CZECH PILOT STUDY OF ROAD HORIZONTAL ALIGNMENT OPTIMIZATION

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Abstract. Inadequate speed has been the biggest contributor to the number of fatalities on Czech roads. High proportion of them occurs on undivided rural roads of lower classes, in curves and their vicinity. One of the solutions of this issue is a consistent road design, which should allow driving with relatively constant speed corresponding to drivers' expectations. The paper describes a pilot study conducted by Centrum dopravního výzkumu, v.v.i. (Transport Research Centre), assesses its results and offers possible solutions. The paper presents the theory, pilot study of Transport Research Centre and interpretation of its results as well as possible solutions.

Keywords. Rural road, horizontal alignment, speed, accident, safety.

INTRODUCTION

Road horizontal alignment has a significant impact on driving and safety. According to PIARC's synthesis (2003), accident performance in curves is up to 4 times higher compared to straight road segments. One of main reasons is due to insufficient accommodation of speed in transitional sections on both curve ends.

Also in the Czech Republic, inappropriate speed has been the most important accident factor for a long time. In total more than one third of Czech road fatalities are related to horizontal curves, while more than half of them were attributed to inappropriate speed. This situation is the most critical on 1st and 2nd class rural roads.

One of solutions of aforementioned situation is road horizontal alignment optimization. Its ideal outcome should be the consistent design, where drivers are provided clear information about situations to be expected. In this respect, route may be seen as a consequence of straight segments and curves. Its consistency may be then assessed in terms of the differences of speed on consecutive road segments – the changes should not be abrupt so as not to surprise the drivers. According to Hassan (2004), applications of this concept have been among the most promising approaches to safe road design.

To evaluate design consistency, measures have to be found. In the literature, 85th percentile speed (V_{85}) and curvature change rate of a segment (CCR_s) are often used (Hassan, 2004). The most common criteria operationalization is introduced in Table 1. It includes the cut-off points defining three classes of design consistency (good, fair, poor) according to seminal works of German professor Lamm and his colleagues (Lamm et al., 1999, 2007).

Table 1. Classification of the consistency level by their impact on road safety, according to Lamm et al. (1999, 2007)

design class 1: good	design class 2: fair	design class 3: poor
$\lvert \Delta CCR_s \rvert \leq 180$	$180 < \lvert \Delta CCR_s \rvert \leq 360$	$\lvert \Delta CCR_s \rvert > 360$
$\lvert \Delta V_{85} \rvert \leq 10$	$10 < \lvert \Delta V_{85} \rvert \leq 20$	$\lvert \Delta V_{85} \rvert > 20$

$\lvert \Delta CCR_s \rvert$ … the difference of curvature of consecutive segments [gon/km]
$\lvert \Delta V_{85} \rvert$ … the difference of operating (85th percentile) speed on consecutive segments [km/h]

After this introduction, the method used is introduced. Next is data processing part description followed by results, discussion and conclusions.

1 METHOD

In order to study the mentioned topic in the Czech conditions, a pilot study has been undertaken. The aims of this study were as follows:

- examination of feasibility of the collection of location data in sufficient quality
- use of data to assess the consistency of horizontal alignment
- determination of the relationship between curvature and speed

The introduction was reported by Ambros and Valentová (2012). Following text describes the conducted pilot study, evaluates its results and shows possible solutions.

One of objective was to test the feasibility of data collection with the use of cheap, commonly available, commercial measuring modules. Therefore, the pilot study used a 66-channel module with an internal antenna on chipset MediaTek MT3329 with FHSS/GFSK modulation and 79 RF channels. Its sensitivity is up to -162 dBm and data transfer rate is 38 400 bps. The accuracy of finding horizontal position without DGPS correction is 3 m.

The road segment Jinačovice – Kuřim on road III/3846 near the city of Brno was selected for the data collection. The route runs from Brno to Tišnov. There are two road segments suitable for the performance of the study: the first one is between Brno and Jinačovice, the other one between Jinačovice and Kuřim. The remaining road segments were influenced by urban areas or their immediate vicinity. The route was covered fifteen times in both directions during April and May 2012. The position data were recorded in the interval of 1 second.

2 DATA PROCESSING

Data processing includes determination of horizontal alignment elements and segmentation as well as calculation of consistency measures (operational speed and curvature change rate) for these segments.

2.1 Horizontal alignment

The collected GPS coordinates in the system WGS 84 were converted into the Czech planar coordinate system JTSK, in which they were used for further calculations. The differences in comparison with the calculations in the initial coordinate system were negligible. The conversion was useful, particularly for the calculation of angles between individual points.

The calculated angles were used for the determination which road segment is straight and which is in a horizontal curve. An angle was determined with the apex of the central of every three measured points (see angles α, β, γ in Fig. 1). The value of the sum of these angles (cumulative angle) was used as a criterion defining a curve. The cumulative angle of five consecutive points (angle ω) seemed to be the most useful. Based on the graphic assessment, a limit value was estimated under which the central point of these five points lay in the curve. This value was later made more accurate by the calculation of curvature between the neighbouring points as 8 gon (7.2 degrees).

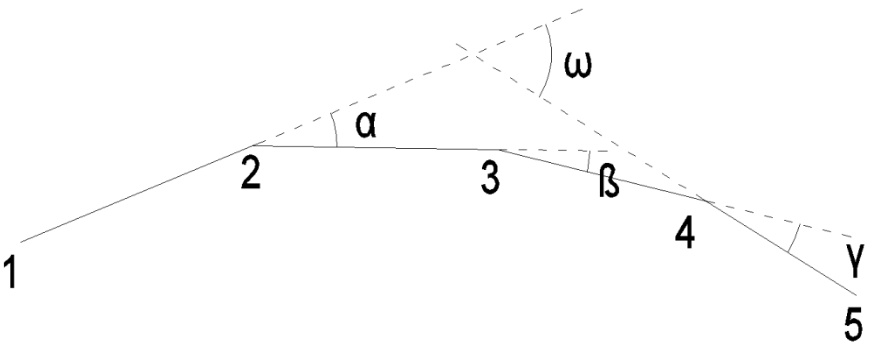

Fig. 1. Scheme of the principle of five-point cumulative angle calculation

Subsequently, straight segments and curves were classified with the use of this criterion. Concerning the inaccuracies of the measurements, excess values may occur even at points outside of the curve or at such point where a lower value was calculated (see example in Fig. 2). Based on the repeated driving and on the assumption of a random error distribution, the minimum number of consecutive points with a cumulative angle above 8 gon was determined to 4 points. In case a point with a lower cumulative angle occurred among the curve points, it was also included in this curve.

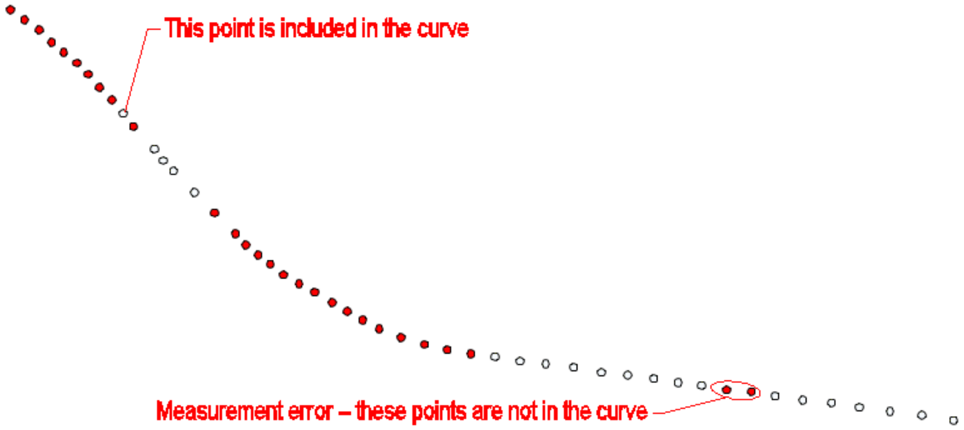

Fig. 2. Example of graphic curve identification

2.2 Curvature change rate

Another step of calculation was to determine the curve radii. These were not determined with a single value for the whole curve, but always with three consecutive points. This way the transition parts of curves were also approximated by the circular curve. The mentioned values were used for the calculation of curvature for individual segments (curves and straight segments). Those segments were considered straight where the discovered curvature ranged between 0 and 50 gon/km. The calculated curvature was used for the classification of the consistency level according to design class values (see Table 1).

2.3 Operating speed

Within the study 85th percentile of measured speeds within individual segments was used as an operating speed. The following Table 2 and the graph in Fig. 3 contain the calculated curvature and speeds for individual segments. In order to perform the assessment, approx. 2.5 km long road segment Jinačovice – Kuřim was selected in this order of direction of driving.

Table 2. Calculated values of curvature and speed in segments

Segment number	Curvature [gon/km]	Average speed [km/h]	Speed V_{85} [km/h]
1	36	84	91
2	99	90	93
3	25	92	95
4	252	73	80
5	43	77	78
6	257	69	72

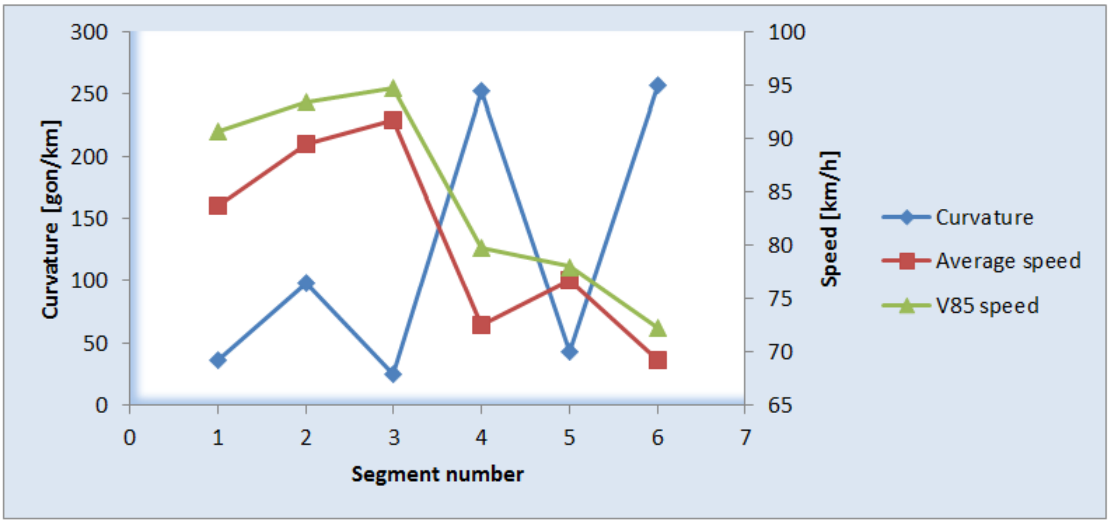

Fig. 3. The course of curvature and speed on road segment Jinačovice – Kuřim

3 RESULTS

The results are given in terms of consistency level of individual curves. Illustrative speed model equation is also introduced. In order to verify the safety performance assessment, accident data analysis results are also mentioned.

3.1 Consistency level

The graph in Fig. 3 shows an obvious reduction of speeds in the curve of a curvature exceeding 250 gon/km. According to Table 2, the curve was considered "fair". This curve is followed by another curve of a significant curvature, however this curve is considered "good" since it may be expected and does not require such change in speed. In the opposite direction, all curves were evaluated as "good" because of the influence of urban area of Kuřim and short distance between curves 3 and 2.

The following Fig. 4 shows the evaluation of curves consistency on the route in question. None of the three assessed curves was classified as "poor".

Fig. 4. Assessment of consistency of three curves of the route in question

3.2 Operating speed model

Based on the measurements, the relationship between curvature and operating speed, the so-called speed model, was derived (see Figure 5). Due to the small amount of data from a single road, it can be only considered as illustrative. In addition, a number of sources recommend using other variables and other function forms (TRB, 2011). Nevertheless, the model is relatively similar to some speed models used in the world, mentioned in literature (Lamm et al., 2007) – see example in Table 3.

Table 3. Equations of relatively similar speed models

Model derived from pilot study	$V_{85} = 91{,}96 - 0{,}061 \cdot CCR_S$
Model derived in Lebanon	$V_{85} = 91{,}03 - 0{,}056 \cdot CCR_S$

The Lebanese speed model, specified in Table 2, has been applied for two-lane rural roads with the maximum speed of 80 km/h. This low speed limit may explain the relative similarity of the mentioned models: the road in question shows less comfortable alignment where the speed limit is only rarely exceeded.

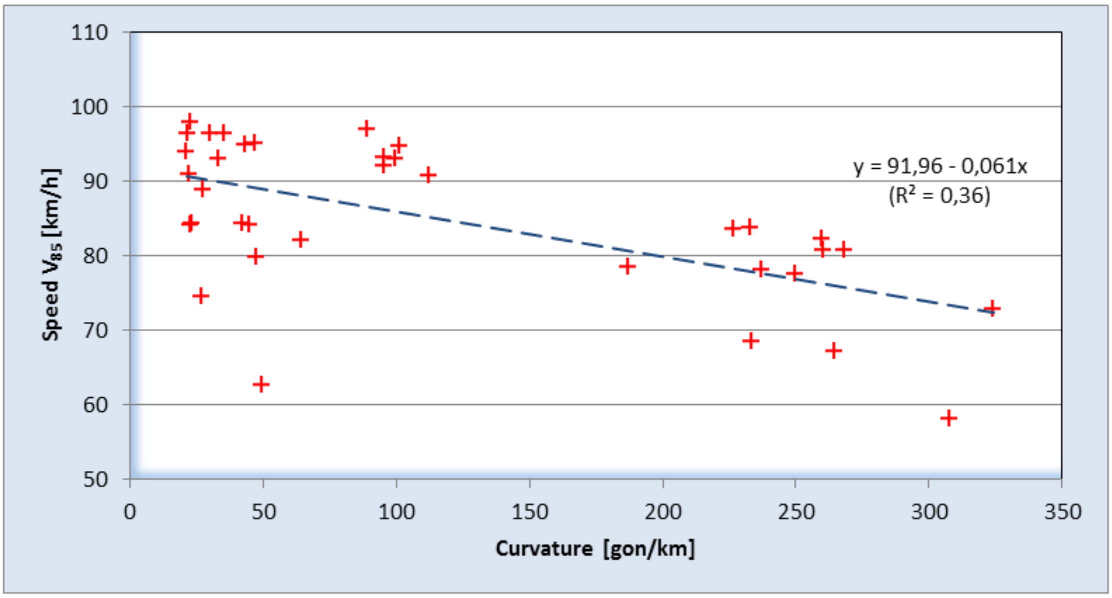

Fig. 5. Illustrative speed model derived from data on the road segment Jinačovice – Kuřim

The decreasing trend of speed is confirmed by the expected relation to the curvature of the road segments in question, as confirmed in the literature. This also illustrates the suitability of applying the criteria of speed and curvature for the assessment of the level of consistency shown in Table 1. In addition, an accident analysis was performed in order to test this classification.

3.3 Accident analysis

The accident analysis in the road segment in question utilized the Police data on road accidents. More than 50 accidents were identified in this road segment in 1998 – 2012. This number was further narrowed down by excluding the accidents in the opposite direction and with the exclusion of accidents in straight road segments. The result amounted to 8 accidents which occurred – according to the Police classification – in the curve or in its vicinity. The accident performance in the three monitored curves (see Fig. 4) was further assessed with the use of the indicators of accident density and accident rate.

The accident density was derived from the number of accidents and the length of road segments. The accident rate was derived from the number of accidents, length of road segments, and their AADTs from the national traffic census. Since AADT was gradually growing, the calculations in individual years when the accidents occurred used the values which were interpolated between the values in the national traffic census. Furthermore, the average of these individual accident rates was used. The results are shown in Table 4 and Fig. 6.

Table 4. Safety indicators for the analysed curves

Curve number	Accident frequency	Accident density	Average accident rate
1	2	0.5	3.7
2	5	1.2	12.1
3	1	0.4	4.2

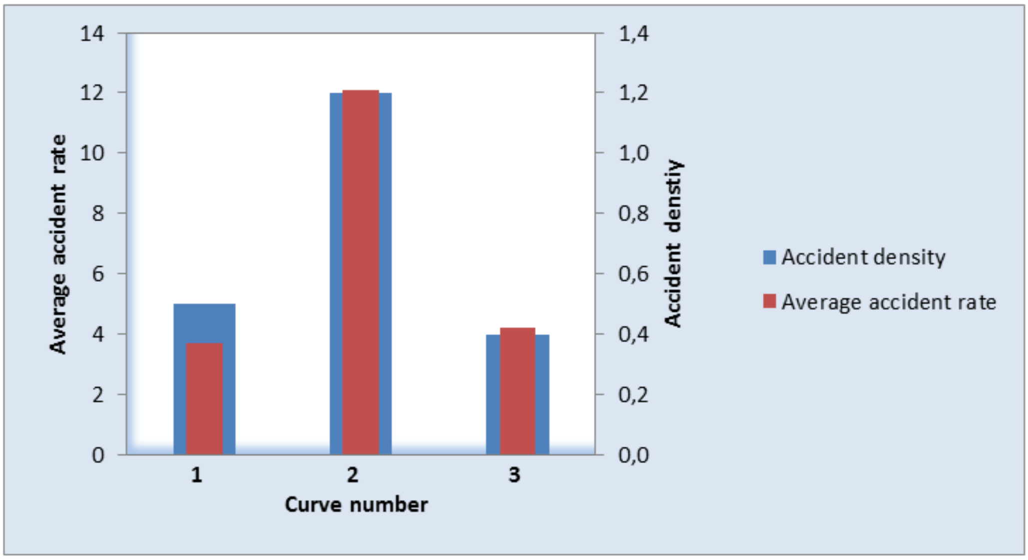

Fig. 6. Graph of accident density and accident rate for individual curves within the analysed route

The mentioned values of both indicators of accident performance make it obvious that the second curve (classified as “fair”) is significantly less safe than the other two, which were classified as “good”. Fig. 7 shows a photograph of the second case: it is a pair of curves where drivers have no information concerning the reduced visibility.

Fig. 7. Photograph of curve 2

4 DISCUSSION

It was shown that utilized classification objectively identifies differences in safety of individual road segments. The ratio between accident rate for "good" and "fair" consistency is about 1 : 3, which corresponds with the findings of similar foreign analyses (Lamm et al., 1999).

The method can be used for example by a road administrator to evaluate selected roads, to compare them, and to determine the importance of the application of road safety measures. A potential low-cost solution to improve road safety in the described locality and in some similar ones can be the timely installed and comprehensible road signing which would inform of this unsatisfactory curve. The consistent road signing provides drivers with clear information which situation they may expect.

It is necessary to point out that there is currently no unified approach to the deployment of suitable warning signs such as chevrons. These can be often found at locations which are not as risky as others where such sign is missing. With the use of the mentioned method, the unsatisfactory curves can also be equipped with a traffic sign "advisory speed limit". It is a useful way to inform drivers who do not drive through this route daily, while not limiting the drivers who are familiar with this route.

Another application can be the determination of the "ideal" operating speed on the basis of the properties of the road segments in question. The speed should reflect both the real speed of vehicles V_{85}, as well as safe speed, hypothetically representing the maximum speed limit. This "ideal" speed may be used already during the road designing stage; the aim is to minimize the difference between the design and real speed. The quality should be then evaluated in the same way as in Table 1, while using the difference between the design and real speed instead of ΔV_{85}.

However it should be noted that it was only a case study. The main objective was to prove the whole procedure and test its results. The described pilot study was realized within an internal grant; the authors are currently planning to perform the study in the form of a full research project in a greater scope. The project will include a data collection from vehicle fleet on a larger area of the road network and among others a specific speed model will be developed, not only for curves, but also for straight road segments. The calculation procedure will also be algorithmized in order to automatize the process. The outcomes of the final project will include a methodology for the application on the Czech road network and recommendations for amendments of the corresponding parts of the national road design standard ČSN 73 6101.

CONCLUSIONS

The aims of the pilot study specified in Introduction chapter were met. The feasibility of the study was verified in practice, and the data were collected and used for the assessment of the consistency of the horizontal alignment. This assessment was confirmed by accident performance in terms of both accident density and accident rate. Furthermore, the relationship between curvature and speed was demonstrated for the illustrative purpose. The result proved that these indicators can be used for the classification of consistency of the road horizontal alignment.

Potential application of hazardous segments of the existing roads is described. Furthermore, mentioned relationship between the level of consistency and road accident rate imply that the consistency can be used as an indirect road safety indicator. The indirect indicator can be thus used proactively, i.e. without waiting for an accident, e.g. during a road safety audit of a project documentation. This way it is possible to come closer to the so-called self-explaining roads. Such roads have homogenous categories whose alignment and equipment correspond with expectations of their users. Since the expectations of drivers correspond with the real situation, the traffic flow on self-explaining roads will be smooth and safe.

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