Procedure for Detecting Errors in Alinement Design and Consequences for Safer Redesign

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A procedure for evaluating the horizontal alinement of two-lane rural roads on the basis of three individual safety criteria is introduced. On the basis of these criteria, design practices are classified into three groups: good, fair, and poor. The procedure can be used to identify potential safety errors in new designs already in the planning stages as well as to detect safety deficiencies in existing roadways. To be effective, the safety evaluation process must be integrated into the modern highway design tools available to highway design engineers of today. These tools consist of computer-automated design (CAD) systems for highway geometric design and normally contain a component for the design of horizontal alinement. To incorporate the safety evaluation process into the horizontal alinement component of a commonly used CAD system, a subprogram for safety computations was developed on the basis of the three individual criteria. The safety evaluation process provides a future assessment of horizontal alinement on the basis of quantitative criteria. Consequently, safety impacts can be included along with the normally considered local, environmental, esthetic, and economic aspects in making decisions on a project. A case study of an existing two-lane rural roadway in southwestern Germany is included. On the basis of safety criteria, sections of the road have poor design. The safety evaluation procedure is applied to the identification of safer redesigns. In a first step for an economical redesign, still sections with fair design practices are included. In a second step for a redesign of an overall sound curvilinear alinement, only good design practices exist.

A safety evaluation process that allows highway engineers to evaluate horizontal alinements is presented in this paper. The safety criteria are based on evaluations of complex data systems developed by the authors in cooperation with Elias M. Choueiri of the State University of New York for the United States (*1,2*) and Germany (*3,4*). Because of the available data bases, the system is applicable only for two-lane rural roads with longitudinal grades of up to 6 percent and annual average daily traffic (AADT) values of 10,000 vehicles per day.

The study is a continuation of the paper of Lamm and Smith in this Record. The model consists of three safety criteria. Safety Criterion I (achieving consistency in horizontal alinement) and Safety Criterion II (harmonizing design speed and operating speed) were already discussed thoroughly in the paper mentioned above. Safety Criteria I and II are based on operating or design speed changes between successive design elements and for single design elements to achieve good designs (for example, by sound curvilinear alinement), to classify fair designs, and to detect poor designs. The quantitative ranges for the safety evaluation process are given in Figure 1.

To avoid repetitions, it is recommended that the reader who is interested in more detailed information about the mathematical background, analysis, development, and assessment of the ranges for Safety Criteria I and II consult the paper by Lamm and Smith in this Record and the corresponding references.

A third safety criterion regarding relevant driving dynamic aspects was basically developed previously (*5*). In this connection it was shown that the side friction factors for curve design assumed in the geometric design guidelines of AASHTO (*16*) and the German Road and Transportation Research Association (*7*) for different design speeds are often exceeded by those demanded by the 85th percentile speeds under realworld conditions. These situations begin with degrees of curve of more than 5 to 6 degrees and correspond to radii of curve of less than 350 to 290 m (1,150 to 950 ft). Furthermore, it can be proved that, in the case of good design practices, the assumed side friction exceeds the demanded side friction. In the case of poor design practices, the demanded side friction exceeds the assumed side friction.

How the geometrically assumed side friction and the demanded side friction are derived for Safety Criterion III (providing adequate dynamic safety of driving) was discussed previously (*5*) with regard to degree of curve, operating speed, and accident rate.

A first synopsis incorporating all three safety criteria into an overall safety module for evaluating road networks was presented previously (*8*). For the application of the safety module, the ranges of the driving dynamic Safety Criterion III were finally established and are shown with insignificant modifications in Figure 1. By using a geographical information system (GIS) in connection with the developed safety module, the designer can immediately recognize different design safety levels (good, fair, poor) by discriminating colors or symbols at the PC screen or on printouts (*8*).

Such a procedure is ideal for obtaining a fast overview of the safety situation of whole or partial road networks, including the combined results of all three so far equally weighted safety criteria. Although the overview is useful, corrective action by the highway engineer requires knowledge of the specific deficiencies for each highway section. Therefore, in cases of new designs, redesigns, and resurfacing, restoration, or rehabilitation or (RRR) projects of specific roadway sections, all three safety criteria must be analyzed individually.

On the basis of the different safety aspects, the results of the three safety criteria in Figure 1 do not always agree. For example:

- A curved section may be classified by Safety Criteria I and II as "good." That would mean the absolute differences between

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CRITERION	GOOD	FAIR	POOR
	DESIGN PRACTICES		
I	$\lvert V85_i - V85_{i+1} \rvert \le 10$ km/h	10 km/h < $\lvert V85_i - V85_{i+1} \rvert \le 20$ km/h	20 km/h < $\lvert V85_i - V85_{i+1} \rvert$
II	$\lvert V85 - V_d \rvert \le 10$ km/h	10 km/h < $\lvert V85 - V_d \rvert \le 20$ km/h	20 km/h < $\lvert V85 - V_d \rvert$
III	$0 \le f_{RA} - f_{RD}$	$-0{,}02 \le f_{RA} - f_{RD} < 0$	$f_{RA} - f_{RD} < -0{,}02$

V85 = 85th Percentile Speed ; V_d = Design Speed
f_{RA} = Side Friction "Assumed" ; f_{RD} = Side Friction "Demand"

FIGURE 1 Ranges of safety criteria for good, fair, and poor design practices.

the 85th percentile speeds of preceding and succeeding design elements (Safety Criterion I) as well as the absolute difference between the 85th percentile speed and the design speed in the curve itself (Safety Criterion II) would fall into the range of ≤10 km/hr. Despite these results, Safety Criterion III may reveal driving dynamic deficiencies, since the superelevation rate in the observed curve is too low, for example; or

- It is possible that Safety Criterion I represents a good safety level for a longer roadway section, whereas Safety Criterion II reveals that fair or even poor design practices exist because of differences between expected 85th percentile speeds and the selected design speed that are too large (Figure 1).

Because of these discrepancies, an individual examination of specific roadway sections on the basis of the three safety criteria makes more sense, contrary to the evaluation of whole road networks by a combined safety module (*8*). This is especially true when the highway engineer has information about the planned or the existing highway, the safety quality (good or fair) to be strived for, and local conditions and available funds. For example, the designer may be able to improve the alinement, in the case of a failure of only one safety criterion, in such a way that the safety deficiency can be eliminated without affecting the other criteria and their impacts on the design.

Note that besides the normal case of a speed that is too low, it is quite possible to select a design speed that is too high. In such a case, the superior goal of safety is of minor importance. However the function of the highway in the road network or the desired traffic quality may cause the design to be uneconomical (see the papers by Lamm and Smith and Lamm et al., this Record).

To recognize safety errors in new designs, redesigns in the planning stages, or designs for necessary safety improvements for RRR projects before implementation, modern planning tools must be made available to the highway engineer. Complex data processing systems must be part of today's planning tools. They are able to support the design and construction of roads beginning with environmental compatibility studies (see paper by Lamm et al., this Record); this is followed by the design processes and continues through the construction phases. Therefore, it would be of great advantage to incorporate an additional subprogram into such a planning system based on the safety evaluation processes of the three individual safety criteria discussed previously. This would allow safety errors in the alinements of new designs and deficiencies in the alinements of existing roadways to be detected and eliminated concurrently with the design or redesign processes.

According to the call for papers for the conference session on which this Record is based, the most recent AASHTO geometric design policy should be addressed. New developments not cited in the Green Book (*6*) are not included. It is extremely difficult, especially for foreign authors, to stay informed about new developments until they are included in the national standards.

FUNDAMENTALS FOR COMPUTER-AIDED HIGHWAY DESIGN

Modern data processing systems for traffic routes should consist of at least the following components:

- Environmental compatibility study,
- Geometric surveying,
- Horizontal alinement,
- Vertical alinement,
- Cross section,
- Graphical layouts (as direct derivations of the computations),
- Three-dimensional evaluation (perspective view), and
- Different construction components.

For the present study the horizontal alinement component is of special interest. Programs for the numerical computation of road axes for horizontal alinements have existed since the 1960s and were first developed by IBM (*9,10*). These programs were related to mainframe computer applications that computed whole systems of roads and interchanges on the basis of descriptive data by using explicitly provided input data. The input data, coordinates of certain fixed points, and basic information about circular and transition curves according to a predesign of the horizontal alinement are provided by the highway engineer and are based on preliminary work on location. The computer then prints out all necessary numerical design data for establishing the future road axes.

However, numerical printouts are difficult to work with, and examination of the results is nearly impossible. Therefore, modern data processing systems have the capability of providing information at both the numerical level and the graphical level, which allows for the immediate change of computational results into graphical layouts or vice versa at the PC screen or on printouts, allowing exact computations and information-control graphics to stand side by side (*11*).

The horizontal alinement component of the commonly used German computer-aided design (CAD) system was selected (*12*) for the possible integration of the new subprogram for evaluating horizontal alinement with the three individual safety criteria. With this component the axes of horizontal alinement can be computed and displayed on a PC screen for various alternatives. This is important not only for studying topographical and local conditions (see, for example, the development of a low-conflict corridor in the paper by Lamm et al. in this Record) but also for making the necessary alinement changes required by the safety evaluation process. Furthermore, all necessary design data for the axis are available in a computer-justified (digital) mode for future processing steps.

It makes sense, therefore, to develop an additional subprogram for the new safety evaluation process on the basis of the three individual criteria and to integrate this into the horizontal alinement component of an overall CAD system. Figure 2 shows the iterative flow of information. In this way the future axes of a specific roadway section could be evaluated automatically. For such a system it is not relevant whether the descriptive input data result from a new design or are related to an existing roadway.

DEVELOPMENT OF A SUBPROGRAM FOR SAFETY CALCULATIONS

Because the subprogram for safety calculations needs only the information about the geometry of the road in a computer-justified (digital) mode, this subprogram can be integrated into any CAD system for highway geometric design. The only assumption is that the system provides a clear data interface for the output of the horizontal design data in digital mode. The flow chart in Figure 2 shows that the input of the descriptive design data is possible for planned or existing roadways. As input data, the safety computation subprogram needs the geometric output data and the elements of the horizontal alinement component, which are as follows:

- Kind of design elements (curve, clothoid, tangent),
- Length of elements,
- Parameters of design elements (radius of curve, parameter of clothoid), and
- Stations.

For the safety computations, the following input data are required:

- Design speed (V_d),
- Pavement (lane) width (LW),
- Superelevation rates (e), and
- Length of independent tangents (TL) (*13*).

Tangents must be defined as *independent* and *nonindependent*. Independent tangents may cause critical changes in the operating speed profile [85th percentile speed (V_{85})] and must be regarded in the design process, whereas nonindependent tangents do not need to be regarded. In this connection the consideration of tangents as dynamic (speed-dependent) elements similar to curves is very important for the evaluation of (speed) transitions between successive design elements [for example, curve to tangent or curve to curve (*13*)].

On the basis of these input data, the relevant design parameters, degree of curve (DC) for the United States and curvature change rate (CCR) for Germany, can be determined (see paper by Lamm and Smith, in this Record). These design parameters are important for estimating the expected V_{85} and the values for side friction assumed (f_{RA}) and side friction demand (f_{RD}) needed for the safety evaluation process shown in Figure 1. The mathematical equations for the relationships between these variables were previously developed by the authors for the United States and Germany. [Readers who are interested in a detailed discussion of the derivations of those equations and the assessments for the design ranges of the safety criteria should consult previous reports for the United States (*1,2,5,8,13–15*; see also the paper by Lamm and Smith, in this Record) and Germany (*3,4,16,17*)].

All pertinent equations, as well as the ranges for the three safety criteria in Figure 1, for evaluating good, fair, and poor design practices are contained in the subprogram safety computations (Figure 2). The process described in Figure 2 is an iterative one. Therefore, an automatic safety evaluation process with regard to the input data listed above is possible for planned or existing road axes.

If this evaluation process does not reveal errors or deficiencies, the following highway geometric design procedure can be pursued. If one or more of the three individual criteria are not fulfilled, however, various design alternatives are evaluated until a satisfactory road axis is established. The procedure will be used in a case study in Germany in the following section and is based on the German assumptions for the relationships discussed earlier (*4,16,17*; see also Lamm and Smith, this Record). Therefore, Figures 3 and 4 in the paper by Lamm and Smith, this Record, are relevant to this case study.

SAFETY EVALUATION FOR THE CASE STUDY

The existing horizontal alinement in Figure 3(*a*) shows a two-lane rural state route in southwestern Germany in the plain of the Rhine River. Accident analysis indicates a high accident frequency and severity at Element 2. The longitudinal grades are less than 2

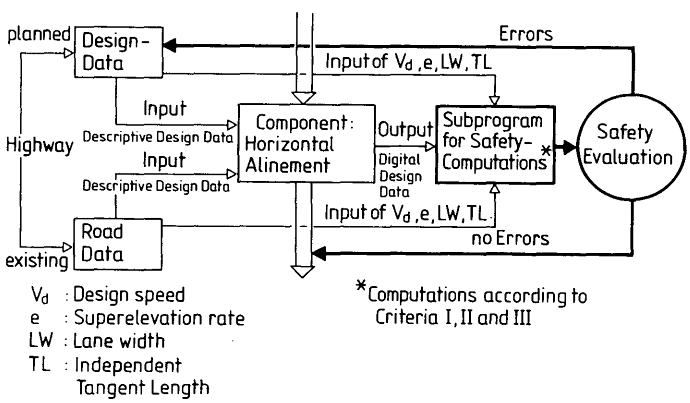

FIGURE 2 Flowchart for highway geometric design with special regard to a safety evaluation process.

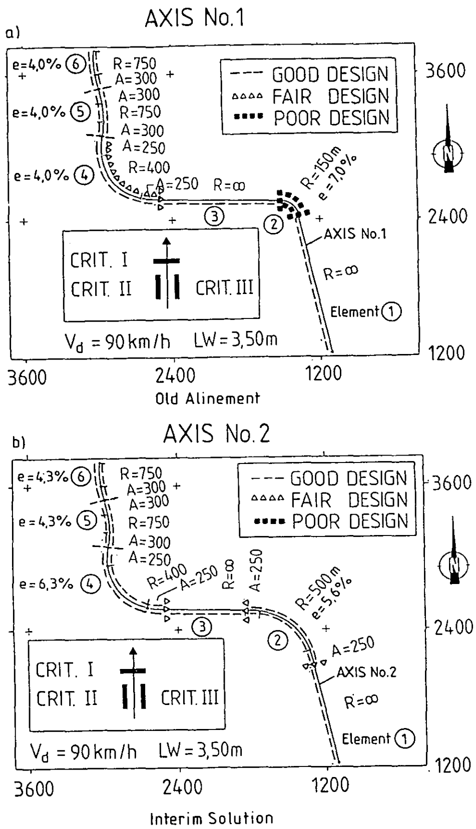

FIGURE 3 Graphical presentation of the safety evaluation process.

percent and the AADT values corresponded to 7,200 vehicles per day in 1991. The old alinement should be improved, and the new alinement should represent the level of good design practice for all three individual safety criteria. Between the stages old and new an interim solution should also be planned in the event that federal funds cannot be provided in full.

Old Alinement

Figure 3(*a*) shows the existing old alinement (Axis No. 1), which was designed in the 1930s. The lane width is 3.50 m, and the original design speed is unknown. A serious accident situation exists in the curve of design element 2 (R = 150 m), which is situated between two long independent tangents (Elements 1 and 3). Sixteen run-off-the-road type accidents occurred from 1989 to 1991; these included 3 fatalities, 6 seriously injured individuals, and 13 lightly injured individuals. The main accident cause, recorded by the police, was "improper speed estimation" in the transition sections and in the curve itself. The main goal, therefore, had to be a reduction in accident severity by appropriately redesigning the old alinement. It is interesting that for the long tangent Sections 1 and 3, no relevant accidents (for example, because of passing vehicles) were recorded.

With the exception of Element 2, all the other curved roadway sections (Elements 4 to 6) corresponded at least to a design speed of 90 km/hr according to the German *Guidelines for the Design of Roads* (*7*). Consequently, it was decided to select 90 km/hr as the design speed to keep the reconstruction costs as low as possible.

The descriptive design data for the old alinement, the design speed of V_d = 90 km/hr the lane width (LW) = 3.50 m, the measured superelevation rates, and the lengths of the independent tangents (Elements 1 and 3) of the old road represented the input data. These data are used for the horizontal alinement component and for the corresponding safety computation subprogram discussed previously and presented in Figure 2.

The output data for the safety evaluation process are listed in numerical mode in Table 1. Table 1 shows the point, made earlier in this paper, that numerical data are difficult to describe and those listings—as valuable as they are for an exact evaluation overview—may be too complex for fast and easy understanding. An analysis of the critical curve (Element 2) indicates that the absolute V_{85} differences between Elements 1 and 2 as well as between Elements 2 and 3 exceed 20 km/hr and reveal poor design according to the ranges of Safety Criterion I in Figure 1. The same is true for Safety Criterion II regarding the absolute difference between V_{85} and design speed and for the driving dynamic Safety Criterion III regarding the difference between the assumed side friction (f_{RA}) and the demanded side friction (f_{RD}) for curve Element 2. (Note that the V_{85} computed automatically by the subprogram on the basis of the CCR values could have been determined from Figure 4 of the paper by Lamm and Smith, this Record, in the case of a manual safety evaluation process.)

A graphical presentation of the numerical results in Table 1 was developed and is presented in Figure 3(*a*); the results can be used at the PC screen or printed out. In this way the different design levels, based on individual Safety Criteria I to III, can be recognized visually by using discriminating colors or symbols. For a better understanding it should be mentioned that the colors or graphical symbols (as in the present case) for Safety Criterion I are arranged vertically to be the road axis, whereas the symbols for Safety Criterion II are located on the left side and those for Safety Criterion III are located on the right side, parallel to the axis.

By evaluating the graphical layout of Figure 3(*a*) it can be recognized at once that the critical curve (element 2) corresponds to poor design practices regarding all investigated safety criteria. This result supports the previous statements about the serious accident situation at this curve site.

In addition, it can be seen that the curve with the radius of 400 m (Element 4) can be evaluated only as a fair design for Safety Criterion I when considering the transition between Elements 3 and 4. Fair design practice could also be noticed for Safety Criterion III in this curve (compare Table 1). The accident situation at this site consisted of one serious, three light, and two property damage accidents during the time period investigated, which supports the findings of the safety evaluation process.

All the other road sections of the existing alinement reveal good design practices and do not need any changes in future redesigns.

Interim Solution

A fair design practice as the minimum requirement for an interim solution was requested for the present case study to keep down the reconstruction costs. Therefore, Figure 3 of the paper by Lamm and Smith, in this Record, was referred to. Related to the critical radius of the curve (Element 2), it was found that to com-

TABLE 1 Numerical Output Data for the Safety Evaluation Process (Old Alinement)

AXIS : 1

ELEM. : 1

RADIUS	STATION FROM	STATION TO	CLOTHOIDS BEFORE	CLOTHOIDS BEHIND	CCR	V85	SUPER-ELEVATION
0	0.00	1190.42	0.00	0.00	0.00	99.70	2.5

CRIT. II : $|V85_1 - V_d|$ = 9.70 => GOOD DESIGN

Transition 1-2 for Crit. I : $|V85_1 - V85_2|$ = 32.98 => POOR DESIGN

ELEM. : 2

RADIUS	STATION FROM	STATION TO	CLOTHOIDS BEFORE	CLOTHOIDS BEHIND	CCR	V85	SUPER-ELEVATION
-150	1190.42	1390.00	0.00	0.00	424.67	67.32	7.0

CRIT. II : $|V85_2 - V_d|$ = 22.68 => POOR DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = -0.09 => POOR DESIGN

Transition 2-3 for Crit. I : $|V85_2 - V85_3|$ = 32.98 => POOR DESIGN

ELEM. : 3

RADIUS	STATION FROM	STATION TO	CLOTHOIDS BEFORE	CLOTHOIDS BEHIND	CCR	V85	SUPER-ELEVATION
0	1390.00	2373.79	0.00	0.00	0.00	99.70	2.5

CRIT. II : $|V85_3 - V_d|$ = 9.70 => GOOD DESIGN

Transition 3-4 for Crit. I : $|V85_3 - V85_4|$ = 15.95 => FAIR DESIGN

ELEM. : 4

RADIUS	STATION FROM	STATION TO	CLOTHOIDS BEFORE	CLOTHOIDS BEHIND	CCR	V85	SUPER-ELEVATION
400	2373.79	3195.87	250.00	-250.00	128.98	83.75	4.0

CRIT. II : $|V85_4 - V_d|$ = 6.25 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = -0.02 => FAIR DESIGN

Transition 4-5 for Crit. I : $|V85_4 - V85_5|$ = 7.66 => GOOD DESIGN

ELEM. : 5

RADIUS	STATION FROM	STATION TO	CLOTHOIDS BEFORE	CLOTHOIDS BEHIND	CCR	V85	SUPER-ELEVATION
-750	3195.87	3586.17	300.00	-300.00	58.82	91.41	4.0

CRIT. II : $|V85_5 - V_d|$ = 1.41 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = 0.03 => GOOD DESIGN

Transition 5-6 for Crit. I : $|V85_5 - V85_6|$ = 1.25 => GOOD DESIGN

ELEM. : 6

RADIUS	STATION FROM	STATION TO	CLOTHOIDS BEFORE	CLOTHOIDS BEHIND	CCR	V85	SUPER-ELEVATION
750	3586.17	3906.89	300.00	0.0	69.04	90.16	4.0

CRIT. II : $|V85_6 - V_d|$ = 0.16 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = 0.03 => GOOD DESIGN

Legend: CCR = German design parameter "Curvature Change Rate", compare Figure 4 in paper by Lamm and Smith, in this Record.

TABLE 2 Numerical Output Data for the Safety Evaluation Process (Interim Solution)

AXIS : 2

ELEM. : 1

	STATION		CLOTHOIDS				SUPER-
RADIUS	FROM	TO	BEFORE	BEHIND	CCR	V85	ELEVATION
0	0.00	852.31	0.00	0.00	0.00	99.70	2.5

CRIT. II : $|V85_1 - V_d|$ = 9.70 => GOOD DESIGN

Transition 1-2 for Crit. I : $|V85_1 - V85_2|$ = 13.80 => FAIR DESIGN

ELEM. : 2

	STATION		CLOTHOIDS				SUPER-
RADIUS	FROM	TO	BEFORE	BEHIND	CCR	V85	ELEVATION
-500	852.31	1642.60	250.00	-250.00	107.25	85.90	5.6*

CRIT. II : $|V85_2 - V_d|$ = 4.10 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = 0.02 => GOOD DESIGN

Transition 2-3 for Crit. I : $|V85_2 - V85_3|$ = 13.80 => FAIR DESIGN

ELEM. : 3

	STATION		CLOTHOIDS				SUPER-
RADIUS	FROM	TO	BEFORE	BEHIND	CCR	V85	ELEVATION
0	1642.60	2288.28	0.00	0.00	0.00	99.70	2.5

CRIT. II : $|V85_3 - V_d|$ = 9.70 => GOOD DESIGN

Transition 3-4 for Crit. I : $|V85_3 - V85_4|$ = 15.95 => FAIR DESIGN

ELEM. : 4

	STATION		CLOTHOIDS				SUPER-
RADIUS	FROM	TO	BEFORE	BEHIND	CCR	V85	ELEVATION
400	2288.28	3110.37	250.00	-250.00	128.98	83.75	6.3*

CRIT. II : $|V85_4 - V_d|$ = 6.25 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = 0.00 => GOOD DESIGN

Transition 4-5 for Crit. I : $|V85_4 - V85_5|$ = 7.66 => GOOD DESIGN

ELEM. : 5

	STATION		CLOTHOIDS				SUPER-
RADIUS	FROM	TO	BEFORE	BEHIND	CCR	V85	ELEVATION
-750	3110.37	3500.66	300.00	-300.00	58.82	91.41	4.3*

CRIT. II : $|V85_5 - V_d|$ = 1.41 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = 0.03 => GOOD DESIGN

Transition 5-6 for Crit. I : $|V85_5 - V85_6|$ = 1.25 => GOOD DESIGN

ELEM. : 6

	STATION		CLOTHOIDS				SUPER-
RADIUS	FROM	TO	BEFORE	BEHIND	CCR	V85	ELEVATION
750	3500.66	3821.38	300.00	0.0	69.04	90.16	4.3*

CRIT. II : $|V85_6 - V_d|$ = 0.16 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = 0.04 => GOOD DESIGN

* Calculated value should be rounded for the construction process.

bine a tangent and a curve in the fair design range the least possible radius is *R* 500 m; see Axis No. 2 in Figure 3(*b*). Furthermore, the authors decided to apply the exact superelevation rates provided by the German guidelines (*7*). For the same safety evaluation procedure, as discussed before but based this time on the descriptive design data for Axis No. 2 and the other relevant input data (such as the same design speed, lane width, superelevation rates, and tangent lengths), the results are listed in Table 2 and shown graphically in Figure 3(*b*). As can be seen, the interim solution reveals fair design practices between Elements 1 to 2, 2 to 3, and 3 to 4. That means, in relation to Safety Criterion I, the absolute differences in the V_{85}s for these element sequences lie somewhere in the range of between 10 and 20 km/hr according to Figure 1. Safety Criterion II and III represent, with no exception, good design practices.

From an economical point of view the alinement in Figure 3(*b*) can be evaluated as favorable because of low construction costs (at least 50 percent less than those for the final curvilinear alinement). However, it is difficult to determine to what extent the remaining transition sections with fair designs may have an unfavorable impact on the accident situation. As a matter of fact, however, for the section with a fair design, higher accident risks can be expected than on sections with good designs (*1,2,5,15*).

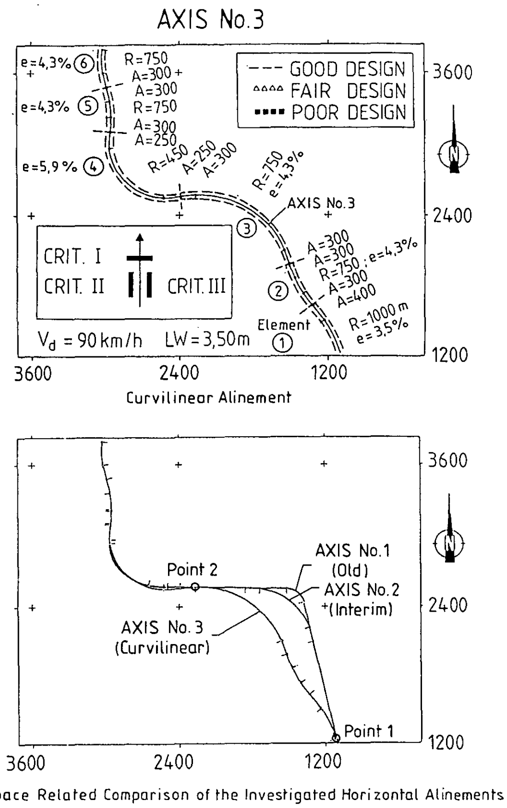

FIGURE 4 Graphical presentation of the safety evaluation process and comparison.

Final Curvilinear Alinement

For safety reasons, good design practices should always be strived for if no other superior goals are of relevant importance. This is true for the new design of multilane as well as two-lane rural roads. Besides the individual Safety Criteria I to III discussed here, one tool for achieving good designs is introduced by the term *curvilinear alinement* or *relation design* in the paper by Lamm and Smith, this Record. This means that single design elements should no longer be put together; rather sound design element sequences should be formed. To support this idea, relationships for the tuning of sound radii of curve sequences were developed in Figure 3 for Germany and in Figure 6 for the United States in the paper by Lamm and Smith, this Record.

For the following relation design in the present case study, the German assumptions were again taken as the basis, and only radii of curves between successive design elements that fell at least into the good range of the above-mentioned diagram (Figure 3 and the paper by Lamm and Smith, this Record) were selected. The resulting curvilinear alinement is shown as Axis No. 3 in Figure 4(*a*). The results of the safety evaluation process according to Table 3 and Figure 4(*a*) show no safety errors or deficiencies on the basis of Safety Criteria I to III. All three criteria confirm good design practices for the curvilinear alinement along the whole two-lane rural roadway section. Thus, it can be expected that the final alinement, presented in Figure 4(*a*) is a sound one.

Other Aspects

It can now be observed that by eliminating the tangent sections a well-balanced curvilinear alinement would result and the risk of run-off-the-road accidents may be reduced.

However, by eliminating the tangents the risk of critical passing maneuvers may increase. Safe passing maneuvers require minimum passing sight distances (PSDs). Therefore, a PSD analysis was conducted on the basis of a minimum PSD of 575 m, which is required for a design speed of 90 km/hr in the German design guidelines (*7*). This analysis involved the roadway from Point 1 to Point 2 in Figure 4(*b*), where the main redesign measures will take place. The rest of the alinement remains more or less unchanged. The result of the PSD analysis revealed for the observed road section that the minimum PSD always exists because of the presence of a large radius of curve between 750 and 1000 m of Axis No. 3. It could even be proved that the PSD requirements are improved decisively by the curvilinear alinement in comparison with the old alinement of Axis No. 1, in which the radius of 150 m may have had an unfavorable influence on the PSD. This is an additional positive aspect resulting from the analysis of road sections by using the three safety criteria. Therefore, negative impacts on traffic safety are not to be expected for the final curvilinear alinement resulting from PSD considerations.

The lateral displacement of Axis No. 3 in comparison with that of Axis No. 1 [see Figure 4(*b*)] is of minor importance, because an environmental compatibility study done as described in the paper by Lamm et al., this Record, revealed that all three axes are located in a low-conflict corridor. Regarding land use, sufficient agricultural land and green land are available for the new corridor (classified as being worthy of a low level of protection), whereas the topography in the plain of the Rhine River plays an inferior role.

APPLICATION FOR THE GREEN BOOK

The introduction of a safety evaluation process for differentiating different design levels (for example, good, fair, and poor) of hor-

TABLE 3 Numerical Output Data for the Safety Evaluation Process (Curvilinear Alinement)

AXIS : 3

ELEM. : 1

RADIUS	STATION FROM	STATION TO	CLOTHOIDS BEFORE	CLOTHOIDS BEHIND	CCR	V85	SUPER-ELEVATION
-1000	0.00	449.12	0.00	-400.00	52.35	92.23	3.5

CRIT. II : $|V85_1 - V_d|$ = 2.23 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = 0.05 => GOOD DESIGN

Transition 1-2 for Crit. I : $|V85_1 - V85_2|$ = 0.78 => GOOD DESIGN

ELEM. : 2

RADIUS	STATION FROM	STATION TO	CLOTHOIDS BEFORE	CLOTHOIDS BEHIND	CCR	V85	SUPER-ELEVATION
750	449.12	834.21	300.00	-300.00	58.47	91.45	4.3*

CRIT. II : $|V85_2 - V_d|$ = 1.45 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = 0.03 => GOOD DESIGN

Transition 2-3 for Crit. I : $|V85_2 - V85_3|$ = 2.13 => GOOD DESIGN

ELEM. : 3

RADIUS	STATION FROM	STATION TO	CLOTHOIDS BEFORE	CLOTHOIDS BEHIND	CCR	V85	SUPER-ELEVATION
-750	834.21	1981.97	300.00	-300.00	76.05	89.33	4.3*

CRIT. II : $|V85_3 - V_d|$ = 0.67 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = 0.04 => GOOD DESIGN

Transition 3-4 for Crit. I : $|V85_3 - V85_4|$ = 4.77 => GOOD DESIGN

ELEM. : 4

RADIUS	STATION FROM	STATION TO	CLOTHOIDS BEFORE	CLOTHOIDS BEHIND	CCR	V85	SUPER-ELEVATION
450	1981.97	2923.83	250.00	-250.00	120.68	84.55	5.9*

CRIT. II : $|V85_4 - V_d|$ = 5.45 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = 0.01 => GOOD DESIGN

Transition 4-5 for Crit. I : $|V85_4 - V85_5|$ = 6.97 => GOOD DESIGN

ELEM. : 5

RADIUS	STATION FROM	STATION TO	CLOTHOIDS BEFORE	CLOTHOIDS BEHIND	CCR	V85	SUPER-ELEVATION
-750	2923.83	3301.17	300.00	-300.00	57.92	91.52	4.3*

CRIT. II : $|V85_5 - V_d|$ = 1.52 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = 0.03 => GOOD DESIGN

Transition 5-6 for Crit. I : $|V85_5 - V85_6|$ = 1.37 => GOOD DESIGN

ELEM. : 6

RADIUS	STATION FROM	STATION TO	CLOTHOIDS BEFORE	CLOTHOIDS BEHIND	CCR	V85	SUPER-ELEVATION
750	3301.17	3621.89	300.00	0.0	69.04	90.16	4.3*

CRIT. II : $|V85_6 - V_d|$ = 0.16 => GOOD DESIGN
CRIT. III : $f_{RA} - f_{RD}$ = 0.04 => GOOD DESIGN

* Calculated value should be rounded for the construction process.

izontal alinement on the basis of the three individual safety criteria discussed here is recommended. The procedure should first be adjusted to the new designs and redesigns of two-lane rural roads because of the serious accident situation observed on this part of the road network. The safety evaluation process should then be incorporated into the horizontal alinement component of an appropriate CAD system for highway geometric design.

In this way it is possible to evaluate safety impacts for the future assessment of horizontal alinements by the use of quantitative criteria, in addition to the normally considered local, environmental, esthetic, and economic criteria.

CONCLUSION

A procedure for enabling highway engineers to evaluate the horizontal alinements of two-lane rural roads by applying three individual safety criteria was presented in this paper.

To recognize safety errors in new designs or redesigns in the planning stages or necessary improvements in RRR projects before implementation, modern planning tools like CAD systems for highway geometric design had to be made available. In this connection for the horizontal alinement component of the overall CAD system, an additional subprogram for a new safety evaluation process was developed. The new subprogram allows for the evaluation of the horizontal alinements of planned or existing roadways on the basis of good, fair, and poor design practices.

In this way it is possible to evaluate safety impacts for the future establishment of horizontal alinement alternatives. This allows change not only from a design point of view but also from a safety point of view.

The procedure was examined by changing the alinement of an existing two-lane rural roadway, which revealed poor design practices, via a fair but economical solution into a sound curvilinear alinement representing only good design levels.

The next research step should be to examine the validity of the results of the proposed safety model with the actual accident situation, for example, to extend the model for hazard rating or estimating the numbers of accidents (classified by rate or severity) for the road segment being considered. First efforts in this direction were made previously (*8*) and revealed good agreement. A statistically sound analysis and evaluation, however, has so far not been possible because of the present insufficient accident data bases, especially regarding single roadway sections with relatively low numbers of accidents. At present corresponding research studies are in the stage of development, and reliable comparative results may be expected in 1995. It should not be forgotten, however, that the ranges of validity according to Figure 1 were established for Safety Criterion I on the basis of mean accident rates (*1,2,15*) and for Safety Criterion III on the basis of in-depth accident investigations (*5,8*).

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