not distinct. Only after a review like this is made should the number of environments used by an agency be reduced.

Another topic that should be considered for future research is the development of a self-correcting environmental assignment procedure that could be incorporated into the Pontis computer code. The motivation for using a survey in this research was that historical data did not exist at the element level. Once the Pontis system has been in place for several inspection cycles, sufficient data will exist so that such a system could automatically partition the elements into the appropriate four environments on the basis of actual inspection data. Such a mechanism would increase the accuracy of the prediction of deterioration and subsequently improve the cost projections of the model. However, additional study is needed before such a procedure is implemented. Because of the updating procedures for deterioration and cost, research must be developed in such a way that the validity of these models is not sacrificed.

Another area in which research is needed is the development of costs that are appropriate at the network level and significant at the project level. (Preliminary phases of this research are currently under way at Clemson University.) Although not addressed in this research, this area should be considered in conjunction with the development of the criteria for the environments. Because costs are required for each element in each environment, work is needed to increase the understanding of how the two are best linked. Although the factors that affect deterioration often affect the cost of the repair—for example, average daily traffic—this is not always the case. Division of the cost of maintenance, repair, and rehabilitative actions into environments is meaningful only in the cases in which the factors affect both deterioration and cost. On the other hand, experience may show that the rates of deterioration are not distinct enough to warrant the environments and that the division is better allocated to the difference in costs. Regardless, it is necessary that the environmental definition be tied with the cost model in such a way that the environments serve a twofold purpose. First, the environments function as a type of deterioration class representing operation practices and climatic exposure, as has been emphasized throughout this study. Second, the definition of the environments might be expanded to include factors that lead to significant cost differences. Such a possibility was beyond the scope of this research but should be explored in future research.

The implementation of Pontis requires devotion of extensive resources. This survey method of defining environments will give a good environmental class without sacrificing the staff hours that are needed in other aspects of implementation. Use of such a method will result in clear definitions for environments so that costs can be adjusted accordingly. With the use of this type of method, objective criteria exist for the assignment of bridge elements to environments. Without such a rational basis for assignment, many of the problems with subjectivity that have been mentioned with the National Bridge Inventory ratings are introduced back into the element-level inspection process.

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