Estimating Bridge-Related Traffic Accident Rates and Costs

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Evaluation of bridges for improvement in bridge management systems depends on accurate estimates of various user and agency costs associated with both the existing structure and the proposed improvement. The results of a study to estimate the annual number of accidents on a bridge and the average per-accident cost are reported. Accident costs are estimated on both the human capital approach and the willingness-to-pay approach. The accident rate relationship was determined by matching more than 2,000 bridge-related accidents to specific bridges and using various forms of regression to develop a prediction equation as a function of specific bridge characteristics.

Traffic safety is an important element of the functional adequacy of any bridge. Using the accident rate at a specific bridge site is one way of measuring the traffic safety: the higher the accident rate, the higher the user cost. It is therefore important that consideration of accident rates be a part of a bridge management system (BMS) and that bridge-related accident costs be available.

Bridge-related accidents are more severe than other accidents (*1*). Vehicles involved in accidents on bridges might hit the bridge structure, hit other vehicles, run off the road at the bridge into the feature intersected, or, in rare instances, fall from the bridge. Such accidents cause more severe injuries to the vehicle passengers and more damage to the vehicle than general accidents. The bridge structure may also suffer damage.

Although accidents in most cases are caused by the negligence of a motor vehicle driver, several other factors contribute to the cause and severity of accidents on bridges. These factors range from environmental effects, such as ice or rain, to bridge structural and geometric deficiencies, such as bridge deck width and approach alignment.

OBJECTIVE

The objectives of the study were to determine analytical methods for estimating bridge-related accident rates for the route over the bridge and to develop a process for estimating the cost of such accidents. Mathematical and statistical methods were developed to allow periodic reanalysis using existing (but then current) North Carolina Department of Transportation (NCDOT) bridge and accident data bases. Statistical Analysis System (SAS) software was used for developing the prediction models and as a framework for developing analysis procedures.

LITERATURE REVIEW

The severity of bridge-related accidents can be compared with that of other accidents in several ways. A study by Michie concluded that bridges are 50 times more hazardous than roadways (*2*). This result was based on determining a ratio for types of fatal accidents in which the vehicle ran off the road and hit a fixed object to gross mileage; a similar ratio for fatal bridge-related accidents to total bridge mileage. The fatality rate for bridge-related accidents was found to be 50 times higher.

Hilton expressed accident severity as an index equal to the ratio of the proportion of persons killed to the proportion of all accidents (*1*). On the basis of the index, it was determined that collisions involving bridges are roughly twice as severe as the average accidents occurring over the same period.

Chen and Johnston studied the relative severity of accidents on a cost basis (*3*). The average cost of accidents involving bridges was estimated to be five to eight times the cost of general motor vehicle accidents.

Several studies have been conducted to identify the major factors influencing bridge-related accidents. A study by Raff, one of the earliest conducted on bridge accidents, found that average daily traffic (ADT), approach sharp curvature, and bridge width had major effects on bridge-related accidents (*4*). According to a survey of Virginia's state police officers and highway engineers (*1*), the width of narrow bridge roadways and the width of curved approaches were the two most important factors contributing to accidents at bridge sites.

A study by Mak and Calcote concluded that bridge narrowness, as defined in terms of shoulder reduction, had a significant effect on accident rates for two-lane undivided structures (*5*). Turner developed a probability table that predicts the number of accidents per million vehicles for various combinations of roadway width and bridge relative width (difference between bridge width and approach roadway width) (*6*).

At least four of the studies developed bridge safety indexes (BSIs). Each study included different factors affecting bridge accident rates in its own BSI (*7–10*); the number of factors included in the BSIs ranged from 7 (*9*) to 13 (*10*). Ivey et al. identified 10 important factors related to approach roadway, bridge geometry, traffic, and roadside distractions (*7*). Mur-

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thy and Sinha used fuzzy sets to determine the relative importance of factors divided into three groups: bridge, approach roadway, and environment (*10*).

Chen and Johnston studied the bridge accident rate problem but lacked a direct link between specific accidents and specific bridges (*3*). Thus, they developed an empirical relationship as a function of bridge width and alignment by iteratively modifying coefficients until results reasonably matched statewide accident totals.

Other significant contributions concerning or related to bridge accidents or costs have been made by Benham and Laguros (*11*), Roberts (*12*), Turner and Rowan (*13*), Brinkman and Mak (*14*), and Kragh et al. (*15*).

BRIDGE ACCIDENT DATA

Data on all reported accidents in North Carolina are stored by NCDOT in an accident data file. The file contains a record for each accident that was reported. More than 70 fields make up this mode record. The data include information related to the accident's location, type, date, severity, road features, road conditions, means of involvement, and speed. Bridge-related accidents are identified by the road feature field. Accident records with the road feature field coded as a 1 indicate a bridge as a feature on the route, either on or near a bridge.

The accident file contains data for the last 6 full years plus the present year. As data are accumulated for the present year, records of the earliest year remain in the file. Thus, accident data for up to 7 full years can exist at certain times.

Although the accident data contain some valuable information, they cannot be used independently for determining a relationship between the accident rate and bridge characteristics. This is because the accident data file neither contains the major bridge characteristics nor identifies clearly the specific bridge that was a feature in the accident. However, the accident data file can be used independently to analyze some of the general trends of bridge-related accidents. The file can also be used to compare the severity of bridge-related accidents with the severity of general traffic accidents. In this study, North Carolina accident data from 1984 to 1989 were analyzed. The annual numbers of all accidents and of bridge-related accidents were found to be fairly uniform, averaging 161,922 and 2,710 (1.7 percent), respectively (*16*).

BRIDGE-RELATED ACCIDENT CHARACTERISTICS AND COSTS

Accident Injury Severity

Although bridge-related accidents represent only about 1.7 percent of all traffic accidents, it is important to evaluate these accidents to try and minimize them with appropriate bridge improvements. The severity of bridge-related accidents is generally higher than the severity of other roadway traffic accidents. However, the degree of severity will vary depending on the approach used for measuring the severity. As indicated earlier, according to previous studies, the severity of bridge-related accidents varied from 2 to 50 times the severity of general roadway traffic accidents.

The NCDOT classifies vehicular accidents as fatal, injury, and property damage–only accidents. An A-B-C injury scale is used to describe the severity level of the injuries, where A is the most severe and C is the least severe. The pattern of bridge-related accident severity is summarized and is compared with other accidents in Table 1.

The average number of persons killed per bridge-related accident in North Carolina was determined to be 0.019. However, the average number of persons killed per other vehicle traffic accident was 0.009. Taking this as a measure of accident severity, it implies that bridge-related accidents are roughly twice as severe as general roadway traffic accidents. This is consistent with Hilton's study, which determined about the same average (*1*).

The ratio comparing the severity of bridge-related accidents with that of other roadway traffic accidents decreased as the injury severity decreased. However, for all injury types but C, bridge-related injuries were more severe than other roadway traffic accident injuries. Furthermore, the total number of injuries per accident was greater for bridge-related accidents. Additional details on characteristics of these accidents are given by Abed-Al-Rahim and Johnston (*16*).

Cost of Bridge-Related Accidents

Chen and Johnston used similar data on relative severity of nonbridge- to bridge-related accidents to determine the average cost of a bridge-related accident (*3*). In 1985 dollars, the estimated cost was $14,710 on the basis of a human capital

TABLE 1 Average Number of Injuries by Type, 1984–1989

Severity of Accident	Total Average Bridge Related Accident Injuries per Year	Average Number of Injuries per Accident		
		Bridge Related Accidents	Other Roadway Traffic Accidents	Ratio of Column 2 to Column 3
Fatal	52	0.02	0.01	2.00
Injury A	352	0.13	0.10	1.30
Injury B	555	0.20	0.19	1.05
Injury C	910	0.34	0.38	0.87

approach, and $31,919 on the basis of a willingness-to-pay approach. (These amounts need annual updating because of inflation and changing relative costs in the economy.)

One method to calculate cost is to combine the bridge-related accident injury data (Table 1), which can be updated periodically by analysis of NCDOT accident data, with injury costs published periodically by available sources (Table 2). Injury costs based on a human capital approach are published annually by the National Safety Council (NSC) (*Accident Facts*). Injury costs based on the willingness-to-pay approach are published about every 3 or 4 years by FHWA (*17*).

Table 2 shows the 1990 injury costs from NSC, the 1988 injury costs from FHWA, and the average property damage reported in bridge-related accidents in 1990 in North Carolina. When extended, this results in an average bridge-related accident cost of $19,800 (1990 dollars) based on the human capital approach and $43,400 (1990 dollars) based on the willingness-to-pay approach.

MODEL FOR PREDICTING BRIDGE-RELATED ACCIDENT RATES

The rate of bridge-related accidents is one indicator of bridge deficiency; therefore, a model is needed for estimating bridge accidents on the basis of available bridge features. Data for each bridge in the state are stored in the North Carolina Bridge Inventory (NCBI). To analyze the accident data and their relation to the bridge characteristics, it was necessary to merge the NCBI file with the accident file. However, the two files cannot currently be merged automatically since the bridges are not identified on a common basis in the two files. Thus, the bridges and accidents had to first be matched manually.

Matching Accidents and Bridges

Because of the effort of the matching process, only those accidents that occurred in a selected number of counties were analyzed. The selection of the five counties was based on their region, population density, and distribution of highway functional classes such that they gave a reasonable representation of the state.

A total of 2,895 bridge-related accidents occurred in those counties between 1983 and 1989. Of these, 2,512 occurred on Interstate, US, NC, state, or city routes, which had the potential of being matched with a bridge number. The routes of the remaining 383 accidents were coded as "other" and thus did not indicate a route name or number.

It was sometimes difficult to identify the bridge on which the accident occurred. In some cases at side-by-side bridges, both the distance and direction from the reference road were coded 0, which made it impossible to identify the bridge on which the accident occurred. It was therefore decided to assign the accident to the bridge with the narrower width if there was a difference, or otherwise to arbitrarily assign the accident to either. Another problem was that a number of the accidents occurred on bridges that were not under the jurisdiction of NCDOT and could not be included in the analysis. The last problem was that apparently some of the accidents were mislocated, erroneously recorded, or not properly identified.

Once a match was made, the bridge number was added to a modified accident file. At the end, 2,104 accidents were matched with bridges. Records of all the accidents that were not matched with a bridge—because they were erroneously recorded data or occurred at pipes or culverts—were deleted from the modified accident file.

As indicated earlier, the accident file was not used independently for developing the rate of accidents involving bridges, since it does not contain the necessary bridge characteristics for such an analysis. The final model developed in this study is intended for integration with the OPBRIDGE program to predict bridge funding needs for NCDOT (*18*). OPBRIDGE extracts the necessary data from the NCBI, which implies that factors used in the accident prediction model must be available in the NCBI file.

The modified accident file was merged with the 1989 NCBI. A new data set containing records of all bridges in the five counties included in the analyses was created. The new data set, which was called the bridge-accident data set, contained bridge characteristics considered to be possible factors for the accident analysis, in addition to the matching level of confi-

TABLE 2 Average Cost of Bridge-Related Accidents

Injury Severity	Average Number of Injuries per Accident	Human Capital Approach (1990 Dollars)		Willingness-to-Pay Approach (1988 Dollars)	
		Average Cost per Injury ($)	Cost per Bridge Related Accident ($)	Average Cost per Injury ($)	Cost per Bridge Related Accident ($)
Fatal	0.02	410,000	8,200	1,500,000	30,000
Injury A	0.13	38,200	5,000	39,000	5,100
Injury B	0.20	8,900	1,800	12,000	2,400
Injury C	0.34	2,900	900	6,000	2,000
Property Damage			3,900		3,900
Total			19,800		43,400

dence and a newly added field for the total number of accidents on each bridge. Thus, it was not necessary to use the modified accident file and NCBI file every time a model was tested. It is important to emphasize that all bridges in the five counties were included since the records with zero accidents were also important in determining the relationship.

Statistical Analysis of Bridge-Related Accidents

This section will summarize the statistical analysis methods used to analyze the bridge-accident data set and develop relationships between the bridge-related accident rate and data concerning the bridge characteristics.

The SAS software was used for developing the prediction model. Two goals are usually set for models that might have many variables contributing to the behavior of the independent variable. The first goal is to provide an equation that is useful for predicting the independent variable, one that has a value for the coefficient of multiple determination (R^2) as close to 1 as possible (*19*). R^2 is a measure of the proportionate reduction of total variation in the dependent variable associated with the use of the set of independent variables (*20*). The other goal is to provide an equation that is economical: one that uses only a few independent variables. The two goals seem to contradict one another since, in general, the more variables in the equation, the higher the R^2 value, but often the benefit of adding more and more variables diminishes.

Since bridge-related accidents might be affected by many factors, it was important, as a first step, to reduce the number of factors to be considered in the analyses. The stepwise procedure (*21*) was used initially to help identify factors that have the most significant effect on the accident rate. The stepwise procedure performs stepwise regression, which is an attempt to search for the "best" model by bringing into the regression equation the factors being considered one by one.

This procedure is applicable only for first-order polynomial models. Higher-order polynomial models were also tested using the GLM procedure of SAS. Whatever the form of the final model, an adjustment would be needed to account for the difference in number of accidents analyzed and the actual number of accidents reported during the period selected. The difference is essentially the number of bridge-related accidents that could not be identified with a specific bridge. A multiplying adjustment factor, AF, for the final model is thus introduced; it is calculated as follows:

$$AF = NOACCR/NOACCM \tag{1}$$

where

AF = adjustment factor to account for difference in number of accidents analyzed and number of accidents reported;
NOACCR = number of bridge-related accidents reported during period selected; and
NOACCM = number of bridge-related accidents matched to specific bridges.

For the data used, NOACCM was 2,104 and NOACCR was 2,895 less those matched to pipes and culverts (about 3.5 percent), or 2,798. The value of AF for this data set was thus determined to be 1.33. The use of a single adjustment factor may not be a perfect approach since the number of unmatched accidents varied from system to system with more being on minor collectors and within cities. However, this approach was viewed as acceptable until a better capability for matching data is available.

First-order polynomials were evaluated first using the stepwise procedure in SAS. Table 3 gives the parameters considered in the analyses. These parameters were divided into two sets. The first set included parameters by which bridges could be grouped: divided versus undivided highways, urban versus rural locations, and highway functional classification. The latter parameter was subdivided into two groups. Group 1 included Interstate and arterial highways, and Group 2 included the collector and local routes. The analysis indicated that separation between divided and undivided highways was not significant. But both the highway classification and rural versus urban groupings were found to be significant. However, because of the limited number of observations, it was not possible to use the two groupings at the same time. The parameter that was the most significant, highway classification in this case, was therefore selected for further consideration.

The second set consisted of parameters that could be used as independent variables in the model. The ADT using the bridge was one of the parameters considered. This parameter was found to be significant in all the models tested. ADT per lane was also considered in the analyses. This was calculated by dividing the ADT by the number of lanes on the bridge. However, ADT per lane was found to be not significant.

The effect of bridge length on the number of bridge-related accidents was also tested. Length was found to be significant at the 5 percent level.

TABLE 3 Parameters for Analysis of Bridge-Related Accidents

Grouping Parameters
Divided versus undivided highways
Rural versus urban
Highway classifications: 1) Interstate and Arterial 2) Collector and Local
Independent Variable Parameters
Average daily traffic
Number of lanes on bridge
Average daily traffic per lane
Bridge length
Approach roadway alignment
Bridge clear deck width
Difference between required clear deck width at an acceptable level of service and existing clear deck width OR Difference between required clear deck width at a desirable level of service and existing clear deck width

Approach roadway alignment was another parameter studied. According to the definition of FHWA, "this item identifies those bridges which do not function properly or adequately due to the alignment of the approaches" (*22*). However, this parameter was found, somewhat surprisingly, to be not significant.

Bridge clear deck width was also considered in the analyses. This is equal to the most restrictive minimum distance between curbs or rails on the structure roadway (*22*). The effect of the bridge clear deck width alone initially was found to be not significant. Thus a parameter relating the bridge clear deck width to the width level of service goals (*23*) was introduced as an alternative; it was based on first calculating the clear deck width goal for either an acceptable or a desirable level of service using the following equation:

$$\text{CDWG} = (\text{NOLANEG} \times \text{LANEG}) + (2 \times \text{SHLDRG}) \quad (2)$$

where

CDWG = clear deck width goal,
NOLANEG = number of lanes needed for selected goal,
LANEG = lane width for selected goal, and
SHLDRG = shoulder width for selected goal.

Width needs of a bridge depend on the volume of traffic on the bridge and the roadway functional classification. The acceptable goals generally correspond to bridge policy for existing bridges to remain in place when the approach roadway is reconstructed. Desirable goals generally correspond to state policy for new bridge construction. NOLANEG was calculated on the basis of study results by Al-Subhi et al. (*18*) as given in Table 4. LANEG and SHLDRG were selected on the basis of study by Johnston and Zia (*23*) as given in Table 5. Although these goals are specific to bridge management in North Carolina, they were based on similar eligibility values in earlier 4R programs and bridge replacement design standards.

A width difference between the goal deck width and actual deck width was then calculated for both acceptable (WDIFACC) and desirable (WDIFDES) levels of service. Two models were therefore evaluated, one for each. These parameters were found to be significant for Group 2 highways but not for Group 1, possibly because the clear bridge deck width on Interstate and arterials are often more compatible with the

TABLE 4 Goals for Minimum Number of Lanes on Bridge (*18*)

Traffic Direction	Average Daily Traffic on Bridge	Acceptable	Desirable
One-Way Traffic	0 -3,000	1	1
	3,001 - 5,000	1	2
	5,001 - 15,000	2	2
	15,001 - 22,500	2	3
	22,501 - 27,500	3	3
	27,001 - 35,000	3	4
	Over 35,000	4	4
Two-Way Traffic	0 - 6,000	2 or 3	2 or 3
	6,001 - 10,000	2 or 3	4 or 5
	10,001 - 30,000	4 or 5	4 or 5
	30,001 - 45,000	4 or 5	6 or 7
	45,001 - 55,000	6 or 7	6 or 7
	55,001 - 70,000	6 or 7	8
	Over 70,000	8	8

TABLE 5 Bridge Clear Deck Width Goals (*23*)

Road Over Functional Classification	Average Daily Traffic	Lane and Shoulder Width Goals, ft (m)			
		Acceptable		Desirable	
		Lane	Shoulder	Lane	Shoulder
Interstate and Arterial	<= 800	10 (3.0)	1 (0.3)	12 (3.7)	4 (1.2)
	801 - 2,000	10 (3.0)	2 (0.6)	12 (3.7)	6 (1.8)
	2,001 - 4,000	11 (3.4)	2 (0.6)	12 (3.7)	8 (2.4)
	> 4,000	11 (3.4)	3 (0.9)	12 (3.7)	8 (2.4)
Major and Minor Collectors	<= 800	9 (2.7)	1 (0.3)	10 (3.0)	2 (0.6)
	801 - 2,000	9 (2.7)	2 (0.6)	11 (3.4)	3 (0.9)
	2,001 - 4,000	10 (3.0)	2 (0.6)	12 (3.7)	3 (0.9)
	> 4,000	10 (3.0)	3 (0.9)	12 (3.7)	3 (0.9)
Local	<= 800	9 (2.7)	1 (0.3)	10 (3.0)	2 (0.6)
	801 - 2,000	9 (2.7)	2 (0.6)	11 (3.4)	3 (0.9)
	2,001 - 4,000	10 (3.0)	2 (0.6)	12 (3.7)	3 (0.9)
	> 4,000	10 (3.0)	3 (0.9)	12 (3.7)	3 (0.9)

Clear Deck Width Goal = (No. Lanes x Lane Width) + (2 x Shoulder Width) goals; thus, the values of DIFACC and DIFDES are not very significant. However, the clear deck widths of bridges on the collector and local routes are often less than the goal clear deck width.

Hence, at the end of the first stage of the analysis, the ADT and bridge length were found to be significant for both groups of highways. In addition, WDIFACC and WDIFDES were found to be significant for Group 2. Higher-order polynomial models were then tested using the significant parameters. However, none was found to produce a better fit.

Several types of transformations, including reciprocal and logarithmic, were tested using the GLM procedures in SAS. Transformations of the independent variables only, dependent variables only, and both combined were considered. The logarithmic transformations generally generated better models (i.e., higher R^2-values and better estimates of the number of accidents) than the other types of transformations that were evaluated.

The ADT, length, difference between goal width and actual width, and, in some cases, the clear deck width were found to be significant. The groupings based on functional classification were eventually dropped because better overall fit (i.e., greater R^2-values) were achieved without the groupings.

The final parameters included were defined as follows:

- ADT;
- CDW: clear deck width in feet (m/3.28);
- LENGTH: bridge length in feet (m/3.28);
- NOACC: number of accidents per year;
- WDIFACC: width difference between the goal clear deck width for an acceptable level of service and the actual bridge clear deck width, but not less than zero, in feet (m/3.28); and
- WDIFDES: width difference between the goal clear deck width for a desirable level of service and the actual bridge clear deck width, but not less than zero, in feet (m/3.28).

A 1 was added to WDIFACC and WDIFDES, so that bridges having a value of 0 for WDIFACC or WDIFDES will not be eliminated when using a logarithmic transformation. The addition has no effect on the end result, since it applies to all the bridges in the analysis.

The resulting equation based on acceptable level of service comparison was found to be

$$\ln(\text{NOACC} + 1) = -0.53 + 0.073 \ln(\text{ADT}) + 0.033 \ln(\text{LENGTH}) + 0.050 \ln(\text{WDIFACC} + 1) \quad (3)$$

or, transforming and multiplying by AF,

$$\text{NOACC} = [e^{-0.53}(\text{ADT}^{0.073})(\text{LENGTH}^{0.033}) \times (\text{WDIFACC} + 1)^{0.050} - 1 \times \text{AF} \quad (4)$$

Equation 3 generated an R^2-value of 0.33.

The equation based on the desirable level of service comparison was found to be

$$\ln(\text{NOACC} + 1) = -0.79 + 0.050 \ln(\text{ADT}) + 0.035 \ln(\text{LENGTH}) + 0.11 \ln(\text{CDW}) + 0.053 \ln(\text{WDIFDES} + 1) \quad (5)$$

or, transforming and multiplying by AF,

$$\text{NOACC} = [e^{-0.79}(\text{ADT}^{0.050})(\text{LENGTH}^{0.035})(\text{CDW}^{0.11}) \times (\text{WDIFACC} + 1)^{0.053} - 1] \times \text{AF} \quad (6)$$

The R^2-value generated for Equation 5 was equal to 0.34.

Although the magnitude of the R^2-values generated was low, it is considered very reasonable for this type of problem. This could be for several reasons. One is the nature of accidents, in which several factors can be attributed to the cause. Some factors may be totally independent of the bridge characteristics. Another reason is that the factors considered in this analysis were limited to those that could be estimated or are already available in the NCBI, which eliminated the consideration of such parameters as speed limit or the road condition at the time of the accident, which also influence accident rates (*16*).

Other methods available in SAS were used to test the significance of the independent variables; the RSQUARE procedure was one. The method identifies subsets of independent variables that give the best prediction by linear regression (*24*). Although the previous methods gave similar results, RSQUARE is different in that it identifies the model with the largest R^2 for the variables being considered. Results generated from this analysis were similar to those obtained using the STEPWISE procedure. This confirmed the validity of the earlier approach. Neverless, the STEPWISE procedure is more appropriate when many independent variables are considered, as in this study.

The logistic procedure was also used. It uses the maximum likelihood method to fit linear logistic regression models for binary or ordinary response data (*24*). Preliminary analyses indicated that the independent variables identified in the earlier models were very similar to those identified using this procedure. However, the models generated by this approach are based on maximum likelihood and will therefore require developing many tables of probabilities for the various parameters used. Such solutions are less easily integrated into bridge management systems. Hence, further development based on logistics was delayed until more data are available.

To evaluate the equations, they were applied to the state bridge inventory. Equations 4 and 6 were used to estimate the number of bridge-related accidents per year for the entire state of North Carolina. When, for an individual bridge, the estimated number of accidents was calculated to be less than zero, the values were assumed to be equal to zero since in reality no fewer than zero accidents can occur. AF was taken to be 1.33, as determined previously.

The annual number of accidents using Equation 4 (acceptable width level of service goal) was estimated to be 2,496 accidents on 9,921 of 14,210 bridges with an average of 0.176 accidents per year per bridge. The annual number of accidents using Equation 6 (desirable width level of service goal) was estimated to be 2,389 accidents on 9,298 of 14,210 bridges with an average of 0.168 accidents per year per bridge. These estimates were slightly less than the statewide average of 2,619 accidents per year (2,710 minus an estimated reduction of 3.5 percent for pipe- and culvert-related accidents). However, the slight underestimate is appropriate since some of the accidents on bridges may have occurred for reasons unrelated to the bridge.

Both equation forms produced reasonable results and had essentially equal fit based on the R^2-values. However, Equation 6 is viewed as preferable for two reasons. First, the estimated number of accidents was slightly closer to the actual annual average. Second, the form of Equation 6 implies, on the surface, that accidents increase as CDW increases. However, actually there is an interaction between CDW and WDIFDES that masks the true relationship since WDIFDES also includes a CDW effect. Equation 6 does not have this appearance problem.

Thus, from Equation 4 and with AF = 1.33, the annual number of accidents on a bridge is estimated to be

$$\text{NOACC} = 0.783(\text{ADT}^{0.073})(\text{LENGTH}^{0.033}) \times (\text{WDIFACC} + 1)^{0.05} - 1.33 \quad (7)$$

When using this equation, it may be noted that the number of accidents for low ADT approaches zero. However, negative values for the number of accidents may be generated for very low values of the independent variables, particularly ADT. For example, the number of accidents at an ADT of less than 200 vehicles per day would be expected to be very low, when considering only bridge-related factors. It is therefore reasonable to assume that at such low variable combinations the number of accidents would be zero. It is also important to interpret the results properly in combination with the width and lane goals that are simultaneously increasing with ADT (Tables 4 and 5).

SUMMARY AND CONCLUSIONS

From the North Carolina data available and methodologies applied, the following conclusions are appropriate:

- Accidents occurring on bridges are generally more severe than other roadway accidents.
- The costs of bridge-related accidents can be reasonably assessed on either the human capital approach or the willingness-to-pay approach.
- Accidents were most significantly predictable on the basis of ADT, bridge length, and clear deck width deficiency.
- Although alignment is believed to be significant, this was not confirmed by analysis of the data available.
- Ability to predict the statewide accumulation of accidents per year was good.
- There is a need for a better ability to link accidents to specific bridges automatically in traffic accident data bases. Possibilities might exist through adding specifically recorded bridge numbers in the accident report, mileposting correlation, or application of geographic information systems.

This paper is intended as an additional contribution toward understanding bridge user costs, which are a significant parameter in the application of bridge management systems. The methods and approaches demonstrated can be further applied as additional bridge accident data become available.

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