



## ANALYSIS OF DESIGN SOLUTIONS IN THE OBJECTS OF GRAVEL ROADS PAVING PROGRAMME IN TERMS OF TRAFFIC SAFETY

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**Abstract.** Recently, the accident rate in Lithuania has been among the highest ones in Europe. The experience of implementing Gravel Roads Paving Programme (Programme) shows that accident rates have been increasing on the reconstructed road sections. This enables to make an assumption that design solutions taken on the reconstructed gravel roads may be not suitable in terms of traffic safety, since, currently, attempts are made to design the mini possible deviation of the project road axis from the existing road axis.

The article evaluates the quality of design solutions in terms of traffic safety in the objects of Programme through the use of the design method applied in West European countries, which is based on safety criteria and enables to evaluate traffic safety not only on the existing but on the designed two-lane suburban roads, i.e. the level of traffic safety is determined in the design stage. The article investigates the road plan solutions in the objects of Programme. Dangerous road sections on the reconstructed or being reconstructed sections were identified, and the analysis of the real or the predictable accident rates on these sections was carried out.

**Keywords:** accident, Curvature Change Rate, operating speed  $V_{85}$ , design speed  $V_d$ , horizontal curve, tangent, safety criterion, side friction.

### 1. Introduction

Safety is one of categories evaluating transport projects (Su *et al.* 2006). Recently, the accident rate in Lithuania has been among the highest ones in Europe, and the implementation of Gravel Roads Paving Programme (Programme) shows that the accident rates on the reconstructed sections have been increasing. This enables to make an assumption that design solutions on the gravel roads under reconstruction may be not suitable in terms of traffic safety, since, currently, attempts are made to design the min possible deviation of the project road axis from the existing road axis.

The findings of the research conducted in West European countries in 1970 showed that sharp variation of the vehicle driving speed between separate road plan elements is one of the main causes of accidents on two-lane subur-

bian roads. Therefore, an objective and reliable methodology was required, which would enable to design the road plan by avoiding undesirable variations of speed and thus improving traffic safety.

In 1988, a new design methodology was introduced in Germany, which promoted the design of roads as fluent spatial lines. The methodology was based on the criteria, which take traffic safety on the existing or designed two traffic lanes on suburban roads into account. In this methodology, the utmost attention is paid to tangent segments as independent elements of the road plan influencing the level of traffic safety on the road.

The findings of the research, later conducted in Germany, USA, Greece and Italy, showed that the variation of the vehicle driving speed and accident rates on the road are best described through the Curvature Change Rate of the single curve ( $CCR_S$ ) (Pratico *et al.* 2007).

$CCR_S$  is calculated by the following formulae:

$$CCR_S = \frac{\frac{L_{c1}}{2R} + \frac{L_{cr}}{R} + \frac{L_{c2}}{2R}}{L} \times \frac{200}{\pi} \times 10^3 = \frac{\frac{L_{c1}}{2R} + \frac{L_{cr}}{R} + \frac{L_{c2}}{2R}}{L} \times 63700, \text{ gon/km} \quad (1)$$

$$CCR_S = \frac{\frac{L_{c1}}{2R} + \frac{L_{cr}}{R} + \frac{L_{c2}}{2R}}{L} \times \frac{180}{\pi} \times 10^3 = \frac{\frac{L_{c1}}{2R} + \frac{L_{cr}}{R} + \frac{L_{c2}}{2R}}{L} \times 57330 = \frac{\alpha}{L} \times 10^3, \text{ deg/km} \quad (2)$$

where  $L = L_{c1} + L_{cr} + L_{c2}$  – the total length of the curve, m;  $L_{cr}$  – the length of circular curve, m;  $R$  – circular curve radius, m;  $L_{c1}, L_{c2}$  – lengths of the first and second transition curves, m;  $\alpha$  – deflection angle, deg.

## 2. Correlations of the road plan geometrical parameters and speeds

### 2.1. The effect of the road plan geometrical parameters on the vehicle driving speed

The occurrence of accidents on suburban roads is mostly influenced by incompatible road plan elements and too high driving speed; hence, speed is the most important criterion when evaluating the compatibility level of the road plan elements geometrical parameters. The concept of operating speed  $V_{85}$  of vehicles driving on dry and clean pavement has been widely used in the design standards of foreign countries. The research carried out in a number of

countries showed, how  $V_{85}$  correlates with the quality of the alignment, which may be described by  $CCR_S$ .

As one can see in Fig. 1,  $V_{85}$  decreases when  $CCR_S$  increases. Based on the research mentioned above, general world regression equations of  $V_{85}$  were written.

The general world regression equation of  $V_{85}$ , when longitudinal cross fall  $i < 6\%$  and  $CCR_S < 1600$  gon/km is as follows:

$$V_{85} = 105,31 + 2 \times 10^{-5} \times CCR_S^2 - 0,071 \times CCR_S. \quad (3)$$

The general world regression equation of  $V_{85}$  when the road longitudinal cross fall  $i > 6\%$  and  $CCR_S < 1600$  gon/km is as follows:

$$V_{85} = 86 - 3,24 \times 10^{-9} \times CCR_S^3 + 1,61 \times 10^{-5} \times CCR_S^2 - 4,26 \times 10^{-2} \times CCR_S. \quad (4)$$

When drafting road reconstruction plans, it is important to select design speed  $V_d$  properly.  $V_d$  is frequently selected improperly if done intuitively (Lamm et al. 2002). The methodology of calculating  $V_d$  according to  $V_{85}$  on the existing road has been developed.

In foreign countries, the average  $CCR_S$  of the existing (old) road is calculated as follows:

$$\overline{CCR_S} = \frac{\sum_{i=1}^{i=n} (CCR_{Si} \times L_i)}{\sum_{i=1}^{i=n} L_i}, \quad (5)$$

where  $\overline{CCR_S}$  – average  $CCR_S$  for the observed roadway section without considering tangents, gon/km;  $CCR_{Si}$  –  $CCR_S$  of the single curve  $i$ , gon/km;  $L_i$  – length of curve  $i$ , m.

Suppose the  $\overline{CCR_S}$  is known,  $V_{85}$  is calculated by regression equations (3) or (4),  $V_d$  is calculated according to

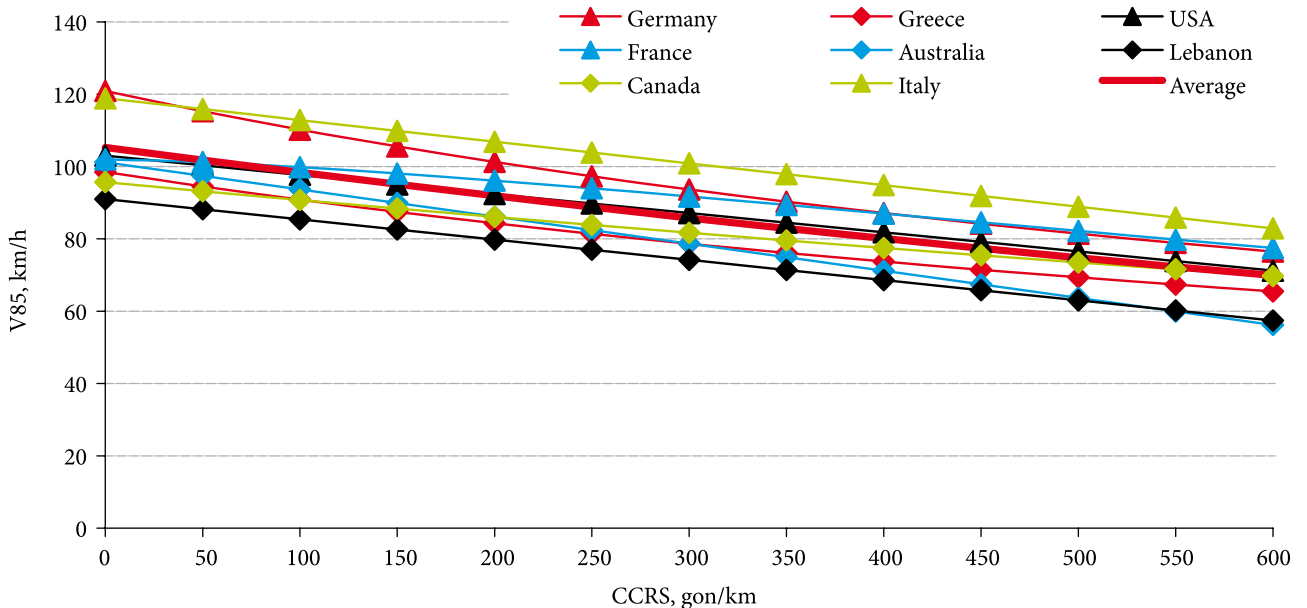


Fig. 1. Dependence of  $V_{85}$  on  $CCR_S$  (Lamm et al. 2007)

V85 or its average  $\bar{V}85$  on the road section under reconstruction.

The methodology of calculating the  $V_d$  is not specified in the current design standards of the Lithuanian Road Administration *Road Technical Regulation KTR 1.01:2008 "Motor Roads"*.

## 2.2. The effect of the road plan elements and their geometrical parameters on accident rate

PIARC (World Road Association) states that:

- accidents on horizontal curves occur from 1,5 to 4 times more frequently than on tangent sections, and the greatest number of accidents occur on the horizontal curves with radii  $R < 400$  m;
- 25–30 % of all fatal accidents occur on horizontal curves;
- approx 60 % of all accidents occurring on horizontal curves is one vehicle driving off the road;
- accidents usually occur at the beginning or the end of the horizontal curve;
- suburban roads designed, according to the design standards which specify the min values of geometrical parameters of the road as a spatial line, are not safe.

The accidents rate on horizontal curves depends not only on the geometrical parameters of the curve (radius, deflection angle, crossfall), but on the adjacent road plan elements. It may be stated that the safety of uniform radius horizontal curves varies: it depends on the compatibility of the road elements.

When reconstructing or constructing new roads, the road plan lines shall be designed properly. In terms of traffic safety, lines are divided into two groups (Lamm *et al.* 2003):

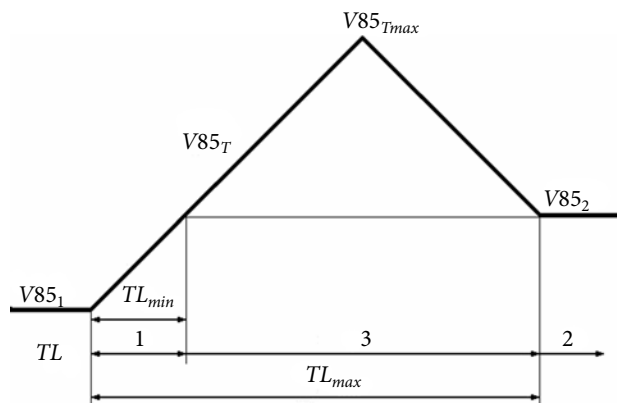
- independent (long and medium lines): these lines have an impact on the level of accident rates, since the vehicles driving speed may be much higher than on the adjacent horizontal curves;
- dependent (short lines).

These lines are divided into dependent and independent lines according to V85, which may be reached when a vehicle drives on a tangent and adjacent horizontal curves (Fig. 2).

When  $TL \geq TL_{max}$ , tangent is independent (long), it is taken into consideration, and the length of a tangent is sufficient for the vehicle to reach max  $V85_{Tmax}$ , a tangent and curves are directly interrelated: a vehicle driving speed on curves depends on the speed on a tangent:

$$TL_{max} = \frac{V85_{Tmax}^2 - V85_1^2}{2 \times 3,6^2 \times a} + \frac{V85_{Tmax}^2 - V85_2^2}{2 \times 3,6^2 \times a} = \frac{2 \times V85_{Tmax}^2 - V85_1^2 - V85_2^2}{22,03}, \quad (6)$$

where  $TL_{max}$  – a distance necessary to reach  $V85_{Tmax}$ , m;  $V85_{Tmax}$  – max speed on a tangent, km/h;  $V85_1, V85_2$  – V85 on the 1<sup>st</sup> and 2<sup>nd</sup> curves, km/h;  $a$  – a vehicle’s acceleration 0,85 m/s<sup>2</sup>.



**Fig. 2.** Speed and length calculation scheme on a tangent:  $V85_1, V85_2$  – V85 on the 1<sup>st</sup> and 2<sup>nd</sup> curves, km/h;  $V85_{Tmax}$  – max speed on a tangent, km/h;  $V85_T$  – speed on a tangent (may reach value  $V85_{Tmax}$ ), km/h;  $TL$  – length of a tangent, m;  $TL_{min}$  – a distance necessary to reach  $V85_2$ , m;  $TL_{max}$  – a distance necessary to reach  $V85_{Tmax}$ , m;  $a$  – a vehicle acceleration 0,85 m/s<sup>2</sup>

When  $TL_{min} \leq TL \leq TL_{max}$ , tangent is independent (medium length), it is taken into consideration. Although the length of a tangent is not sufficient to reach max  $V85_{Tmax}$ , a tangent and curves are directly interrelated: a vehicle driving speed on curves depends on the speed on a tangent, which, in this case, is calculated as follows:

$$V85_T = \sqrt{\frac{V85_1^2 + V85_2^2 + 2 \times 3,6^2 \times a \times TL}{2}} = \sqrt{\frac{V85_1^2 + V85_2^2 + 22,03 \times TL}{2}}, \quad (7)$$

where  $V85_T$  – speed on a tangent (may reach value  $V85_{Tmax}$ ), km/h;  $V85_1, V85_2$  – V85 on the 1<sup>st</sup> and 2<sup>nd</sup> curves, km/h;  $a$  – a vehicle’s acceleration 0,85 m/s<sup>2</sup>;  $TL$  – length of a tangent, m.

When  $TL \leq TL_{min}$ , line is dependent (short), and it is not taken into consideration, the 1<sup>st</sup> and 2<sup>nd</sup> curves are directly interrelated: a vehicle’s driving speed on the second curve depends on a vehicle’s speed on the 1<sup>st</sup> curve:

$$TL_{min} = \frac{|V85_1^2 - V85_2^2|}{2 \times 3,6^2 \times a} = \frac{|V85_1^2 - V85_2^2|}{22,03}, \quad (8)$$

where  $TL_{min}$  – a distance necessary to reach  $V85_2$ , m;  $V85_1, V85_2$  – V85 on the 1<sup>st</sup> and 2<sup>nd</sup> curves, km/h;  $a$  – a vehicle acceleration 0,85 m/s<sup>2</sup>.

## 3. Evaluation of the min horizontal curves radii specified in KTR 1.01:2008 "Motor Roads" by using safety criteria

Accident rate and safety criteria enough to determine for eliminating accident causes on operational level (Леонювич, Кашевская 2007). A large body of the research can be used to analyze and evaluate the fundamental relationships between accident situation, highway geometric design, driving behaviour, and driving dynamics. These factors form

the basis for the development of 3 quantitative safety criteria used to evaluate the hazards of two-lane rural roads with respect to new designs, redesigns, restoration, rehabilitation, or resurfacing projects, and existing alignments (Cafiso et al. 2004).

To evaluate the min horizontal curves radii  $R_{min}$ , specified in the Road Technical Regulations *KTR 1.01:2008 "Motor Roads"*, the methodology (Lamm et al. 2007) based on I, II and III safety criteria, i.e. the stability of  $V_d$ , the stability of  $V85$  and the dynamic stability on horizontal curves, was used.

$V_d$  shall be considered stable if the  $V_d$  is stable on road sections as long as possible. The stability of  $V_d$  is sufficient when the difference between  $V85$  and  $V_d$  does not exceed 10 km/h (Table 1).

$V85$  shall be considered stable when  $V85$  is stable between two adjacent road plan elements (between two adjacent curves or between a tangent and a curve). The stability of  $V85$  is sufficient when the difference between speeds  $V85$  on two adjacent road plan elements does not exceed 10 km/h (Table 1).

The dynamic stability on the curves is a criterion of a vehicle driving stability and cost-effectiveness (Table 1). The criterion of the dynamic stability on the curves enables to compare an "assumed" side friction  $f_{RA}$  with demanded side friction  $f_{RD}$  calculated for  $V85$ .

Side friction "assumed"  $f_{RA}$  is calculated according to the following formula:

$$f_{RA} = n \times 0,925 \times f_T, \tag{9}$$

where  $n$  – an ultimate assumed side friction ( $n = 0,6$  for the old roads,  $n = 0,4$  for the newly designed roads); 0,925 – coefficient showing the correlation between longitudinal and side frictions;  $f_T$  – tangential friction factor:

$$f_T = 0,59 - 4,85 \times 10^{-3} \times V_d + 1,51 \times 10^{-5} \times V_d^2. \tag{10}$$

Side friction "demanded"  $f_{RD}$  is calculated by the formula:

$$f_{RD} = \frac{V85^2}{127 \times R} - i, \tag{11}$$

where  $f_{RD}$  – side friction demanded (actually needed);  $V85$  – 85<sup>th</sup>-percentile speed, km/h, with respect to  $CCR_S$ ;  $i$  – cross-fall of the carriageway in superelevation, %;  $R$  – horizontal curve radius, m.

$V_d$  stability criterion is calculated for each road plan element separately (an independent line or a curve),  $V85$  stability criterion – for 2 subsequent road elements (an independent line and a curve or 2 curves); the criterion of dynamic stability on curves is calculated for each curve separately.

The I, II and III safety criteria make up the traffic safety module. This module is classified according to the design level (good, fair or poor). To identify the level of traffic safety module, safety criteria weight coefficients, i.e. good design level weight coefficient +1, fair design level weight coefficient 0 or poor design level weight coefficient -1, are used. The design level of the road section traffic safety module in both driving directions has been identified by adding up the safety criteria of the road plan elements and calculating their average value on the whole road section. Solutions to correct the road plan are taken according to the traffic safety module design level (Table 2).

To evaluate  $R_{min}$  safety criterion, specified in *KTR 1.01:2008 "Motor Roads"*, the following two case studies have been simulated:

- 1 – a long tangent precedes the horizontal curve, i.e.  $TL \geq TL_{max}$ , tangent length is sufficient for a vehicle to reach  $V85_{Tmax}$ ;
- 2 – medium length tangent precedes the horizontal curve, i.e.  $TL_{min} \leq TL \leq TL_{max}$ , tangent length is not sufficient for the vehicle to reach  $V85_{Tmax}$ .

In case study 1 (a long tangent), the following results were obtained:

**Table 1.** Safety criteria classification (Lamm et al. 2007)

Safety criterion	Design levels		
	good (+) permissible differences $ CCR_{Si} - CCR_{Si+1}  \leq 180$	fair (0) tolerated differences $180 \leq  CCR_{Si} - CCR_{Si+1}  \leq 360$	poor (-) non-permissible differences $ CCR_{Si} - CCR_{Si+1}  > 360$
I	$ V85_i - V_d  \leq 10$	$10 \leq  V85_i - V_d  \leq 20$	$ V85_i - V_d  > 20$
II	$ V85_i - V85_{i+1}  \leq 10$	$10 \leq  V85_i - V85_{i+1}  \leq 20$	$ V85_i - V85_{i+1}  \geq 20$
III	$f_{RA} - f_{RD} \geq +0,01$	$-0,04 \leq f_{RA} - f_{RD} < +0,01$	$f_{RA} - f_{RD} \leq -0,04$

**Table 2.** Design levels of traffic safety module, when taking solutions concerning the road plan correction

Traffic safety module		Road plan correction measures
interval	design levels	
$x \geq 0,5$	good (+)	Not required
$-0,5 < x < 0,5$	fair (0)	Various engineering measures enabling to reduce the speed variation and improve the dynamic stability on curves
$x \leq 0,5$	poor (-)	Required

- a long line has no effect on the design level of traffic safety module, when the  $R > 400$  m behind such line;
- traffic safety module design level is satisfactory, when the  $300 \text{ m} > R > 400 \text{ m}$  behind the long line;
- traffic safety module design level becomes dangerous, when the  $R < 300$  m behind the long line, and the reasons of the dangerous design level are as follows:
  - the stability of  $V_d$  is not guaranteed since  $V_{85}$  on the curve exceeds the  $V_d > 20 \text{ km/h}$ ;
  - the stability of  $V_{85}$  is not guaranteed because the difference between speeds  $V_{85}$  on a tangent and a curve exceeds  $20 \text{ km/h}$ ;
  - the dynamic stability on the curve is not guaranteed.

In case study 2 (a medium line), better results were obtained. When the  $R < 300$  m behind the medium line, traffic safety module design level is fair since the stability of  $V_{85}$  is guaranteed for all radii specified in the Road Technical Regulations *KTR 1.01:2008 "Motor Roads"*.

#### 4. Methodology of design solutions analysis in terms of traffic safety

The analysis of design solutions of 8 gravel road sections reconstruction has been conducted in terms of traffic safety. All investigated sections are on the roads of regional significance of category V. The total length of the investigated roads is 39,26 km.

To analyze the design solutions taken on the gravel road reconstruction, each section under investigation was divided into separate sections so that one section would correspond to one road plan element. The analysis was carried out in 3 stages:

I stage – identification of dangerous segments on the road sections under investigation through the use of safety criterion;

II stage – analysis of data on accidents on the road sections under investigation;

III stage – statistical analysis between the accidents on the road sections under investigation and dangerous road segments through the use of safety criterion.

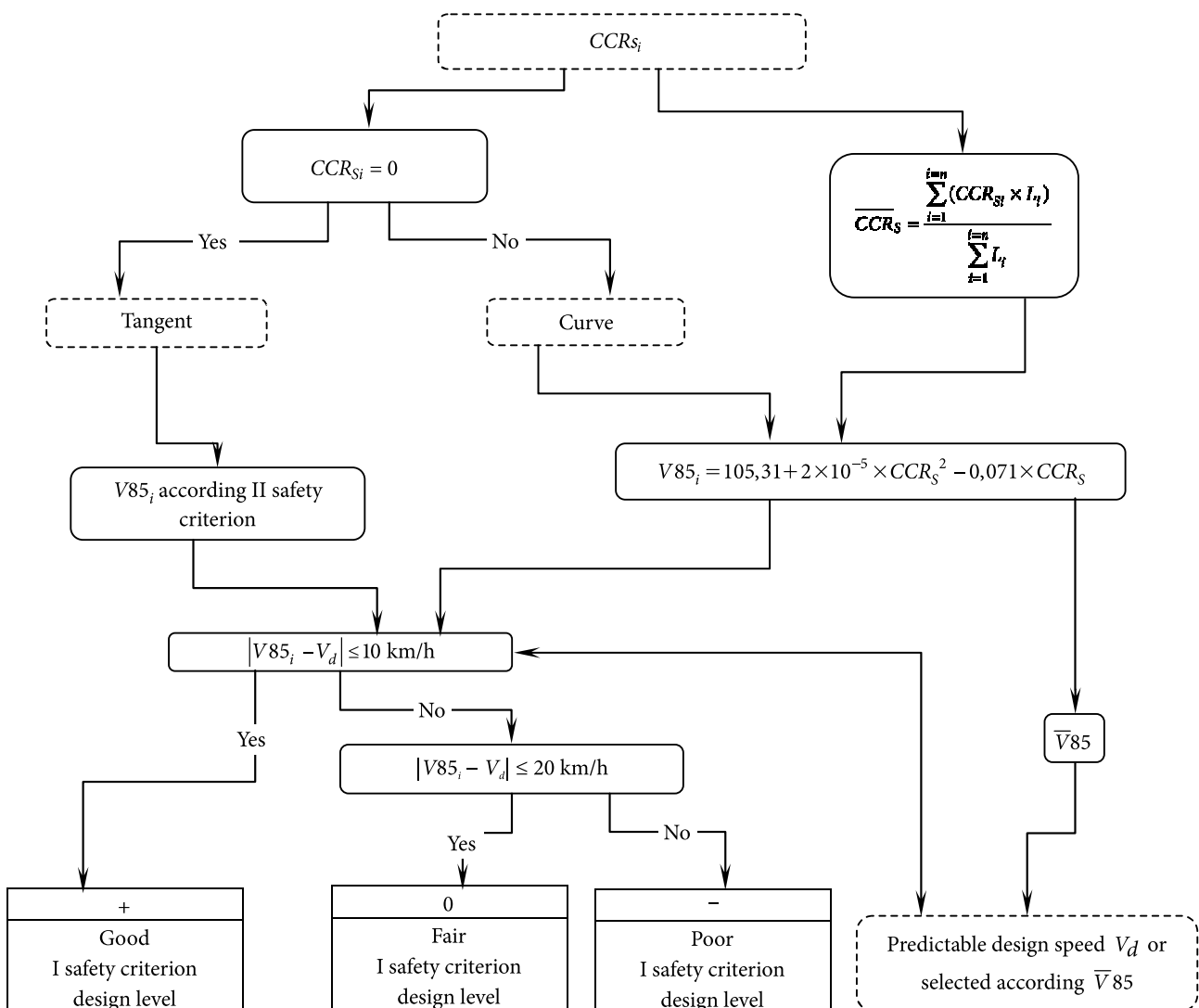


Fig. 3. Algorithm of identifying the I safety criterion design level

**4.1. Identification of dangerous segments on the road sections under investigation**

Identification of dangerous segments on the road sections under investigation was carried out in the following order:

- 1) calculation of  $CCR_s$  for each segment;
- 2) calculation of  $V85$  on each segment based on the general regression equations (3)–(4) of  $V85$ ;

- 3) analysis of segments through the use of the I, II and III safety criteria according to the values of  $V85$  in them, when identifying the design level for each criterion according to a separate algorithm (Figs. 3–5);
- 4) identification of the design level of the traffic safety module for each segment, by summing up the identified safety criterion design levels and calculating their average value;

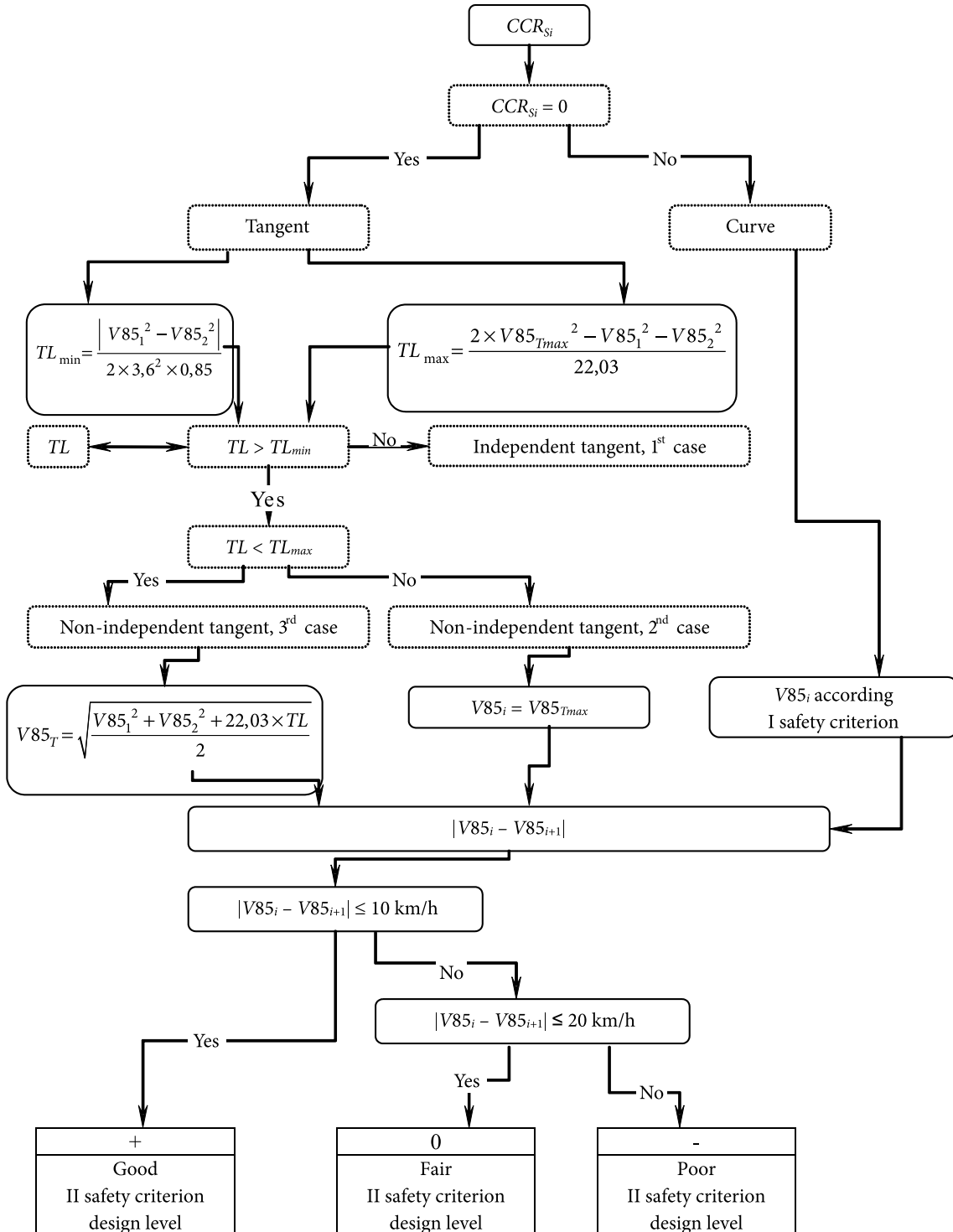


Fig. 4. Algorithm of identifying the II safety criterion design level

5) identification of a dangerous segment according to the obtained dangerous design level of the traffic safety module.

Dangerous segments were identified in both traffic directions.

#### 4.2. Data on accident rate on the road sections under investigation

When collecting road accident data in Lithuania, a lot of attention is paid only to the registered road accidents, i.e. personal injury accidents or fatal accidents. The data on damage-only accidents, i.e. accidents when people are not involved, but vehicles are damaged or freight is lost, are collected only by the road police divisions and stored only for 3 years. Therefore, only the analysis of registered accidents was carried out in this research. Moreover, the data on accident places are not accurate since the accuracy of registering the accident places has not been higher than 50 m so far.

Data on the accidents on the road sections under investigation have been obtained from the database of the state company *Transport and Road Research Institute*.

#### 4.2.1. Statistical analysis between the accident rate on the road sections under investigation and dangerous road segments, identified by safety criteria

Statistical correlation between accident rate on the sections under investigation and dangerous road segments, through the use of safety criteria, was identified by Spirmen's correlation coefficient (Čekanavičius, Murauskas 2000). The positive value of Spirmen's correlation coefficient shows a direct correlation of variables, and the negative value shows an inverse correlation.

Two independent samples were taken for the analysis, i.e. criteria sample and accidents sample. The criteria sample is made for segments, where the design level of the traffic safety module is good or fair (0) and poor segments (1). Accidents sample is made for segments with no accidents registered (0), and segments with no accidents registered (1), and accidents on intersections are ignored.

#### 4.2.2. Research findings

By the analysis of the geometrical parameters using safety criteria of the road plan elements on the selected 8 road sections, 11 dangerous road segments, were identified, the total length of which is 1,84 km, which makes up 4,7 %

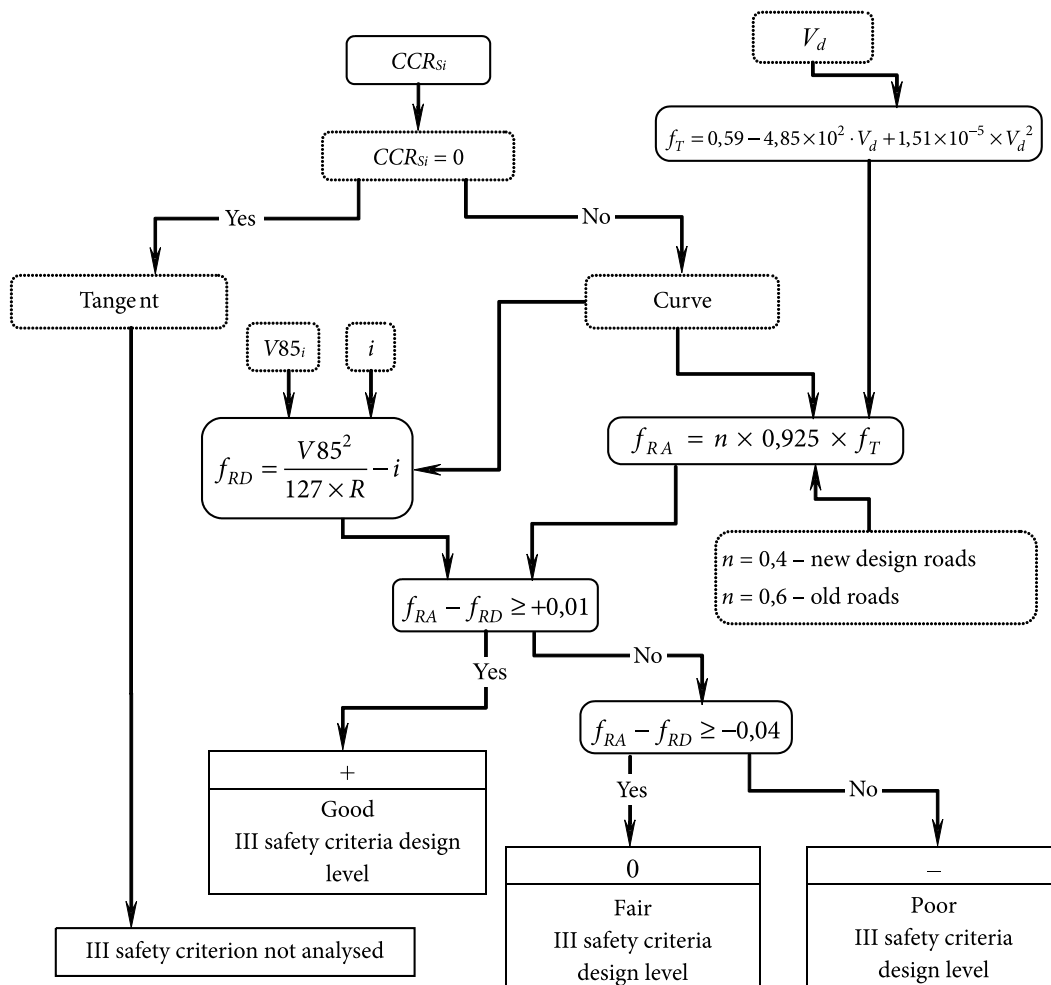


Fig. 5. Algorithm of identifying the III safety criterion design level

of the total length of the investigated sections. Road segments are dangerous due to the following reasons:

- differences of speeds  $V_{85}$  on the adjacent road plan elements exceed 20 km/h, i.e. road plan elements are not compatible;
- the dynamic stability on horizontal curves is not guaranteed.

On the investigated sections, among identified dangerous road segments and registered accidents on them the obtained value of the coefficient is 0,69 (Table 3). These values statistically correlate with the importance level  $\alpha = 0,01$ , i. e. the identified dangerous segments correlate with real accidents occurring on them.

**Table 3.** Spirmen's criterion results

	Criteria sample	Accident sample
Correlation coefficient	1	0,69
Sample	83	83
Importance $p$	0	0,000

## 5. Conclusions and recommendations

1. The design solutions of gravel road reconstruction do not improve traffic safety. There are 4,7 % of potentially dangerous segments in the reconstructed road sections.

2. Approx 50 % of the registered accidents occur on the segments identified as dangerous ones. Having carried out the statistical analysis, the correlation between dangerous road segments and real accidents was found. Therefore, it could be stated that safety criteria method is adequate and it is recommended to apply this method when drafting road reconstruction and construction projects.
3. To ensure dependable results of the safety criteria method, it is recommended:
  - to conduct research of vehicles driving speeds and write regression equations of  $V_{85}$  for Lithuania;
  - to unify the registration of the registered and non-registered accidents and store them in databases;
  - to increase the accuracy of registering accident places, e.g. through the use of GPS (Geographic Positioning System) receivers.
4. When drafting gravel road reconstruction projects, it is recommended to ensure the compatibility of the

road plan elements. Essential road plan correction is required only when  $V_{85}$  differences exceed 20 km/h on the adjacent road plan elements.

5. It is recommended to supplement the Road Technical Regulations *KTR 1.01:2008 "Motor Roads"* by the following:
  - the requirement to apply a certain methodology to calculate  $V_{d5}$ ;
  - to specify the permitted combinations of  $R$  and the length of tangents between them in Table "The min curve radii, taking length  $L$  of tangent into consideration" or to regulate the calculation methodology.

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