OPTIMAL GEOMETRIC DESIGN DECISIONS FOR HIGHWAY SAFETY

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The continuing high accident rate on the highways and the associated social and economic cost have made improvement in highway safety one of the high priority objectives of agencies responsible for road investment and management. Our knowledge of factors contributing to highway accidents is not complete, nor is our knowledge of the value of accident reductions. In dealing with these problems, the highway engineer must make decisions with respect to model or models to use or to develop ways to deal with the uncertainty of his predictions and evaluations, and changes to implement. This paper presents a framework that was developed to deal with these and related problems and describes its pilot applicator to a rural spot-improvement problem in the Midwest.

•THE CONTINUING high accident rate on the highways and the associated social and economic cost have made improvement in highway safety one of the high priority objectives of road investment and management agencies at all levels of government (23). As a result of the importance of this problem, much effort has been expended to increase our knowledge of those factors affecting highway safety and to provide the information needed for making sound decisions about programs designed to improve safety performance. Research has substantially increased our knowledge of the relationships between traffic safety levels and variables potentially or actually within the control of highway management, including the vehicle (25), roadway, driver, and environment. This knowledge, however, is not complete (9, 14). In some cases, the relationships are only vaguely known, while in others the models resulting from the research predict different levels of effectiveness for identical changes or actions in the same situation (3). Similarly, the costs associated with a particular accident level and composition are not known precisely, and different results are obtained in different studies (4). Thus, there is considerable uncertainty associated with the prediction of accident levels resulting from actions or decisions intended to increase safety, and there is uncertainty in the value of such accident rate changes (19).

These conditions lead to many problems for the highway engineer who makes decisions about means to improve safety, whether in designing a new highway or in modifying an existing one. First, he must decide on a methodology to use for predicting accident rates, including the possibility of using existing predictive relationships or of developing his own. Second, he must select or devise a means for evaluating the alternatives. Third, he must decide on how to modify, if at all, the results of safety level predictions and the associated evaluations in order to make them more realistic by using his own and his colleagues' experience and judgment. Finally, he should employ a methodology that explicitly considers information on the extent to which predictions and evaluation may be in error.

The research reported in this paper was directed toward the development of a decision-making framework that explicitly deals with these problems facing the highway engineer.

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The research concentrated on the relationships between geometric design and accident levels, although the methodology could be applied to other factors such as vehicle standards and enforcement. A description is given of the informational base on which geometric design decisions must be made with respect to traffic safety. This provides the basis for the decision-making framework presented. Finally, the results of an application to a high accident problem at a rural midwestern location are presented.

PREDICTION AND EVALUATION

Prediction

A substantial amount of work has been done on the relationship of accident rates and one individual geometric design feature such as shoulder width, lane width, and curves (1, 5, 7). Ideally, one desires a highly inclusive model that simultaneously relates accident rate to highway geometrics, vehicle characteristics, driver behavior, traffic characteristics, and environment including weather and pavement conditions. Obviously, these relationships are highly complex and interactive and are only partly understood at this time (16, 19).

However, some equations have been structured that attempt to assess the relationship of certain combinations of geometric design components to accident rates (10, 11). Typical of these are those by Kihlberg and Tharp (17) and those by Dart and Mann (21). The Kihlberg and Tharp equations use a logarithmic relationship to test whether significant differences in accident rates exist between sections that have the same ADT but possess a variety of combinations of curves, grade, structure, and intersection and sections that are geometrically pure but of the same general highway type. These relationships are developed as follows (17):

$$\log \bar{A} = a + b_1 \log \bar{T} + b_2 \log^2 \bar{T} \tag{1}$$

where

$\bar{T}$ = mean ADT; and
$\bar{A}$ = mean annual number of accidents on a 0.3-mile section.

When, from original regression analysis runs, the a, b_1, and b_2 are found, the smooth curve is computed as follows:

$$y_i = a + b_1\hat{x}_{1i} + b_2\hat{x}_{2i} \tag{2}$$

where

$\hat{x}_{1i}$ = $\frac{1}{2}(\log T_{Li} + \log T_{Ui})$;
T_{Li} = lower ADT limit of the ith class;
T_{Ui} = upper ADT limit of the ith class;
$\hat{x}_{2i}$ = $\hat{x}^2_{1i}$; and
antilog y_i = $\bar{A}_i$ = predicted number of accidents in the ith ADT class.

Likewise, typical of the Mann and Dart regression results is the result found for total accidents (21):

$$\begin{aligned} Y_1 = \text{total accidents/100 mvm} &= 41.32 - 1.23X_2 - 0.54X_3 - 0.67X_6 + 0.03X_2X_3 \\ &+ 0.02X_3X_6 - 0.0009X_3X_9 + 0.034X_3X_{11} \\ &- 0.2X_4X_{11} + 0.009X_5X_9 \end{aligned} \tag{3}$$

where

X_1 = number of lanes, total for both directions;
X_2 = percentage of trucks;
X_3 = traffic volume-capacity ratio for operation at level of service B;
X_4 = lane width, ft;

X_5 = shoulder width, ft;
X_6 = cross slope, in./ft;
X_7 = percentage of continuous obstructions (percentage of highway length);
X_8 = marginal obstructions per mile;
X_9 = horizontal alignment, percentage of length in excess of 3 deg;
X_{10} = vertical alignment, percentage of length in excess of 3 percent; and
X_{11} = traffic access points per mile.

Percentage of continuous obstruction is defined as the percentage of the total length of a highway section that has some roadside feature or obstacle that runs for more than a few feet on either or both sides of the roadway. Such a feature would be a deep roadside ditch or steep side slope that presents an obstacle to a vehicle safely leaving the roadway in an emergency at posted highway speeds.

Marginal obstructions per mile are defined as the total number of discrete objects on both sides within the cleared right-of-way per mile of a highway section. Those objects may be a driveway embankment culvert, roadway culvert, headwall, tree, or telephone pole. This term is not to be confused with the term used in capacity analysis to refer to marginal obstruction within 6 ft of the pavement edge.

Several problems exist if one considers using either of these typical predictors.

1. In almost all instances, when used on the same rural section, the resulting accident rates predicted by one model are substantially different from those predicted by the other. This raises the problem of choice of predictive relationship and the question of whether it is better to develop a relationship specifically for the region and sites under consideration.
2. Each of the results is based on data from local areas, and the question of transferability of results to other problem areas exists. This further reinforces the problems mentioned earlier.
3. An obvious problem in the quality of the relationships is the omission of certain highly important variables, which are often difficult to measure. The most critical of these in highway safety are the driver and his responses and the vehicle type and condition.
4. The engineers involved normally have a substantial background of experience and judgment to draw from when they view the results of predictive models, such as those described here. Any overall evaluation methodology using predictive relationships should utilize this judgment.

Evaluation

In addition to prediction, certain evaluation techniques have been developed for studying accident phenomena associated with geometric design. These are based on a variety of criteria for decision as to whether a site is considered hazardous. These criteria, thoroughly discussed by Jorgensen (16) are stated briefly as follows: number method, rate method, number-rate method, and rate quality control method (8, 15).

All of them can induce some distortion, depending on the position taken by the analyst with respect to number of accidents and exposure. Different rates, numbers, or levels of confidence (in the case of the rate quality control method) can result in differing groups of sites being declared as hazardous.

The current evaluation techniques make recommendations on the basis of appropriate knowledge of capital and maintenance costs, accident costs, time, delay, and comfort and convenience costs (2, 18). The following commonly used techniques are familiar to the highway engineering community (16): total minimum annual cost, benefit-cost ratio, rate of return, net benefits, and cost-effectiveness analysis.

Appropriate costs for various types of accidents have recently been studied in detail (30, 31). In addition, monetary relationships between fatal and severe-injury accidents and an appropriate equivalent number of property-damage accidents are available (26).

The evaluation of safety consequences in dollar measurements alone has been a point of contention for some time. Various groups affected by accident phenomena attach different values to the consequences, such as those involving injury to the occupants, roadside property damage, and the resulting congestion and inefficiency of the highway system. Therefore, the solutions may be dependent on, or altered by, the viewpoints of groups included. It is important to consider as wide a variety of viewpoints as possible in any evaluation process conducted by officials of a public agency. The evaluation schemes may possibly be broadened to make use of any or all of the economic evaluation techniques given earlier and also may incorporate as many points of view as possible.

Summary

The pertinent aspects of the prediction and evaluation phases of traffic safety problems are summarized as follows:

1. In the assessment of accident rates, the wide variety of quality of relationships and data bases in relation to geometric design variables often results in substantially different predictions of rates for the same highway section.
2. The judgment and insight of the designer can be used to modify results of models to yield a more accurate prediction for local situations that have great influence on accident rates. Well-documented, typical situations of this type include local sections with very poor driver behavior despite reasonably adequate design, such as those where there is a large incidence of drunken drivers or drivers in certain age groups who operate vehicles carelessly and recklessly.
3. It appears possible to incorporate the usual engineering evaluation techniques into a decision-making framework that allows the public agency to consider as many points of view as possible.
4. There is often uncertainty associated with the costs for alleviating the situation. In addition, the benefits accruing from design modification are subject to even greater uncertainty. These aspects of uncertainty should be incorporated into the decision-making framework.

The next section discusses an approach based on decision theory for dealing with these aspects of prediction and evaluation of alternative design modifications to improve safety.

DECISION THEORY APPROACH

Decision theory is a managerial tool that has been developed for dealing with problems similar to those encountered in this field of highway engineering; it has been widely used in dealing with business problems (27). To understand the adaptions for and applications to highway safety investment decisions, one must first know the major characteristics of the theory.

Basic Problem Structure

The basic approach is to break large, complex decisions into a sequence of smaller, more manageable components (12, 28). The purpose of the entire process is, of course, to come to a conclusion regarding the best geometric design improvement from a safety standpoint and one satisfactory from other viewpoints such as traffic flow and cost. This decision is usually termed an action in decision theory, and the alternative actions correspond to alternative geometric designs.

To decide on the best action requires information on the value of the alternative actions. Usually in engineering design this information is gathered through the use of predictive and evaluative models, tempered by the engineer's judgment. This gathering of information on the value of alternatives is termed in decision theory an experiment, and the resulting information is called the experimental outcome. In this application, the alternative experiments are alternative predictive and evaluative models, and the outcomes are evaluations of the various alternative designs.

Because the experiments are performed and the outcomes observed before the best action is decided on, the sequence of the steps is as shown in Figure 1. This type of diagram is called a decision tree. The example deals with the problem of improving the safety performance of a short section of rural road with a complex alignment through

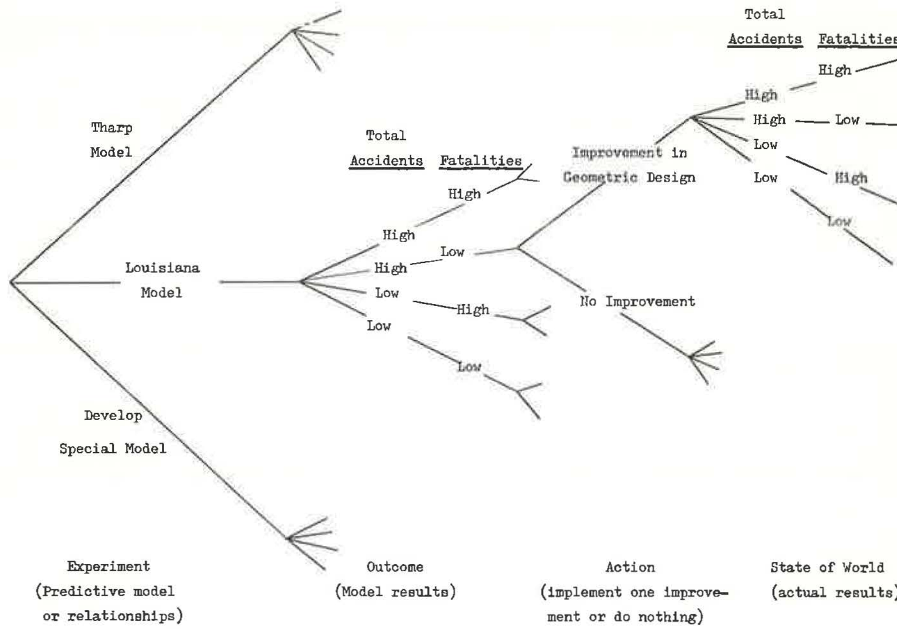

Figure 1. Decision tree for evaluating geometric design improvements.

geometric design changes. For simplicity, this example is limited to 2 alternative actions: (a) improve alignment and profile and install a median barrier and (b) make no improvement. (In an actual study there would be more alternatives.) The decision on action is to be made on the basis of whether there is a significant reduction in total accidents and in fatalities.

The first decision to be made is how to predict the accident rates for each alternative. Three experiments are shown in Figure 1: the Kihlberg and Tharp model, the Mann and Dart (Louisiana) model, or a new model. Each line emanating from the left point represents one experiment. Emanating from each experiment are the 4 possible outcomes if the improvement were made, corresponding to combinations of high or low accidents and fatalities. If no improvement were made, presumably the existing rate would continue (approximately).

After an experiment is performed, the outcome is known, and the action can be selected. Because of space limitations, the alternative actions are shown after only one outcome, but they would all emanate from each.

Only after an action is actually undertaken—such as installing a median barrier—will the true outcome (as opposed to that predicted by the experiment) be known. Because it is desirable to include reference to possible deviations from predictions, the framework includes the possible actual results after actions. These are called states of the world and are shown in this simple example as emanating from only one action; they are possible after each.

This completes the decision theory framework. The first decision to be addressed is that of which experiment to perform. Once the experiment is selected, it is performed and the outcome observed. Then the best action, based on the information available, can be selected and implemented. The means for making these decisions is presented in the following section.

Information Needs

The information needed to employ decision theory is a combination of objective information and subjective information; the engineer draws on his experience in a manner appropriate to his problem. Although the mathematics of the theory cannot be presented here, it is important to understand the conceptual basis of it.

The first type of information needed is an overall measure of the value of each possible sequence of an experiment, outcome, action, and state of the world; this measure is called a utility. For this problem, utilities include the costs associated with use of and possible development of a model; the costs of implementing an action, either geometric changes or no changes; and the costs and benefits associated with the resulting accident rate, presumably in comparison with the present condition. In the example shown in Figure 1, there would be 24 such utilities.

The other information is in the form of probabilities. One set consists of the probability of each state of the world occurring, given an action prior to the using of any models. For safety problems, these undoubtedly would be based on the judgment of the engineers. The second is information about the predictive accuracy of the various models or experiments. One form is the probability that an experiment will yield a particular outcome, given that a state of the world is true. If there is a high probability that the outcome of an experiment will correspond to the state of the world, then the experiment or model is an accurate one. Again, in this case, such information is likely to be based on the engineer's judgment. This may seem arbitrary, but at least the method takes into account the accuracy of models, and the judgmental factor is made explicit.

Results

This information and the mathematical techniques of decision theory are used in the method first to identify that experiment for which the expected utility is greatest. Then that experiment is performed, and its outcome is observed. At this point the best action is selected and implemented. These are the primary results of use to the engineer.

In addition, other useful information may be obtained. For example, the increase in expected utility resulting from developing better predictive models is easily obtained. Information is provided on a range of possible outcomes resulting from an action and not from just a single "best estimate." However, rather than discuss theory further, we return to actual applications.

EXAMPLE APPLICATION

The example involves a rural site in the Midwest shown in Figure 2. The section is 0.321 mile long, has 4 lanes, is undivided, has no access control, and has reasonably complicated alignment. Its geometric and operating features are given in Table 1. The

TABLE 1

GEOMETRIC AND OPERATING CHARACTERISTICS OF RURAL ROAD SECTION FOR EXAMPLE PROBLEM

Characteristic	Description	Characteristic	Description
Number of lanes, undivided	4	Present speed limit, mph	50
Access control	None	Present ADT	22,000
Length of section, miles	0.321	1980 forecast ADT	29,000
Pavement type	PCCP	Trucks, percent	15
Lane width, ft	11	Present peak-hour volumes	
Shoulder type	Gravel	Westbound	1,700
Shoulder width, ft	8	Eastbound	1,400
Grade, percent	3	Present peak-hour volume-capacity ratio	0.5
Length of grade down in westbound direction, miles	0.26	Present total accident rate/mvm	6.71
Curve radius, ft	1,000	Present fatal accident rate/mvm	0.024
Curve angle, deg	5.7		
Number of traffic conflict points	12		
Number of obstructions	31		

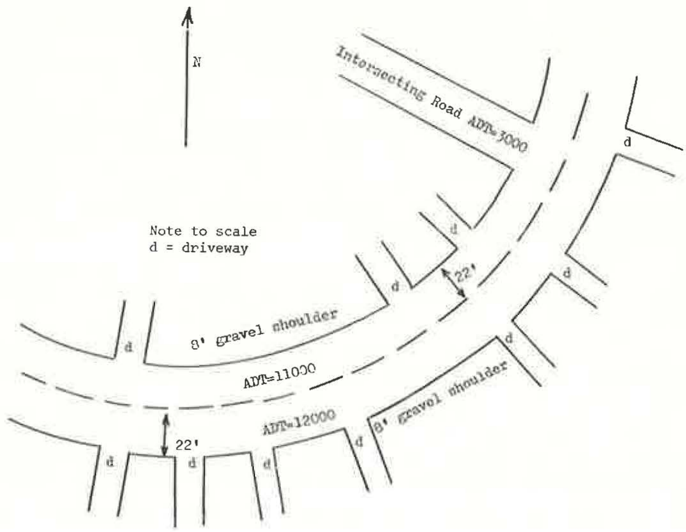

Figure 2. Midwest road section.

problem was formulated in a decision theory framework described in the following.

Experiments

The following possible sources of information on accident rates with 1980 projected traffic and conditions were considered as experiments: experiment 1—use Kihlberg and Tharp log regressions; experiment 2—use Mann and Dart multiple regressions; and experiment 3—develop new predictive model.

Outcomes and States of the World

The possible outcomes and states of the world were arranged to identify thresholds of a total accident rate and a fatality rate that were significantly different from the average rate for a facility type. This average could be the present average or the predicted average for some future year. In this case, the present statewide averages for 4-lane, undivided facilities were used: 7.0 total accidents/mvm and 0.03 fatal accidents/mvm. The thresholds of significantly different rates were identified by using the following quality control formula (13):

$$\lambda_p = \lambda_c + 1.65\sqrt{\frac{\lambda_c}{E}} - \frac{1}{2(E)} \qquad (4)$$

where

λ_p = critical rate of significant difference at a 95 percent confidence level;
λ_c = average rate for facility type; and
E = total annual exposure, million vehicle miles (mvm).

Solving this equation with the averages yielded the following: λ_p = 9.3 total accidents/mvm and 0.38 fatal accidents/mvm.

States of the world and outcomes were formed of all possible rate combinations that could possibly influence geometric design. These included the following:

State or Outcome	Total Accident Rate/mvm	Fatal Accident Rate/mvm	State or Outcome	Total Accident Rate/mvm	Fatal Accident Rate/mvm
1	≥9.30	≥0.38	3	<9.30	≥0.38
2	≥9.30	<0.38	4	<9.30	<0.38

Thus, the set of all relevant possibilities ranges from a significantly high total and significantly high fatal rate, a high total and low fatal rate, a low total and high fatal rate, to a statistically insignificant total and fatal rate.

Alternatives

The information on operating characteristics given in Table 1, investigation of enforcement accident report summaries, and visits to the site revealed that the predominant accident types were rear-end, left-turn, and head-on. All fatals were head-on accidents, and rear-end and left-turn accidents were associated with the presence of driveways and poor skidding resistance on the section. In terms of long-range preliminary planning, the following 4 alternatives were considered:

1. Resurface to appropriate skid resistance standards;
2. Reconstruct section with improved alignment and profile, install partial access control, and eliminate direct driveway access through provision of parallel access facilities to the intersecting road;
3. Make same improvements as in alternative 2 but, in addition, install median barrier and selected median openings; and
4. Make no improvement.

Subjective Information

Based on the traffic projections and past accident history of the site given in the Appendix, a subjective prediction was made of significantly high total rates with equal likelihood of significantly high fatal rates. Also, comparison of the results of all predictors with actual rates at other sites led to the subjective development of probabilities of experimental outcomes for each state of the world that might exist. Specifically, the Kihlberg and Tharp (17) regressions appear reasonably accurate in forecasting so that the outcome of the experiment should correspond closely to the state of the world. In contrast, the Mann and Dart (21) regressions seem to underestimate the rates substantially.

Utilities and Rewards

There are 2 basic components of the utility structure of a model such as this one. One component is that associated with the labor and management cost of the experiment and with the penalty for degree of error in prediction. In our case, error cost can be substantial. Hence there is a utility, U_1, that represents the penalty for error resulting from the use of an experiment in prediction of an outcome that differs from the actual state of the world. The second component utility, U_2, represents the benefits and costs resulting from various actions taken under different states of the world. These are the benefits and costs usually addressed in studies of the value of accident reductions.

Several approaches may be used to arrive at this latter utility component. One is the traditional highway engineering evaluation of net benefits in monetary units resulting from benefits of accident reduction, benefits or costs or both in traffic operations, and capital improvement costs. For each combination of state of the world and alternative action, the resulting annual capital cost, changes in operating and maintenance costs, and reduction in total dollar costs of accidents yield a utility measured in dollars and representing many points of view. An alternative would be to consider each affected group or point of view separately, without necessarily converting all gains and losses into monetary units, and then to assign a utility to each alternative and state of the world combination. Regardless of the approach, a utility measure of value is needed.

For the sake of convenience in demonstrating the model, the total utility of a combination of experiment, outcome, alternative, and state of the world was assumed to be additive and linear on U_1 and U_2; i. e., $U_T = U_1 + U_2$, with U_1 indexed on a scale of 0 to 70 and U_2 on a scale of 0 to 80. However it should be pointed out that either U_1 or U_2 may be a nonlinear complex functional form and that $U_T = f(U_1, U_2)$ may likewise be quite complex. Appropriate inputs for developing U_2 are given in Table 2, and a partial list of utilities is given in the Appendix.

TABLE 2

INPUTS TO EVALUATION OF U_2

Alternative	Annual Capital Cost ($)	Change in Annual Maintenance Cost ($)	Change in Annual User Cost	Change in Accidents if Rate Is Significant (percent)	
				Total	Fatal
1	5,000	-1,000	Negligible	-35	-26
2	20,000	-1,200	Negligible	-40	-30
3	25,000	-500	Negligible	-40	-50
4	0	-1,000	No change	+24	+100

Note: Life = 15 years; interest rate = 6 percent.

Evaluation

The problem was evaluated with SBDT, a computer program developed for this study. Data given in Table 3 show that use of experiment 1, the Kihlberg and Tharp regression, is optimal. The results of experiment 1 are also given in Table 3 and predict a significantly high total and fatal rate. In this particular example it is optimal to take action 2 regardless of the outcome of the experiment, although in the general case the optimal action could depend on the experimental outcome.

Sensitivity Analysis

An important component of any evaluation is the study of the sensitivity of decisions to changing values of pertinent parameters. This is especially important when model inputs are uncertain. One desirable feature of this model and computer program is that it allows one to examine the effects of uncertainty on optimal decisions very easily. If the sensitivity analysis reveals that the same decision (in this case, first the experiment and then the action) is best regardless of the values of the uncertain parameters (within the possible or likely range), then the single best decision can be identified. However, if the optimal decision varies with these uncertain values, then no single decision is best and the range of variation in the uncertain parameters should be reduced through more information and better estimation.

In this example, the sensitivity analysis indicated that the optimal experiment and action described earlier are best over the likely range of uncertain input parameters. The Kihlberg and Tharp experiment is best over all ranges of the probability of each of the states of the world, except when the probability of insignificant accident rates (state 4) is greater than 0.5. Similar results were obtained for the sensitivity analyses of the probabilities describing the prediction accuracy of the models. For all reasonable levels, the Kihlberg and Tharp model appeared best for this particular site. The development of a special model never became optimal, for the costs were too high.

TABLE 3

EVALUATION RESULTS

If Experiment	Yields Outcome	Take Action	Item	Quantity
1	1	2	Number of experiments	3
1	2	2	Number of outcomes	4
1	3	2	Number of actions	4
1	4	2	Number of states	4
2	1	2		
2	2	3	Total accidents/mvm	12.19565
2	3	2	Total injury-producing	
2	4	2	accidents/mvm	4.62885
3	1	2	Total property-	
3	2	2	damage-only	
3	3	2	accidents/mvm	7.84199
3	4	2	Total fatalities/mvm	0.05837

Note: Experiment 1 yields optimum 108.050 and outcome 12.20, 0.06.

CONCLUSIONS

In the research underlying this paper an attempt has been made to develop an engineering design methodology that is responsive to the needs of highway engineers concerned with improving traffic safety through geometric design changes. Such a methodology should explicitly consider the fact that accident relationships are not perfect predictors and that many such relationships, each giving different results, may apply to a given problem. Also, the design engineer often possesses much knowledge, based on his experience and judgment, that should be used in the selection of predictive relationships, the evaluation of alternatives, and the final selection of a design alternative. The framework based on decision theory does deal with these aspects of the problem.

The application described here and others have demonstrated the efficacy of this approach. The availability of the associated computer code used in these applications should make further application and use by operating agencies possible. Furthermore, the same framework should be applicable to other highway design and management problems both within and outside of the field of safety.

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APPENDIX

INFORMATION FOR EVALUATION

Given information is shown in Figure 3 and computed information in Figures 4, 5, and 6. In all figures, Q = θ.

MARGINAL MEASURES ON Q

Q1	.300
Q2	.300
Q3	.200
Q4	.200

CONDITIONAL MEASURES ON Z EXPERIMENT

	E1				E2				E3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Z1	.30	.40	.20	.25	.25	.15	.20	.10	.40	.30	.25	.25
Z2	.30	.30	.20	.20	.25	.25	.20	.10	.20	.30	.25	.25
Z3	.20	.20	.50	.25	.25	.25	.20	.30	.20	.20	.25	.25
Z4	.20	.20	.10	.25	.25	.35	.40	.50	.20	.20	.25	.25

Figure 3. Given marginal and conditional measures.

MEASURES ASSOCIATED WITH E1

	JOINT				MARG ON
Z	Q1	Q2	Q3	Q4	Z
Z1	.090	.120	.040	.050	.300
Z2	.090	.090	.040	.040	.260
Z3	.060	.060	.100	.050	.270
Z4	.060	.060	.020	.050	.190

MEASURES ASSOCIATED WITH E2

	JOINT				MARG ON
Z	Q1	Q2	Q3	Q4	Z
Z1	.075	.045	.040	.020	.180
Z2	.075	.075	.040	.020	.210
Z3	.075	.075	.040	.060	.250
Z4	.075	.105	.080	.100	.360

MEASURES ASSOCIATED WITH E3

	JOINT				MARG ON
Z	Q1	Q2	Q3	Q4	Z
Z1	.120	.090	.050	.050	.310
Z2	.060	.090	.050	.050	.250
Z3	.060	.060	.050	.050	.220
Z4	.060	.060	.050	.050	.220

Figure 4. Computed measures.

REVISED CONDITIONALS FOR Q WITH E1

Z	Q1	Q2	Q3	Q4	SUM
Z1	.300	.400	.133	.167	1.000
Z2	.346	.346	.154	.154	1.000
Z3	.222	.222	.370	.185	1.000
Z4	.316	.316	.105	.263	1.000

REVISED CONDITIONALS FOR Q WITH E2

Z	Q1	Q2	Q3	Q4	SUM
Z1	.417	.250	.222	.111	1.000
Z2	.357	.357	.190	.095	1.000
Z3	.300	.300	.160	.240	1.000
Z4	.208	.292	.222	.278	1.000

REVISED CONDITIONALS FOR Q WITH E3

Z	Q1	Q2	Q3	Q4	SUM
Z1	.387	.290	.161	.161	1.000
Z2	.240	.360	.200	.200	1.000
Z3	.273	.273	.227	.227	1.000
Z4	.273	.273	.227	.227	1.000

Figure 5. Revised conditionals.

PARTIAL LIST OF UTILITIES

E	Z	A	Q	U_T	U_1	U_2
1	1	1	1	85	65	20
1	1	1	2	90	50	40
1	1	1	3	105	40	65
1	1	1	4	60	30	30
1	1	2	1	120	65	55
1	1	2	2	125	50	75
1	1	2	3	110	40	70
1	1	2	4	50	30	20
1	1	3	1	145	65	80
1	1	3	2	100	50	50
1	1	3	3	115	40	75
1	1	3	4	40	30	10
1	1	4	1	70	65	5
1	1	4	2	55	50	5
1	1	4	3	45	40	5
1	1	4	4	105	30	75
1	2	1	1	80	60	20
1	2	1	2	105	65	40
1	2	1	3	95	30	65

E	Z	A	Q	U_T	U_1	U_2
1	2	1	4	60	30	30
1	2	2	1	115	60	55
1	2	2	2	140	65	75
1	2	2	3	100	30	70
1	2	2	4	50	30	20
1	2	3	1	140	60	80
1	2	3	2	115	65	50
1	2	3	3	105	30	75
1	2	3	4	40	30	10
1	2	4	1	65	60	5
1	2	4	2	70	65	5
1	2	4	3	35	30	5
1	2	4	4	105	30	75
1	3	1	1	70	50	20
1	3	1	2	70	30	40
1	3	1	3	130	65	65
1	3	1	4	75	45	30
1	3	2	1	105	50	55
1	3	2	2	105	30	75
1	3	2	3	135	65	70

Figure 6. Utilities.