Safety Module for Highway Geometric Design

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Three safety criteria for evaluating curved roadway sections including transition sections were analyzed in order to address these important target areas for reducing accident frequency and severity. These criteria are (a) achieving consistency between successive design elements; (b) harmonizing design speed and operating speed, especially on wet pavements; and (c) providing adequate dynamic safety of driving. The above safety criteria constitute the core of the overall safety module proposed in this study for classifying road networks or roadway sections (or both), existing or planned, as good, fair, or poor designs. The evaluation process of the safety module, encompassing separate evaluation processes for each of the above safety criteria as well as for the combination of all three criteria, can be done manually by using the Geographic Information System known as "SPANS." By using discriminating colors or symbols with SPANS, the resulting separate or combined design safety levels can be easily recognized by the highway engineer. For the case study in this paper, the actual accident rates for the majority of the investigated roadway sections corresponded with the results of the overall safety module, or the results were at least on the safe side. Generally speaking, the results in this paper appear to be pointing in the right direction for evaluating roadway sections and networks using various safety criteria. The proposed procedure verifies for the first time that the evaluation of roadway sections or networks by an overall safety module is possible for design, redesign, rehabilitation, and restoration strategies.

Comparative analyses and statistical evaluations of accidents in Western Europe and the United States revealed that the rural road network system, which consists mainly of two-lane rural roads, represents between 60 and 70 percent of the total number of fatalities on both continents. It is estimated that half of these fatalities, or at least 30 percent, occur on curved roadway sections, primarily when drivers exceed the critical speed of a curve and thereby loose control. Based on this percent figure, it can be estimated that in 1990 about 13,000 persons in the U.S.A. and about 15,000 in the countries of the European Union lost their lives at curved sites, or in transition sections (*1*).

From the point of view of highway design and traffic safety engineers, it can be said, then, that curved roadway sections, including transition sections, represent one of the most important target areas for reducing accident frequency and severity. It should be noted that curved roadway sections are especially dangerous for young drivers between the ages of 15 to 25 years (*1*).

Based on these fatality figures, the need for a safety module appears to be a necessity. This safety module is defined by a classification system based on three individual safety criteria defined in the following, and should be able to analyze the relationships between highway geometric design, driver behavior, the accident situation, and driving dynamics on road networks or roadway sections, or both. Because of the complexity that exists between these issues, linking this safety module with existing data processing systems for highway engineering or with Geographic Information Systems (GIS), or both, is very significant.

BACKGROUND

During the period from 1940 to 1970, the only direct safety criterion in geometric design guidelines available to highway engineers in most Western European Countries and the U.S.A., was mainly directed toward evaluating the dynamic safety of driving, such as calculating for a given design speed, minimum radii of curves, super-elevation rates, necessary stopping sight distances, minimum radii of crest vertical curves, and so forth (*2,3*).

Since the 1960s, many experts have recognized the fact that abrupt changes in operating speeds lead to accidents on two-lane rural roads, and that these speed inconsistencies may be largely attributed to abrupt changes in horizontal alignment (*4–7*). Since the 1970s, two additional indirect design criteria related to traffic safety have been provided in the geometric design guidelines of some European countries. German, Swedish, and Swiss designers, for instance, are partially provided with design criteria to ensure design consistency between design elements, and to harmonize design speed and operating speed (*8–11*).

Research studies conducted over the past two decades have shown that, in the area of highway geometric design, three safety criteria should be addressed in order to gain direct or indirect safety advantages (*4–6,12–14*). These criteria are (I) achieving consistency between successive design elements; (II) harmonizing design speed and operating speed, especially on wet pavements; and (III) providing adequate dynamic safety of driving.

Criteria I to III were the subject of a number of reports, publications, and presentations by the authors (*11–20*). These investigations included (a) processes for evaluating horizontal design consistency and inconsistency between successive design elements, (b) processes for evaluating design speed and operating speed differences, and (c) processes for evaluating the differences between side friction assumed and side friction demand on curved roadway sections.

The above criteria will constitute the core of the overall safety module proposed in this study for (a) examining consistency or inconsistency between successive design elements, (b) examining the expected operating speed in relation to the design speed, and (c) examining the dynamic safety of driving on curved roadway sections. It is recommended that road networks or roadway sections (or both), existing or planned, be evaluated by the safety module, mainly in relation to good, fair, and poor design practices.

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CRITERION I: ACHIEVING CONSISTENCY BETWEEN SUCCESSIVE DESIGN ELEMENTS

Achieving consistency in horizontal alignment, and thereby a consistent operating speed, is an important, safety criterion to be considered in the design and redesign of two-lane rural highways or networks to avoid possible critical driving maneuvers, which may in turn lead to unfavorable accident risks (*17–20*).

In this connection, the 1984 AASHTO Policy on the Geometric Design of Highways and Streets (*21*) recommends the following:

- Consistent alignment always should be sought;
- Sharp curves should not be introduced; and
- Sudden changes from areas of flat curvature to areas of sharp curvature should be avoided.

Therefore, a method for identifying consistencies or inconsistencies between successive design elements is, without a doubt, of great importance for enhancing traffic safety. Research that evaluated the impact of design parameters (degree of curve, length of curve, super-elevation rate, lane width, shoulder width, sight distance, gradient (up to 6 percent), posted speed, and traffic volume on a data base (the present data bases contain road sections with gradients up to 6 percent and traffic volumes between 500 and 10,000 vehicles per day) of 322 two-lane curved highway sections in New York State demonstrated that the most successful parameter in explaining much of the variability in operating speeds (V85) and accident rates (ACCR) was the degree of curve (*12,14,15*). The relationship of operating speed-accident rate and degree of curve are quantified by the regression models presented in Table 1, and schematically shown in Figure 1(*a*) (*14*). Similar results were found in the Federal Republic of Germany (see Table 1 and Figure 1(*b*) (*8,22*). The German data base consisted of 204 two-lane rural curved highway sections.

For a better understanding, the following reading is conducted with respect to Figure 1(*a*) for U.S. conditions. For a curve with a degree of curve (DC) = 10° and a lane width (LW) = 12 ft, an operating speed (V85) = 50 mph, and an accident rate (ACCR) = 10.5, accidents per 106 vehicle miles may be expected.

Note that the relationships in Figure 1, with the exception of those in the upper part of Figure 1(*b*) between operating speed and degree of curve in the Federal Republic of Germany, are linear. Generally speaking, the results of both figures show a certain degree of similarity. It should be noted that the American accident rates are related to all accidents, whereas the German ones are related only to run-off-the-road accidents. This difference may explain the lower accident rate values in Germany. As the figures show, operating speeds decrease with increasing degree of curve, whereas accident rates increase with increasing degree of curve.

Based on a literature review and research experiences gained by the authors in the U.S.A. (*6,11,12,14–16*) and in Europe (*7,13,23*), the changes in operating speeds between successive design elements (Table 2) provide a reasonable and quantifiable classification system for differentiating good, fair, and poor design practices. The classification system is based largely on mean accident rates (*15,17*).

TABLE 1 Regression Equations of Operating Speeds and Accident Rates for the FRG and for the U.S.A.

FEDERAL REPUBLIC OF GERMANY

12 ft.: $V85 = 37.50 + 24.81 \cdot e^{(-0.145 \cdot DC)}$ ①

10 ft.: $V85 = 37.50 + 23.03 \cdot e^{(-0.190 \cdot DC)}$ ②

≥11 ft.: $ACCR^{*} = -0.29 + 0.37 \cdot DC; R^2 = 0.33$ ③

<11 ft.: $ACCR^{*} = -0.50 + 0.55 \cdot DC; R^2 = 0.35$ ④

(for ROR*-Accidents, only)

UNITED STATES OF AMERICA

12 ft.: $V85 = 59.75 - 1.00 \cdot DC; R^2 = 0.82$ ①

10 ft.: $V85 = 55.65 - 1.02 \cdot DC; R^2 = 0.75$ ②

12 ft.: $ACCR = -0.55 + 1.08 \cdot DC; R^2 = 0.73$ ③

10 ft.: $ACCR = -1.02 + 1.51 \cdot DC; R^2 = 0.30$ ④

(for all Accidents)

Legend:

V85 = Estimate of the operating speed, expressed by the 85th-percentile speed for passenger cars (mph),

DC = Degree of curve (degree/100 ft.), range: 0° to 25°,

R^2 = Coefficient of determination,

ACCR = Estimate of accident rate including all accidents (acc./10^6 vehicle-miles),

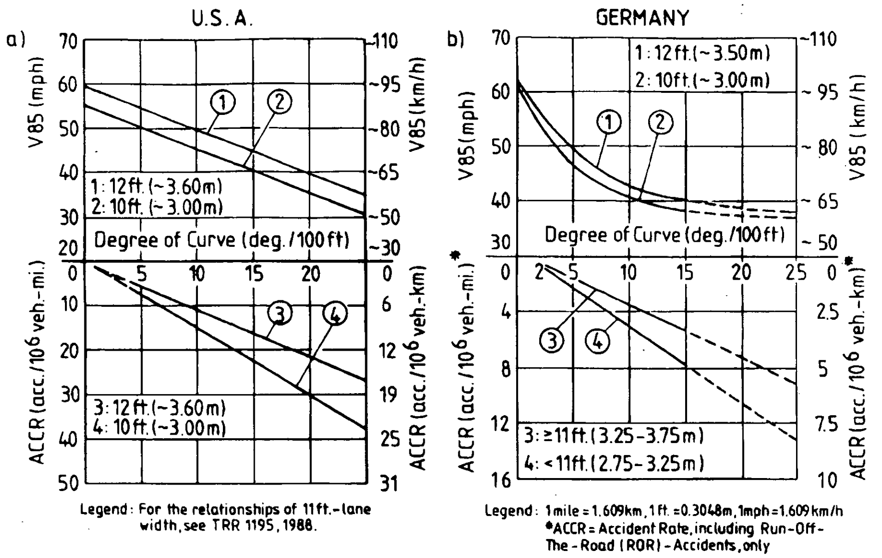
$ACCR^{*}$ = Estimate of accident rate including Run-Off-The-Road accidents (acc./10^6 vehicle-miles), only.

With respect to degree of curve, the 85th-percentile speed can be determined for every curve or independent tangent [for defining and classifying independent tangents, see the work of Lamm et al. (*16*)] by using Figure 1(*a*) for the U.S.A. and Figure 1(*b*) for Germany. By knowing the 85th-percentile speed of every design element, the speed differences between successive design elements (V85) can be calculated, and the observed road section or road network can then be classified as good, fair, or poor design. The speed changes corresponding to Criterion I are listed in Table 2 for different design levels.

Since for this study geographical information on road sections or road networks, such as design elements, operating speeds, and accidents, are available, a GIS appears to be the most suitable method for solving the complex relationships through the safety module proposed here. A Canadian program known as SPANS (*24–26*), developed by TYDAC Technologies, was used in this paper for analysis of the various safety criteria which make up the core of the overall safety module. The benefit of SPANS is that data of different formats and from different origins can be read in, analyzed, and displayed together. In this study, the display is made on a digitized map (see Figure 2) superimposed on the following with the results of the safety criteria. The case study reported in this paper is related to Ehingen County in Southwest Germany. Because of monetary constraints, the authors were unable to conduct similar case studies in the U.S.A.

It should be noted that the safety evaluation process of Criterion I can be performed manually for every two successive design elements. However, this is time consuming, not only with respect to this criterion, but also for Criteria II and III, as well as for the combination of all three criteria. Therefore, it is more efficient to use a GIS.

The results of Safety Criterion I, "Achieving Consistency Between Successive Design Elements," are shown in Figure 2, which was developed by SPANS. Originally, discriminating colors were used to easily recognize good, fair, and poor designs. Since colors cannot be presented in a TRR publication, discriminating



Legend: For the relationships of 11ft.-lane width, see TRR 1195, 1988.

Legend: 1mile = 1.609km, 1ft. = 0.3048m, 1mph = 1.609km/h
*ACCR = Accident Rate, including Run-Off-The-Road (ROR)-Accidents, only

FIGURE 1 Nomogram for evaluating operating speeds and accident rates as related to degree of curve for the U.S.A. and Germany (West).

symbols had to be applied. The roadway sections in Figure 2, graphically not interpreted by symbols, were not included in this investigation.

CRITERION II: HARMONIZING DESIGN SPEED AND OPERATING SPEED

All reviewed highway geometric design guidelines (*8–10,21,27,28*) indicate that the design speed should be constant along longer roadway sections. Research investigations (*4,5,13*) have shown that the driving behavior on curved roadway sections often exceeds by substantial amounts the design speed on which the original design of the road section was based, especially at lower design speed levels. Therefore, harmonizing design speed and operating speed is another important safety criterion that should be considered in the design, redesign, or rehabilitation processes (or all) of two-lane rural highways and networks.

To achieve this goal, the 85th-percentile speed (V85) of every independent tangent or curve must be tuned with the existing or selected design speed (V_d), according to the recommended design speed criteria shown in Table 2.

By calculating the differences between the 85th-percentile speed and the design speed, a curved roadway section design can then be classified as good, fair, and poor. If needed, the results of Safety Criterion II could be shown in a graphical presentation similar to Figure 2.

CRITERION III: PROVIDING ADEQUATE DYNAMIC SAFETY OF DRIVING

Skid resistance research investigations (*19,29–31*) have indicated that sufficient friction supply should be a main safety consideration in designing, redesigning, or resurfacing roadways. Glennon et al. (*32*) indicated that the probability of a highway curve becoming an accident black spot increases with decreasing pavement skid resistance (side friction factor).

Safety Criterion III examines whether or not assumed side friction factors for curve design, as proposed in the geometric design guidelines of the U.S.A. (*21*) and the Federal Republic of Germany (*33*), are sufficient for actual driving behavior on curves or curved sections. In this study, the American data base consists of 197 curved roadway sections located in New York state, and the German data base consists of 204 curved roadway sections located in Ehingen county in Southwest Germany (*22*).

To achieve the objective of Criterion III, a comparative analysis of side friction demand (f_{RD}) and side friction assumed (f_R) was carried out. The results are shown in Figure 3 for the U.S.A. and Germany. The assumed side friction was derived from actual geometric design data collected in the field (U.S.A.) or was obtained from the design data bank of Stuttgart (Germany).

By knowing design speed (or recommended speed), degree of curve, and super-elevation rate in the U.S.A. [refer to Lamm et al. (*20*) and the AASHTO policy (*21*)], or the design speed, radius of curve, and super-elevation rate in Germany [refer to the work of Steffen (*22*) and "Guidelines for the Design of Roads (RAL-L-1)" (*33*)], the assumed side friction factor was determined. Side friction demand was calculated from the same geometric design data, but was related to actual observed operating speeds (V85) on the curves under study (see Figure 1). Side friction assumed and demand were then calculated, based on the fundamental driving dynamic formulas for curve design (*20*):

$$f_{R(D)} = [(V)^2 \times (DC)/85{,}660] - e \qquad \text{(United States)}$$

$$f_{R(D)} = (V^2/15\,R) - e \qquad \text{(Germany)}$$

f_R, f_{RD} = side friction assumed/demand (−)

where

V = design speed (V_d) or operating speed (V85) [mph];
DC = degree of curve (degree/100 ft);
R = radius of curve (ft); and
e = super-elevation rate (ft/ft).

$$\text{Conversion: } DC = \frac{360°}{2\pi R} = \frac{5729.6}{R} \text{ (degree/100 ft).}$$

TABLE 2 Recommended Ranges for Design Practices for Criteria I and II for the Federal Republic of Germany and the United States of America

RECOMMENDED CONSISTENCY CRITERIA (FRG and U.S.A.)

CASE 1 (GOOD DESIGN):

Range of change in operating speed: $\Delta V85 \leq 6$ mph (10 km/h).

For these road sections, consistency in horizontal alignment exists between successive design elements, and the horizontal alignment does not create inconsistencies in vehicle operating speed.

CASE 2 (FAIR DESIGN):

Range of change in operating speed: $6 \text{ mph} < \Delta V85 \leq 12$ mph (20 km/h).

These road sections may represent at least minor inconsistencies in geometric design between successive design elements. Normally, they would warrant traffic warning devices, but no redesigns.

CASE 3 (POOR DESIGN):

Range of change in operating speed: $\Delta V85 > 12$ mph (20 km/h).

These road sections have strong inconsistencies in horizontal geometric design between successive design elements combined with those breaks in the speed profile that may lead to critical driving maneuvers. Normally, redesigns are recommended.

RECOMMENDED DESIGN SPEED CRITERIA (FRG and U.S.A.)

CASE 1 (GOOD DESIGN):

$V85 - V_d^* \leq 6$ mph (10 km/h).
No adaptions or corrections are necessary.

CASE 2 (FAIR DESIGN):

$6 \text{ mph} < V85 - V_d \leq 12$ mph (20 km/h).
Superelevation rates must be related to V85 to ensure that side friction assumed will accomodate to side friction demand.

CASE 3 (POOR DESIGN):

$V85 - V_d > 12$ mph (20 km/h).
Normally, redesigns are recommended.

$^*V_d$ = Design Speed, V85 = 85th-percentile Speed

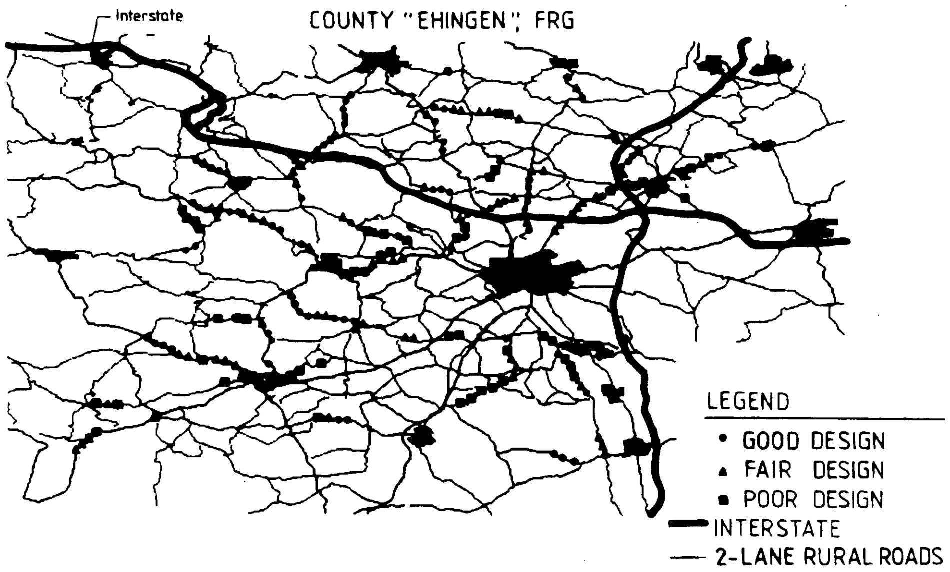


FIGURE 2 Digitized map of the road network of the county "Ehingen," FRG [30] results of criterion I.

The relationships of side friction assumed and demand, and degree of curve are quantified by the regression models shown in Table 3(*a*) and graphically presented in Figure 3.

A comparison of the relationships in the U.S.A. and Germany (Figure 3) clearly indicates that, in both countries, the points at which the curves for side friction assumed and demand intersect fall between 5 and 6 degrees. These values correspond to radii of curve between 290 and 350 m (960 to 1150 ft).

The curves for side friction demand are highly comparable between the U.S.A. and Germany. With respect to side friction assumed, the values in the U.S.A. are higher than in Germany; this is the result of lower friction factors in the German guidelines than in the American guidelines (*19*). Furthermore, the figures show that, in both countries, the side friction assumed is higher than the side friction demand on curves up to 5 degrees (Germany) and up to 6 degrees (U.S.A.). For degrees of curve greater than these values, the figures show that (a) the side friction demand is higher than the side friction assumed, and (b) the gap between side friction demand and assumed increases with increasing degree of curve. That means that, from a driving dynamic safety point of view, beginning with the point at which the two curves intersect between 5 and 6 degrees, the probability of critical driving maneuvers increases with increasing degree of curve.

On the basis of the recommendations for good, fair, and poor design practices, it is clear that the point of intersection should lie in the range of fair design practices. In the case of good design practices, side friction assumed exceeds side friction demand, whereas in the case of poor design practices, side friction demand exceeds side friction assumed.

Again, on the basis of recommendations for good, fair, and poor design practices, it can be said, as a first approximation, that (a) a difference Δf_R of $+0.02$ to -0.02 between side friction assumed and demand lies in the range of fair design practices [(Figure 3(*a*)]; (b) a difference greater than $+0.02$ lies in the range of good designs, and (c) a difference less than -0.02 lies in the range of poor designs [see Table 3(*b*)]. Recent studies conducted in Germany to examine

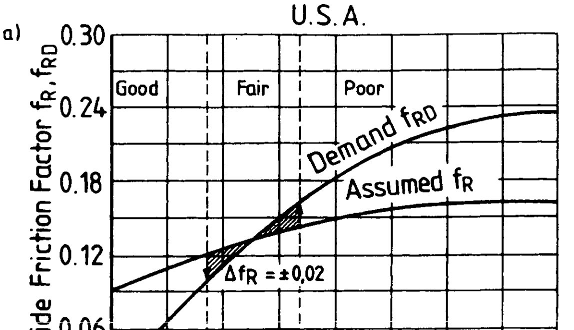


FIGURE 3 Relationship between side friction assumed/demand and degree of curve for the U.S.A. and Germany.

TABLE 3 Regression Equations for Side Friction Assumed/Demand and Recommended Ranges for Good, Fair, and Poor Design Practices (Criterion III)

FEDERAL REPUBLIC OF GERMANY
$f_R = 0.078 + 7.95 \cdot 10^{-3} \cdot DC - 2.9 \cdot 10^{-4} \cdot (DC)^2$; $R^2 = 0.408$ $f_{RD} = 0.023 + 2.02 \cdot 10^{-2} \cdot DC - 4.7 \cdot 10^{-4} \cdot (DC)^2$; $R^2 = 0.679$
UNITED STATES OF AMERICA
$f_R = 0.092 + 8.10 \cdot 10^{-3} \cdot DC - 2.3 \cdot 10^{-4} \cdot (DC)^2$; $R^2 = 0.887$ $f_{RD} = 0.014 + 2.25 \cdot 10^{-2} \cdot DC - 5.7 \cdot 10^{-4} \cdot (DC)^2$; $R^2 = 0.864$
Legend: f_R = assumed Side friction f_{RD} = demand Side friction   DC = Degree of curve (deg/100 ft.), range: 0° to 20° R^2 = Coefficient of determination.

RECOMMENDED DRIVING DYNAMICS CRITERIA (FRG and U.S.A.)

CASE 1 (GOOD DESIGN):

$\Delta f_R \geq + 0,02$

No adaptions or corrections are necessary.

CASE 2 (FAIR DESIGN):

$+ 0,02 > \Delta f_R \geq - 0,02$

Superelevation rates must be related to V85 to ensure that side friction assumed will accommodate to side friction demand.

CASE 3 (POOR DESIGN):

$\Delta f_R < - 0,02$

Normally, redesigns are recommended.

Δf_R = difference between side friction assumed and side friction demand (see Figure 3a)

in detail the ranges of Safety Criterion III, as based on larger data bases, led to slight changes with respect to the ranges in Table 3 (*34*).

If requested, the results of Safety Criterion III ("Providing Adequate Dynamic Safety of Driving") could be also shown schematically similar to Figure 2.

COMBINATION OF CRITERIA I TO III FOR AN OVERALL SAFETY MODULE

The results of Criteria I to III (see, for example, Figure 2 for Criterion I) and the recommendations provided in Tables 2 and 3(*b*) indicate the existence of roadway sections that exhibit different design safety levels. The reason for this is that each of the discussed safety criteria does represent a separate safety aspect in highway geometric design. It may happen, for example, that the transition section between a tangent and a curve would correspond to poor design, whereas the design speed or the assumed side friction factor, or both, for the observed curve are well in order, or vice versa.

As an overall safety evaluation procedure, the previously discussed three safety criteria will be combined here in an overall safety module. Table 4 shows the classification system of the safety module, as based on Criteria I to III, for good, fair, and poor design levels. All three criteria are weighed equally. With one exception, at least two of the three criteria must correspond in the decision process to assess the design safety level. The developed procedure represents the current state of knowledge. Changes or improvements concerning the boundaries of the safety module may be achieved through the use of larger data bases.

TABLE 4 Classification of the Safety Module for Good, Fair, and Poor Design Levels

CLASSIFICATION	
by Criteria I to III	of the Safety Module
1	2
3 × good 2 × good / 1 × fair 2 × good / 1 × poor	GOOD DESIGN
3 × fair 2 × fair / 1 × good 2 × fair / 1 × poor 1 × good / 1 × fair / 1 × poor	FAIR DESIGN
3 × poor 2 × poor / 1 × good 2 × poor / 1 × fair	POOR DESIGN

Figure 4 schematically shows (using discriminating symbols) the results of the overall safety module for a case study in Ehingen County in Southwest Germany for good, fair, and poor designs. The sections without symbols in the figure were not subject to analysis.

The discussed procedure indicates that the evaluation process of roadway sections or networks by an overall safety module is possible, and that this safety module includes the three discussed quantitative safety criteria in geometric highway design for the first time.

To determine the degree of agreement between the developed safety module and actual accident rates on the observed roadway sections, a 3-year case study was conducted. The results are shown in Figure 5. As can be observed from this figure, the circular symbol, which represents full agreement, and the triangular symbol, which represents a lower accident rate than the safety module would predict, predominate. Thus, it can be concluded that in the majority of investigated road sections the actual accident rate corresponds well with the developed safety module, or the results are at least on the safe side. Only in rare cases of the quadratic symbol is the actual accident rate higher than the predicted one.

Despite the presence of erroneous cases, the developed module does provide sound results. It should be noted that in the field of accident research the relationships are not simple or direct ones, but rather are very often complex, and changes in accidents are often the result of the interplay of many factors besides the investigated three safety criteria. A GIS, such as SPANS, plays a very important role here.

The results of the overall safety module, which includes for the first time the three quantitative safety criteria in geometric highway design, appear to be pointing in the right direction for evaluating roadway sections or networks with respect to design, redesign, rehabilitation, and restoration strategies.

Note that safety strategies, such as the ones developed here, have been known for decades in other civil engineering fields such as structural engineering, water resources engineering, and so forth.

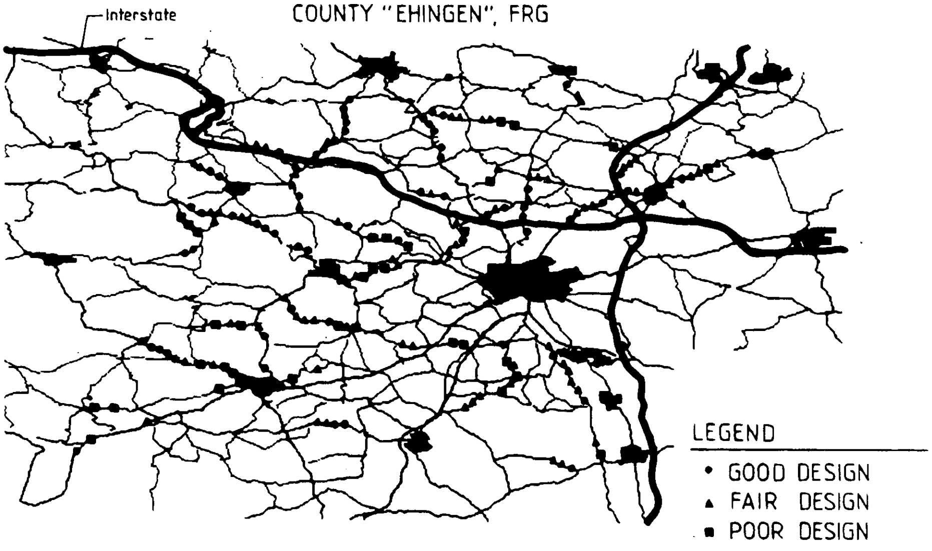


FIGURE 4 **Results of the overall safety module.**

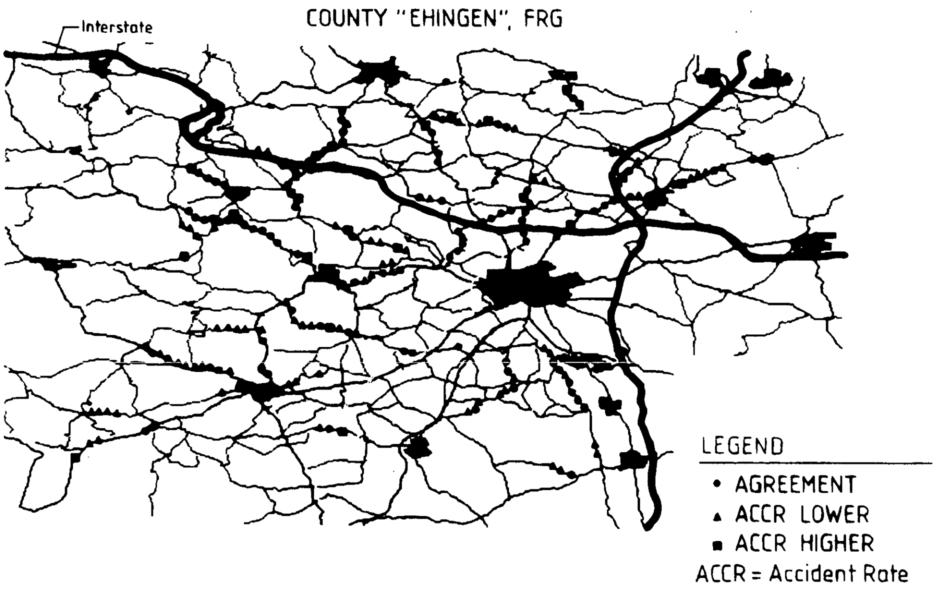


FIGURE 5 **Level of agreement between safety module and actual accident rate.**

CONCLUSION

Three safety criteria for evaluating curved roadway sections, including transition sections, were analyzed to address these important target areas for reducing accident frequency and severity.

Criterion I: Achieving Consistency in Horizontal Alignment

Research studies conducted in the U.S.A., which evaluated the impact of design parameters and traffic volume, demonstrated that the most successful parameter in explaining much of the variability in operating speeds and accident rates was the degree of curve. Similar results were found in the Federal Republic of Germany. In both countries, operating speeds decrease with an increasing degree of curve, whereas accident rates increase with an increasing degree of curve. Based on these findings, changes in operating speeds between successive elements, based largely on mean accident rates, were developed to classify highway sections, networks, or both.

Criterion II: Harmonizing Design Speed and Operating Speed

To achieve this goal, the 85th-percentile speed of every independent tangent or curve must be tuned with the existing or selected design speed according to the recommended design speed ranges.

Criterion III: Providing Adequate Dynamic Safety of Driving

This criterion examines whether or not the assumed side friction factors for curve design in the highway geometric design guidelines of a given country are sufficient for actual driving behavior in curves or curved sections.

For both the U.S.A. and the Federal Republic of Germany, this study has found that the curves for side friction assumed and demand intersect, and that the point of intersection lies in the range of fair design. In the case of good design practices, side friction assumed exceeds side friction demand, whereas in the case of poor design practices, side friction demand exceeds side friction assumed.

The above safety criteria constituted the core of the overall safety module proposed in this study for classifying road networks and roadway sections–or both–existing or planned, as good, fair, or poor designs. Criteria I to III can be applied manually or by using the GIS known as SPANS. By using discriminating colors or symbols (as in this paper), the designer could easily and immediately recognize different design safety levels for each individual criterion.

For a general evaluation process, the three safety criteria were combined (equally weighed) in an overall safety module.

The developed module represents the current state of knowledge. Changes or improvements concerning the boundaries of the safety module can certainly be achieved through the use of larger data bases. Again, by using discriminating symbols with SPANS, the designer could easily apply the overall safety module and immediately recognize different safety levels, this time representing the combined impact of the three safety criteria.

To determine the degree of agreement between the results of the developed safety module and actual accident rates on observed roadway sections, a case study was conducted. For the majority of the investigated roadway sections, the actual accident rate corresponds well with the results of the developed safety module, or the results were at least on the safe side. In very few cases, the actual accident rate was higher than the predicted one.

In closing, the results of the overall safety module, at least based on the investigated case study, appear to be pointing in the right direction for evaluating roadway sections and networks with respect to design, redesign, rehabilitation, and restoration strategies.

Such a safety evaluation process, based on the discussed three individual safety criteria (combined or not combined in a safety module), should be a substantial part of modern highway geometric design guidelines.

But further accident research is needed to establish reliable boundaries for Safety Criterion III, as well as to assign possible individual weights to the three safety criteria for combining them in a safety module.

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