conflicts) of the total conflict count. A basic problem with existing data and relationships is that they are ill-defined. Data have not been adequately stratified, and analyzed accordingly, for significant conditional parameters such as highway ADT, crossroad ADT, number of approach legs, number of lanes, and type of traffic control. Also, reliable estimates of the within-site variability of conflicts are not available.

Another very distinct problem in using existing data and relationships on conflicts is that conflict definitions and sampling procedures vary significantly. With conflict definitions, an additional weakness is that none has a completely objective base. The field determination of a conflict occurrence depends on the observer's judgment of temporal variables such as the initial gap between leading and following vehicles or the magnitude of deceleration. Use of the brake-light application as a criterion creates additional sampling error because of the proportion of vehicles with nonoperative brake lights.

This discussion is not intended to quench enthusiasm on the conflict-analysis concept but rather to caution potential users and, more importantly, to encourage a more rigorous development of an appropriate data base. For conflict-analysis techniques to be useful, they must embody appropriate definitions and sampling procedures that allow a practical (cost-effective) method to reliably predict the expected annual average number of accidents for a particular site condition.

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Publication of this paper sponsored by Committee on Effectiveness of Operational Measures.

Determining Hazardousness of Spot Locations

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This paper presents a procedure to assess hazardousness at spot locations on all highway facilities except freeways and in central business districts. Indications of hazardousness included in the rating procedure are number of accidents per year, accident rate in terms of annual traffic volumes, accident severity, volume/capacity ratio, sight distance, traffic conflicts, erratic maneuvers, driver expectancy, and information-system deficiencies. A raw-data format was selected for each of these indicators, and a scaling technique was developed that permits the combination of inputs from the several indicators to produce a hazardousness rating on a scale from 0 to 100. The procedure may be used even if data on all indicators are not available for a given site (level of confidence in the results diminishes). Sixteen traffic engineers and safety experts, representing 14 states, were invited to two workshops to review the procedures formulated and to assist in establishing the weights to be assigned to each of the indicators. The general concept underlying the convergence-of-evidence procedure is highly acceptable to the safety personnel who participated in the workshops. Of special note is the development of a workable form for obtaining subjective evaluations of hazardousness in various highway situations.

Within the past decade, safety-improvement programs have received increased attention by the federal government and the various state highway and transportation agencies. Substantial funds have been, and are being, allocated to safety improvements of various types. Implicit in all these programs is the need for a systematic process for identification of hazardous locations and a method for assigning priorities to the treatment of the high-hazard locations identified.

Virtually all identification and priority schemes currently in use are based on computerized accident-record systems. These procedures, although efficient, relatively easy to implement, and generally acceptable, have limitations. The following are some examples of the limitations:

1. Accident records are not always available for all classes of roadways within a given jurisdiction;
2. Considerable disagreement exists as to the specific accident measures that should be included in the hazardous-location identification process (e.g., number of accidents, accident rate, severity, and trend with time), the appropriate form for the measures selected, and the relative weights to be assigned to each measure;
3. Year-to-year consistency of accident experience is lacking at specific locations; and
4. Past accident experience is not appropriate where major changes in geometrics or traffic-control measures have been implemented (e.g., initial signalization of an intersection, change to one-way street operations, major channelization projects, and changes in speed limit) or where major changes in traffic characterictics have occurred (e.g., increased traffic volumes associated with the opening of a new shopping center or apartment complex).

The objective of this study was to develop a procedure for ranking hazardous locations for all highway facilities except freeways and central business districts (CBDs). Both accident and nonaccident measures, or predictors, are included in the formula proposed for establishing the degree of hazardousness (the potential for accidents in the near future) at spot locations within the highway system. If accident measures are available and appropriate, these measures are to be supplemented with the nonaccident measures; if applicable accident records are not available, the nonaccident measures can be used to assess hazardousness in a manner consistent with the more comprehensive formula.

The procedures developed do not address selection of appropriate remedial treatments for the sites identified as hazardous or cost-effectiveness of alternative investment programs.

HAZARDOUSNESS-RATING FORMULA

Potential Indicators

A comprehensive list of both accident-based and non-accident-related candidate indicators, for inclusion in the procedure, was compiled by a search through relevant literature and as a result of suggestions by traffic engineers and safety experts. The accident-based indicators included in the initial list and derivable from most state accident-record systems are

1. Number of accidents per year,
2. Accident rate,
3. Accident severity,
4. Trend in accident numbers, and
5. Night-to-day ratio.

The objective nonaccident indicators (requiring quantitative measurements but relatively free of subjectivity in data-collection procedures) included in the initial list were

1. Traffic conflicts,
2. Erratic maneuvers,
3. Speed,
4. Speed variance,
5. Acceleration noise,
6. Lateral-placement variance,
7. Headway distribution,
8. Average daily traffic (ADT),
9. Volume/capacity ratio,
10. Percentage of unfamiliar drivers,
11. Traffic violations,
12. Skid resistance,
13. Sight distance, and
14. Access points in vicinity.

The other nonaccident indicators, requiring subjective evaluation on a "good" to "bad" scale, initially considered were

1. Driver expectancy,
2. Adequacy of information system,
3. Evidence of driver errors, and
4. Environmental factors.

Final List of Indicators

The original list of 23 potential indicators was pared to 9 for inclusion in the hazardousness-rating formula (HRF). Personnel from eight state highway and transportation agencies and one major city assisted in selecting the indicators most appropriate for the intended purposes. The 9 indicators are

1. Number of accidents per year,
2. Accident rate,
3. Accident severity,
4. Volume/capacity ratio,
5. Sight distance,
6. Traffic conflicts,
7. Erratic maneuvers,
8. Driver expectancy, and
9. Adequacy of information system (later altered in form to information-system deficiencies to be consistent with procedural format).

Philosophy of the Hazardousness-Rating Procedure

A single procedure flexible enough to be applicable at various types of sites (such as signalized and unsignalized intersections, horizontal curves, and lane drops) is highly desirable because funds must often be allocated to spot improvements as a comprehensive category. The procedures developed are appropriate for the various spot types and, further, can be used even if data on all indicators are not available for a given site (level of confidence in the results would be diminished).

Each indicator is a measure of hazardousness in some degree but is not entirely satisfactory in defining overall hazardousness. The concept underlying HRF is that the composite hazardousness rating provided by the degree of convergence of evidence of the individual indicators provides a reasonably accurate prediction of future accident experience (e.g., restricted sight distance is definitely a factor in the hazardousness at a given location, but analyses of sight-distance restrictions do not provide accurate estimates of future accident experience). The same is true of each of the other indicators, including any of the indicators based on records of past accident experience. Some indicators are better than others; this variance is reflected in the differing weights assigned to the individual indicators.

General Form of HRF

The general form of HRF is

$$HI = \{\Sigma[W_i(IV)_i]\}/\Sigma W_i \qquad (1)$$

where

HI = hazardousness index for site under study,

W_i = weighting factor for indicator i,
IV_i = indicator value for indicator i (described below under scaling), and
ΣW_i = sum of weighting factors for all indicators used at study site.

Indicator values range from 0 to 100; larger numbers indicate higher degrees of hazardousness. The sum of the weighting factors for all nine indicators included in HRF is 1.00. However, if data are not available for all the indicators, HI can be normalized to a scale of 0 to 100 by dividing the summation of the weighted indicator values used by the sum of the weights that correspond to the indicators used; i.e., no matter which indicators are available, the range of potential HI at a given site is 0 to 100. Therefore, all sites are rated on a single scale. The greater the value of ΣW_i is, however, the greater the confidence in the results of the rating procedure will be.

Scaling

For the HI derived from the weighted combination of the individual inputs to be meaningful, the raw data for each indicator must be scaled to a value of 0 to 100. Further, the hazardousness implied by a particular IV for one indicator must be consistent with that implied by the same IV for all other indicators. Charts for converting raw data to IVs for each of the nine selected indicators were developed. Four control values were used to establish each of these charts.

1. A value of 0 was used for an indicator raw score that indicated the site made no contribution to hazardousness. For example, a site at which there had been no accidents within the past 3 years would be assigned an IV of 0.
2. A value of 33 was used for an indicator raw score that separated hazardous and normal sites. For example, a site at which there had been an annual average of 2.0 accidents within the past 3 years would be assigned an IV of 33.
3. A value of 67 was used for an indicator raw score that separated very hazardous and critical sites. For example, a site at which there had been an annual average of 10 accidents within the past 3 years would be assigned an IV of 67.
4. A value of 100 was used for an indicator raw score that indicated a higher degree of hazardousness. For example, a site at which there had been an annual average of 50 accidents within the past 3 years would be assigned an IV of 100.

The chart for converting the number of accidents per year to an IV, as based on the four control values described above, is shown in Figure 1. A similar rationale was applied to the other indicators in deriving control values and developing the transformation charts.

Sixteen traffic engineers and safety experts, representing 14 states, were invited to two workshops to review the procedures formulated by the project staff, to assist in establishing the control values to be used on the transformation charts, and to assist in establishing the weights to be assigned to each of the IVs. The methodology was described by the project staff and was then applied by the workshop participants at 12 sites before the final indicator weights were established.

Derivation of HRF

Using the weights that were assigned by the participants at the two workshops, we established the following equation for assessing the hazardousness at various spot locations.

$$\begin{aligned} HI = {} & (0.145)(\text{IV of number of accidents}) \\ & + (0.199)(\text{IV of accident rate}) \\ & + (0.169)(\text{IV of accident severity}) \\ & + (0.073)(\text{IV of volume/capacity ratio}) \\ & + (0.066)(\text{IV of sight distance}) \\ & + (0.053)(\text{IV of traffic conflicts}) \\ & + (0.061)(\text{IV of erratic maneuvers}) \\ & + (0.132)(\text{IV of driver expectancy}) \\ & + (0.102)(\text{IV of information-system deficiencies}) \end{aligned} \quad (2)$$

If all the indicators are not used at a particular site, the right side of the equation must be divided by the sum of the weights (coefficients) for the indicators used. For example, if erratic-maneuvers data are not available, the right side of the equation is divided by (1.000 - 0.061) or 0.939.

RESEARCH RESULTS

The primary product of the research effort is a users manual (2). This manual spells out the procedures to be followed in applying HRF to assess the relative hazardousness of spot locations of interest. The scaling charts and the computation forms necessary for implementing the procedure are also included in the manual.

Sixteen traffic-safety-program personnel from 14 states assisted in developing the final form of HRF and the scaling charts. The inputs of the traffic-safety personnel were derived from their participation in two workshops that were conducted near the conclusion of the project. The participants reviewed a draft of the draft users manual, provided weights for the nine indicators in HRF, visited 12 sites and assessed driver expectancy and information-system deficiencies through the use of the forms developed within the project, and provided an estimate of the relative hazardousness of each of the 12 sites on a scale 0 to 100. These estimates, or ratings, of site hazardousness were to be based on information generally available to safety-program officials (and furnished to the participants) but were to be independent of the specific procedures developed within the project for combining the various raw-data inputs. In fact, the site ratings were made after a field visit to the sites but before the participants were provided data on the subjective indicator ratings of their colleagues or the weights assigned to each indicator.

Because the accident-indicator data and objective non-accident-indicator data (volume/capacity ratio and sight distance, in this case, because collecting traffic conflicts and erratic-maneuver data was not feasible) are available and average ratings for the subjective non-accident indicators were obtained in the workshop, a number of comparisons of consistency among the indicators and the independent site ratings are possible.

Table 1 gives the IVs for each of the indicators, the HI values, and the group site ratings for each of the 12 study sites. Each IV was derived by transforming the indicator raw-score value to an IV through use of the appropriate scaling chart. Data for traffic conflicts and erratic maneuvers were not obtained. The HI values were computed by multiplying each IV by its respective weight, summing these products, and then dividing by the sum of the weights of the indicators used. Group site ratings were derived by averaging the individual ratings assigned by the 16 workshop participants. The weights assigned to the indicators are as follows:

Indicator	Weight	Indicator	Weight
Number of accidents per year	14.5	Volume/capacity ratio	7.3
Accident rate	19.9	Sight distance	6.6
Accident severity	16.9	Driver expectancy	13.2
		Information deficiency	10.2

The correlation coefficients for all pairs of indicators are given in Table 2. For example, the correlation of accident rate to driver expectancy is 0.458.

FINDINGS AND CONCLUSIONS

The findings are based on analyses of data at 12 study sites. Because this is a relatively small sample size for the complexity of the problem, the results of the statistical analysis should be interpreted with caution, and the researcher should exercise caution in generalizing the results to other situations. Furthermore, for a given site the HI value is a weighted average of the individual IVs, and the significance of the correlation coefficient between the HI values and a particular indicator, or

Figure 1. Chart for converting number of accidents to indicator values.

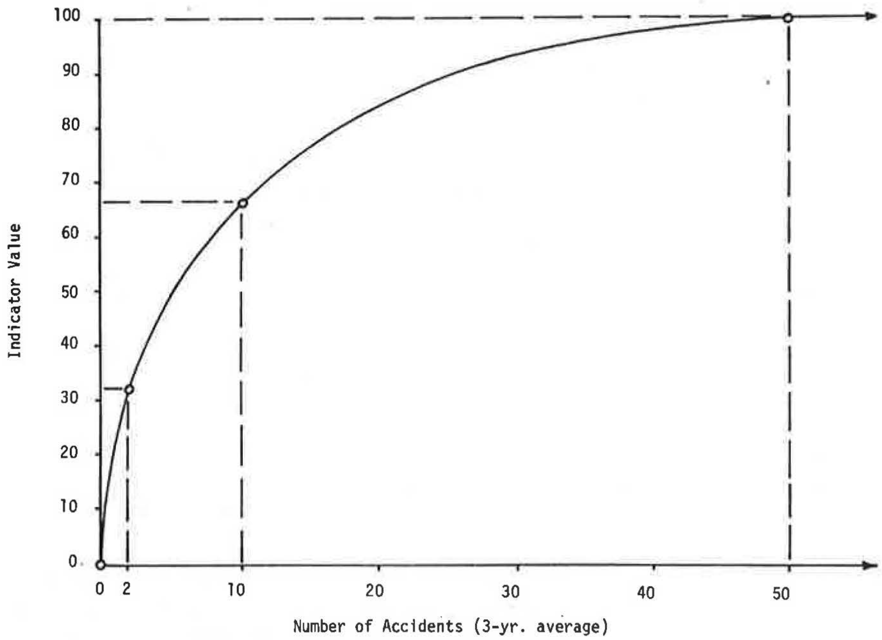

Table 1. Indicator values, HI values, and group site ratings.

Site Number	Indicator Value: Accidents per Year	Accident Rate	Accident Severity	Volume/ Capacity Ratio	Sight Distance	Driver Expectancy	Information Deficiency	HI Values	Group Site Ratings
22 to 48	39	11	42	45	0	25	30	28	22
22 to 97	48	63	66	38	33	86	79	61	80
22 to 98	46	55	68	47	42	41	45	51	46
22 to 99	68	22	44	38	0	51	55	42	38
36 to 4	59	49	70	22	0	37	47	47	42
36 to 6	61	48	63	32	3	38	36	45	43
36 to 26	39	20	69	32	9	41	55	40	33
38 to 18	42	14	43	41	9	44	53	35	22
38 to 31	50	34	60	31	33	60	52	47	57
38 to 32	52	26	41	36	2	21	26	31	32
38 to 37	72	57	44	37	15	39	52	49	56
50 to 1	52	51	61	67	0	56	63	53	58

Table 2. Correlation coefficients.

Indicator Value	Accidents	Accident Rate	Accident Severity	Volume/ Capacity Ratio	Sight Distance	Driver Expectancy	Information Deficiency	HI Values
Accident rate	0.424	–	–	–	–	–	–	–
Accident severity	-0.174	0.549	–	–	–	–	–	–
Volume/capacity ratio	-0.207	0.080	-0.146	–	–	–	–	–
Sight distance	-0.198	0.395	0.366	-0.017	–	–	–	–
Driver expectancy	0.001	0.458	0.406	0.137	0.405	–	–	–
Information deficiency	0.031	0.420	0.382	0.191	0.269	0.916	–	–
HI values	0.291	0.891	0.647	0.125	0.487	0.781	0.746	–
Group-site ratings	0.305	0.841	0.473	0.103	0.458	0.792	0.692	0.928

Figure 2. Rating form for driver expectancy problems.

Ratings:

0 -- Nothing unexpected or unusual at this location.

Actions required (if any) entirely consistent with driving strategy on approach.

Standard geometry, with pathway(s) for intended movement(s) clearly evident.

No interferences by other traffic likely.

1 --

2 --

3 -- Situation somewhat unexpected.

Driver must be alert, but should be able to respond adequately at "last minute" to most combinations of adverse circumstances.

Some initial confusion on intended path(s) or movement(s).

Interference from other traffic may create some degree of confusion or uncertainty for average driver.

4 --

5 --

6 --Very unusual situation; will "surprise" many unfamiliar drivers.

Driver required to make major change in driving tactics from those employed over past few miles.

At least a "near accident" almost expected if driver is even moderately inattentive; evasive actions likely to be required.

Intended pathway(s) confusing under fairly normal traffic or lighting conditions.

Other traffic, or lack of it, aggravates situation and misleads driver or deprives him of important cues.

Approach	Rating 0	1	2	3	4	5	6
A							
B							
C							
D							

group of indicators, must be interpreted in that light.

Findings

1. Correlation coefficients given in Table 2 indicate relatively low correlations between all pairs of individual indicators except for driver expectancy and information-system deficiencies. The low coefficients may be interpreted as an indication of the independence of the indicators. The higher correlation between driver expectancy and information-system deficiencies (0.916) indicates a strong relationship between the two subjective indicators. This relationship, in turn, means that reformulating the two indicator rating forms so that they better reflect two different aspects of hazardousness or perhaps combining the two forms into a single subjective indicator may be advisable; i.e., not much useful information is derived by including the second subjective indicator in the present form.

2. The high correlation between the accident rate and group site ratings (0.841) indicates that the safety experts place considerable emphasis on accident rate in estimating overall site hazardousness. (This emphasis is confirmed by their assigning the highest weight to the accident-rate indicator.)

3. Although the number-of-accidents indicator carries a higher weight in determining HI (as assigned by the workshop participants), the two subjective indicators correlate better with the group site ratings. This result may indicate that safety experts place a higher value on their subjective opinions, based on field examinations of the sites, than they express under the formalism of written relative weight assignments.

4. The group site ratings correlate highly with HI values (0.928). This result can be interpreted in at least two ways.

a. The two values are largely independent but, because they are both measures of true hazardousness, a high correlation coefficient is to be expected. In effect, the HRF procedure breaks down the assessment of hazardousness to a series of complementary value judgments. First the indicators were selected, then an appropriate format for the raw-data inputs was devised, the scaling charts were developed, and finally weights were assigned to each indicator. On the other hand, site rating is a single-value judgment and involves informal integration of raw data inputs by the individual. If this interpretation is accepted, one has the choice of employing HRF or the collective judgment of 16 safety experts. A secondary analysis indicates that the mean of the correlation coefficients between each individual's site ratings and HIs was 0.784; the range was from 0.560 to 0.874; therefore, an individual is not likely to assess the true hazardousness nearly as well as HRF.

b. The two values were not really arrived at independently; i.e., even though efforts were made to discourage the participants from employing the HRF concept in their assessment of the site hazardousness, they did use the workshop techniques in integrating the raw-data inputs. (Enough control was exerted to ensure that they did not use the scaling charts and numerical forms directly.)

5. The objective non-accident indicators did not correlate nearly so well with the group site ratings as the other classifications of indicators. This result may mean that appropriate data formats and scaling charts have not been formulated for the sight distance and volume/capacity ratio indicators, which have considerable intuitive appeal. In fact, these two indicators were selected from a large number of potential indicators during the early stages of this project.

Conclusions

1. The concept of HRF to assess relative hazardousness at spot locations appears to be valid, based on the results of the workshops and limited statistical analyses.
2. The concept was highly acceptable to the safety-program personnel who participated in the workshops where the procedures were discussed in detail and employed in the field. In fact, more than 90 percent of those attending the workshop rated the concept as very worthwhile and deserving of further development and testing. (This conclusion was derived from an end-of-workshop questionnaire administered by the Federal Highway Administration.)
3. Development of an effective, workable rating form for quantifying subjective, nonaccident indicators was accomplished by the project (Figure 2). In testing the rating forms for the 12 study sites, we observed that consistency among participants increased with familiarity, which indicates that the subjective indicators might be consistently quantified through the rating forms provided. Further, comparison of indicator weightings assigned at the beginning of the workshop with those assigned at the end of the workshop show that the weights for the subjective indicators were increased considerably after the participants had used the forms and procedures.
4. A users manual (2) developed within this project is a workable document. The workshop participants reviewed and used draft copies of the manual; only minor revisions were suggested, and these have been incorporated in the final draft.

PROGRAMMATIC APPLICATION

Collecting all the indicator data at all spot locations within a particular jurisdiction is not practical. Some of the indicators (particularly traffic conflicts and erratic maneuvers) require extensive data-collection efforts; use of any non-accident-related indicators requires a visit to the site, at a minimum.

Therefore, using the HRF methodology as a screening process is not feasible; the value of HRF lies in comparative assessment of hazardousness of sites of varying characteristics and with differences in the assessment data available or collectible. The methodology is particularly advantageous if one desires to include sites with and without accident histories in a single, comprehensive evaluation scheme.

A possible procedure for identifying hazardous locations and assessing their relative hazardousness in a specific jurisdiction is as follows:

1. Select the top 20 sites (an arbitrary number but perhaps twice the number for which treatment funds are likely to be available) on the basis of the accident-records system alone (this screening process can be accomplished by developing a computer program and format to provide partial hazardousness indexes on the basis of the first three terms of HRF),
2. Add 5 sites for which a number of citizen complaints have been registered,
3. Add 5 sites that the safety officials know to be hazardous even though few or no accidents have occurred (perhaps because of chance, new construction, or major change in operational characteristics),
4. Collect the non-accident-indicator data for these 30 sites, and
5. Compute the relative hazardousness of the 30 sites on the basis of the comprehensive HRF.

RECOMMENDED FUTURE RESEARCH

This research effort, although limited in scope and sample size, indicates that the concept of an HI scheme is valid and acceptable to the highway safety community. More than 90 percent of the participants introduced to the concepts and procedures at the two workshops indicated that they felt further development is warranted. The following specific areas are suggested for future research efforts.

1. Large-scale, long-range validation is needed. A possible procedure would be to rank a large number of sites in a given state by the HI and the priority-ranking scheme currently employed by that state. Analysis of the accident experience at those sites in the following 3 years should give an indication of which method most accurately defines future accident potential.
2. The scaling charts should be refined. Compilation and analysis of the distributions of raw-data scores to be encountered in the various indicators would permit development of scaling charts with more consistent meanings among indicators for given IVs. For example, a value of 67 could be assigned to the raw score, which is exceeded in only 1 percent of all cases encountered.
3. The traffic-conflict and erratic-maneuvers indicators should be developed. Giving adequate attention to traffic conflicts and erratic maneuvers was not possible within the constraints of this project. As a result, the IV curves derived for these indicators are the most suspect and are not backed by any use within the workshop.
4. HRF should be incorporated into safety-improvement programs. Although incorporation would call for the opening of a wider area of research than that of identification of hazardous locations, a methodology to assess the benefits of potential remedial treatments (in terms of reductions in HI) must be developed before the techniques developed within this project can be fully effective in the allocation of funds for safety-improvement programs.

ACKNOWLEDGMENTS

The research study on which this paper is based was funded by the Office of Research and Development, Federal Highway Administration, U.S. Department of Transportation. A final report (1) on the project describes the research methodology employed in developing and validating HRF. The specific charts, graphs, and computational procedures required for implementation are included in an accompanying users manual (2).

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Publication of this paper sponsored by Committee on Effectiveness of Operational Measures.

**Mr. Taylor and Mr. Thompson were with Pennsylvania State University when this research was performed.*