A NEW PROCEDURE FOR EVALUATING TRAFFIC SAFETY ON TWO-LANE RURAL ROADS

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ABSTRACT

This paper is based on research of the authors emphasizing traffic safety and highway geometric design, which has led to the development of three quantitative safety criteria for distinguishing sound and poor design practices on both planned and existing two-lane roadway sections. The safety criteria are directed toward the achievement of

- design consistency (Safety Criterion I),
- operating speed consistency (Safety Criterion II), and
- driving dynamic consistency (Safety Criterion III)

in highway design.

All three criteria are evaluated in terms of three ranges, described as “Good”, “Fair” and “Poor”. Cut-off values between the three ranges are developed.

Furthermore, it is dealt with the issues: design speed, operating speed, and sound friction factors. A comparative analysis of the actual accident situation with the results of the Safety Criteria reveals a convincing agreement.

It is known, that signs and markings can improve the safety record of a road section. However, the improvement is seldom substantial and certainly not to the level of transforming a “poor” design to a “good” design.

The developed safety evaluation process is meeting with acceptance in the professional highway engineering community. It has been adopted or referenced in their geometric design guidelines by several Roads Agencies internationally including those in Canada, Greece, Hungary, Italy, Japan, South Africa, and partially in the United States. It is thus reasonable to suggest that the methodology has gained international acceptance.

Thirty case studies were analyzed. The results confirm that the classification system agrees well with the outcome of large accident databases.

KEY WORDS

SPEED / SAFETY/ CONSISTENCY IN THE ALIGNMENT / CURVATURE CHANGE RATE OF THE SINGLE CURVE / SAFETY CRITERIA / ACCIDENT RATES.

1. ROAD SAFETY EVALUATION

Since more than ten years the Institute for Highway and Railroad Engineering (ISE) of the University of Karlsruhe developed, tested and applied in practical design- and safety-related work, three quantitative safety criteria. Those criteria, when properly applied, are intended to provide rural two-lane highways with:

- design consistency,
- operating speed consistency, and
- driving dynamic consistency,

to enhance traffic safety.

1.1. Highway Safety Evaluation Terminology

Research that evaluated the impact of design parameters on two-lane rural highway sections in the United States, in Germany, Greece, and Italy demonstrated, that the most successful parameter in explaining road characteristics and the corresponding driving behavior, respectively accident situation, is the design parameter “Curvature Change Rate of the Single Curve (CCR_S)”. The simple formula for determining CCR_S with transition curves is given by the following equation (Lamm, 1999; Lamm, 2003/2004):

$$CCR_S = \frac{\left(\frac{L_{Cl1}}{2R} + \frac{L_{Cr}}{R} + \frac{L_{Cl2}}{2R}\right)}{L} \cdot \frac{200}{\pi} \cdot 10^3 = \frac{\left(\frac{L_{Cl1}}{2R} + \frac{L_{Cr}}{R} + \frac{L_{Cl2}}{2R}\right)}{L} \cdot 63{,}700 \qquad \text{(Eq. 1)}$$

where:

CCR_S = curvature change rate of the single circular curve with transition curves [gon/km],

L = $L_{Cl1} + L_{Cr} + L_{Cl2}$ = overall length of unidirectional curved section [m],

L_{Cr} = length of circular curve [m],

R = radius of circular curve [m],

L_{Cl1}, L_{Cl2} = lengths of clothoids (preceding and succeeding the circular curve), [m].

(The dimension “gon” corresponds to 400 degrees in a circle instead of 360 degrees according to the European definition.)

To get a better overview of the real accident situation CCR_S was arranged into different design-, respectively CCR_S-classes for 6 large databases, one from the U.S.A., four from Germany and one from Greece, which fundamentally all reveal similar results. The results of one of these databases is listed in Table 1 for the mean accident rate.

The significant results of Table 1 indicate (Lamm, 1999; Lamm, 2003/2004):

1. gentle curvilinear horizontal alignments consisting of tangents or transition curves, combined with curves up to CCR_S-values of 180 gon/km experienced the lowest average accident risk, classified here as “good design”;

2. the mean accident rate on sections with CCR$_S$-values between 180 and 360 gon/km was at least twice or three times as high as that on sections with CCR$_S$-values up to 180 gon/km, classified here as “fair (tolerable) design”;
3. the mean accident rate on sections with CCR$_S$-values greater than 360 was about five to eight times higher than that on sections with CCR$_S$-values of up to 180 gon/km, classified here as “poor design”.

Table 1 - t-Test Results of Mean Accident Rates for Different CCR$_S$-Classes for Germany (West) and for the U.S.A. (Lamm, 2003/2004)

Design/ CCR$_S$-classes [gon/km]	**Mean AR**	**$t_{calc.}$ $t_{crit.}$**	**Significance; Remarks**
Database 1: Germany (2726 Two-Lane Rural Test Sites), 2001 Including Run-Off-The-Road-, Head-on-, and Deer Accidents			
			Considered as
0 - 180	0.33		--- Good design
		28.04 > 1.65	Yes
> 180 - 360	1.12		--- Fair design
		14.09 > 1.65	Yes
> 360	2.52		--- Poor design

Legend:
AR = accident rate (acc. per 10^6 veh.-km) according to Eq. (6) in Figure 2.
Dear means Animal

Based on the presented results of accident research, it can be assumed that the proposed CCR$_S$-ranges represent a sound classification system for the arrangement of good, fair (tolerable) and poor design practices in modern highway geometric design.

1.2. Three quantitative safety criteria for highway geometric design

The defined design classes (CCR$_S$-classes) are associated with the afore mentioned three safety criteria to develop an overall quantitative safety evaluation procedure for new designs, and existing or old alignments of two-lane rural roads. The quantitative ranges for the safety criteria are introduced in Table 2 (Lamm, 1999; Lamm, 2003/2004).

Safety Criterion I

Of special interest in modern highway geometric design is “Achieving Design Consistency”. That means, the design speed (V_d) shall remain constant on longer roadway sections, and shall be tuned at the same time with the actual driving behavior, expressed by the 85th-percentile speed (V85) of passenger cars under free flow conditions.

This is guaranteed by the good design level of Safety Criterion I in Table 2, that means the difference between 85th-percentile speed and the design speed shall not exceed 10 km/h along the whole observed roadway section. In this way, the road characteristic is well balanced for the motorist along the course of the roadway.

Safety Criterion II

The 85th-percentile speed shall be consistent along the roadway section, as well. This is guaranteed by the good design level of Safety Criterion II “Achieving Operating Speed Consistency” between two successive design elements (either from curve to curve or from tangent to curve). That means the 85th-percentile speed differences between two design elements also should not exceed 10 km/h for good design practice (Table 2). Accordingly speed differences between 10 and 20 km/h correspond to fair design levels, whereas speed differences greater than 20 km/h definitely classify poor design for Safety Criteria I and II.

Safety Criterion III

A well balanced driving dynamic sequence of individual design elements within a road section with the same design speed promotes a consistent and economic driving dynamic pattern. This is guaranteed by Safety Criterion III “Achieving Driving Dynamic Consistency” for the good design level in Table 2. This Safety Criterion relies heavily on sound driving dynamic assumptions for tangential and side friction factors, as will be explained lateron.

As demonstrated, Safety Criteria I and II are related to speed differentials. Two speeds are of interest, being the design speed and the operating speed (Table 2).

Table 2 - Quantitative Ranges for Safety Criteria I to III for Good, Fair, and Poor Design Classes (Lamm, 1999; Lamm, 2003/2004)

Safety Criterion	**DESIGN (CCR_S)-CLASSES**		
	GOOD (+)	**FAIR (o)**	**POOR (-)**
	Permissible Differences $\lvert CCR_{Si} - CCR_{Si+1} \rvert$ $\leq$ 180 gon/km	Tolerated Differences 180 gon/km < $\lvert CCR_{Si} - CCR_{Si+1} \rvert$ $\leq$ 360 gon/km	Non-Permissible Differences $\lvert CCR_{Si} - CCR_{Si+1} \rvert$ > 360 gon/km
I[1)]	$\lvert V85_i - V_d \rvert$ $\leq$ 10 km/h	10 km/h < $\lvert V85_i - V_d \rvert$ $\leq$ 20 km/h	$\lvert V85_i - V_d \rvert$ > 20 km/h
II[2)]	$\lvert V85_i - V85_{i+1} \rvert$ $\leq$ 10 km/h	10 km/h < $\lvert V85_i - V85_{i+1} \rvert$ $\leq$ 20 km/h	$\lvert V85_i - V85_{i+1} \rvert$ > 20 km/h
III[3)]	$+ 0.01 \leq$ $f_{RA} - f_{RD}$	$- 0.04 \leq$ $f_{RA} - f_{RD}$ $< + 0.01$	$f_{RA} - f_{RD}$ $< - 0.04$

Legend:

1) Related to the individual design elements “i” (independent tangent or curve) in the course of the observed roadway section.
2) Related to two successive design elements, “i” and “i+1” (independent tangent to curve or curve to curve).
3) Related to one individual curve.

(The term “independent tangent” will be explained later on.)

curvature change rate of the single curve [gon/km] ,
V_d = design speed [km/h] ,
$V85_i$ = expected 85th-percentile speed of design element “i” [km/h] .
f_{RA} = side friction assumed [-]
f_{RD} = side friction demanded [-]

Operating Speed

The term operating speed (V85) is nowadays well defined and is used in conjunction with the new design parameter “Curvature Change Rate of the Single Curve” according to

Figure 1, in order to describe the road characteristics in combination with operating speed backgrounds for many countries. For example, for a CCR_S-value of 250 gon/km a V85 of 82 km/h can be expected for the operating speed background of Greece and such one of 104 km/h for Italy. On tangents the CCR_S-value is zero (CCR_S = 0 gon/km) that means, according to Figure 1, that the operating speed on long tangents will be of the order of 105 km/h on average.

Design Speed

In contrast, the originally selected design speed often is not known with respect to existing or old alignments, which encompass about 70 to 80 % or even more of our road networks, and the assessments for new design speeds are often not convincing. Therefore, a new procedure, which takes into account the overall characteristics of the roadway, was developed in order to assign sound design speeds to new designs, redesigns or RRR-projects. This can be done by determining the average CCR_S-value across the length of the observed roadway section without considering intervening tangents.

This average CCR_S can be calculated as (Lamm, 1999):

$$\varnothing CCR_S = \frac{\sum\limits_{i=1}^{i=n} (CCR_{Si} \cdot L_i)}{\sum\limits_{i=1}^{i=n} L_i} \qquad \text{(Eq. 2)}$$

where:

$\varnothing CCR_S$ = average curvature change rate of the single curves across the section under consideration without regarding tangents [gon/km] ,
CCR_{Si} = curvature change rate of the i-th curve [gon/km] ,
L_i = length of the i-th curve [m].

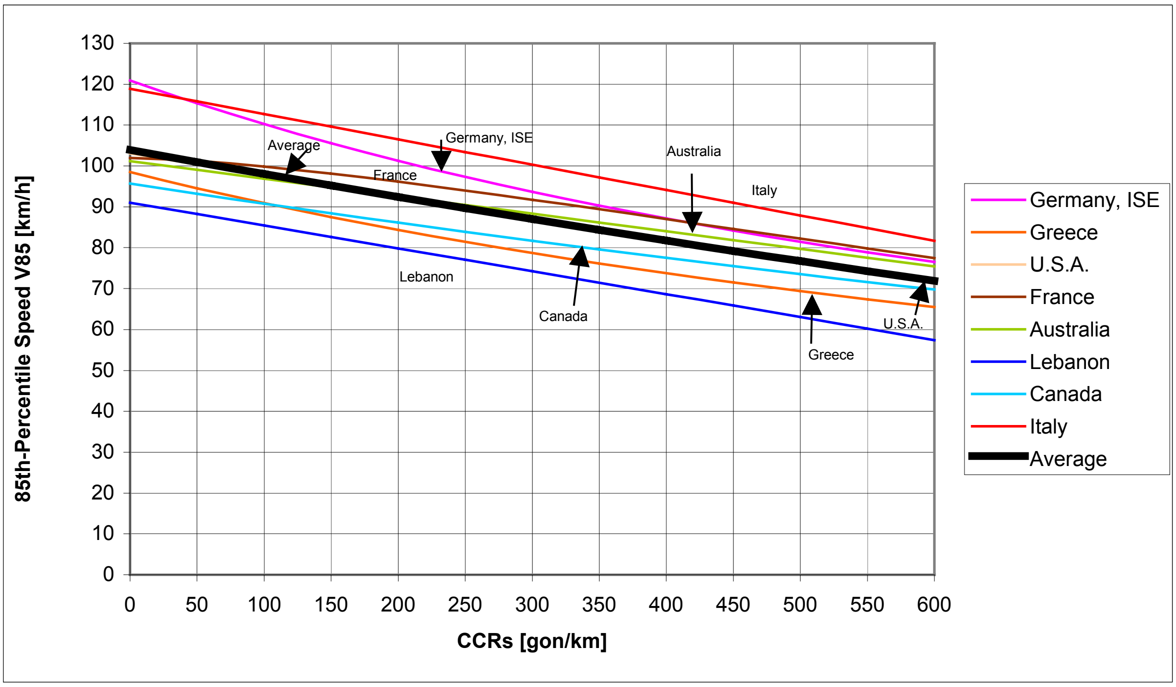


Figure 1 - Operating Speed Backgrounds for Two-Lane Rural Roads in Different Countries for Longitudinal Grades G < = 6 %

This average $\varnothing CCR_S$-value can then be taken as the basis for determining an average 85th-percentile speed $\varnothing V85$, recommended as the best choice for the design speed for the investigated roadway section.

Knowing the design speed and the individual 85th-percentile speeds, Safety Criteria I and II can be evaluated at once as good, fair or poor design with respect to the already afore explained ranges for Safety Criteria I and II in Table 2.

Friction Related Criterion

Safety Criterion III compares according to Table 2 side friction assumed (f_{RA}) for curve design with side friction demanded (f_{RD}) for cars riding through the curve at the 85th-percentile speed level. Based on skid resistance databases from Germany, Greece and the U.S.A., Equation 3 in Table 3 could be developed as appropriate for the tangential friction factor in modern highway geometric design (for new developments, see also (Lamm, 2002).

Table 3 - Listing of Formulas with Respect to Safety Criterion III (Lamm, 1999; Lamm, 2003/2004)

f_T = tangential friction factor in modern highway geometric design [-]
= $0.59 - 4.85 \cdot 10^{-3} \cdot V_d + 1.51 \cdot 10^{-5} \cdot V_d^2$ (Eq. 3)

f_{RA} = side friction "assumed" [-]
= $n \cdot 0.925 \cdot f_T$ (Eq. 4)

n = utilization ratio of side friction [%/100]
= 0.40 for hilly/mountainous topography; new designs
= 0.45 for flat topography; new designs
= 0.60 for existing (old) alignments

f_{RD} = side friction "demanded" [-]
= $\dfrac{V85^2}{127 \cdot R} - e$ (Eq. 5)
R = radius in the observed circular curve [m]

e = superelevation rate [%/100]

The side friction assumed is a fraction of tangential friction and corresponds to Equation 4 in Table 3, where "n" expresses the permissible utilization ratio for side friction assumed in comparison to tangential friction, and the factor 0.925 represents tire specific influences. As can be seen, different utilization ratios are suggested for new designs, separated according to hilly/ mountainous and flat topography, as well as for existing (old) alignments. Quantitative ranges of values for the differences between side friction assumed (f_{RA}) and side friction demanded (f_{RD}) were developed on the basis of the above-mentioned databases, arranged in respect of good, fair (tolerable) and poor design practices and are listed in Table 2. Note, that for the poor design level in Table 2 the difference between

$$f_{RA} - f_{RD} < -0{,}04$$

would mean, that at such a curved site already 4 percent of superelevation would have been missing for a safe ride.

Tangents

Having considered the curved portions of the road, the tangents also require attention. The reader, who is interested in the complex procedure for tuning tangents in the safety evaluation process should consult the “Highway Design and Traffic Safety Engineering Handbook”, (Lamm, 1999 pp. 1844 - 1846) or References (Lamm, 2002; Lamm, 2003/2004; Eberhard, 1997).

1.3. Safety Evaluation Process

With respect to Table 2 actuel values for V_d, V85, f_{RA}, f_{RD} for the investigated roadway section respectively roadway element have to be calculated and compared with the corresponsing ranges in order to classify good, fair and poor design. Case studies for the safety evaluation process with respect to the three safety criteria are given in (Lamm, 1999; Lamm, 2002; Lamm, 2003/2004).

2. INFLUENCE OF ROAD EQUIPMENT ON TRAFFIC SAFETY

Based on new research work of Beck (Beck, 1998), it had to be expected, that besides the design parameters also the road equipment has influence on the accident situation. Therefore, basic relationships between highway geometric design, accident situation and road equipment should additionally be clarified, and through field-investigations it was found that typical levels of road equipment can be defined, as follows :

Level 1 “Road Markings”: edgeline marking, solid centerline, broken centerline etc.
Level 2 “Traffic Control Devices”: curve warning sign, reverse turn warning sign, hill warning sign, speed limit sign, chevron alignment sign with up to 3 arrows (individual or on one board), as well as combinations.
Level 3 “Traffic Control Devices”: road equipment which exceeds level 2, for example, multiple chevron alignment signs with more than 3 arrows (individual or on one board), as well as combinations with level 2.

The following investigations include 79 sections of two-lane rural roads with an overall length of 212 kilometers, which consist of 1466 individual elements (curves or tangents). The overall number of recorded “Run-Off-the-Road” accidents and “Deer” accidents was 723 within three years (Zumkeller, 1998; Lamm, 2000).

The influence of the three levels of road equipment on the accident rate and the accident cost rate was individually investigated for the design-parameters: pavement width, radius of curve, and curvature change rate of the single curve. Because of space constraints the influence of pavement width and radius of curve on the accident rate cannot be discussed in the following. The reader, who is interested in a more detailed discussion, should consult (Lamm, 2000).

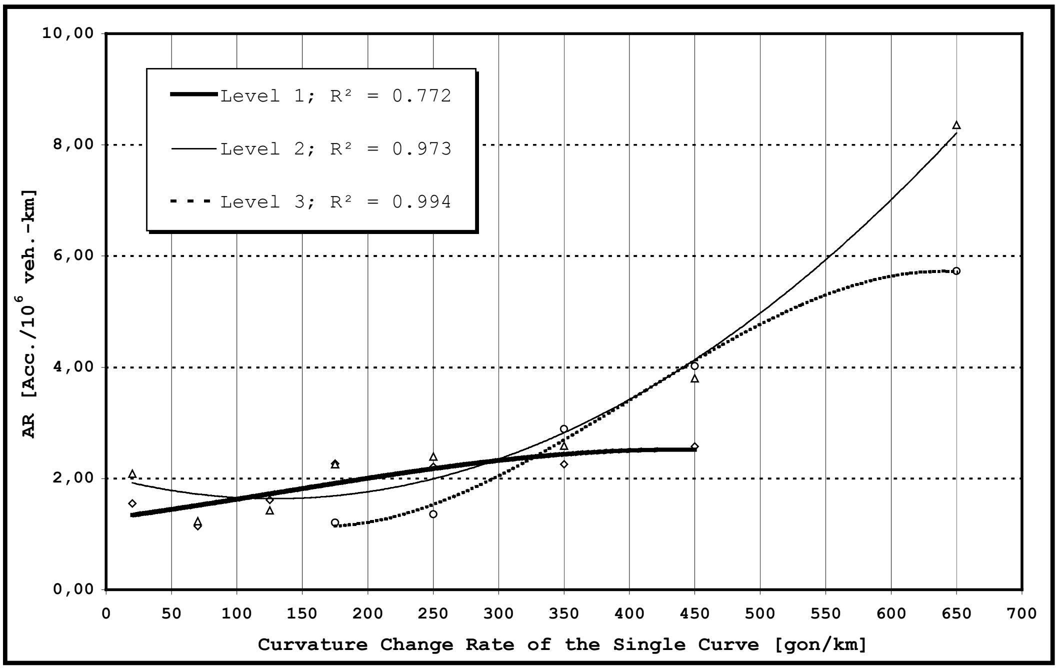
2.1. Curvature Change Rate of the Single Curve

Figure 2 shows the relationships between the accident rate and the curvature change rate of the single curve for the three road equipment-levels. Up to about 300 gon/km the regression curves of levels 1 and 2 are nearly identical, that means in more critical areas the signing according to level 2 lowers the accident rates down to a classification according to level 1.

Correspondingly, levels 2 and 3 reveal also a nearly identical course between 300 gon/km and 500 gon/km. Note, in this case the road equipment-level 3 lowers here high safety deficiencies to those comparable to level 2. Field investigations have shown that such a success could be reached especially through the repetition of multiple chevron alignment signs with more than three arrows (individual or more than one board). Beginning with $CCR_S \geq 450$ gon/km level 3 reveals significant improvements in contrast to level 2 signing. This leads to the request, that inconsistencies in the alignment have to be either redesigned or reconstructed, at least for CCR_S-values greater than 450 gon/km. If that is not possible, they should be at least secured by signing according to level 3. So far, only the results of the accident rate are schown in Figure 2. Note, that the relationsships for the accident cost rate reveal comparable trends.

In this connection the equipment of multiple chevron alignment signs and guardrails throughout the curve can significantly improve the optical guidance, especially at night and under wet surface conditions.

Figure 2 - Relationships between Accident Rate and Curvature Change Rate of the Single Curve for the Three Levels of Road Equipment (Zumkeller, 1998; Lamm, 2000)



Legend:

$$AR = \frac{accidents \cdot 10^6}{AADT \cdot 365 \cdot T \cdot L} \quad [\text{accidents per } 10^6 \text{ vehicle kilometers}] \qquad (Eq. 6)$$

where
AR = accident rate
AADT = average annual daily traffic, vehicles / 24 h
L = length of the investigated section, km
T = length of the investigated time period, yr
365 = number of days / yr

2.2. Road Equipment and Safety Criteria

In the last part of this paper the evidence of the results between safety criteria (Table 2) and actual accident situation was examined.

Note, that curved roadway sections, which are classified by the safety criteria as "good design" in comparison to those, classified as "poor design" represent for poor design still about 10 times higher accident rates and -cost rates than for good design, despite of the application of the most stringent traffic control devices according to level 3 in Table 4. Besides, it was found, that curved sections with low endangerment-potential in general are equipped according to level 1, whereas curved sections with relatively high endangerment-potential reveal for the most part traffic control devices according to level 3. Nevertheless , even level 3-road equipment is often not able to sufficiently diminish the danger of accidents at critical roadway-sections. That means, that furthermore in those cases redesign-, reconstruction or RRR-strategies are in the forefront for improving traffic safety or the installment of stationary radar devices becomes necessary, for example, to reduce excessive speeds.

Table 4 - Relationships between Good / Poor Design Practices and Mean Accident Rates and Cost Rates for 99 Curved Sections (Zumkeller, 1998; Lamm, 2000)

Safety Evaluation	Mean AR	Mean ACR	Number of Investigated Curves
Good Design	0.23	1.56	69
Poor Design	1.94	15.81	30

3. CONCLUSION AND OUTLOOK

A methodology whereby the alignment of a road can be tested for consistency has been developed. By using the good ranges of the three safety criteria sound alignments in plan and profile can be achieved, which are well tuned to the expected driving behavior of the motorists and may reduce significantly accident risk and -severity.

So far, for easing the danger of accident spots, accidents already had to be occurred, in order to find out that the spot or the roadway section is dangerous, for example, for future decision-making of countermeasures. The great advantage of the new Safety Concept is, that already in the design stages the safety criteria can predict the endangerment (low, medium, high) for new alignments. Additionally, they are also appropriate for statements about the safety conditions of existing (old) roadway sections or whole road-networks. In this way the highway- and traffic safety engineer is provided with quantitative tools, in order to evaluate the expected accident situation and to correct in advance deficiencies regarding new designs, or to plan in time sound countermeasures for highly endangered existing or old alignments.

Furthermore, three road equipment-levels with respect to individual design parameters and relative accident numbers were investigated. It was found that the application of signing and guardrails is obviously conducted by the responsible authorities according to the level of endangerment of the respective roadway section. Especially regarding the new design parameter "curvature change rate of the single curve" with respect to the accident rate in Figure 2, the sensible classification of road equipment according to levels 1 to 3 could be confirmed. The road equipment-levels lead to a reduction, respectively, to an adaptation of accident risk and accident severity, however certainly not to a weakening or even to a questioning of the developed safety conception.

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