SafetyAdvisor: Framework for Performing Roadside Safety Assessments

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A software tool for assisting roadway designers in assessing the safeness of roadside designs is described. The SafetyAdvisor is an interactive Windows 3.0 program that graphically displays the roadway and hazardous objects along it. The probability of observing no severe or fatal accidents in a year is used as a measure of the safety of the roadway. This measure is calculated using user-definable probablistic expressions. The SafetyAdvisor provides a convenient computational framework for estimating the effectiveness of different roadway design alternatives.

A prototype safety assessment software tool, the SafetyAdvisor, was developed to aid engineers in assessing the safeness of roadway sections and alternative designs (*1*). The SafetyAdvisor was developed for 386 and better-compatible personal computers using C++ (*2*) running under Windows 3.0 (*3*). Input is accomplished through ASCII text files that describe the roadway geometry, the operational conditions, and the locations of hazards. Output is displayed graphically to the user. The assessment tool calculates the probability of not observing a fatal or severe accident within the next year on the basis of the roadway characteristics that the user supplies. The safety scale, displayed in the view along with a representation of the roadway, is calculated on the basis of probability models that are stored in ASCII text files that can be modified using a standard text editor. The SafetyAdvisor automatically finds the appropriate model and calculates the safety scale on the basis of the observable characteristics of each roadway segment.

MATHEMATICAL MODEL

The safety scale measures the probability that an accident of a particular severity will not be observed within a 1-year period. This scale is based on the assumption that accidents are a random Poisson process as described by the following equation (*4,5*):

$$P(x) = \frac{e^{-\lambda t} (\lambda t)^x}{x!} \quad (1)$$

In the context of safety assessment, x is the number of accidents, λ is the accident rate, and t is the period of time being considered. The condition $x = 0$, $t = 1$ represents the probability of observing no accidents in a period of 1 year. Recalling that $x!$ of zero is 1 and λt to the zero power is 1, the following expression is obtained:

$$S = e^{-\lambda} = e^{-P(I) \cdot \text{ADT}} \quad (2)$$

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where λ, the accident rate, has been replaced by $P(I) \cdot$ ADT. $P(I)$ is the probability that any one trip through the segment will result in an accident of severity I or greater. Severity, I, could be defined in several ways: a fatal accident, an injury accident, a tow-away accident, or any accident at all. ADT is the average daily traffic volume in vehicles per day. The units of $P(I)$ are accidents per vehicle per day per year, so the units of $P(I) \cdot$ ADT are accidents of severity I per year.

If the accident rate [i.e., λ or $P(I) \cdot$ ADT] were zero, the safety scale would be 1 (i.e., no chance of an accident of severity I occurring). For a given traffic volume, the safety scale decreases as the probability of an accident, $P(I)$, increases. Similarly, for a given probability of an accident, the safety scale decreases as the traffic volume increases.

Although the safety scale, S, is a physically meaningful measure of the absolute safeness of the roadway, it does not show how safe a particular site is with respect to other similar sites. If the absolute safety scale, S, of each segment of roadway in a jurisdiction were measured and recorded, the standard deviation of S could be obtained. A relative safety scale, z_s, could be defined as the difference between the observed and the mean values of S divided by the standard deviation of S:

$$z_s = \frac{(S_{\text{obs}} - S_{\text{avg}})}{\sigma_s} \quad (3)$$

where

S_{obs} = observable absolute safety scale of a particular roadway segment;
S_{avg} = mean absolute safety scale of roadways with similar functional classifications; and
σ_s = standard deviation of the safety scale for similar roadways.

The relative safety scale represents the number of standard deviations that a particular observed absolute safety scale is above or below the mean safety scale for that functional class. This is exactly how most states define a hazardous location using accident rates.

Estimating the number of injury accidents involves summing the effects of all of the potentially hazardous events that a vehicle could encounter while traversing the segment. The probability of an accident of severity I involving a particular hazard is given by (*6*)

$$P(I)_i = P(E)_i \, P(C \mid E)_i \, P(I \mid C)_i \quad (4)$$

where

$P(E)$ = probability of encroaching onto the roadside,
$P(C \mid E)$ = probability of colliding with an object given that an encroachment has occurred, and
$P(I \mid C)$ = probability of a severity I injury given that a collision has occurred.

The probability of experiencing an injury accident on a road segment could be estimated by combining the $P(I)_i$ of each hazard in the segment. The subscript i denotes a particular scenario like running off the road and striking a tree or overturning on a steep side slope. Equation 4 can be used to combine all of the possible hazards the vehicle occupant is likely to encounter along the highway.

Encroachments initiate a sequence of events that sometimes results in an accident. The collision model, $P(C \mid E)$, describes the probability that an encroachment will progress into an accident. The severity model, $P(I \mid C)$, is the probability that if a collision occurs it will have severity I. A general form for the three conditional probabilities in Equation 4 can be written as

$$
\begin{aligned}
P_j(E) &= \prod_{k=1}^{l} a_k b_k^{c_k} \\
P_j(C \mid E) &= \prod_{k=1}^{l} d_k e_k^{f_k} \\
P_j(I \mid C) &= \prod_{k=1}^{l} g_k h_k^{i_k}
\end{aligned} \qquad (5)
$$

The symbol Π indicates that each term is multiplied by the next term or, more generally, that each term is functionally connected to the last term. The values for a_k through i_k are characteristics of the roadway or constants. The values could come from analytical methods, statistical analyses, or experience. The important concept is that the encroachment, collision, and severity are predicted by some set of measurable characteristics of the highway. The mathematical basis for the SafetyAdvisor software is more fully described in other publications (*1,7,8*).

DESCRIPTION OF SAFETYADVISOR

Solving a safety assessment problem by hand or with computer software involves three types of information: data, mathematical models, and procedures. In the context of safety assessment, data are the observable characteristics of the roadway. The mathematical models transform the basic data into abstract quantities that describe the effect of each hazard. The safety assessment procedure takes these abstract quantities and transforms them into a single measure of the safety of the whole roadway. Typical roadside safety software tools like Roadside or the Benefit Cost Analysis Program (BCAP) represent the mathematical models and procedures in computer code; the data are input by the user. The SafetyAdvisor is structured differently since only the procedure is represented as computer source code. The data and the mathematical models are provided as inputs. The advantage of this technique is that specific mathematical models can be easily changed and updated as better models become available. Changing the encroachment model in Roadside, for example, would require changing the source code, recompiling, and redistributing the executable version. Changing the encroachment model in the SafetyAdvisor requires changing an input file with a text editor; no software needs to be modified.

Data Files

Input data files are all standard ASCII text files that can be manipulated with any standard ASCII text editor like the Windows Notepad editor (*3*). Table 1 shows the typical input file format. A quotation mark in any of the files delimits a comment, and all key words are terminated with a colon. The user must provide a project file and three characteristics files to perform a safety assessment using the SafetyAdvisor:

- Project file—contains the names of the hazard, operational conditions, and roadway geometrics characteristics files as well as other data needed to start the assessment procedure. The upper left example in Table 1 shows a project file for the SafetyAdvisor.
- Roadway Geometric file—contains information about roadway characteristics that change from location to location. The degree of curvature and grade are examples of the type of information that can be stored in this file. The lower left example in Table 1 shows an example of a simple geometric characteristics file.

TABLE 1 Example Roadway Characteristics File

Project File

```
TITLE:     An example road
NAME: example.prj
HAZARD DATA: ex_haz
OPCOND DATA: ex_op
ALIGNMENT DATA: ex_road
STARTING SEGMENT: 100
SEGMENT INCREMENT: 50
```

Operational Conditions File

```
"File name: ex_op.txt
"Operation conditions
ADT: 2000
Speed: 35
Lane_width: 11
Clearzone_width: 10
Shoulder_width: 2
Grade: -5
Mean_Safety_Scale: 0.9669
Stnd_Dev_Safety_Scl: 0.022
```

Roadway Geometric File

```
"File name: ex_road.txt
"Roadway characteristic file
Location: 100
  Curvature: 0
Location: 150
  Curvature: 30
Location: 200
  Curvature: 30
Location: 250
  Curvature: 30
```

Hazard Location File

```
"File name: ex_haz.txt
"Hazardous location file
"steep side slope
Location: 101 slope
     offset: 8,
     length: 200,
     slope: -0.75
Location: 300 slope
.
.
```

- Operational Conditions file—contains information about characteristics that are constant over the entire roadway. Information like the posted speed, lane widths, shoulder types, and traffic volume could be stored in this file. The upper right example in Table 1 shows an operational conditions file for the SafetyAdvisor.
- Hazard Location file—contains a list of hazards, their locations, and their characteristics. Each hazard name must correspond to the file name of a hazard severity model (discussed in the next section). For example, using the hazard name SLOPE will cause the program to search the current directory for a model file named "slope.mdl." This file has the information required to calculate the severity of the collision. The lower right example in Table 1 shows a simple example of a hazardous location file. This file only has one hazard, a steep side slope. The values after the hazard name (slope) are characteristics of that particular hazard. A more typical hazardous location file would contain the locations and characteristics of trees, guardrails, utility poles, slopes, and any other roadside objects for which the user has mathematical severity models.

The program does not require any particular set of characteristics or key words to perform an analysis. The program reads in a line of text and searches for a character string terminated by a colon. This string becomes the name of a characteristic. For example, Grade and Speed in Table 1 are defined as characteristics of the whole road when this file is read into the software. The value following the colon is the value associated with the new characteristic name. Grade has the value −5 and Speed has the value 35. Slope is defined as a characteristic of the segment from station 101 to station 300 since it appears in the hazard location file (Table 1, lower right example). If a new characteristic is needed, all the user needs to do is type it into either the geometric, operational conditions, or hazardous locations input files with the corresponding values.

Input Model Files

Model files are required to calculate the values for the probabilities of encroachment, collision, and severity needed to evaluate Equation 4. Although they may, users need not ever interact with these files. They can be developed and distributed by the user's agency or national organizations such as FHWA, NCHRP, or AASHTO. Three types of model files correspond to the three conditional probabilities in Equation 4:

- Encroachment Model files, like the first example shown in Table 2, specify the details of the encroachment model to be used in evaluating the hazard.
- Collision Model files, like the second example shown in Table 2, estimate the probability that a collision will occur with the hazard given that an encroachment occurs.
- Severity Model files, like the third example shown in Table 2, estimate the probability that a collision with the specified type of hazard will result in an accident of severity *I*.

All model files have the structure and format shown in Table 2. The key words Name and Type identify comments about the source and type of the model. The next group of lines identifies the algebraic terms of the model. Each new term is identified with the key word Term. There is no limit on the number of terms that can be in a mathematical model. Each term is composed of four parts: operator, coefficient, variable, and exponent. These parts are stored as strings so the values can be either numbers or strings of text characters.

TABLE 2 Example Probability Model Files

```
Encroachment Model File
Name: Roadside Design Guide
Type: Run-off-road   encroachments
Term: *{0.0005*0.8909^GRADE[-6,-2]}
Term: *{1.0*1.25^CURVATURE[-6,6]}
Term: *{LENGTH[6,100]*0.00018939^1.0}

Collision Model File
Name: Roadside Design Guide
Type: Run-off-road collision model
Term: *{0.1520*1.0435^SPEED}
Term: *{1.0*0.9036^OFFSET}

Severity Model File -- Steep Slope
NAME: Steep Slopes -- Roadside Design Guide
TYPE: Severity
Term: *{0.001286*0.0007412^SLOPE[-0.1,-0.7]}
Term: *{1.0*0.9800^SPEED[40.,70.]}

Severity Model File -- G4 Guardrail
NAME: G4 Guardrail -- Roadside Design Guide
TYPE: Severity
Term: *{3.065e-08*SPEED[40.,70.]^3.}
```

When the safety scale is being calculated the SafetyAdvisor searches the Hazard file (e.g., Table 1) for hazards in the active segment. Each time the SafetyAdvisor encountered the word "slope" in the hazard characteristics file (Table 1) it would search the current directory for a model file named "slope.mdl." The SafetyAdvisor would read in this model file and interpret each value as either a numerical value or a string. For the first term in the hazard model file (Table 2, third example), the values 0.001286 and 0.0007412 would be recognized as numerical values and assigned to the coefficient and variable of the term. The next group of characters is the string Slope. This will represent the "exponent" of the term. Since this is not a numerical value the SafetyAdvisor looks through all the characteristics files (Table 1) for the character string Slope in the currently selected segment. If Slope is found, the number following the word is used in the equation. The value for the Slope in Table 1 is −0.75. If a value cannot be found the user is asked for one. Square brackets are optional limits on the values that can be taken by the parameter. Slope, for example, must have a value of between −0.1 and −0.7, as shown in Table 2; if the value found in the characteristics file is outside that range the closest boundary value is used and a warning message is printed in the log file.

This method makes the SafetyAdvisor flexible since the program itself makes no assumptions about the data needed to perform a safety assessment. Slope is just an arbitrary string to the software; the information in the model files and the input files gives it meaning. If future research indicates that a variable Surface-Type is an important component of a predictive probablistic model, this new variable can be added to the model and input files with a text editor; no coding changes would be required in the software.

Scenario Files

Hazardous events can be grouped into common hazardous scenarios. Run-off-road accidents, for example, represent a variety of cases all involving the vehicle leaving the traveled way and entering the roadside. The user identifies the hazardous objects and characteristics along the side of the road in the hazard file, but there must be a mechanism for correctly associating a particular hazard with the correct encroachment and collision models. The scenario list defines the encroachment and collision model that should be used in conjunction with the hazard model. A scenario list for run-off-road hazards would have the following form:

Run_off_Road: rdge, rdgc

[tree, pole, wall, g4, slope]

"Run-off-road" is the arbitrary scenario name, and "rdge" and "rdgc" are the names of the encroachment and collision model files that should be found on the disk (Table 2). The square brackets contain all of the names of the hazards that belong to the run-off-road hazardous scenario. Collisions with trees, poles, walls, and guardrails are all members of the run-off-road scenario group, so the same encroachment and collision models will be used when these hazards are detected in the hazard file. This list can be added to, modified, and changed to suit the user's needs.

Program Output

Several graphical views are available to the user in the prototype software for viewing the input data and the analysis results. The plan view, the only view discussed in this paper, is a graphical representation of the data in the input file, as shown in Figure 1. (The SafetyAdvisor displays much more information on a color VGA monitor than is possible to show in black and white figures.) Figure 1 is based on information in the characteristics files (e.g., Table 1). Changing the width of the clear zone or the degree of horizontal curvature will cause the screen to be redrawn with the new values. Functions for drawing some hazards like trees, guardrails, fences, and slopes have been included.

The text in the upper left corner of the view identifies the segment, the safety scale on that segment, the relative safety scale, and

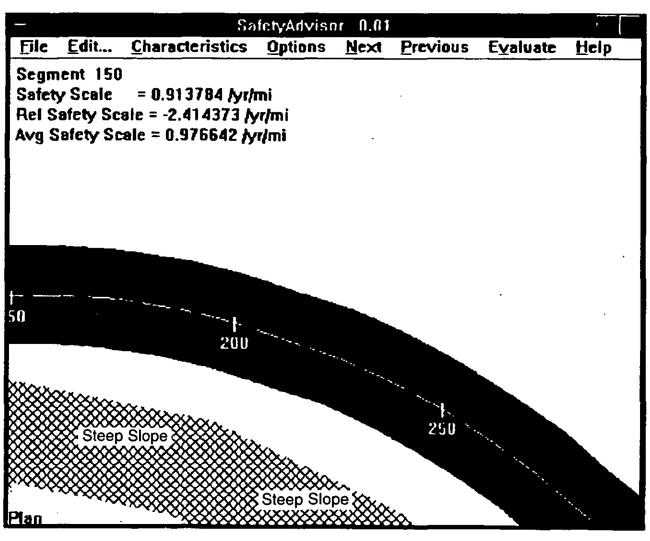

FIGURE 1 SafetyAdvisor view at Station 1 + 50: unshielded slope alternative.

the current running average safety scale on the roadway. Once the input files are assembled, the analysis proceeds by simply moving up and down the roadway by pressing the Next or Previous buttons. Each time the user presses the Evaluate, the Next, or the Previous buttons, the software calculates the safety scale and relative safety scale and displays it on the screen. The user may add, remove, or change hazardous objects and instantly see the effect on the safety scale. For example, the user could remove a tree, widen a lane, install a guardrail, or flatten a side slope and see how much the absolute and relative safety scales change. This feature makes what-if analyses easy to perform and provides a tool that the engineer can use to explore alternatives quickly.

There are a number of limitations to this prototype software related to programming and run-time efficiency. Many more features could be added to the code to make it even more flexible and easy to use. The purpose of this research, however, was to demonstrate how the safety scale could be used to assess roadway safeness. More detail on limits on roadway lengths, processing time, and input restrictions can be found in the program documentation (*1*).

EXAMPLE MODELS

The 1988 AASHTO *Roadside Design Guide* (*9*) contains the most widely disseminated guidelines for designing roadsides. Appendix A of the guide presents a cost-effectiveness approach to making roadside design decisions. The *Roadside Design Guide* contains models for encroachment, collision, and severity that could be transformed into the formats described in Equation 5.

Models based on the *Roadside Design Guide* (*9*) are used in the next section to present an example problem. The derivation of these models is not presented here but can be found in the documentation of the program (*1*). Although the *Roadside Design Guide* models are used throughout this paper to illustrate the use of the SafetyAdvisor, they should not automatically be considered authoritative or recommended. The *Roadside Design Guide* models are simply the first steps in developing models of encroachment, collision, and severity. Much research will be required to develop better, more realistic probablistic models, but the models are sufficient to illustrate how this type of probablistic method could be used.

There must be one severity model for each type of hazard found along the roadside. A mathematical severity model of a collision with a tree will be much different from a model of a guardrail collision. Finding a mathematical approximation of the probability of an injury I in an accident scenario involves two steps: a measure of severity must be selected, and the severity measure must be formulated in terms of the probability $P(I \mid C)$.

The first step is to choose a severity measure. There are several choices: all accidents, all tow-away accidents, all injury accidents, and all fatal accidents are measures of severity that have been used in the past. The societal cost of each of these severity levels and the weighted cost of distributions of these levels have also been used. The most costly accidents are the severe and fatal injury accidents, the so-called A + K accidents. One reasonable measure of severity is the probability of observing an A + K accident in a particular collision scenario; this is the measure of severity that will be used in this example.

The assumed percentage of accident type (severity) as a function of severity index is given in the 1989 AASHTO *Guide Specifications for Bridge Railings* (*10*). If the severe (A) and fatal (K) accidents are summed together and plotted against the severity index, a linear regression of these values will yield (assuming a cubic function) the following expression ($R^2 = 0.98$) (*1*):

$$P(\mathrm{A+K}) = 0.001286\ (\mathrm{SI}^3) \qquad (6)$$

where SI is the 1977 barrier guide severity index (*11*).

This expression provides a reasonable way to map SIs to the probability of sustaining an A + K injury. This relationship is presented as a method for linking the probability of experiencing an A + K injury with the widely used severity indexes used in the barrier guide and the *Roadside Design Guide*.

Steep cross slopes are a common roadside hazard that are often shielded using guardrails. Table 3 shows the SIs recommended by Clinger (*12*) for side slopes on embankments as a function of slope and travel speed. These values, like most values associated with the *Roadside Design Guide*, are subjective estimates of the severity of accidents on side slopes. The severity of the accident is presumed to be a function of the magnitude of the slope (all of these slopes are negative, i.e., downhill) and the departure speed of the vehicle. A linear regression of the natural log of SI with the two independent variables (speed and slope) yields the following:

$$\mathrm{SI} = (0.0905C)\ (0.9933^V) \qquad (7)$$

where C is the cross slope of the roadside and V is the assumed mean travel speed. Equation 8 can now be used to transform these SIs to the probability of a slope-related accident resulting in an A + K injury:

$$P(\mathrm{A+K} \mid C) = 0.001286\ (\mathrm{SI})^3$$

$$P(\mathrm{A+K} \mid C) = 0.001286\ [(0.0905^C)\ (0.9933^V)]^3$$

$$P(\mathrm{A+K} \mid C) = 0.001286\ (0.0007412^C)\ (0.9800^V) \qquad (8)$$

This form can be used directly by the SafetyAdvisor as shown in Table 2. If a vehicle becomes involved in an accident on a steep side slope, this equation provides a method for estimating the probability that the accident will result in an A + K injury. A severity model for collisions with a G4 (1S) guardrail is shown in Table 4.

EXAMPLE PROBLEM

Site Characteristics

The following example is presented to show how the safety scale can be used to rank different roadway sites, perform benefit–cost analyses, and explore design alternatives as well as to illustrate the use of the SafetyAdvisor software.

TABLE 3 Average Severity Indexes of Accidents on Side Slopes

	Speed (mph)			
Slope	40	50	60	70
10:1	0.4	1.1	1.8	2.5
6:1	1.2	1.7	2.6	3.1
4:1	2.0	2.7	3.6	4.5
3:1	2.3	3.1	4.0	4.9
2:1	3.4	4.3	5.4	6.8

TABLE 4 Severity Indexes for G4(1S) Guardrails

Speed (mph)	Severity Index
40	2.6
50	3.1
60	3.6
70	4.3

The example road has a traffic volume of 2,000 vehicles per day with a downgrade of 5 percent and horizontal curvature of 30 degrees. A −3:4 (rise:run) side slope is on a 15-ft embankment on the right side of the roadway (going in the direction of increasing station numbers), and a tall cut is on the left. The side slope on the fill embankment is not shielded by a guardrail. The objective of this analysis will be to determine whether adding a guardrail will have a significant effect on the safeness of the roadway.

The characteristics are summarized in Table 1 for the geometrics, operational conditions, and hazard characteristics files, respectively. Only the run-off-road hazardous scenario will be considered. The encroachment and collision models for the run-off-road scenario are shown in Table 2. Only two hazard models are needed for this model—the steep side slope model and the G4 guardrail model shown in Table 2. Figure 1 shows the plan view of the unshielded example road at Station 1 + 50. The absolute and relative safety scales of this segment (from 1 + 50 to 2 + 00) are 0.9138 and −2.41 (shown in the upper left corner of the screen in Figure 1). As the engineer moves along the roadway by pushing the Next button, the safety scale values along the length of the roadway can be observed. The lowest (i.e., least safe) segment for the example roadway is between stations 1 + 50 and 2 + 00. If the engineer would like to see the effect of placing a guardrail along the road, the Edit menu selection could be chosen and a guardrail could be added to the hazard file, and the SafetyAdvisor view would be updated to include the new guardrail as shown in Figure 2.

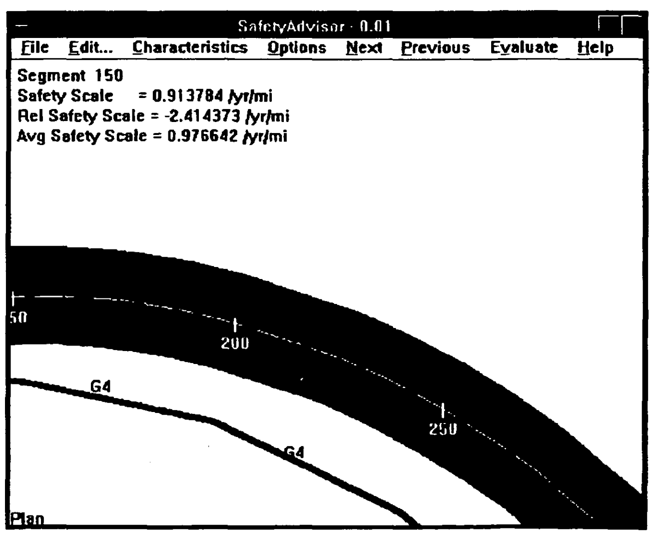

FIGURE 2 SafetyAdvisor view at Station 1 + 50: guardrail alternative.

The safety scales for the unshielded side slope alternative and the shielded side slope alternative (i.e., with a guardrail) are shown in Table 5. The right portion of the table shows the safety scale and the average safety scale for each homogeneous segment of roadway for the unshielded site. The left portion of the table shows the results for the site with a guardrail installed. The maximum difference between the safety scale on the improved roadway and the original unimproved roadway is 0.0665 on Segments 1 + 50 to 2 + 00 (e.g., $S_{guardrail} - S_{slope} = 0.9803 - 0.9138 = 0.0665$). Installing the guardrail reduced the probability of observing a serious accident by 0.0665.

Economic Analysis

Guardrail installation costs approximately $15 per foot, or $79,200 per mile. The *Roadside Design Guide* (*9*) recommends values of $110,000 and $500,000 for severe and fatal injuries, respectively. In 1984 and 1985 there were almost 25 times more injury accidents than fatal accidents on rural primary roads like this example roadway, so the weighted average A + K accident cost is (*13*)

$$\frac{(110{,}000 \cdot 25) + (500{,}000 \cdot 1)}{26} = \$125{,}000 \quad (9)$$

Assuming a 20-year design life and a 4 percent rate of return and assuming that the societal cost of a typical severe accident is $125,000 (*9*), the present worth (*PW*) of the accident cost reduction is

$$PW_{\text{acc. cost reduction}} = 13.59 \cdot 0.0665 \cdot 125{,}000$$

$$PW_{\text{acc. cost reduction}} = \$112{,}967 \quad (10)$$

The benefit–cost ratio for this improvement is the $112,967 accident cost reduction divided by the $79,200 cost of installing the guardrail, or 1.4. According to this analysis, the project is cost-beneficial since the present worth of the cost is less than the present worth of the accident reduction.

The benefit-cost approach, however, is dependent on the values chosen for each injury category and the rate of return. The analysis presented in the previous paragraph used the *Roadside Design Guide* cost values (*9*), but a recent FHWA technical advisory (*14*) advises using $11,000 and $1,500,000 for values of an injury and a fatal injury, respectively. The average weighted A + K accident cost using these values would be

$$\frac{(1{,}500{,}000 \cdot 1) + (11{,}000 \cdot 25)}{26} = \$68{,}269 \quad (11)$$

If $68,269 is substituted for $125,000, a benefit–cost ratio of 0.86 is obtained, indicating that the project is not cost-beneficial. This example shows one of the problems with decision criteria based on economic factors alone: the answer is dependent on the economic values chosen for the value of a severe or fatal injury and economic values like the rate of return. This is a valid method for allocating monetary resources but may not be adequate for measuring safeness. A method that does not rely on economic quantities would help engineers in establishing an absolute ranking that is only a function of the characteristics of the roadway and not the economic values currently in vogue. Calculating the safety scale provides such a method.

Safety Assessment

An alternative to an economic analysis would be to use the safety scale directly. The lowest safety scale in the uncorrected section of roadway shown in Table 5 was 0.9138. Does this represent a safe, a typical, or an unsafe roadway? Data from the Highway Safety Information System (HSIS) for Maine between 1986 and 1988 indicate that on average there were 242 fatal and severe roadside-related accidents on rural two-lane roadways, similar to the example roadway. The HSIS data also indicate that there are 7,191 mi of two-lane undivided roadway in the state, so the A + K accident rate is the 242 A + K accidents divided by the 7,191 mi of roadway, or 0.0337 A + K roadside accidents per mile of two-lane rural undivided roadway per year. Assuming that these values can be used for the example roadway, this value can be inserted directly into Equation 2 to calculate the safety scale:

$$S = e^{-\lambda} = e^{-0.0337} = 0.9669 \quad (12)$$

The least-safe road segment of the example road had a safety scale of 0.9138 (Table 5), making it less safe than other similar roads. If the county ranked all of its potential improvements by the observed safety scale, the county engineer could simply correct sites starting with the road with the lowest value on the safety scale and work up the list until the year's funding was exhausted or until a certain minimum safety scale was attained on all roads, say 0.95.

Another approach would be to use the relative safety scale defined in Equation 3. The average safety scale for this type of roadway (at least in Maine) was found to be 0.9669. If the standard devi-

TABLE 5 Results of SafetyAdvisor Analysis: South Berry Chapel Road

	G4(1S) Guardrail		-3:4 Slope	
Station	Safety Scale	Relative Safety Scale	Safety Scale	Relative Safety Scale
100	0.9948	1.27	0.9766	0.44
150	0.9803	0.61	0.9138	-2.41
200	0.9803	0.61	0.9138	-2.41
250	0.9803	0.61	0.9138	-2.41
300	0.9803	0.61	0.9138	-2.41

ation were known the relative safety scale could be calculated directly from Equation 3. In this case the standard deviation is not known but it can be estimated since the safety scale is an exponential distribution. The standard deviation for Equation 12 would be the square root of 1/ADT, in this case 0.022 (*5*). The relative safety scale for this unimproved roadway is therefore

$$z_s = \frac{S - \overline{S}}{\sqrt{1/\mathrm{ADT}}}$$

$$z_s = \frac{0.9138 - 0.9669}{\sqrt{1/2{,}000}}$$

$$z_s = -2.41 \qquad (13)$$

The safety scale for this segment of the roadway is estimated to be more than two standard deviations below those for other similar roadways, making it a poor segment. This value is independent of any subjective cost estimates, and it allows the engineer to assess this particular site solely with respect to its geometric, operational, and hazard characteristics.

After the addition of the guardrail the lowest safety scale is estimated to be 0.9803 (left column of Table 5 for Station 1 + 50). The relative safety scale of the improved segment of roadway would be

$$z_s = \frac{S - \overline{S}}{\sqrt{1/\mathrm{ADT}}}$$

$$z_s = \frac{0.9803 - 0.9669}{\sqrt{1/2{,}000}}$$

$$z_s = 0.61 \qquad (14)$$

The roadway is slightly better than average, so it is performing at least as well as other roadways in the jurisdiction.

This simple example problem has demonstrated the following:

1. Traditional cost-benefit analyses can be performed by using the safety scale.
2. The safety scale and the relative safety scale can be used to evaluate the effectiveness of proposed countermeasures.
3. Use of the relative safety scale provides a means of determining how unsafe a particular site is compared with other similar roadways without the need for resorting to subjective measures like severity indexes, the value of a life or serious injury, and the assumed rate of return.

CONCLUSIONS

The safety assessment method described in this paper is a useful technique for (*a*) ranking problem sites, (*b*) evaluating alternative designs, and (*c*) allocating scarce highway improvement resources. The SafetyAdvisor provides engineers with a quick, reliable, and easy-to-use tool for performing this type of safety assessment. The software tool separates the process of performing safety analysis from the details of the probablistic models. More improved probablistic models can easily be incorporated into the procedure without having to change the source code of the SafetyAdvisor. There are many probablistic models that need to be developed and validated to provide confidence in the SafetyAdvisor's assessments, but these efforts can easily be merged with the existing models by using software tools like the SafetyAdvisor. The SafetyAdvisor establishes a rational methodology for performing safety assessments without the need for having all of the best probablistic models up front before useful computer software can be developed.

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