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MODELING HIGHWAY GEOMETRIC DESIGN CONSISTENCY USING OPERATING SPEED AND SAFETY DATA

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'I think everything happens for
a reason, although I'm not sure
what that reason is yet'

(cit. John Lesli)

Introduction

The road-safety is one of the most important priorities of socio-economic policy of E.U. which advanced several programs for enhancing and improving safety Standard in the member Countries. Italy is one of the European Countries that has not yet achieved the results envisioned in the "*European Road Safety Action Program, Halving the number of road accident victims in the European Union by 2010: A shared responsibility*". The existing Italian road network, as indicated in the "Bozza per gli Interventi di Adeguamento delle strade esistenti" (2006), is composed by long planimetric development with geometrical, functional and multiform traffic conditions. The defined design criteria are very different and not quite congruent with the current operating conditions. The "Bozza per gli Interventi di Adeguamento delle strade esistenti", according with D.M. 22/04/2004, disciplines the design criteria and implementation of treatments, structural or non-structural, on existing road network, approved and incorporated into the planning and programming schedule of government bodies and / or operators. These criteria are geared to improving the operational capability and safety of roads, in compliance with the existing environmental, archaeological, landscape and economy restrictions. The current regulation D.M. 5/11/2001 states that treatments on existing roads for the improvement of road consistency, must be performed by adapting to these standards. The transition between sections that reflect the current regulation and sections where the adaptation has been considered not be possible, must be resolved to avoid the introduction of unsafe conditions. The Directive 2008/96/EC of the European Parliament and of the Council on Road infrastructure Safety Management required the establishment and implementation of procedures relating to road safety impact assessments, road safety audits, the management of road network safety and safety inspections by the Member States that are essential tool for preventing possible dangers for all road users and also in case of road works. The research aims to provide integrated procedures to investigate the relationships between road alignment consistency and crash risk factors integrating safety into roadway management process. Factors directly related to road safety conditions are infrastructure/environmental features, human factors, vehicle conditions. On a road element, drivers usually appreciate two prevalent measures of good driving performance: speed and comfort. Drivers select speed using perceptual and "road message" cues. By identifying these cues, drivers can establish self-regulating speeds with minimal or no enforcement. In fact, crashes can be defined as the result of bad decisions made by drivers. One way to accommodate for human information processing limitations is to design roadway environments in accordance with driver expectations: a road design that's aligned with the driver limitations and expectations can help increase the likelihood of drivers responding to particular situations and information correctly and quickly. When a roadway alignment helps drivers anticipate changes, and meets previous requirements, it's marked out a good geometric consistency. The road analyzed is the S.P. 430, a variant of the state highway S.S. 18, the "Tirrenia Inferiore", which is the major road, after freeway A3, and is also one of the most important and long in Southern Italy, considering that go through Tyrrhenian coast along the road and railway Naples - Reggio Calabria, linking the two largest urban centers of Campania and Calabria. The road project dates back to 1973, and was carried out prior to the development and introduction of the D.M. 5/11/2001, having been subject during the years to a series of interventions that have changed the geometric regularity. By using project cartographies and information collected onsite and the help of Civil Design software, the horizontal-vertical alignment was drawn with the definition of the exact succession of the road elements. Road and crash features have been studied as follows: a) geometric and traffic data collected by site surveys and by verifying documents at the Land Registry of the roads; b) speed values collected at specific sections by using laser detectors placed in tactical locations and hidden from the view of drivers; c) crash reports analyzed at the administrative offices of the Province for a study period of 8 years. Road alignment consistency was evaluated and a prediction model was calibrated by a sensitive analysis to match the road with one only global measure of consistency for the entire development, and no with speed reductions between two following elements. Nine homogenous road elements were identified. The starting point of the analysis was the operating speed profiles and the assessment of two parameters for each investigated road: a) the area bounded by the speed profile and the average weighted speed lines, and b) the standard deviation of speeds along a road horizontal alignment. Negative exponential function has been adopted to calibrate the model. Next step has been the evaluation of relationship between the road consistency, road alignment and crashes. The alignment consists of a variety of design elements that combine to create a facility that serves traffic safely and efficiently, consistent with the facility's intended function. Each alignment element should complement others to achieve a consistent, safe, and efficient design. Each homogenous road element has been associated with the following information; parameter of consistency, design criteria not satisfied, size of the combinations not satisfied, the frequency of the combination, the number of times when in the presence of a combination were recorded crashes and the total number of accidents for combination. Lastly, the Empirical Bayesian evaluation method was applied to estimate the average crash rate frequency on the "sites" in the "before" configuration, current configuration referring to the CNR 80 regulation , and the "after" configuration, expected configuration with the adoption of the design criteria indicated in the DM 05/11/2001. The work presented can be an useful tool for body government to identify hot spot of the road network and evaluate the effective treatments to improve road safety.

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1. Literature review

The Directive 2008/96/EC of the European Parliament and of the Council on Road infrastructure Safety Management pointed up the need to carry out safety impact assessments and road safety audits, in order to identify and manage high accident concentration sections within the Community. It also had set the target of halving the number of deaths on the roads within the European Union between 2001 and 2010. This Directive required the establishment and implementation of procedures relating to road safety impact assessments, road safety audits, the management of road network safety and safety inspections by the Member States that are essential tool for preventing possible dangers for all road users and also in case of road works.

One way to accommodate for human information processing limitations is to design roadway environments in accordance with driver expectations: a road alignment that it's easy to be predicted by drivers, it's characterized by a good consistency. Roads provided with a good horizontal-vertical alignment can help avoid abrupt reductions in speed between consecutive geometric elements and, consequently, they can help to decrease the crash frequency.

Design consistency" refers to the condition where in the roadway alignment does not violate driver expectations (NCHRP, 2003)

Many researchers (Transportation Research Circular E151 of TRB of the National Academies, July 2011: Modeling Operating Speed) have verified that one of the parameters to most influence a safe driving is the operating speed variable and the design consistency evaluation is one of several promising tools that can be employed by roadway designers to improve roadway safety management process.

Glennon et al. (1978) were among the first to suggest that design consistency should be recognized as an underlying principle in highway design. However, there remains a general lack of explicit criteria for combining contiguous basic design elements. Without such criteria, designers will continue to incorporate inconsistent geometric elements into highways.

Earlier, the American Association of State Highway Officials (AASHO) (1972) developed the Driver Expectancy Checklist, in which design consistency was a major parameter. The results strongly suggest that only proper coordination among all roadway and terrain features can achieve good design consistency.

Messer (1980) presented a methodology to evaluate consistency based on driver-behavior principles associated with workload ratings for different geometric features. For example, because sharper curves are generally more troublesome, a driver's workload increases with the degree of curvature and with the deflection angle of the curve. Using the same reasoning Messer also suggested that excessively long curves were accident inducing and should be discouraged. Similarly, he proposed some general design recommendations for consistent horizontal and vertical alignments and intersections.

Polus and Dagan (1988) developed and tested several models to evaluate highway-design consistency, including a spectral analysis model for the horizontal alignment; the proposed methods could be adopted for the vertical alignment, as well. They tested their consistency models on theoretical sample roads that they developed. The spectral model had the highest correlation with a logical consistency rating established in previous research and with engineering judgment. Earlier, Polus (1980) Investigated the relationship between longitudinal geometric measures (such as the average radius, or the ratio between the minimum and maximum radius of an alignment) and safety levels on two-lane rural highways. He proposed that safety correlated with a similarity in design elements (quantified by the proposed measures) and, therefore, with consistency. He reasoned that drivers tended to build up an expectation of what the upcoming roadway would be like, based on their immediate previous driving experience.

Gibreel et al (1999) presented a comprehensive literature review of highway geometric design consistency mainly on two-lane rural highways in North America and Europe. Previous research work on highway geometric design consistency is categorized into three main areas: (1) Speed considerations; (2) safety considerations; and (3) performance considerations. (See Figure 1) Speed considerations address the different effects of geometric parameters on the prediction of operating speed. Based on operating speed, design consistency of highway elements can be evaluated. Safety considerations explain the different relationships between highway safety and highway/traffic elements, vehicle stability, and low-cost improvements. Performance considerations address the different effects on driver workload, driver anticipation, highway aesthetics, and interchange design. Based on this review, a framework for highway design consistency is proposed, and recommendations for future research work on design consistency are suggested, including the need to develop operating speed consistency models based on 3D analysis.

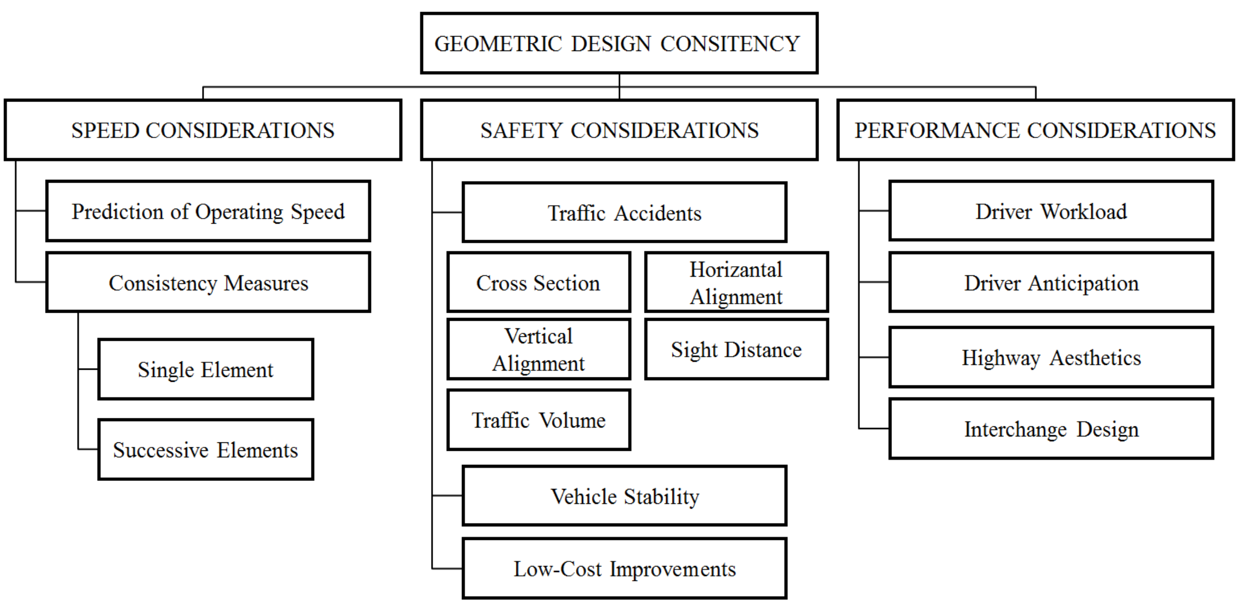


Figure 1– Main Areas of Geometric Design Consistency

Speed is an important factor that is usually considered in the route selection or the choice of transportation mode. The attractiveness of different highways is weighed by the road user in terms of time, convenience, and cost. The actual operating speed is defined as the speed selected by the highway users when not restricted by other users [i.e., free-flow conditions (Poe et al. 1996)] and is normally represented by the 85th percentile speed. Many factors affect prediction of operating speed, such as radius of horizontal curve, length of horizontal curve, sight distance, super elevation rate, side friction factor, and pavement conditions. There are various methods of predicting operating speed, followed by consistency evaluation measures on a single geometric element and successive elements. It should be noted that previous research work was limited to rural highway sections with the following characteristics: (1) Intersections are not present; (2) no physical features adjacent to or in the course of the highway section that may create abnormal hazard; (3) shoulders are paved and the sections are delineated; (4) pavement width does not change; and (5) grades are <5%.

The most commonly used criteria to evaluate highway design consistency were based on operating speed. For a single geometric element, design consistency is evaluated by comparing the design speed V_d and operating speed V_{85}. For successive geometric elements, design consistency is evaluated based on the operating speed on these elements.

For a single element design speed is defined as the maximum safe speed that can be maintained over a specified section of a highway when conditions are so favorable that the design features of the highway govern (AASTHO 1994). Based on the difference between V_{85} and V_d, different approaches were developed to evaluate design consistency on a single highway element.

Some of the approaches recommended by European countries to achieve consistency between operating and design speeds have been summarized by Brenac (1996). In the United Kingdom, the design speed is determined through an iterative method. An initial alignment is defined based on a trial design speed, and then the operating speed is predicted using a statistical model. By comparing operating and design speeds, the designer can, if necessary, adjust some parts of the alignment or change the design speed to make it close to V_{85}. The advantage of this approach is that it ensures consistency between design and operating speeds. In the German standards, a design speed is used to determine the minimum radii of the horizontal and vertical alignments and the maximum values of gradient. Then, the operating speed is predicted for road sections according to the CCR and road width and is used to design other elements such as super elevation rates. However, it was suggested that the difference between operating and design speeds should not exceed 20 km/h, otherwise, the design speed should be raised or the alignment characteristics should be modified to reduce the operating speed (Brenac 1996).

The French practice is similar to the German practice except that operating speed is defined at each point of the alignment. The operating speed is then used to check the available sight distance along the alignment. However, because these approaches can ensure design consistency on an individual element only, additional design rules were recommended to achieve consistency between successive elements (Brenac 1996).

In the United States, a design speed concept based on operating speed has been proposed by Leisch and Leisch (1977). The objective of this concept was to better meet driver expectations and achieve operational consistency. It was recommended that the difference between operating and design speeds on a specific highway section should not exceed a maximum of 15 km/h. Furthermore, the operating speed difference between passenger cars and trucks on a specified element should also be restricted to 15 km/h. In another study by Lamm et al. (1988b, 1995) to evaluate the design consistency of independent highway elements, the relationship among accident rate, geometric characteristics of horizontal curves, and difference between V_d and V_{85} was investigated. Based on mean accident rates, the difference between V_d and V_{85} was suggested as a criterion to evaluate design consistency as follows (Lamm et al. 1988b, 1995):

- Good design: $V_{85} - V_d \leq 10$ km/h (no alignment corrections are necessary).
- Fair design: 10 km/h $< V_{85} - V_d \leq$ 20 km/h (corrections are required: superelevation rate and stopping sight distance must be related to the expected V_{85}).
- Poor design: $V_{85} - V_d > 20$ km/h (redesign of these hazardous locations is required based on the value of V_{85}).

In addition to using V_{85} as a guide for selecting V_d, the posted speed should also be selected based on V_{85}. Fitzpatrick et al. (1997) studied the relationships between design speed, operating speed, and posted speed on two-lane rural highways and found that V_{85} on horizontal curves was less than V_d for all curves with $V_d > 70$ km/h and greater than V_d for most curves with $V_d < 70$ km/h. It was concluded that when operating speed is higher than design speed, a speed inconsistency condition will arise at this location. This inconsistency results from using the minimum safe values for the design elements. Although liability concerns may arise when the posted speed exceeds V_d, it was concluded that V_{85} is an appropriate posted speed limit even for those highway sections that have V_d less than V_{85}.

For successive elements different measures were proposed to evaluate design consistency of highway sections with multiple elements, especially those with two successive elements. These measures include: (1) average curvature, which was defined as the sum of central angles of horizontal curves in a specific highway section divided by the length of this section; (2) average hilliness, which was defined as the sum of the distances between each crest vertical curve and the following sag vertical curve in a specific highway section divided by the length of this section; (3) length ratio, which was defined as the sum of horizontal and vertical curve lengths in a specific highway section divided by the length of this section; (4) average radius, which was defined as the average radius of a set of horizontal curves in a specific highway section; and (5) design radius, which was defined as the average radius divided by the minimum radius related to the design speed on a specific highway section (Lamm et al. 1986). It should be mentioned that the alignment consistency is directly proportional to the average radius and design radius, while it has an inverse relationship with average curvature, average hilliness, and length ratio. However, the simplest and most common method to evaluate design consistency on successive elements is based on operating speed values (Lamm et al. 1988a). Different combinations of successive elements have been studied: long tangent followed by a horizontal curve and two successive horizontal curves with or without a short tangent.

In Russia, Babkov (1968) concluded that consistent and safe design of horizontal alignment could be achieved when the difference in operating speed between two successive elements did not exceed 15% of the speed on the preceding element. Speed-profile models have subsequently been used in different European countries to determine the difference in V_{85} on the approach tangent and the following curve.

Switzerland was the first country to incorporate this difference into its design practice as a consistency measure (Krammes et al. 1994). Kanellaidis et al. (1990) determined V_{85} on the tangent that is based on speed data and used the model of (5) to estimate V_{85} on the following horizontal curve. It was suggested that a good design can be achieved when the difference between V_{85} on the tangent and the following curve does not exceed 10 km/h. Based on mean accident rates; Lamm et al. (1995) suggested another criterion to evaluate design consistency between a tangent and the following curve as follows:

• Good design: range of change in $V_{85} \leq$ 10 km/h (consistency exists).

• Fair design: 10 km/h < range of change in $V_{85} \leq$ km/h (minor inconsistency exists, traffic warning devices are required).

• Poor design: range of change in V_{85} > 20 km/h (strong inconsistency exists, redesign is recommended).

Other models were also developed to express the speed reduction between a tangent and the following curve as a function of the geometric parameters and pavement condition in terms of present serviceability rating (Al-Masaeid et al. 1995). The results indicated that the radius of curve (degree of curve), length of vertical curve within the horizontal curve, gradient, and pavement condition affected the design consistency significantly. Three models of operating speed reduction between a tangent and the following curve were formulated as follows:

$$\Delta V = 3.30 + 1.58 \cdot D \quad (1)$$

$$\Delta V = 1.84 + 1.39 \cdot D + 4.09 \cdot P + 0.07 \cdot G^2 \quad (2)$$

$$\Delta V = 1.45 + 1.55 \cdot D + 4 \cdot P + 0.00004 \cdot L_V{}^2 \quad (3)$$

Where ΔV = operating speed reduction between tangent and curve (km/h); P = pavement condition (for present serviceability rating ≥3, P = 0, otherwise P = 1); G = gradient (%); and Lv = length of vertical curve within the horizontal curve (m). It should be noted that the models of (1)–(3) were recommended for horizontal curves on a flat gradient, a specific gradient, and vertical curves, respectively. Based on (1) and the criterion suggested by Lamm et al. (1995) for good, fair, and poor design, it was concluded that a good design can be achieved if the degree of curve D on flat grades is <4.247. For a horizontal curve combined with another gradient or a vertical curve, values for the maximum degree of curve were suggested depending on the gradient or the length of vertical curve, respectively. For two successive horizontal curves with different V_{85} and a short intermediate tangent, the minimum tangent length that promotes operating speed consistency was investigated by Lamm et al. (1988a). It was recommended that the tangent length that would guarantee speed consistency should be determined based on V_{85} of the two curves. Based on Newton's laws of motion and the assumption that the average deceleration rate is equal to 0.85 m/s^2 this length can be determined as follows (Lamm et al. 1988a):

$$L_T \frac{V_{AV} \cdot \Delta V_{85}}{11.064} \tag{4}$$

Where L_T = minimum tangent length (m); V_{av} = average of V_{85} on the two successive curves (km/h); and ΔV_{85} = difference between V_{85} on the two successive curves (km/h). For two successive horizontal curves without an intermediate tangent, the design guide by the American Association of State Highway and Transportation Officials (AASHTO) recommended that the ratio of the flatter radius to the sharper radius should not exceed 3:2 (AASHTO, 1994). The speed reduction between the two successive curves was modeled by Al-Masaeid et al. (1995) as follows:

$$\Delta V = 5.081 \cdot \left(\frac{1}{r_2} - \frac{1}{r_1} \right) \tag{5}$$

Where r_1 and r_2 = radius of the first and second curves, respectively (m). Using a maximum speed reduction of 10 km/h that corresponds to a good design, the minimum and maximum radii of the second curve can be calculated for a specific radius of the first curve. However, it is expected to evaluate the design consistency of successive highway elements more accurately when considering the 3D nature of highway alignments. In addition, research work on consistency measures to evaluate successive highway elements should be extended, in terms of explicit and applicable design consistency criteria, to include the different combinations of highway elements. A common shortcoming in all of the preceding models is considering the horizontal curves in 2D alignment and vertical alignment separately except for the model of (3), which included, in addition, the length of vertical curve.

Achieving highway geometric design consistency is an important issue in the design and evaluation of rural highways to attain smooth and safe traffic operation.

Castro et al (2011) presented a research carried out in Colombia consisting of a study of vehicle speeds on tangents and curves of two-lane rural highways. Car speeds were measured on the approach tangent and at the beginning, middle, and end points of curves by using two radar meters. The operating-speed prediction models were developed. The speed change experienced by drivers from tangent to curve was also studied, and a model is presented that predicts this change. Finally, the model developed for operating-speed prediction at the midpoint of curves was compared with equivalent models calibrated in other countries and applied to a Colombian highway. This comparative study highlights the importance of using speed-prediction models calibrated according to local conditions.

Polus et al. (2000) developed a family of nonlinear models for predicting operating speeds on tangent sections of two-lane highways. The independent variables were the length of the tangent section and the radii of the curves prior to and after the tangent section. These models, jointly with those suggested by Krammes et al. (1995) for estimating operating speed on curves, were used during the development of speed profiles for formulating a consistency model for two-lane highways in the present research.

Anderson and Krammes (2000) estimated the reduction in 85th percentile speeds from the approach tangent to the midpoint of the following curve. They found that a statistically significant relationship existed between mean speed reduction and mean accident rate: sites with higher speed reductions showed higher accident rates. This important finding was further investigated in this research through the development of a relationship between speed profile variability, as a measure of the design consistency of two-lane highways, and expected crash rates.

Krammes and Hayden (2003) discussed the Interactive Highway Safety Design Model (IHSDM), which has been in development in the U.S. for several years. This model includes a consistency module with two aspects: large differences between the assumed design speed and the 85th percentile speed and large changes in the 85th percentile speed between tangents and curves.

Polus and Mattar-Habib (2004) studied consistency of design on two-lane rural highways and to ascertain the existence of a relationship between consistency and safety level. The immediate objectives were to develop new, independent measures of consistency that could reflect the similarity (or lack thereof) of performance along an entire level or hilly section, to develop a new consistency model, and to find the relationship between the new model and crash rates on two-lane rural highways. Two consistency measures were developed: the first was the relative area bounded by the speed profile and the average weighted speed; the second was the standard deviation of operating speeds in each design element along the entire section investigated. Following an extensive sensitivity analysis of these two measures, thresholds that quantified the design quality were suggested. Based on the two independent measures, a consistency model was developed; and thresholds for good, acceptable, and poor design consistency of any section were proposed. Additional analysis was conducted on the relationship between the proposed consistency model and the safety level of two-lane highways. This was done initially on a limited data set of nine local, two-lane highway sections. It was found that as design consistency increased, crash rates decreased significantly. In a second phase, the analysis was expanded and the same consistency model was applied to a data set of 28 two-lane U.S. highways. It was found that crash rates decreased when the consistency value increased.

Camacho-Torregrosa at al. (2013) presented a new methodology to evaluate road safety in both the design and redesign stages of two-lane rural highways. This methodology is based on the analysis of road geometric design consistency, a value which will be a surrogate measure of the safety level of the two-lane rural road segment. The consistency model is based on the consideration of continuous operating speed profiles. The models used for their construction were obtained by using an innovative GPS-data collection method that is based on continuous operating speed profiles recorded from individual drivers. This new methodology allowed the researchers to observe the actual behavior of drivers and to develop more accurate operating speed models than was previously possible with spot-speed data collection, thereby enabling a more accurate approximation to the real phenomenon and thus a better consistency measurement. Operating speed profiles were built for 33 Spanish two-lane rural road segments, and several consistency measurements based on the global and local operating speed were checked. The final consistency model takes into account not only the global dispersion of the operating speed, but also some indexes that consider both local speed decelerations and speeds over posted speeds as well.

After the statistical analysis, the proposed model for relating crash data to road geometry results as: where C is the design consistency index, calculated as:

$$ECR = \frac{1}{2.40939 + 0.00403287 \cdot C} \qquad (6)$$

Where C is the design consistency index, calculated as follows:

$$C = \frac{\bar{V}_{85}^{-2}}{\Delta V_{85}} \qquad (7)$$

The development of this new model and consistency index provides a new design consistency measure for an entire road segment. Moreover, since the model presents the relationship between consistency and crash rate, it is possible to use that parameter as a surrogate measure to evaluate road safety and estimate the number of accidents with victims. Consequently, the results of this research can be an innovative tool for assisting engineers at the design or redesign stages, enabling them to evaluate the consistency and road safety of several possible solutions and to ultimately choose the safest one. In addition, the presented model can be also applied to estimation of the crash rates of an existing road where accident data are not available.

Park and Saccomanno (2006) assessed the safety implications of using the conventional DV85 and introduce a hierarchical model for considering individual vehicles speed consistency. A new speed differential measure called 85MSR was included in the study, measure that reflects the 85th percentile maximum speed reduction between two successive highway elements as experienced by the same vehicle or driver.

These findings lead to important implications for introducing engineering treatments to improve safety along in two-lane rural highways based on the criteria of speed consistency. Results show: (1) The 85MSR measure is more flexible than conventional ΔV_{85} measure for estimating speed differential between successive highway elements. This is because the 85MSR does not require a strong independency assumption for speeds established by vehicles in these elements. The 85MSR measure is better to capture the full speed variance between successive elements and hence is better able to identify safety problems for treatment: (2) The conventional $\Delta V85$ measure is tangible because of the problem called ‘‘ecologic fallacy’’. Inasmuch as this problem, researchers tend to reach a misguided conclusion that the conventional ΔV_{85} suggests adequacy of explanation of their study data, when such a conclusion is not justified. Therefore, a disaggregated approach is necessary and required to be modeled: (3) A multi-level model (i.e. a hierarchical data analysis) provides additional insights that cannot be captured using a single-level modeling approach. Using a multi-level model in this paper we found that the majority of speed differential in individual vehicle speeds can be accounted for by distinct vehicle/ driver characteristics rather than the geometric features of the corresponding highway section: (4) Decision makers in highway engineering fields should be more conservative when they decide to alter geometric features such as the curvature of a curve based solely on increasing safety. There might be other more cost-effective means to achieve these safety objectives. We note that this conclusion is based on an assumption that the speed differential is positively associated with the likelihood of accidents. However, this assumption has not been validated.

Ng and Sayed (2004) presented eight accident prediction models that relate design consistency to road safety. Six models investigate the relationship between individual design consistency measures and accident occurrence and show the direction of correlation as expected. For a more comprehensive evaluation of the impact of design consistency on road safety, two models that incorporate several design consistency measures to quantify the impact are developed. The models show that when design consistency is considered, the safety performance of an alignment is improved. A qualitative comparison is made to compare accident prediction models that explicitly consider design consistency with those that rely on geometric design characteristics for predicting accident occurrence. The comparison, while limited to fictitious alignments and not real data, shows that the first type may be superior as it can potentially locate more inconsistencies and reflect the resulting effect on accident potential more accurately than the second. The prediction accuracy of accident prediction models is limited by the quality of their independent variables. As such, the models developed in this study depend heavily on the design consistency measures used. Therefore, future research effort should be devoted to improving the prediction of these measures. In addition, the models developed in this study are limited to horizontal curves and tangents only. More work is needed to expand the applicability to sections that are combined with vertical curves as well as to other types of highways.

Hassan (2004) presented a critical review of the concept of highway geometric design consistency, criteria and parameters for its evaluation, and its relationship to safety performance. A number of concerns or challenges to the current state of knowledge and practice were outlined with the objective of refining and improving the concept and its applicability. The main conclusion that can be drawn based on this review is that despite these challenges and concerns, the theory remains promising but improvements are necessary. Some research work has already been carried out and more is still needed in a worldwide collaborative effort to overcome these challenges:

• An optimum data collection procedure to capture actual drivers'speed behavior needs to be developed and agreed on. Such a procedure must not influence drivers' behavior through the introduction of perceived speed enforcement.

• Operating speed is not strongly correlated to alignment features need to be further verified once the optimum data collection procedure has been developed. If this finding is confirmed using a larger database, alternative approaches to the simple regression analysis should be developed to predict operating speed on the different features of the highway alignment. In the following study, Misaghi and Hassan (2005) found, compared to the results of previous studies, the relationship between the operating speed at the middle of a horizontal curve and the horizontal curve radius or other alignment parameters is relatively weak. Many reasons could have contributed to this finding including the smaller number of restrictions in site selection, most importantly including curves with nearby intersections and driveways. It is also hypothesized in this study that another main reason for this observation is the nonintrusive approach for speed data collection using traffic counters/classifiers. As shown in the paper, the use of a radar gun causes drivers to slow down because of their perception of speed enforcement. The presence of such a potentially dominating factor as perception of speed enforcement might conceal other factors that would normally influence drivers' speed selection. Such factors as length and urgency of trip as well as driver's familiarity with the road and level of speed enforcement may be impossible to account for but might dominate the driver's choice of speed in the absence of perceived speed enforcement.

• Research on friction factors for highway design in general, including consistency evaluation, is long overdue, and so is a comprehensive research to examine how the friction assumed and demanded have changed with the evolution in the vehicle and pavement industries. This research will need to be updated frequently to keep the highway design parameters on track with the ever-evolving automobile industry.

• Driver workload is another area in which comprehensive research is urgently needed. • Evaluating design consistency on the basis of absolute values such as visual demand or ratio of curve radius to average radius of a section will always favor larger radii. Therefore, a criterion based on a differential value would be more appropriate and needs to be developed.

• Analysis of the relationship between the different candidate evaluation criteria speed and safety performance should be performed using the more accurate Poisson or negative binomial regression. The results should then be put in a form usable by highway practitioners.

• The optimum size of an area to be covered by a prediction model needs to be estimated. The trade-offs between developing a more general, but less accurate, model on the basis of the data from a large area and a more specific, but more accurate, model covering a smaller area must be considered. This consideration is particularly important for countries that extend over large areas with different dominant environmental, topographic, and even demographic characteristics.

Mattar-Habib et al (2008) presented the calibration of an enhanced-consistency model which was developed initially by Polus et al (2005). The values of the consistency were calculated using data collected from two countries: Israel and Germany. 26 Israeli road segments and 83 German road segments were investigated in order to examine the relationship between crash occurrence and road consistency. The relationship between crash probabilities and road consistency was described by a Poisson model. The model's parameters were calibrated using maximum likelihood method. It was found that the German and Israeli calibrated models were relatively close to each other. It can be noticed clearly that the trend of the two calibrated models is similar; as road consistency improves, the average crash numbers estimated decrease significantly. The enhanced-consistency model and the software may be used to determine consistencies of different alternatives during the planning of new highways or the reconstruction of existing roads. Adherence to high consistency levels adds another dimension to the planning process, beyond the use of minimum criteria of geometric design, and therefore consequently assures a higher level of safety.

Dell'Acqua and Russo (2011) illustrated the use of new, different variables to better analyze the performance of drivers on some Italian low-volume roads. Four operating speed prediction models were calibrated and validated for tangents and circular curves to improve the design of the operating speed profiles for two travel directions. The operating speed prediction models were prepared by using the remainder of the speed values collected that did not fall in the transitions. Two operating speed models were produced for the tangents: the first one for lengths of greater than 500 m and the second one for lengths of less than 500 m. Two operating speed models were also produced for the circular curves: the first for a mean CCR for a homogeneous roadway segment greater than 240 gon/km and the second for a CCR of less than 240 gon/km. All models were then validated by analysis of some statistical parameters by comparing predicted speed values with observed speed values not included in the calibration phase. A continuous operating speed profile can be designed for the total length of the low-volume roads analyzed by using the results of the preceding transition study and one of four operating speed prediction models, depending on the tangent length and the CCR. Different variable types were used to properly analyze actual driver speed behavior: functional factors—that is, a pavement distress indicator, an intersection indicator, and the number of residential driveways per kilometer; geometric factors—that is, the length of the single element, the radius of the circular curve, the CCRS, the CCR of the homogeneous roadway segment, and the width of the travel lane plus shoulders; and speed factors—that is, the speed on the preceding curve. Pavement distress indicators are important for improving operating speed prediction models. The severity of each distress is identified by use of a four-point scale ranging from 0 to 3. The results obtained illustrate improvements to preceding prediction models: the values of the residuals between the observed and predicted operating speed values are lower than the initial residuals, and their distribution around the mean is low, which was confirmed by the performance diagrams. In conclusion, the V_{85} profiles can be used to develop safety analyses of existing low-volume roads. In fact, it is possible to design measures to improve roadway safety conditions by estimating at each road element the difference between the operating speed value obtained by using speed prediction models and the speed value suggested by standards. The countermeasures needed to improve roadway conditions can be derived from analysis of each explanatory variable introduced in the prediction models, which can help to improve or worsen driver speed behavior. Moreover, the four operating speed prediction models described for tangents and circular curves are transferable to other low-volume roads, provided that these roads have the features of those adopted in the calibration phase. Four models in particular can be applied to all roads located in areas with level terrain and vertical grades of less than 6%; however, these models may not be used for rural roads with spiral transition curves between the geometric tangent and circular elements on the horizontal alignment. The results are valuable for practitioners because they can use the difference between the operating speed obtained with the models and the standard design speed to determine the best solution that allows the standard design speed to be similar to the predicted operating speed by use of the explanatory variables introduced in the operating speed prediction models. Finally, the explanatory variables introduced in the prediction models presented can be used to improve road safety, as mentioned above, but various structural and nonstructural operations to improve roadway safety conditions are driven more by economic requirements than by social needs.

Russo et al (2012) illustrated an investigation on two-lane rural roads in the Southern Italy without spiral horizontal transition curves to check a prediction consistency model. Original results were compared with consistency-prediction models available in the scientific literature to check several alternative designs and select the alternative with the highest consistency. A negative exponential consistency model was tested based on the relative area measure and the standard deviation of speeds; this consistency formulation well-analyzes the design consistency of the examined roads and the coefficients of the equations move away slightly from the values proposed in the literature and similar assessment of design consistency as Lamm and Choueiri's indicators.

Morcillo et al (2014) calculated consistency based on operating speed on two-lane rural highways of the province of Granada. Three consistency measures were calculated for 506 homogeneous road sections: the relative area, which represents the area bounded by the speed profile and average speed of a road segment, the standard deviation of the operating speed in each design element along the road segment and the consistency model defined by Polus and Mattar-Habib (2004), based on the previous measures introduced. Some discrepancies have been found in the results obtained.

Dell'Acqua et al (2013) described a revision of a prediction model illustrated in the scientific literature that makes it possible to assess the consistency of the total length of a highway by using a single parameter. This prediction consistency model makes it possible to define alternative road interventions to improve road safety by selecting the solution with the highest consistency. Speed data collection was carried out by placing the KV laser at selected stopping places on the studied two-lane rural road, and the V_{85}-value for each investigated geometric element was calculated according to the requirements shown earlier. Because two V_{85}-values for each surveyed road element are available by changing the travel direction, two speed profiles were traced and the criterion of Lamm and Choueiri was used to define the worst result among those derived from this analysis between the two travel directions on each administrative road segment. The consistency prediction model available in the scientific literature was tested by obtaining a single measurement of horizontal consistency for the total highway length: two independent operating speed measures (Ra and σ) were calculated to calibrate the consistency model. The prediction model for consistency C is performed by using a sensitivity analysis; the consistency of the overall road segment length results, not just the individual speed differentials between two successive elements. A negative exponential consistency model was tested based on the relative area measurement and the standard deviation of speed. Finally, a model to relate the crash number with the congruency measure was developed and a negative exponential function was obtained that links horizontal consistency and accidents.

Garcia et al (2013) presented a new model of design consistency for evaluating the quality of tangent-to-curve transitions on two-lane rural roads. The proposed model is based on the hypothesis that "design consistency" may be defined as the difference between drivers' expectations and road alignment behavior. The road alignment behavior at one station may be estimated by means of the operating speed at that point. Drivers' expectations may be estimated by the inertial operating speed, defined as the average operating speed of the previous 1 km road segment, at the same point. The difference between those two parameters, the ICI, results in a new approach to the evaluation of road consistency. The ICI and the associated consistency thresholds were developed by studying the operating speed profiles of 88 two-lane rural road segments and considering both driving directions, which included 1,686 tangent-to-curve transitions. V_{85}inertial − V_{85} was calculated at the beginning point of the curve of each transition. The relationship between those results and the crash rate associated to each transition from 2001 to 2010 was examined. This relationship highlighted that higher crash rates corresponded to higher ICI values. Therefore, a high ICI is linked to a higher crash probability. Both a graphical and a statistical analysis were performed to establish the thresholds of the consistency model. According to those analyses, the consistency of road alignment at every location may be considered good when the ICI is lower than 10 km/h, fair when it is between 10 and 20 km/h, and poor when it is higher than 20 km/h. The proposed consistency model was validated through its application to the empirical operating speed profiles of 20 road segments that included 370 tangent-to-curve transitions. The ICI values obtained were correlated to the number of crashes that occurred at the studied transitions. The validation process revealed that the transitions with a higher ICI value presented more collisions.

Each of these models, therefore, while providing important results of a general nature and identifying a number of independent variables to correlate the road elements geometry to the speed, cannot be considered universally valid; the reason is to be found in the differences, sometimes substantial, including a national reality and the other (and sometimes even between different local realities within countries) in terms of the topography of the surrounding territory, weather conditions, , user habits. The effort of all the experts, at the time of calibration and calibration of a prediction model, is, in any case, addressed to overcoming the problems that prevent the translation of a complete and reliable predictive model.

2. Data Collection

2.1 Introduction

The Road Safety Center of the Salerno Provincial Department of Transportation since 1999 started an extensive monitoring campaign of vehicular traffic conditions, as part of a project aimed at developing a strategy to dynamically plan rural drivability, and treatments for improving road safety. Monitoring activities are generally a valuable tool for an administration to identify critical network situations and assess its effectiveness. The considerable human and social costs related to the accident phenomena led, in the last two decades, researchers around the world to the development of procedures to improve road safety; in particular there have been improvements in the relevant legislation of many countries, not excluding Italy. The current regulation D.M. 5/11/2001 expects that Infrastructure Administrations adopt monitoring campaigns for the analysis of driver behavior and the relationships that govern its interaction with the road. This research work was carried out in accordance with the expectation set by the D.M. 5/11/2001. The campaigns were planned and executed by the road section of the Department of Civil, Architectural and Environmental Engineering of the University of Naples "Federico II", in collaboration with the Road Safety Center of the Salerno Provincial Department of Transportation. One of the first monitoring steps was developed during the biennium 2003 - 2004, where the data collection campaign was organized to examine the driver behavior on two-lane rural roads. During the experimental campaign more than 80 infrastructures were analyzed, some of which are not under the control of Salerno Province (state highways), to include all the characteristics of the entire road network. A monitoring campaign more complex, compared to that developed in the years 2003 and 2004 was performed in 2006 with the adoption of high performance equipment. During planning, data collection sections were selected in strategic positions along the road corridors to collect speed values on the tangent, circular curve and spiral transition elements; a sample of the results is used for the analysis of the research work presented here.

2.2 Road Analyzed and Geometric Characteristics Detected

The road analyzed is the S.P. 430, a variant of the state highway S.S. 18, the "Tirrenia Inferiore", which is the major road, after freeway A3, and is also one of the most important and long in Southern Italy, considering that go through Tyrrhenian coast along the road and railway Naples - Reggio Calabria, linking the two largest urban centers of Campania and Calabria (Figure 2).

S.P. 430 is part of the road network of Salerno Province (Southern Italy), passing through the National Park of Cilento and Vallo of Diano.

Figure 2- S.S. 18 (blue line), S.P. 430 (dot line) e A3 (green line)

Figure 3 shows sample cross sections of the S.P. 430.

Figure 3- S.P. 430 cross sections

The road project dates back to 1973, and was carried out prior to the development and introduction of the D.M. 5/11/2001.

S.P. 430 is a single carriageway with a width equal to 10.50 m, lanes width equal to 3.75 m and shoulder width equal to 1.50 m. SP430 is composed by 91 circular curves elements with a radius varying in the range 250m-3000m; by 121 tangent element with a maximum length of 1757 m; by 17 tunnels with a variable length between 40m (tunnel Mascale km 150+320) to 1368m (tunnel San Vito Km 143 +200); and by 48 viaducts with a minimum length of 32 m and a maximum length of 717 m. The hinterland connections are made possible by 17 road interchange. The grade level is in the order of six percent (6%).The general speed limit is 90 km/h and is reduced to 80/60 km / h in sections with local speed limits.

Table 1 shows an overview of the Main Geometric Features of SP430 road.

Table 1- Overview of the Main Geometric Features of S.P. 430 road

	Tangent Length (m)	Curve Length (m)	Circular Radius (m)	Transition Curve Length (m)	Grade (%)
Min Value	11.32	1.21	250	53.67	0.10
Med Value	281.38	202	696.08	150.69	2.97
Max Value	1626.33	800	3700	616.03	6.00
Standard Deviation	272.58	157.30	644.11	79.60	2.03
CV	0.97	0.78	0.93	0.53	0.68

Table 2 shows the Average Daily Traffic (ADT) detected for the main Municipalities crossed by the S.P. 430. The ADT is defined as the ratio between the number of vehicles transiting in a year and the number of days of the same and is measured in veh/day.

Table 2- ADT of the Main Municipality crossed by S.P. 430 road

Municipality	AADT (veich/day)
Capaccio	9560
Agropoli	7405
Lustra	5973
Casal Velino	5907
Castelnuovo Cil.	5291
Vallo della Luc.	4288
Ceraso	3745
Celle di Bulgheria	2032
Roccagloriosa	2029
S. Giovanni a P.	2283

The preliminary task was the design of the infrastructure. This step is mandatory, since the analyzed road during the years has been subject to a series of interventions that have changed the geometric regularity. By using project cartographies and information collected onsite, the horizontal-vertical alignment was drawn. This activity was carried out with special software called "Civil Design" (Figure 4). The geometric layout was carried out referring to the previous Italian Standard CNR 80, because the S.P. 430 has been built in the 70s-80s.
This task led to the definition of the exact succession of the road elements, including information on the progressive start and end of the road element, the length, the angle of deviation in grads, the radius of curvature etc.

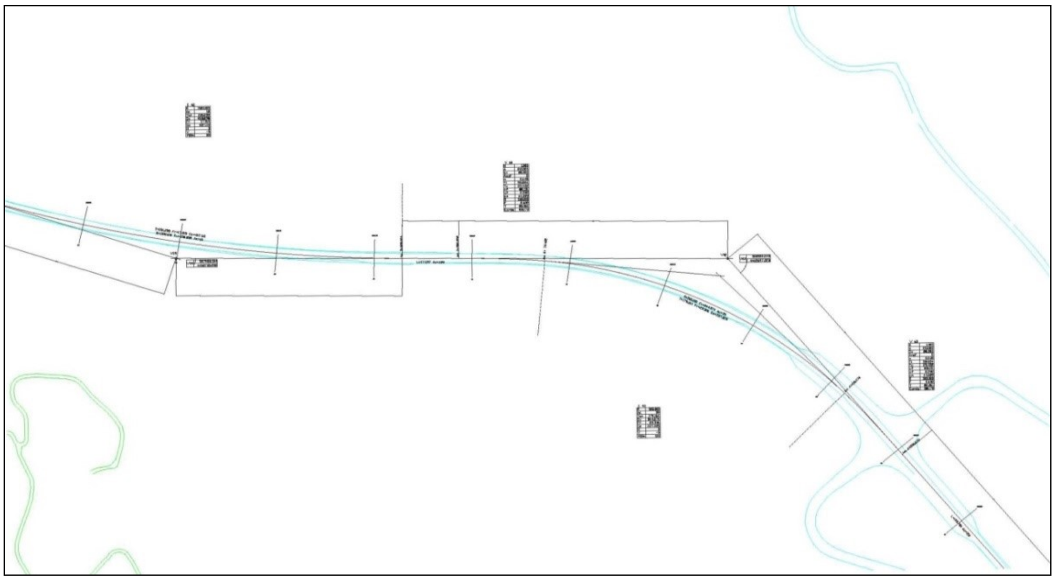


Figure 4 - Output of the geometric layout of S.P. 430 by using Civil Design Software

Based on the geometric layout output, S.P. 430 is composed by 398 geometric elements; of which 91 tangent elements, 121 circular curves and 186 spiral transition curves, which are divided into 154 tangent-curve-tangent spiral transitions, 28 curve-tangent-curve spiral transitions and 4 curve-curve spiral transitions, for a total road length equal to 72.65 km.
Figures 5-10 show the different histograms of frequencies for each geometric element, in order to highlight which class contains more elements. To determine the number of classes on the basis of intervals of equal size, the Sturges formula was used which gives the size of the group as follow:

$$m = 1 + 3.322 * \log (n) \quad (8)$$

Where n is the number of elements to be grouped into different classes.

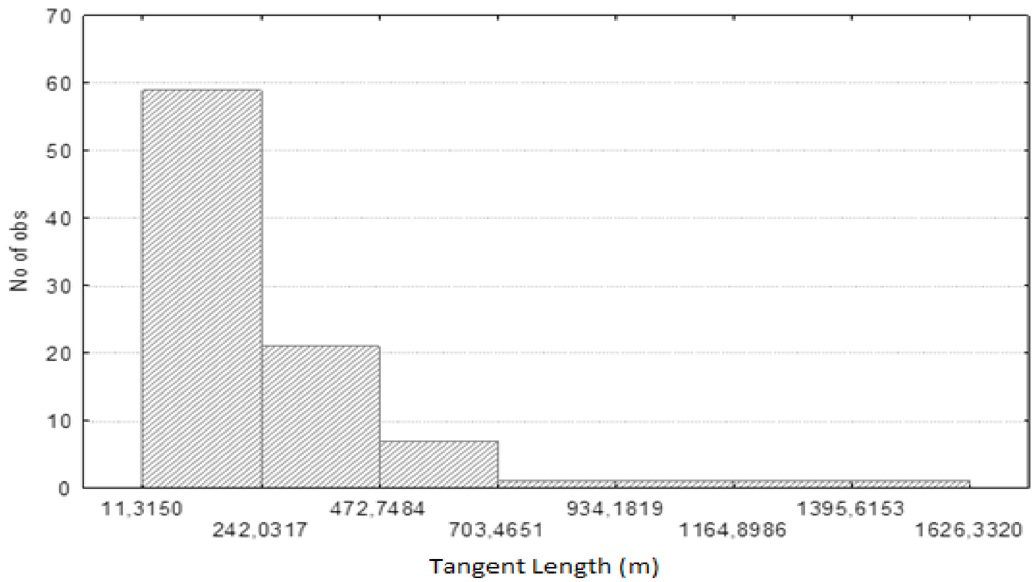


Figure 5 - Histogram of Frequency of Tangent Length Class

The class that includes the largest number of elements is the one that includes the tangent element length between 11.315 and 242.031 m, the smallest classes include the tangent element length between: (703.465-934181) m, (934.181-1164.898) m, (1164.898-1395.615) m and (1395.615-1626.332) m.

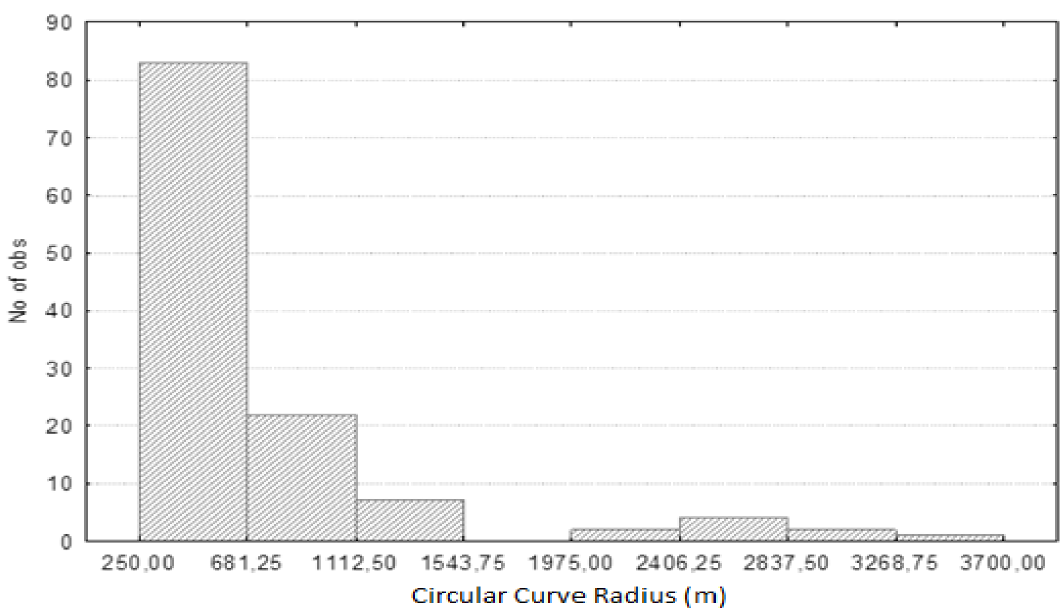


Figure 6 - Histogram of Frequency of Circular Curve Radius Class

The class that includes the largest number of elements is the one that includes the circular curve radius between 250.00m and 681.25m, and the smallest class is between 3268.75m and 3700.00 m.

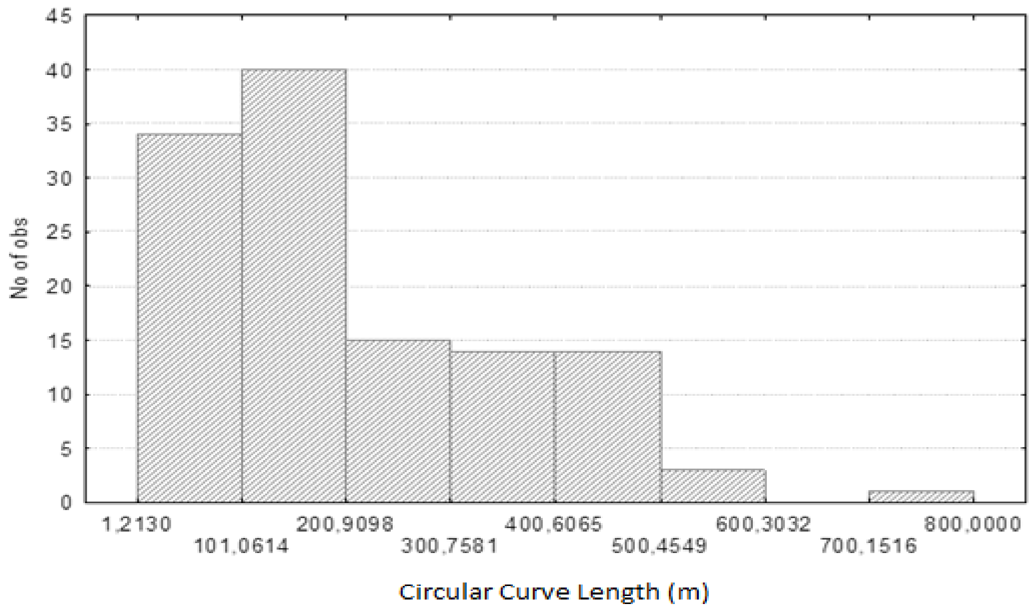


Figure 7 - Histogram of Frequency of Circular Curve Length Class

The 121 circular curves show a length histogram of frequency divided into seven classes, the largest class includes circular curves with a length between 101.061 and 200.909 m, there are no circular curves in the range between 600.303 and 700.151 m while the smallest class ranges between 700.151 m and 800.00 m.

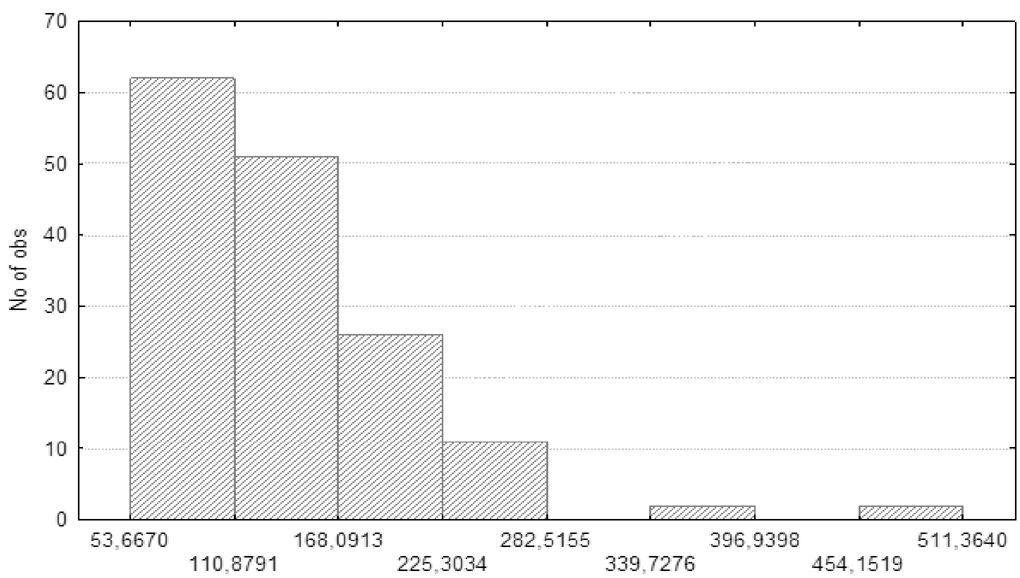


Figure 8 - Histogram of Frequency of Tangent-to-Circular Curve Transition Curve Length Class

The class with the largest number of the Tangent-to-Circular Curve Transition elements is the range between 53.667 m and 110.879 m, while the least are the ranges 339.727m - 396.939 m and 454.151 - 511.364 m.

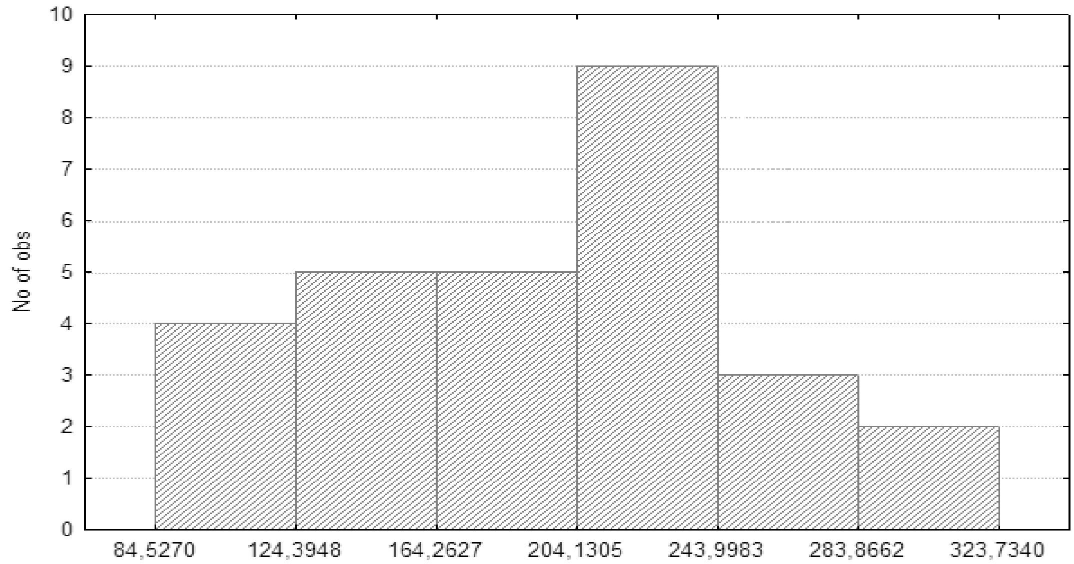


Figure 9 - Histogram of Frequency of Circular Curve-to-Tangent-to-Circular Curve Transition Curve Length Class

The histogram of the frequencies of the Circular Curve-to-Tangent-to-Circular Curve Transition is divided into 6 classes, the most frequent class includes elements between 204.13m and 243.99 m, while the class with the least number of elements ranges between 283.86 and 323.73 m.

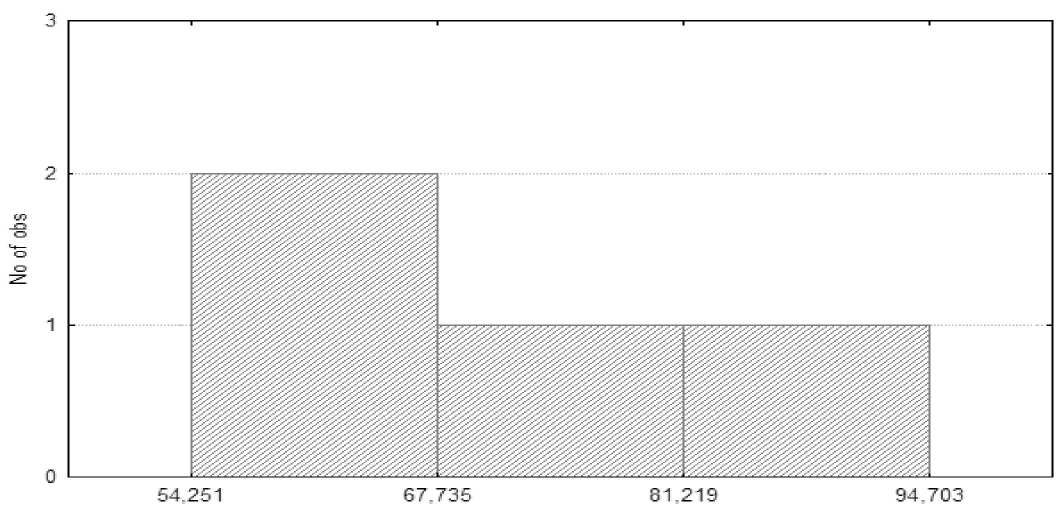


Figure 10 - Histogram of Frequency of Circular Curve-to- Circular Curve Transition Curve Length Class

The S.P. 430 geometric layout showed the presence of 4 Circular Curve-to- Circular Curve Transition Curve with moderate length. The length of the largest class is in the range between 54.251 m and 67.735 m.

The next step in the analysis was to calculate the medium curvature change rate (CCR_m) of the infrastructure. The CCR_m, measured in gon/km is defined as the sum of the absolute values of angular changes in the horizontal alignment divided by the total length of the road section.
Figure 11 shows the CCR_m of S.P. 430 which equals 61.34 gon/km.

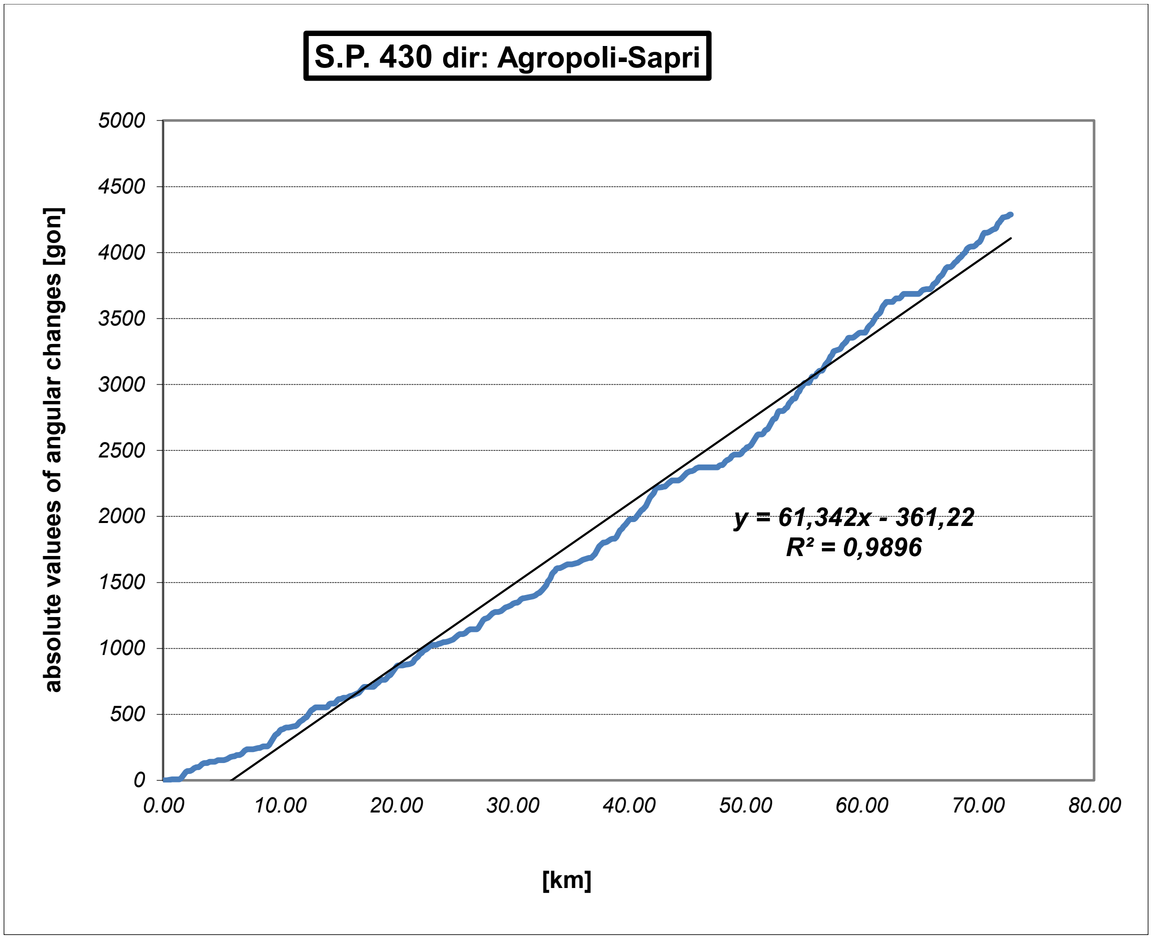


Figure 11 - CCRm of S.P. 430

Table 3 includes the geometric features of each element of S.P. 430 road

Table 3 - Geometric Features of each element of S.P. 430 road

							Tangent-to-Circular Curve			Curve-to- Circular Curve				Circular Curve-to-Tangent-to-Circular Curve						
N.	Element Type	Starting Post (Km)	Final Post (Km)	Tangent Length (m)	Radius Circular Curve (m)	Circular Curve Length (m)	R (m)	A	Transition Curve Length (m)	R1 (m)	A	R2 (m)	Transition Curve Length (m)	R1 (m)	A1	Transition Curve Length 1(m)	Tangent Length (m)	R2 (m)	A2	Transition Curve Length 2(m)
1	T	98.100	98.381	280.94																
2	C	98.381	98.864		3700	482.734														
3	T	98.864	99.484	620.705																
4	ST	99.484	99.630				500	270	145.8											
5	C	99.630	100.044		500	414.156														
6	ST	100.044	100.190				500	270	145.8											
7	T	100.190	100.402	211.381																
8	ST	100.402	100.577				700	350	175											
9	C	100.577	100.765		700	188.453														
10	ST	100.765	100.940				700	350	175											
11	T	100.940	101.132	192.023																
12	ST	101.132	101.296				550	300	163.636											
13	C	101.296	101.441		550	145.273														
14	ST	101.441	101.605				550	300	163.636											

15	T	101.605	101.880	275.664																
16	C	101.880	102.090		1300	209.473														
17	T	102.090	102.557	467.23																
18	C	102.557	102.798		1300	241.156														
19	T	102.798	103.329	530.825																
20	ST	103.329	103.579				1100	525	250.568											
21	C	103.579	103.905		1100	325.964														
22	ST	103.905	104.133				1100	500	227.273											
23	T	104.133	104.235	102.675																
24	C	104.235	104.412		1000	176.901														
25	T	104.412	104.679	266.505																
26	ST	104.679	104.860				600	330	181.5											
27	C	104.860	105.121		600	260.764														
28	ST	105.121	105.303				600	330	181.5											
29	T	105.303	105.811	508.864																
30	C	105.811	106.267		2500	455.391														
31	T	106.267	106.394	126.884																
32	C	106.394	106.664		1300	270.697														
33	T	106.664	107.067	402.912																
34	ST	107.067	107.200				400	230	132.25											
35	C	107.200	107.732		400	532.539														
36	ST	107.732	107.864				400	230	132.25											
37	T	107.864	107.907	43.068																
38	ST	107.907	108.018				400	210	110.25											

39	C	108.018	108.147		400	129.33														
40	ST	108.147	108.257				400	210	110.25											
41	T	108.257	108.330	72.861																
42	ST	108.330	108.466				800	330	136.125											
43	C	108.466	108.538		800	72.248														
44	ST	108.538	108.675				800	330	136.125											
45	T	108.675	108.891	215.969																
46	C	108.891	109.362		3000	471.856														
47	T	109.362	109.468	105.651																
48	ST	109.468	109.605				550	274.928	137.428											
49	C	109.605	109.851		550	245.525														
50	CF	109.851	110.123											550	285.684	148.392	0	500	248.421	123.426
51	C	110.123	110.183		500	59.997														
52	CF	110.183	110.418											500	247.447	122.46	0	450	224.952	112.452
53	C	110.418	110.807		450	389.681														
54	ST	110.807	110.915				450	219.97	107.526											
55	T	110.915	110.955	40																
56	ST	110.955	111.043				500	210	88.2											
57	C	111.043	111.105		500	62.096														
58	ST	111.105	111.193				500	210	88.2											
59	T	111.193	112.139	945.352																
60	ST	112.139	112.237				450	210	98											
61	C	112.237	112.380		450	143.254														
62	ST	112.380	112.478				450	210	98											

63	T	112.478	112.821	342.585																
64	ST	112.821	112.913				500	215	92.45											
65	C	112.913	113.124		500	211.002														
66	ST	113.124	113.217				500	215	92.45											
67	T	113.217	113.377	160.58																
68	C	113.377	113.603		1500	225.457														
69	T	113.603	113.896	293.765																
70	ST	113.896	114.032				800	330	136.125											
71	C	114.032	114.097		800	64.586														
72	ST	114.097	114.233				800	330	136.125											
73	T	114.233	114.346	113.047																
74	C	114.346	114.805		1500	458.898														
75	T	114.805	114.863	57.597																
76	ST	114.863	114.951				500	210	88.2											
77	C	114.951	115.295		500	344.074														
78	ST	115.295	115.383				500	210	88.2											
79	T	115.383	116.170	787.125																
80	ST	116.170	116.278				450	219.97	107.526											
81	C	116.278	116.340		450	61.726														
82	CF	116.340	116.625											450	253.552	142.864	0	450	253.552	142.864
83	C	116.625	116.736		450	110.811														
84	ST	116.736	116.844				450	219.97	107.526											
85	T	116.844	117.176	332.626																
86	ST	117.176	117.256				500	199.698	79.759											

87	C	117.256	117.429		500	173.315														
88	CF	117.429	117.625											500	221.207	97.865	0	500	221.207	97.865
89	C	117.625	118.198		500	573.391														
90	ST	118.198	118.278				500	199.698	79.759											
91	T	118.278	118.670	392.265																
92	C	118.670	119.001		2500	330.789														
93	T	119.001	119.072	70.512																
94	ST	119.072	119.262				2000	616.026	189.744											
95	C	119.262	119.485		2000	223.427														
96	CC	119.485	119.580							2000	217.604	400	94.703							
97	C	119.580	119.733		400	152.923														
98	CF	119.733	119.995											400	229.04	131.148	0	400	229.04	131.148
99	C	119.995	120.105		400	109.935														
100	CF	120.105	120.322											400	223.917	125.347	0	450	203.561	92.083
101	C	120.322	120.392		450	70.232														
102	CF	120.392	120.716											450	289.29	185.975	0	750	321.433	137.759
103	C	120.716	121.066		750	350.139														
104	ST	121.066	121.279				750	399.74	213.056											
105	T	121.279	121.611	331.717																
106	ST	121.611	121.709				800	279.98	97.986											
107	C	121.709	121.727		800	17.517														
108	ST	121.727	121.825				800	279.98	97.986											
109	T	121.825	121.891	66.479																
110	ST	121.891	122.021				1000	360	129.6											

111	C	122.021	122.082		1000	61.52														
112	ST	122.082	122.212				1000	360	129.6											
113	T	122.212	122.368	156.159																
114	ST	122.368	122.600				1500	590.429	232.404											
115	C	122.600	123.023		1500	422.267														
116	CC	123.023	123.077							1500	266.841	700	54.251							
117	C	123.077	123.458		700	381.493														
118	ST	123.458	123.617				700	333.387	158.782											
119	T	123.617	123.882	264.473																
120	ST	123.882	124.067				700	360	185.143											
121	C	124.067	124.309		700	241.927														
122	ST	124.309	124.494				700	360	185.143											
123	T	124.494	125.062	568.61																
124	ST	125.062	125.183				400	220	121											
125	C	125.183	125.625		400	442.006														
126	ST	125.625	125.746				400	220	121											
127	T	125.746	125.819	73.036																
128	ST	125.819	126.015				700	370	195.571											
129	C	126.015	126.428		700	412.719														
130	ST	126.428	126.623				700	370	195.571											
131	T	126.623	126.902	278.195																
132	ST	126.902	127.155				800	450	253.125											
133	C	127.155	127.506		800	351.44														
134	ST	127.506	127.759				800	450	253.125											

135	T	127.759	127.764	5.17																
136	ST	127.764	128.006				800	440	242											
137	C	128.006	128.166		800	159.895														
138	ST	128.166	128.408				800	440	242											
139	T	128.408	128.527	118.529																
140	ST	128.527	128.677				600	300	150											
141	C	128.677	128.875		600	198.446														
142	ST	128.875	129.025				600	300	150											
143	T	129.025	129.106	80.839																
144	C	129.106	129.906		3086.488	800														
145	T	129.906	129.917	11.315																
146	ST	129.917	130.092				700	350	175											
147	C	130.092	130.256		700	163.773														
148	ST	130.256	130.431				700	350	175											
149	T	130.431	130.448	17.292																
150	ST	130.448	130.548				400	199.948	99.948											
151	C	130.548	130.574		400	25.258														
152	CF	130.574	130.776											400	190.367	90.599	0	250	166.989	111.541
153	C	130.776	130.781		250	4.734														
154	CF	130.781	131.025											250	182.469	133.18	0	300	182.469	110.983
155	C	131.025	131.176		300	151.49														
156	CF	131.176	131.400											300	174.865	101.915	0	250	174.856	122.298
157	C	131.400	131.542		250	141.83														
158	ST	131.542	131.665				250	175.076	122.606											

159	T	131.665	131.679	13.634																
160	ST	131.679	131.779				400	200	100											
161	C	131.779	131.888		400	109.626														
162	ST	131.888	131.988				400	200	100											
163	T	131.988	132.202	214.324																
164	ST	132.202	132.377				700	350	175											
165	C	132.377	132.675		700	297.223														
166	ST	132.675	132.850				700	350	175											
167	T	132.850	133.250	400.333																
168	ST	133.250	133.761				1100	750	511.364											
169	C	133.761	134.184		1100	422.502														
170	ST	134.184	134.695				1100	750	511.364											
171	T	134.695	134.878	182.936																
172	ST	134.878	135.228				350	350	350											
173	C	135.228	135.586		350	357.418														
174	ST	135.586	135.936				350	350	350											
175	T	135.936	136.081	145.52																
176	ST	136.081	136.241				1000	400	160											
177	C	136.241	136.574		1000	332.564														
178	ST	136.574	136.734				1000	400	160											
179	T	136.734	136.914	180.582																
180	ST	136.914	137.059				350	225.297	145.025											
181	C	137.059	137.364		350	305.173														
182	CF	137.364	137.588											350	217.263	134.867	0	300	163.365	88.951

183	C	137.588	137.628		300	39.693														
184	CF	137.628	137.848											300	209.082	145.718	0	300	149.344	74.346
185	C	137.848	137.850		300	1.986														
186	CF	137.850	138.053											300	174.407	101.393	0	300	174.407	101.393
187	C	138.053	138.102		300	48.791														
188	ST	138.102	138.209				300	179.493	107.393											
189	T	138.209	138.566	356.885																
190	ST	138.566	138.691				500	250	125											
191	C	138.691	139.220		500	529.152														
192	ST	139.220	139.345				500	250	125											
193	T	139.345	139.356	11.071																
194	ST	139.356	139.599				300	270	243											
195	C	139.599	139.941		300	341.688														
196	ST	139.941	140.184				300	270	243											
197	T	140.184	140.186	2.112																
198	ST	140.186	140.288				250	160	102.4											
199	C	140.288	140.417		250	128.452														
200	ST	140.417	140.519				250	160	102.4											
201	T	140.519	140.733	214.105																
202	ST	140.733	140.958				2500	750	225											
203	C	140.958	141.009		2500	50.739														
204	ST	141.009	141.234				2500	750	225											
205	T	141.234	141.247	12.919																
206	ST	141.247	141.392				350	225	144.643											

207	C	141.392	141.431		350	39.529														
208	ST	141.431	141.576				350	225	144.643											
209	T	141.576	141.603	26.888																
210	ST	141.603	141.703				400	200	100											
211	C	141.703	141.725		400	22.571														
212	ST	141.725	141.825				400	200	100											
213	T	141.825	142.392	566.426																
214	ST	142.392	142.658				600	400	266.667											
215	C	142.658	143.123		600	464.596														
216	ST	143.123	143.390				600	400	266.667											
217	T	143.390	143.520	130.226																
218	ST	143.520	143.733				750	400	213.333											
219	C	143.733	143.909		750	175.915														
220	ST	143.909	144.122				750	400	213.333											
221	T	144.122	145.749	1626.332																
222	ST	145.749	145.850				500	225	101.25											
223	C	145.850	145.906		500	55.62														
224	ST	145.906	146.007				500	225	101.25											
225	T	146.007	146.160	153.544																
226	ST	146.160	146.317				400	250	156.25											
227	C	146.317	146.420		400	103.013														
228	ST	146.420	146.576				400	250	156.25											
229	T	146.576	146.649	72.748																
230	ST	146.649	146.849				450	300	200											

231	C	146.849	146.977		450	128.377														
232	ST	146.977	147.177				450	300	200											
233	T	147.177	147.658	481.167																
234	ST	147.658	147.783				500	250	125											
235	C	147.783	147.993		500	209.939														
236	ST	147.993	148.118				500	250	125											
237	T	148.118	148.124	5.608																
238	ST	148.124	148.188				400	160	64											
239	C	148.188	148.235		400	47.317														
240	ST	148.235	148.299				400	160	64											
241	T	148.299	148.367	68.366																
242	ST	148.367	148.421				800	207.204	53.667											
243	C	148.421	148.623		800	201.971														
244	CC	148.623	148.688							800	228.333	400	65.17							
245	C	148.688	149.180		400	491.692														
246	ST	149.180	149.249				400	166.483	69.291											
247	T	149.249	149.594	344.735																
248	ST	149.594	149.694				400	200	100											
249	C	149.694	149.839		400	145.575														
250	ST	149.839	149.939				400	200	100											
251	T	149.939	149.982	42.78																
252	ST	149.982	150.069				375	180	86.4											
253	C	150.069	150.525		375	456.217														
254	ST	150.525	150.611				375	180	86.4											

255	T	150.611	150.704	92.65																
256	ST	150.704	150.769				260	130	65											
257	C	150.769	150.967		260	198.54														
258	ST	150.967	151.032				260	130	65											
259	T	151.032	151.360	327.214																
260	ST	151.360	151.445				600	225.646	84.86											
261	C	151.445	151.619		600	174.23														
262	CF	151.619	151.754											600	209.288	73.002	0	275	130.805	62.218
263	C	151.754	151.868		275	113.761														
264	CF	151.868	152.073											275	171.489	106.94	0	260	160.27	98.794
265	C	152.073	152.076		260	2.125														
266	CF	152.076	152.199											260	149.006	85.395	0	350	114.62	37.536
267	C	152.199	152.202		350	3.162														
268	ST	152.202	152.260				350	142.444	57.973											
269	T	152.260	152.413	153.496																
270	ST	152.413	152.478				260	130	65											
271	C	152.478	152.645		260	166.617														
272	ST	152.645	152.710				260	130	65											
273	T	152.710	152.740	30.091																
274	ST	152.740	152.806				260	131.105	66.11											
275	C	152.806	152.918		260	111.956														
276	CF	152.918	153.107											260	175.287	118.175	0	300	146.073	71.124
277	C	153.107	153.156		300	48.42														
278	ST	153.156	153.232				300	150.914	75.916											

279	T	153.232	153.591	359.21																
280	ST	153.591	153.656				300	139.642	65											
281	C	153.656	153.852		300	195.716														
282	ST	153.852	153.917				300	139.642	65											
283	T	153.917	154.142	225.677																
284	ST	154.142	154.208				300	140.436	65.741											
285	C	154.208	154.300		300	91.885														
286	CF	154.300	154.464											300	159.917	85.244	0	400	177.685	78.93
287	C	154.464	154.473		400	8.775														
288	ST	154.473	154.535				400	157.448	61.974											
289	T	154.535	154.725	190.426																
290	ST	154.725	154.788				325	142.477	62.46											
291	C	154.788	155.036		325	247.932														
292	CF	155.036	155.188											325	157.525	76.351	0	325	157.525	76.351
293	C	155.188	155.196		325	7.555														
294	CF	155.196	155.284											325	117.113	42.202	0	300	117.113	45.718
295	C	155.284	155.474		300	190.047														
296	CF	155.474	155.609											300	142.35	67.545	0	300	142.35	67.545
297	C	155.609	155.732		300	123.134														
298	ST	155.732	155.798				300	140.436	65.741											
299	T	155.798	155.817	18.852																
300	ST	155.817	155.901				2000	411.955	84.853											
301	C	155.901	156.240		2000	338.227														
302	CC	156.240	156.311							2000	188.403	400	70.991							

303	C	156.311	156.514		400	203.787														
304	CF	156.514	156.725											400	229.9	132.135	0	300	153.267	78.302
305	C	156.725	156.734		300	8.914														
306	CF	156.734	156.818											300	130.206	56.512	0	400	105.859	28.015
307	C	156.818	156.991		400	172.761														
308	ST	156.991	157.053				400	157.448	61.974											
309	T	157.053	157.378	324.842																
310	ST	157.378	157.490				800	300	112.5											
311	C	157.490	157.929		800	439.021														
312	ST	157.929	158.042				800	300	112.5											
313	T	158.042	158.283	241.164																
314	T	158.283	158.434	151.155																
315	ST	158.434	158.594				250	200	160											
316	C	158.594	158.670		250	76.013														
317	ST	158.670	158.830				250	200	160											
318	T	158.830	158.837	7.074																
319	ST	158.837	159.026				400	275	189.063											
320	C	159.026	159.445		400	418.234														
321	ST	159.445	159.634				400	275	189.063											
322	T	159.634	159.642	8.409																
323	ST	159.642	159.752				250	165.559	109.639											
324	C	159.752	159.919		250	167.386														
325	CF	159.919	160.142											250	180.286	130.012	0	300	166.931	92.887
326	C	160.142	160.168		300	25.535														

327	ST	160.168	160.272				300	176.617	103.979											
328	T	160.272	160.797	525.322																
329	ST	160.797	160.930				300	200	133.333											
330	C	160.930	160.940		300	10.041														
331	ST	160.940	161.074				300	200	133.333											
332	T	161.074	161.398	324.877																
333	ST	161.398	161.543				350	225	144.643											
334	C	161.543	161.604		350	60.421														
335	ST	161.604	161.748				350	225	144.643											
336	T	161.748	163.050	1302.095																
337	ST	163.050	163.189				450	250	138.889											
338	C	163.189	163.291		450	101.723														
339	ST	163.291	163.430				450	250	138.889											
340	T	163.430	163.454	24.403																
341	ST	163.454	163.554				1500	387.298	100											
342	C	163.554	163.588		1500	34.239														
343	ST	163.588	163.688				1500	387.298	100											
344	T	163.688	164.031	342.895																
345	ST	164.031	164.176				350	225	144.643											
346	C	164.176	164.317		350	141.016														
347	ST	164.317	164.462				350	225	144.643											
348	T	164.462	164.492	30.407																
349	ST	164.492	164.661				300	225	168.75											
350	C	164.661	164.770		300	108.752														

351	ST	164.770	164.938				300	225	168.75											
352	T	164.938	164.960	21.891																
353	ST	164.960	165.086				350	210	126											
354	C	165.086	165.380		350	293.433														
355	ST	165.380	165.506				350	210	126											
356	T	165.506	165.785	279.22																
357	ST	165.785	165.940				500	278.375	154.986											
358	C	165.940	166.141		500	200.731														
359	CF	166.141	166.363											500	222.391	98.916	0	400	222.391	123.644
360	C	166.363	166.431		400	67.903														
361	CF	166.431	166.521											400	151.897	57.682	0	250	89.351	31.935
362	C	166.521	166.522		250	1.213														
363	ST	166.522	166.577				250	117.03	54.784											
364	T	166.577	166.590	13.295																
365	ST	166.590	166.667				500	196.81	77.468											
366	C	166.667	166.850		500	182.376														
367	CF	166.850	167.024											500	189.171	71.571	0	350	189.171	102.245
368	C	167.024	167.201		350	177.769														
369	CF	167.201	167.330											350	182.801	95.475	0	1000	182.801	33.416
370	C	167.330	167.437		1000	107.129														
371	ST	167.437	167.547				1000	330.984	109.55											
372	T	167.547	167.773	225.922																
373	ST	167.773	167.946				500	294.362	173.298											
374	C	167.946	168.067		500	120.928														

375	ST	168.067	168.240				500	294.362	173.298											
376	T	168.240	168.263	22.715																
377	ST	168.263	168.379				250	170	115.6											
378	C	168.379	168.567		250	188.309														
379	ST	168.567	168.683				250	170	115.6											
380	T	168.683	168.903	220.49																
381	ST	168.903	169.063				1000	400	160											
382	C	169.063	169.411		1000	348.113														
383	ST	169.411	169.571				1000	400	160											
384	T	169.571	169.607	35.448																
385	ST	169.607	169.692				300	160	85.333											
386	C	169.692	169.860		300	168.15														
387	ST	169.860	169.956				300	170	96.333											
388	T	169.956	169.962	5.873																
389	ST	169.962	170.122				250	200	160											
390	C	170.122	170.127		250	4.649														
391	ST	170.127	170.287				250	200	160											
392	T	170.287	170.323	36.546																
393	C	170.323	170.665		2500	341.979														
394	T	170.665	170.683	18.003																
395	ST	170.683	170.772				450	200	88.889											
396	C	170.772	170.800		450	27.5														
397	ST	170.800	170.889				450	200	88.889											
398	T	170.889	170.968	79.42																

2.3 Instrument used for speed data collection

Speed data collection was carried out in environmental and traffic conditions using a laser. The conditions were the following: dry roads, free flow conditions, daylight hours and good weather conditions.
The device used to measure the speed was a "KV Laser". The principle of operation of the laser gun is based on the emission and reception of a pair of laser beams, directed perpendicularly to the geometric road axis; the laser beams are harmless to drivers.
The KV Laser is composed of a laser detection system, software to collect data, a rechargeable battery and physical supports for installation. The instrument was installed on a tripod placed beside the highway, as shown in Figure 12, and suitably hidden from the drivers view, because perceptible presence of the device could affect drivers' speed, possibly assuming it to be a police control.

Figure 12 - Detection device setup

The instrument records the time for each vehicular transit (date, time, minutes and seconds), speed (in km / h), the length (in meters) and the travel direction in binary variables (in "direction 0" and "direction 1"); it is worth mentioning that the instantaneous speed is deduced by calculating the time lag associated with the transit of the vehicle from the first to the second photocell. The velocity measurements are not free from errors, not exceeding 10% and observed in the following two circumstances:
- Time interval of less than 0.5 seconds between consecutive passing vehicles, in the opposite direction, corresponding to the same measuring station;
- Axis of the laser beams projected on low refractive surfaces.

The data sample does not include measurements on heavy vehicles, or vehicles with temporal spacing of less than five seconds between two successive moving vehicles. These conditions are necessary to ensure the free flow conditions.

2.4 Speed Data Collection Results

The data was collected in 2011, between the months of October and November; and in 2012 between the months of February and July. The KV Laser was placed in 40 different sections along the S.P. 430 starting in kilometer 98 + 850 (Capaccio Municipality) and km 169 + 350 (Santa Marina Municipality). The above 40 sections were further subdivided as follows:
• 25 sections on tangent element (indicating the two speed measurements, one in each direction);

• 15 sections on the middle circular curve (indicating the two speed measurements, one in each direction);
Table 4 shows the lists of the main sections listing the kilometers, day of measurement and the Municipality .

Table 4 - Speed Data Collection Section Details

Day	Km	Municipality	Direction
3/18/2012	98+850	Capaccio	A
3/18/2012	103+500	Agropoli	B
11/3/2011	106+800	Agropoli	A
2/28/2012	120+700	Lustra	B
11/3/2011			
6/30/2012	126+900	Casal Velino	A
7/2/2012			
7/4/2012	127+500	Salento	A
7/3/2012			
7/9/2012	127+700	Salento	B
7/10/2012	128+680	Castelnuovo	B
7/11/2012			
10/29/2011	129+170	Castelnuovo	A
10/28/2011			
4/28/2012	129+750	Castelnuovo	B
7/17/2012	131+700	Vallo della	B
4/22/2012	132+150	Vallo della	A
4/22/2012	132+650	Vallo della	B
4/2/2012	133+900	Vallo della	A
4/2/2012	134+800	Vallo della	A
3/23/2012	136+450	Vallo della	B
3/23/2012	136+950	Vallo della	A
7/13/2012	137+400	Vallo della	B
7/16/2012	139+350	Ceraso	A
3/27/2012	141+850	Ceraso	A
7/31/2012	157+950	Celle di Bulgaria	B
6/21/2012	158+300	Celle di Bulgaria	B
6/18/2012	158+850	Celle di Bulgaria	A
6/19/2012			
6/22/2012	159+500	Celle di Bulgaria	B
6/24/2012			
7/6/2012	159+850	Celle di Bulgaria	A
6/23/2012	160+500	Celle di Bulgaria	A
6/25/2012			
6/26/2012	160+800	Celle di Bulgaria	A
6/29/2012			
6/26/2012	161+220	Celle di Bulgaria	B
6/27/2012			
7/4/2012	161+950	Celle di Bulgaria	A

3/14/2012	162+400	Celle di Bulgaria	B
3/14/2012	163+000	Roccagloriosa	B
7/19/2012	164+200	Roccagloriosa	A
7/20/2012	165+300	Roccagloriosa	B
7/16/2012	165+900	Roccagloriosa	B
7/25/2012	166+600	San Giovanni a	B
7/19/2012	166+950	San Giovanni a	A
7/20/2012	167+950	San Giovanni a	A
7/26/2012	168+600	San Giovanni a	B
7/27/2012	169+250	San Giovanni a	A
7/27/2012	169+630	Santa Marina	B

Table 5 shows the time of the survey for each section, and then the total hours of measurements to provide context on the amount of time used to collect information.

Table 5 - Road Element, Length and hours of measurements

km	Road Element	Length (m)	Hours of measurements
98+850	tangent	223.418	13:00:00
103+500	circular curve	190.979	13:00:00
106+800	circular curve	282.892	13:00:00
120+700	circular curve	566.721	26:00:00
126+900	tangent	218.28	14:00:00
127+500	circular curve	662.833	14:00:00
127+700	tangent	182.542	7:00:00
128+680	circular curve	385.787	14:00:00
129+170	circular curve	776.955	13:00:00
129+750	circular curve	776.955	13:00:00
131+700	tangent	105.124	7:00:00
132+150	tangent	327.468	13:00:00
132+650	circular curve	515.631	13:00:00
133+900	circular curve	1010.869	13:00:00
134+800	tangent	547.901	13:00:00
136+450	circular curve	232.84	13:00:00
136+950	tangent	344.019	13:00:00
137+400	circular curve	454.052	7:00:00
139+350	tangent	165.874	7:00:00
141+850	tangent	745.699	13:00:00
157+950	tangent	147.652	7:00:00
158+300	tangent	143.713	7:00:00
158+850	circular curve	654.955	15:00:00
159+500	circular curve	315.784	14:00:00
159+850	tangent	616.092	7:00:00

160+500	circular curve	178.125	14:00:00
160+800	tangent	445.442	14:00:00
161+220	tangent	1452.694	14:00:00
161+950	tangent	1452.694	7:00:00
162+400	tangent	1452.694	13:00:00
163+000	tangent	134.922	13:00:00
164+200	circular curve	329.925	7:00:00
165+300	tangent	403.725	7:00:00
165+900	tangent	152.672	7:00:00
166+600	tangent	102.474	7:00:00
166+950	tangent	77.671	7:00:00
167+950	tangent	143.391	7:00:00
168+600	tangent	388.656	7:00:00
169+250	tangent	198.889	7:00:00
169+630	tangent	120.572	7:00:00
TOTAL		13947.238	440:00:00

A total of 440 hours were recorded, of which 43% were made of the sections with 7 hours of measurements, 35% with 13 hours of measurements; 18% with 14 hours of measurements and 3% with 15 and 26 hours of measurements. In total 440 hours were recorded, of which 238 hours were recorded on tangent elements while the remaining 202 hours belong circular curves elements.

2.5 Crash Data Analysis

The Draft for the interventions of adjustment of existing roads (Bozza per gli Interventi di Adeguamento delle strade esistenti) dated March, 21st 2006, indicate that the characterization of hazardous road elements have to consider a lapse of time of five years, be extended to a significant portion of the road elements and refer to total accidents or only to accidents involving deaths and injuries as defined by ISTAT.

A crash data collection has been conducted from 2003 to 2010.

The aim of the crash data analysis is to identify the possible relationships existing between the geometric and functional characteristics of the road analyzed and the crash types and numbers of accidents.

First, it was create an informatic database through the use of Traffic Police Report. The database includes the following information about the incident: Section relief accident (progressive Km), environmental conditions, crash type, road surface conditions and the vehicles type involved (with information about the passengers and their consequences caused by the accident). Table 6 shows an Overview of the Main Crash Features.

Table 6 - Overview of the Main Crash Features

N. Element	Element Type	N. crashes	N. crashes with injuries	N. crashes with death	N. crashes. PDO	N. injury crashes
1	T	1	1	0	0	1
2	C	1	1	0	0	1
3	T	5	3	0	2	3
4	ST	1	1	0	0	1
5	C	0	0	0	0	0
6	ST	0	0	0	0	0
7	T	1	0	0	1	0
8	ST	1	1	0	0	1
9	C	0	0	0	0	0
10	ST	0	0	0	0	0
11	T	2	2	0	0	2
12	ST	1	1	0	0	1
13	C	5	3	0	2	3
14	ST	1	1	0	0	1
15	T	0	0	0	0	0
16	C	1	1	0	0	1
17	T	1	1	0	0	1
18	C	0	0	0	0	0
19	T	5	3	0	2	3
20	ST	3	3	1	0	3
21	C	3	3	1	0	3
22	ST	0	0	0	0	0
23	T	0	0	0	0	0
24	C	3	1	0	2	1
25	T	3	0	0	3	0
26	ST	0	0	0	0	0
27	C	1	1	1	0	1
28	ST	1	1	0	0	1
29	T	4	4	0	0	4
30	C	1	0	0	1	0
31	T	0	0	0	0	0
32	C	0	0	0	0	0
33	T	2	1	0	1	1
34	ST	0	0	0	0	0
35	C	8	5	1	3	5
36	ST	1	1	0	0	1
37	T	1	0	0	1	0
38	ST	2	2	0	0	2
39	C	3	2	0	1	2
40	ST	0	0	0	0	0
41	T	1	1	0	0	1

42	ST	1	0	0	1	0
43	C	1	1	0	0	1
44	ST	3	2	1	1	2
45	T	1	0	0	1	0
46	C	0	0	0	0	0
47	T	0	0	0	0	0
48	ST	0	0	0	0	0
49	C	0	0	0	0	0
50	ST	3	1	0	2	1
51	C	1	0	0	1	0
52	ST	0	0	0	0	0
53	C	1	0	0	1	0
54	ST	0	0	0	0	0
55	T	0	0	0	0	0
56	ST	0	0	0	0	0
57	C	0	0	0	0	0
58	ST	0	0	0	0	0
59	T	7	4	0	3	4
60	ST	0	0	0	0	0
61	C	1	0	0	1	0
62	ST	0	0	0	0	0
63	T	1	0	0	1	0
64	ST	1	0	0	1	0
65	C	0	0	0	0	0
66	ST	1	1	0	0	1
67	T	0	0	0	0	0
68	C	3	3	0	0	3
69	T	0	0	0	0	0
70	ST	0	0	0	0	0
71	C	1	1	0	0	1
72	ST	2	0	0	2	0
73	T	0	0	0	0	0
74	C	0	0	0	0	0
75	T	0	0	0	0	0
76	ST	0	0	0	0	0
77	C	2	1	0	1	1
78	ST	1	0	0	1	0
79	T	8	4	0	4	4
80	ST	0	0	0	0	0
81	C	0	0	0	0	0
82	ST	0	0	0	0	0
83	C	0	0	0	0	0
84	ST	0	0	0	0	0
85	T	0	0	0	0	0

86	ST	0	0	0	0	0
87	C	1	0	0	1	0
88	ST	0	0	0	0	0
89	C	0	0	0	0	0
90	ST	0	0	0	0	0
91	T	1	0	0	1	0
92	C	3	0	0	3	0
93	T	0	0	0	0	0
94	ST	0	0	0	0	0
95	C	0	0	0	0	0
96	CC	0	0	0	0	0
97	C	0	0	0	0	0
98	ST	1	0	0	1	0
99	C	0	0	0	0	0
100	ST	1	0	0	1	0
101	C	0	0	0	0	0
102	ST	1	0	0	1	0
103	C	2	2	0	0	2
104	ST	0	0	0	0	0
105	T	3	0	0	3	0
106	ST	0	0	0	0	0
107	C	0	0	0	0	0
108	ST	0	0	0	0	0
109	T	0	0	0	0	0
110	ST	3	1	0	2	1
111	C	0	0	0	0	0
112	ST	0	0	0	0	0
113	T	0	0	0	0	0
114	ST	3	0	0	3	0
115	C	2	1	0	1	1
116	CC	0	0	0	0	0
117	C	1	1	0	0	1
118	ST	0	0	0	0	0
119	T	0	0	0	0	0
120	ST	0	0	0	0	0
121	C	1	1	1	0	1
122	ST	1	1	0	0	1
123	T	3	2	0	1	2
124	ST	0	0	0	0	0
125	C	1	1	1	0	1
126	ST	1	0	0	1	0
127	T	0	0	0	0	0
128	ST	0	0	0	0	0
129	C	1	1	1	0	1

130	ST	0	0	0	0	0
131	T	3	2	0	1	2
132	ST	1	0	0	1	0
133	C	1	0	0	1	0
134	ST	1	1	0	0	1
135	T	0	0	0	0	0
136	ST	1	0	0	1	0
137	C	0	0	0	0	0
138	ST	1	1	0	0	1
139	T	1	0	0	1	0
140	ST	2	1	0	1	1
141	C	1	0	0	1	0
142	ST	7	2	0	5	2
143	T	1	0	0	1	0
144	C	5	4	0	1	4
145	T	0	0	0	0	0
146	ST	1	0	0	1	0
147	C	1	1	0	0	1
148	ST	0	0	0	0	0
149	T	0	0	0	0	0
150	ST	0	0	0	0	0
151	C	0	0	0	0	0
152	ST	0	0	0	0	0
153	C	0	0	0	0	0
154	ST	4	1	0	3	1
155	C	1	0	0	1	0
156	ST	6	3	0	3	3
157	C	1	0	0	1	0
158	ST	5	4	0	1	4
159	T	0	0	0	0	0
160	ST	4	1	0	3	1
161	C	2	0	1	1	1
162	ST	0	0	0	0	0
163	T	0	0	0	0	0
164	ST	0	0	0	0	0
165	C	2	2	0	0	2
166	ST	4	3	1	1	3
167	T	8	2	0	6	2
168	ST	1	0	0	1	0
169	C	1	0	0	1	0
170	ST	10	5	0	5	5
171	T	3	2	0	1	2
172	ST	2	1	0	1	1
173	C	16	6	1	10	6

174	ST	7	3	2	4	3
175	T	6	1	0	5	1
176	ST	8	4	0	4	4
177	C	3	2	0	1	2
178	ST	1	0	0	1	0
179	T	0	0	0	0	0
180	ST	0	0	0	0	0
181	C	0	0	0	0	0
182	ST	2	1	0	1	1
183	C	1	0	0	1	0
184	ST	0	0	0	0	0
185	C	0	0	0	0	0
186	ST	0	0	0	0	0
187	C	0	0	0	0	0
188	ST	0	0	0	0	0
189	T	1	1	1	0	1
190	ST	0	0	0	0	0
191	C	2	2	1	0	2
192	ST	0	0	0	0	0
193	T	0	0	0	0	0
194	ST	1	0	0	1	0
195	C	0	0	0	0	0
196	ST	10	4	1	6	4
197	T	0	0	0	0	0
198	ST	3	3	0	0	3
199	C	1	1	0	0	1
200	ST	0	0	0	0	0
201	T	0	0	0	0	0
202	ST	0	0	0	0	0
203	C	0	0	0	0	0
204	ST	0	0	0	0	0
205	T	0	0	0	0	0
206	ST	0	0	0	0	0
207	C	0	0	0	0	0
208	ST	0	0	0	0	0
209	T	0	0	0	0	0
210	ST	0	0	0	0	0
211	C	0	0	0	0	0
212	ST	0	0	0	0	0
213	T	4	1	0	3	1
214	ST	0	0	0	0	0
215	C	1	1	0	0	1
216	ST	0	0	0	0	0
217	T	0	0	0	0	0

218	ST	1	1	0	0	1
219	C	2	0	0	2	0
220	ST	4	0	0	4	0
221	T	8	3	0	5	3
222	ST	0	0	0	0	0
223	C	0	0	0	0	0
224	ST	1	1	0	0	1
225	T	0	0	0	0	0
226	ST	0	0	0	0	0
227	C	0	0	0	0	0
228	ST	0	0	0	0	0
229	T	0	0	0	0	0
230	ST	0	0	0	0	0
231	C	0	0	0	0	0
232	ST	0	0	0	0	0
233	T	1	1	0	0	1
234	ST	1	1	0	0	1
235	C	0	0	0	0	0
236	ST	0	0	0	0	0
237	T	0	0	0	0	0
238	ST	0	0	0	0	0
239	C	0	0	0	0	0
240	ST	0	0	0	0	0
241	T	0	0	0	0	0
242	ST	0	0	0	0	0
243	C	0	0	0	0	0
244	CC	0	0	0	0	0
245	C	1	1	0	0	1
246	ST	0	0	0	0	0
247	T	0	0	0	0	0
248	ST	0	0	0	0	0
249	C	0	0	0	0	0
250	ST	0	0	0	0	0
251	T	0	0	0	0	0
252	ST	0	0	0	0	0
253	C	0	0	0	0	0
254	ST	0	0	0	0	0
255	T	0	0	0	0	0
256	ST	0	0	0	0	0
257	C	0	0	0	0	0
258	ST	0	0	0	0	0
259	T	0	0	0	0	0
260	ST	1	0	0	1	0
261	C	0	0	0	0	0

262	ST	0	0	0	0	0
263	C	0	0	0	0	0
264	ST	0	0	0	0	0
265	C	0	0	0	0	0
266	ST	0	0	0	0	0
267	C	0	0	0	0	0
268	ST	0	0	0	0	0
269	T	0	0	0	0	0
270	ST	0	0	0	0	0
271	C	0	0	0	0	0
272	ST	0	0	0	0	0
273	T	0	0	0	0	0
274	ST	0	0	0	0	0
275	C	0	0	0	0	0
276	ST	0	0	0	0	0
277	C	0	0	0	0	0
278	ST	0	0	0	0	0
279	T	1	1	0	0	1
280	ST	0	0	0	0	0
281	C	1	0	0	1	0
282	ST	0	0	0	0	0
283	T	0	0	0	0	0
284	ST	0	0	0	0	0
285	C	0	0	0	0	0
286	ST	0	0	0	0	0
287	C	0	0	0	0	0
288	ST	0	0	0	0	0
289	T	0	0	0	0	0
290	ST	0	0	0	0	0
291	C	0	0	0	0	0
292	ST	0	0	0	0	0
293	C	0	0	0	0	0
294	ST	0	0	0	0	0
295	C	0	0	0	0	0
296	ST	0	0	0	0	0
297	C	0	0	0	0	0
298	ST	0	0	0	0	0
299	T	0	0	0	0	0
300	ST	0	0	0	0	0
301	C	1	1	0	0	1
302	CC	0	0	0	0	0
303	C	0	0	0	0	0
304	ST	0	0	0	0	0
305	C	0	0	0	0	0

306	ST	0	0	0	0	0
307	C	0	0	0	0	0
308	ST	0	0	0	0	0
309	T	0	0	0	0	0
310	ST	0	0	0	0	0
311	C	1	1	0	0	1
312	ST	0	0	0	0	0
313	T	0	0	0	0	0
314	T	0	0	0	0	0
315	ST	0	0	0	0	0
316	C	0	0	0	0	0
317	ST	0	0	0	0	0
318	T	0	0	0	0	0
319	ST	0	0	0	0	0
320	C	5	4	0	1	4
321	ST	3	2	0	1	2
322	T	0	0	0	0	0
323	ST	0	0	0	0	0
324	C	0	0	0	0	0
325	ST	0	0	0	0	0
326	C	0	0	0	0	0
327	ST	1	0	0	1	0
328	T	1	0	0	1	0
329	ST	0	0	0	0	0
330	C	0	0	0	0	0
331	ST	3	2	1	1	2
332	T	0	0	0	0	0
333	ST	0	0	0	0	0
334	C	0	0	0	0	0
335	ST	0	0	0	0	0
336	T	0	0	0	0	0
337	ST	1	1	1	0	1
338	C	0	0	0	0	0
339	ST	0	0	0	0	0
340	T	0	0	0	0	0
341	ST	0	0	0	0	0
342	C	0	0	0	0	0
343	ST	0	0	0	0	0
344	T	0	0	0	0	0
345	ST	0	0	0	0	0
346	C	0	0	0	0	0
347	ST	0	0	0	0	0
348	T	0	0	0	0	0
349	ST	0	0	0	0	0

350	C	0	0	0	0	0
351	ST	3	2	0	1	2
352	T	0	0	0	0	0
353	ST	1	0	0	1	0
354	C	0	0	0	0	0
355	ST	0	0	0	0	0
356	T	1	1	0	0	1
357	ST	0	0	0	0	0
358	C	0	0	0	0	0
359	ST	0	0	0	0	0
360	C	0	0	0	0	0
361	ST	0	0	0	0	0
362	C	0	0	0	0	0
363	ST	0	0	0	0	0
364	T	0	0	0	0	0
365	ST	0	0	0	0	0
366	C	0	0	0	0	0
367	ST	1	0	0	1	0
368	C	1	0	0	1	0
369	ST	0	0	0	0	0
370	C	0	0	0	0	0
371	ST	0	0	0	0	0
372	T	0	0	0	0	0
373	ST	0	0	0	0	0
374	C	1	1	0	0	1
375	ST	6	3	0	3	3
376	T	0	0	0	0	0
377	ST	0	0	0	0	0
378	C	0	0	0	0	0
379	ST	0	0	0	0	0
380	T	0	0	0	0	0
381	ST	4	4	1	0	4
382	C	0	0	0	0	0
383	ST	1	0	0	1	0
384	T	1	1	0	0	1
385	ST	0	0	0	0	0
386	C	1	1	0	0	1
387	ST	0	0	0	0	0
388	T	0	0	0	0	0
389	ST	0	0	0	0	0
390	C	0	0	0	0	0
391	ST	0	0	0	0	0
392	T	0	0	0	0	0
393	C	4	1	2	1	3

394	T	1	1	0	0	1
395	ST	0	0	0	0	0
396	C	0	0	0	0	0
397	ST	0	0	0	0	0
398	T	0	0	0	0	0

Table 7 shows the partition of the total accidents in property damage only (PDO) and injury crashes for the different road element type.
Totally, 344 accidents were observed on the S.P. 430 from 2003 to 2010, which of 167 PDO, and 177 that have registered at least one injured or dead.

Table 7 - Overview of the Main Crash Features for the different road element type

	Tangent	Circular Curve	Transition Curve	TOT
N. PDO crashes	48	43	76	167
N. Injury crashes	43	62	72	177

Figure 13 and 14 show the largest number of accidents, have occurred on a transition curve, with 46% for PDO and 41% for injury crashes.

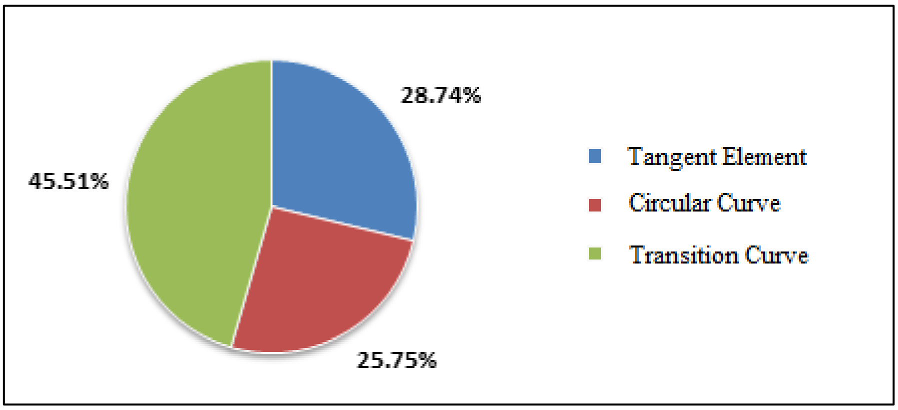


Figure 13 - Percentage of PDO crashes for the different road element type

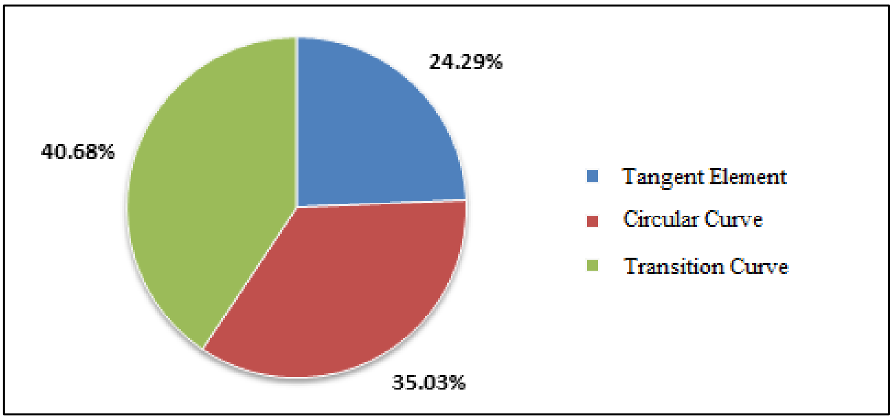


Figure 14 - Percentage of injury crashes for the different road element type

Figure 15 shows the Crash Severity for the different road element type. In particular the largest number of injured was observed in crashes occurring on circular curve elements; 124 out of a total of 321 observed. The largest number of deaths was observed on transition curve elements, 16 out of a total of 33 observed.

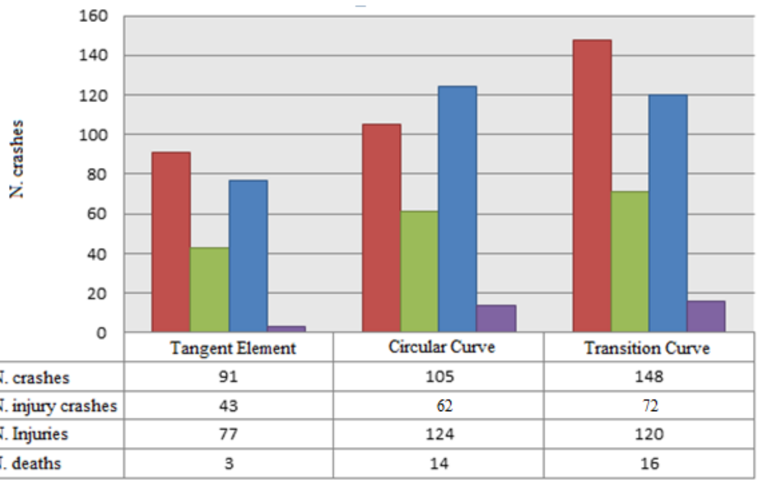


Figure 15 - Crash Severity for the different road element type

Figure 16 shows the crashes by varying the crash type.

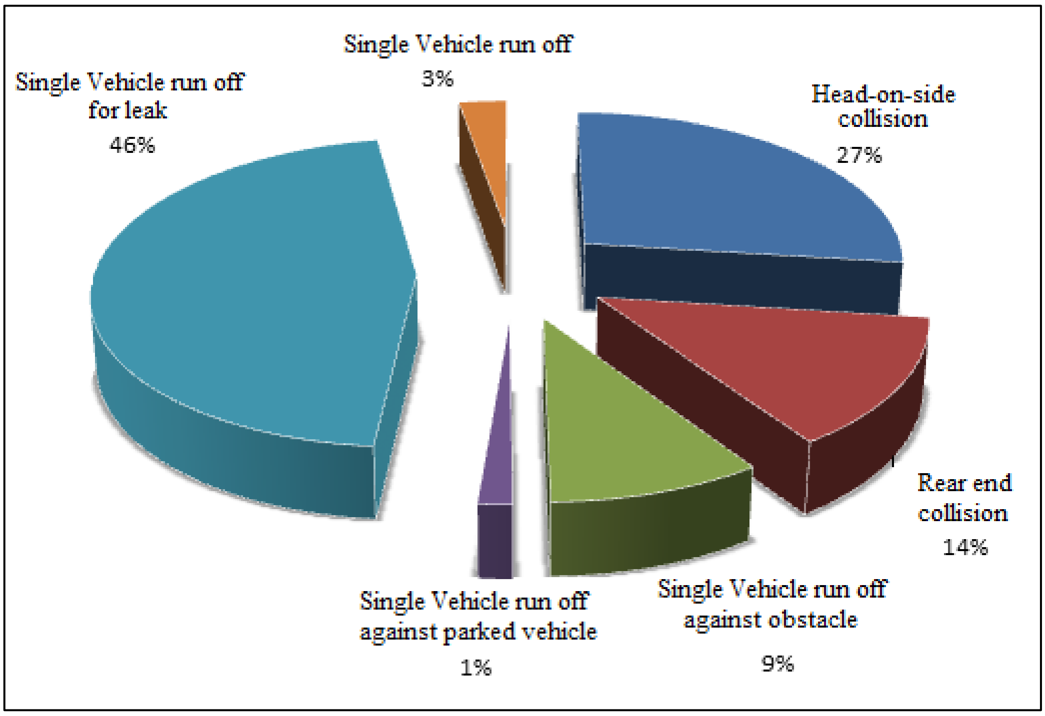


Figure 16 - Percentage of Crash Type

3. Element of Design

3.1 Introduction

The alignment of a highway or street produces a great impact on the environment, the fabric of the community, and the highway user. The alignment consists of a variety of design elements that combine to create a facility that serves traffic safely and efficiently, consistent with the facility's intended function. Each alignment element should complement others to achieve a consistent, safe, and efficient design. Common to all classes of highways and streets are several principal elements of design. These include sight distance, super elevation, traveled way widening, grades, horizontal and vertical alignments, and other elements of geometric design.

The D.M. 5/11/2001 identifies different functional classes of highways and streets with an associate value of design speed (See Figure 17). The functional class A refers to freeway with a value of design speed V_p of 90 km/h if rural context and 80 km/h in urban context. Local street are indicated with the functional class F with a V_P = 40 Km/h for rural roads and 25 Km/h for urban roads.

TIPI SECONDO IL CODICE		AMBITO TERRITORIALE	DENOMINAZIONE	V_p min [km/h]
AUTOSTRADA	A	EXTRAURBANO	STRADA PRINCIPALE	90
			STRADA DI SERVIZIO (EVENTUALE)	40
		URBANO	STRADA PRINCIPALE	80
			STRADA DI SERVIZIO (EVENTUALE)	40
EXTRAURBANA PRINCIPALE	B	EXTRAURBANO	STRADA PRINCIPALE	70
			STRADA DI SERVIZIO (EVENTUALE)	40
EXTRAURBANA SECONDARIA	C	EXTRAURBANO		60
URBANA DI SCORRIMENTO	D	URBANO	STRADA PRINCIPALE	50
			STRADA DI SERVIZIO (EVENTUALE)	25
URBANA DI QUARTIERE	E	URBANO		40
LOCALE	F	EXTRAURBANO		40
		URBANO		25

Figure 17 - Overview of the main characteristics by varying rod type

3.2 Horizontal Alignment

To achieve balance in highway design, all geometric elements should, as far as economically practical, be designed to operate at a speed likely to be observed under the normal conditions for that roadway for a vast majority of motorists. Generally, this can be achieved through the use of design speed as an overall design control. The design of roadway curves should be based on an appropriate relationship between design speed and curvature and on their joint relationships with super elevation (roadway banking) and side friction. Although these relationships stem from the laws of mechanics, the actual values for use in design depend on

practical limits and factors determined more or less empirically. These limits and factors are explained in the following discussion. When a vehicle moves in a circular path, it undergoes a centripetal acceleration that acts toward the center of curvature. This acceleration is sustained by a component of the vehicle's weight related to the roadway super elevation, by the side friction developed between the vehicle's tires and the pavement surface, or by a combination of the two. Centripetal acceleration is sometimes equated to centrifugal force. However, this is an imaginary force that motorists believe is pushing them outward while cornering when, in fact, they are truly feeling the vehicle being accelerated in an inward direction. In horizontal curve design, "lateral acceleration" is equivalent to "centripetal acceleration"; the term "lateral acceleration" is used in this policy as it is specifically applicable to geometric design.
From the laws of mechanics, the basic equation that governs vehicle operation on a curve is:

$$\frac{0.01e+f}{1-0.01qf}=\frac{v^2}{gR}=\frac{0.0079V^2}{R}=\frac{V^2}{127R} \qquad (9)$$

Where:
q = rate of roadway superelevation, percent
f = side friction (demand) factor
v = vehicle speed, m/s
g = gravitational constant, 9.81 m/s^2
V = vehicle speed, km/h
R = radius of curve measured to a vehicle's center of gravity, m

Equation 2, which models the moving vehicle as a point mass, is often referred to as the basic curve equation. When a vehicle travels at constant speed on a curve super elevated so that the f value is zero, the centripetal acceleration is sustained by a component of the vehicle's weight and, theoretically, no steering force is needed. A vehicle traveling faster or slower than the balance speed develops tire friction as steering effort is applied to prevent movement to the outside or to the inside of the curve. On non-super elevated curves, travel at different speeds is also possible by utilizing appropriate amounts of side friction to sustain the varying lateral acceleration.

3.2.1 Circular Curve

Limiting values for super elevation rate (q_{max}) and side friction demand (f_{max}) have been established for curve design in the D.M. 5/11/2001. Using these established limiting values in the basic curve formula permits determining a minimum curve radius for various design speeds. Use of curves with radii larger than this minimum allows super elevation, side friction, or both to have values below their respective limits.
Table 8 shows side friction (demand) factor by varying road functional class and vehicle speed.

Table 8 – Side friction value for the different road functional class

Vehicle speed (km/h)	25	40	60	80	100	120	140
f_{max} for A, B, C, F rural roads	-	0.21	0.17	0.13	0.11	0.10	0.09
f_{max} for D, E, F, urban roads	0.22	0.21	0.20	0.16	-	-	-

The minimum radius is a limiting value of curvature for a given design speed and is determined from the maximum rate of super elevation and the maximum side friction factor selected for design (limiting value of f). Use of sharper curvature for that design speed would call for super elevation beyond the limit considered practical or for operation with tire friction and lateral acceleration beyond what is considered comfortable by many drivers, or both. The minimum radius of curvature is based on a threshold of driver comfort that is sufficient to provide a margin of safety against skidding and vehicle rollover. The minimum radius of curvature is also an important control value for determining super elevation rates for flatter curves. The minimum radius of curvature, Rmin, can be calculated directly from the simplified curve Equation 9 . This equation can be recast to determine Rmin as follows:

$$R_{\min} = \frac{V^2}{127(q_{\max} + f_{\max})} \tag{10}$$

Based on the maximum allowable side friction factors from Table 9 gives the minimum radius for the different road functional classes calculated using Equation 10.

Table 9 – Minimum Radius value for the different road functional class

TIPI SECONDO IL CODICE		AMBITO TERRITORIALE	DENOMINAZIONE	V_p min [km/h]	q_{max}	$f_{t\,max}$	Raggio minimo [m]
AUTOSTRADA	A	EXTRAURBANO	STRADA PRINCIPALE	90	0,07	0,118	339
			STRADA DI SERVIZIO (EVENTUALE)	40	0,07	0,210	45
		URBANO	STRADA PRINCIPALE	80	0,07	0,130	252
			STRADA DI SERVIZIO (EVENTUALE)	40	0,035	0,210	51
EXTRAURBANA PRINCIPALE	B	EXTRAURBANO	STRADA PRINCIPALE	70	0,07	0,147	178
			STRADA DI SERVIZIO (EVENTUALE)	40	0,07	0,210	45
EXTRAURBANA SECONDARIA	C	EXTRAURBANO		60	0,07	0,170	118
URBANA DI SCORRIMENTO	D	URBANO	STRADA PRINCIPALE	50	0,05	0,205	77
			STRADA DI SERVIZIO (EVENTUALE)	25	0,035	0,220	19
URBANA DI QUARTIERE	E	URBANO		40	0,035	0,210	51
LOCALE	F	EXTRAURBANO		40	0,07	0,210	45
		URBANO		25	0,035	0,220	19

For radius value more than R_{min} are used the abacus in Figure 18.

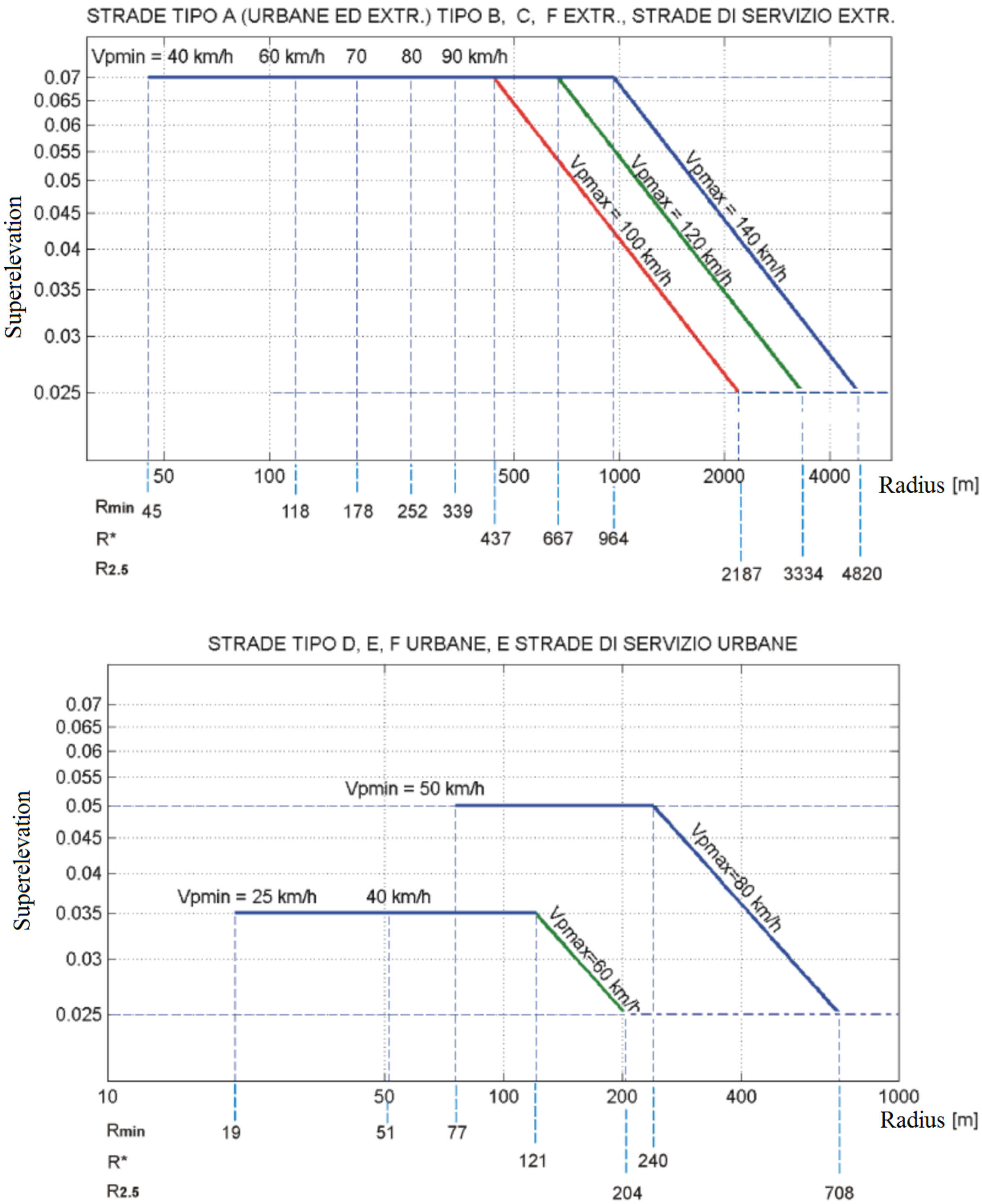


Figure 18 - Abacus for the determination of circular curve radius value

A circular curve, to be correctly perceived by the drivers, needs to have a length corresponding to a travel time of at least 2.5 seconds, referring to the design speed of the circular curve.
The relationships between the radii R_1 and R_2 of two circular curves are regulated by the abacus shown in Figure 19. In particular, for the road with class A and B the ratio must lie in the "good area"; for the other classes can be lie in the “acceptable area".

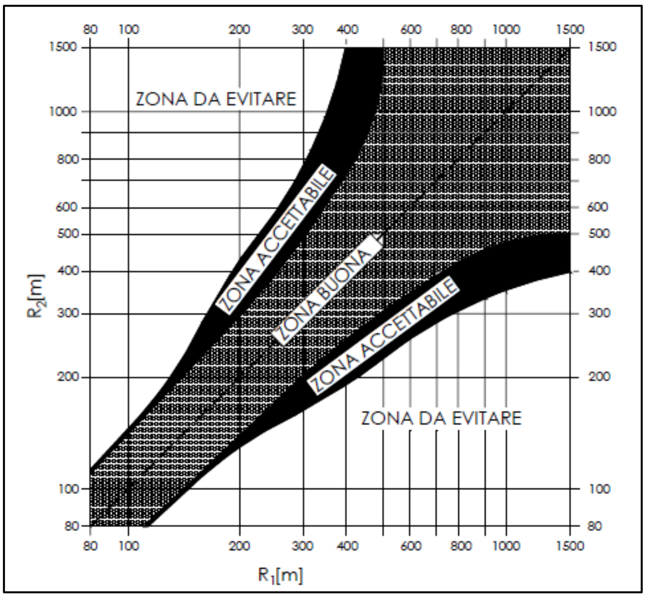


Figure 19 - Relations between two consecutive circular radius curves

Between a tangent element with length Lr and the smallest radius among the two curves connected to the tangent element, even with the interposition of a spiral curve, it must be respected the relations:

$$R > L_R \quad \text{if} \quad L_R < 300m \qquad (11)$$

$$R \geq 400\,m \quad \text{if} \quad L_R \geq 300m \qquad (12)$$

3.2.2 Tangent Element

To avoid high operating speed, the monotony, the difficult assessment of sight distances and to reduce glare when driving at night, the maximum tangent length Lr can be evaluated with Equation 6.

$$L_R = 22 \cdot Vp\,\text{max} \qquad (13)$$

Where Vp max is the upper limit of the design speed of the road, in km / h.

Also, a tangent element, in order to be perceived by the user, must have a length not less than the values reported in the Table 10.

Table 10 – Minimum Tangent Length Design criteria by varying Design Speed Value

Design Speed (km/h)	40	50	60	70	80	90	100	110	120	130	140
Min Tangent Length (m)	30	40	50	65	90	115	150	190	250	300	360

3.2.3 Spiral Curve Transitions

Any motor vehicle follows a transition path as it enters or leaves a circular horizontal curve. The steering change and the consequent gain or loss of lateral force cannot be achieved instantly. For most curves, the average driver can follow a suitable transition path within the limits of normal lane width. However, combinations of high speed and sharp curvature lead to longer transition paths, which can result in shifts in lateral position and sometimes actual encroachment on adjoining lanes. In such instances, incorporation of transition curves between the tangent and the sharp circular curve, as well as between circular curves of substantially different radii, may be appropriate to make it easier for a driver to keep the vehicle within its own lane.

The principal advantages of transition curves in horizontal alignment are the following:

1. A properly designed transition curve provides a natural, easy-to-follow path for drivers, such that the lateral force increases and decreases gradually as a vehicle enters and leaves a circular curve. Transition curves minimize encroachment on adjoining traffic lanes and tend to promote uniformity in speed. A spiral transition curve simulates the natural turning path of a vehicle.
2. The transition curve length provides a suitable location for the super elevation runoff. The transition from the normal pavement cross slope on the tangent to the fully super elevated section on the curve can be accomplished along the length of the transition curve in a manner that closely fits the speed-radius relationship for vehicles traversing the transition. Where super elevation runoff is introduced without a transition curve, usually partly on the curve and partly on the tangent, the driver approaching the curve may need to steer opposite to the direction of the approaching curve when on the super elevated tangent portion to keep the vehicle within its lane.
3. A spiral transition curve also facilitates the transition in width where the traveled way is widened on a circular curve. Use of spiral transitions provides flexibility in accomplishing the widening of sharp curves.
4. The appearance of the highway or street is enhanced by applying spiral transition curves. The use of spiral transitions avoids noticeable breaks in the alignment as perceived by drivers at the beginning and end of circular curves. Figure 20 illustrates such breaks, which are more prominent with the presence of super elevation runoff.

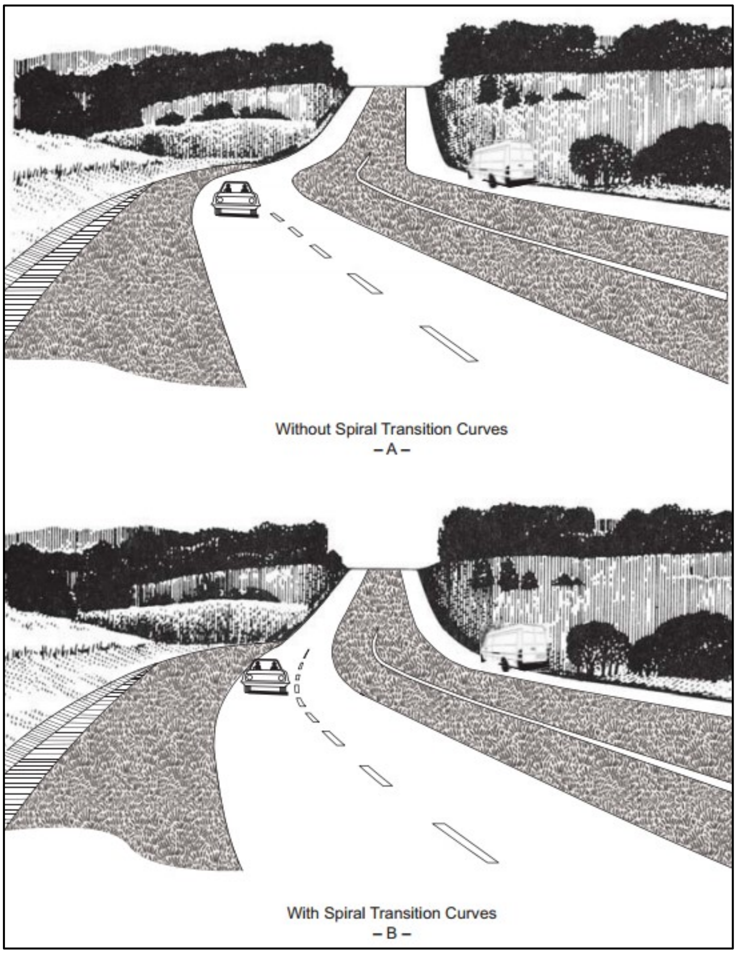


Figure 20 – Transition Spirals

In the alignment transition section, a spiral or compound transition curve may be used to introduce the main circular curve in a natural manner (i.e., one that is consistent with the driver's steered path). Such transition curvature consists of one or more curves aligned and located to provide a gradual change in alignment radius. As a result, an alignment transition gently introduces the lateral acceleration associated with the curve. While such a gradual change in path and lateral acceleration is appealing, there is no definitive evidence that transition curves are essential to the safe operation of the roadway and, as a result, they are not used by many agencies.

When a transition curve is not used, the roadway tangent directly adjoins the main circular curve. This type of transition design is referred to as the "tangent-to-curve" transition.

The equation of the transition curve is shows in Equation 7:

$$r \times s^n = A^{n+1} \tag{14}$$

Where:

r = Radius of Circular curve at the end of the spiral in the generic point

s = Length measured along the spiral curve in the generic point

A = Parameter of spiral curve (clothoid)

n = shape parameter; if n = 1, si Spiral Transition Curve

Figure 21 shows the evolution of the generic transition curve.

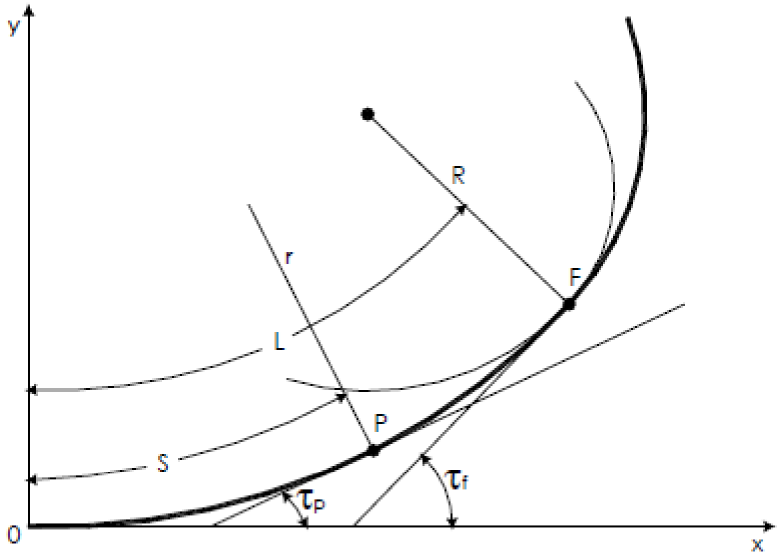


Figure 21 - Evolution of the generic transition curve

Where:
F = Final point of the spiral
R (m) = Radius of Circular curve
L (m) = Length of the spiral curve
τ_P = Angle of curve in the first point P on the spiral
τ_F= Angle of curve in the final point F on the spiral

Generally, the Euler spiral, which is also known as the clothoid, is used in the design of spiral transition curves. The radius varies from infinity at the tangent end of the spiral to the radius of the circular arc at the end that adjoins that circular arc. By definition, the radius of curvature at any point on an Euler spiral varies inversely with the distance measured along the spiral. In the case of a spiral transition that connects two circular curves having different radii, there is an initial radius rather than an infinite value. The following equation, developed in 1909 by Shortt (1909) for gradual attainment of lateral acceleration on railroad track curves, is the basic expression used by some highway agencies for computing minimum length of a spiral transition curve:

$$L = \frac{0.0214V^3}{RC} \quad (15)$$

Where:
L = minimum length of spiral, m
V = speed, km/h
R = curve radius, m
C = rate of increase of lateral acceleration, m /s^3

The factor C is an empirical value representing the comfort and safety levels provided by the spiral curve. The value of $C = 0.3\ m/s^3$ is generally accepted for railroad operation, but values ranging from 0.3 to 0.9 m/s^3 have been used for highways. This equation is sometimes modified to take into account the effect of super elevation, which results in much shorter spiral curve lengths. Highways do not appear to need as much precision as is obtained from computing the length of spiral by this equation or its modified form. A more practical control for the length of spiral is that it should equal the length needed for super elevation runoff.
The most important transition curves types are Tangent-to-Curve Transition, Curve-to-Tangent-to-Curve Transition, and Curve-to-Curve Transition.
Figure 22 shows the design criteria for the different transition curves type.

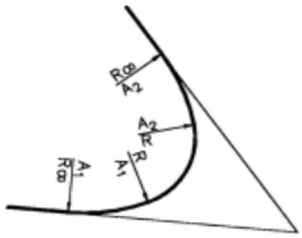
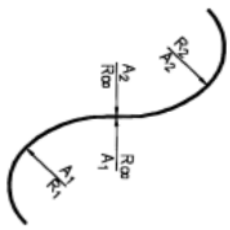
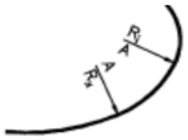
Transition Curve Type	Specifications
Tangent-to-Circular Curve Transition Curve 	$A_1 > A_{min}$ $A_2 > A_{min}$ $\frac{R}{3} < A_1 < R$ $\frac{R}{3} < A_2 < R$ $\frac{2}{3} \leq \frac{A_1}{A_2} \leq \frac{3}{2}$
Circular Curve-to-Tangent-to-Circular Curve Transition Curve 	$R_2 \leq R_1$ $A_1 \geq A_{min}$ $A_2 \geq A_{min}$ Asymmetric $A_1 \neq A_2$ $\frac{R_1}{3} \leq A_1 \leq R_1$ $\frac{R_2}{3} \leq A_2 \leq R_2$ $\frac{2}{3} \leq \frac{A_1}{A_2} \leq \frac{3}{2}$ Symmetric $A_1 = A_2 = A$ $\frac{R_1}{3} \leq A \leq R_2$
Circular Curve-to- Circular Curve Transition Curve 	$R_x \leq R_i$ $A_{min} \leq A$ $\frac{R_{i1}}{3} \leq A \leq R_{x1}$

Figure 22 – Design criteria for different transition curves type

3.2.4 General Control for Horizontal Alignment

A number of general controls are recognized in practice. These controls are not subject to theoretical derivation, but they are important for efficient and smooth-flowing highways. Excessive curvature or poor combinations of curvature limit traffic capacity, cause economic losses from increased travel time and operating costs, and detract from a pleasing appearance. To avoid these poor design practices, the general controls that follow should be used where practical:

- Alignment should be as directional as practical, but should be consistent with the topography and help preserve developed properties and community values. A flowing line that conforms generally to the natural contours is preferable to one with long tangents that slashes through the terrain. With curvilinear alignment, construction scars can be kept to a minimum and natural slopes and growth can be preserved. Such design is desirable from a construction and maintenance standpoint. In general, the number of short curves should be kept to a minimum. Winding alignment composed of short curves should be avoided because it usually leads to erratic operation. Although the aesthetic qualities of curving alignment are important, long tangents are needed on two lane highways so that sufficient passing sight distance is available on as much of the highway length as practical.
- In alignment developed for a given design speed, the minimum radius of curvature for that speed should be avoided wherever practical. The designer should attempt to use generally flat curves, saving the minimum radius for the most critical conditions. In general, the central angle of each curve should be as small as the physical conditions permit, so that the highway will be as directional as practical. This central angle should be absorbed in the longest practical curve, but on two-lane highways, the exception noted in the preceding paragraph applies to preserve passing sight distance.
- Consistent alignment should always be sought. Sharp curves should not be introduced at the ends of long tangents. Sudden changes from areas of flat curvature to areas of sharp curvature should be avoided. Where sharp curvature is introduced, it should be approached, where practical, by a series of successively sharper curves.
- Sharp curvature should be avoided on long, high fills. In the absence of cut slopes, shrubs, and trees that extend above the level of the roadway, it is difficult for drivers to perceive the extent of curvature and adjust their operation accordingly.
- The “broken-back” or “flat-back” arrangement of curves (with a short tangent between two curves in the same direction) should be avoided except where very unusual topographical or right-of-way conditions make other alternatives impractical. Except on circumferential highways, most drivers do not expect successive curves to be in the same direction; the preponderance of successive curves in opposite directions may develop a subconscious expectation among drivers that makes successive curves in the same direction unexpected. Broken-back alignments are also not pleasing in appearance. Use of spiral transitions or compound curve alignments, in which there is some degree of continuous super elevation, is preferable for such situations. The term “broken-back” usually is not applied when the connecting tangent is of considerable length. Even in this

case, the alignment may be unpleasant in appearance when both curves are clearly visible for some distance ahead.

- Changing median widths on tangent alignments should be avoided, where practical, so as not to introduce a distorted appearance.

3.3 Vertical Alignment

Vertical curves to effect gradual changes between tangent grades may be any one of the crest or sag types depicted in Figure 23. Vertical curves should be simple in application and should result in a design that enables the driver to see the road ahead, enhances vehicle control, is pleasing in appearance, and is adequate for drainage. The major design control for crest vertical curves is the provision of ample sight distances for the design speed; while research (Fambro et al, 1997) has shown that vertical curves with limited sight distance do not necessarily experience frequent crashes, it is recommended that all vertical curves should be designed to provide at least the stopping sight distances. Wherever practical, longer stopping sight distances should be used. Furthermore, additional sight distance should be provided at decision points.

For driver comfort, the rate of change of grade should be kept within tolerable limits. This consideration is most important in sag vertical curves where gravitational and vertical centripetal forces act in opposite directions. Appearance also should be considered in designing vertical curves. A long curve has a more pleasing appearance than a short one; short vertical curves may give the appearance of a sudden break in the profile due to the effect of foreshortening.

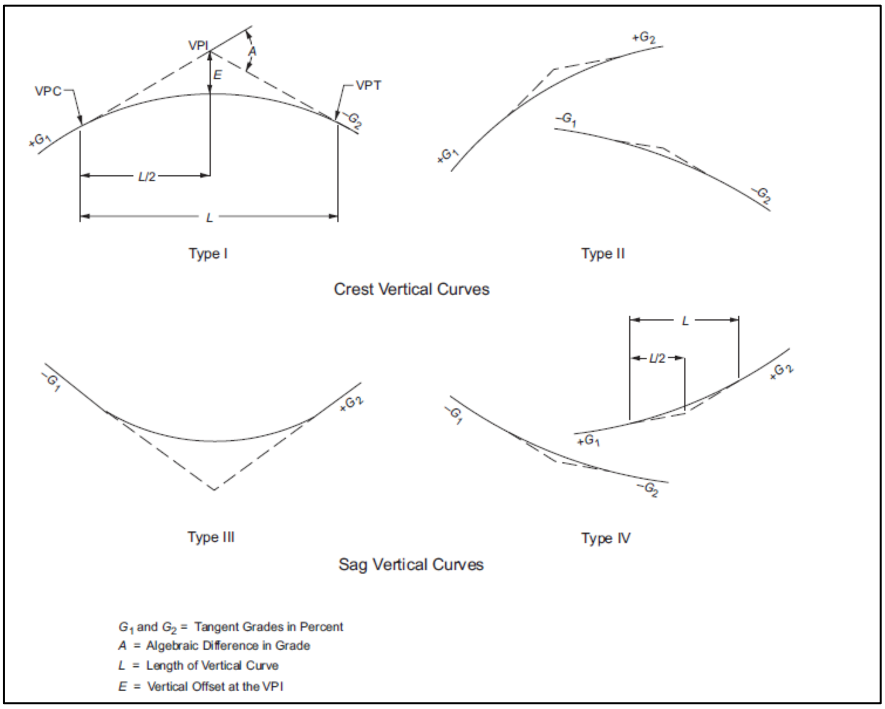


Figure 23 – Type of Vertical Curves

3.3.1 Crest Vertical Curves

Minimum lengths of crest vertical curves based on sight distance criteria generally are satisfactory from the standpoint of safety, comfort, and appearance. An exception may be at decision areas, such as ramp exit gores, where longer sight distances and, therefore, longer vertical curves should be provided; Figure 24 illustrates the parameters used in determining the length of a parabolic crest vertical curve needed to provide any specified value of sight distance. The basic equations for length of a crest vertical curve in terms of algebraic difference in grade and sight distance follow:

$$L = \frac{A \cdot S^2}{2 \cdot \left(h_1 + h_2 + 2\sqrt{h_1 \cdot h_2}\right)} \quad \text{when S > L} \qquad (16)$$

$$L = 2 \cdot \left(S - \frac{h_1 + h_2 + 2 \cdot \sqrt{h_1 \cdot h_2}}{A} \right) \quad \text{when S < L} \qquad (17)$$

Where:
L = length of vertical curve, m
A = algebraic difference in grades, percent
S = sight distance, m
h_1 = height of eye above roadway surface, m
h_2 = height of object above roadway surface, m

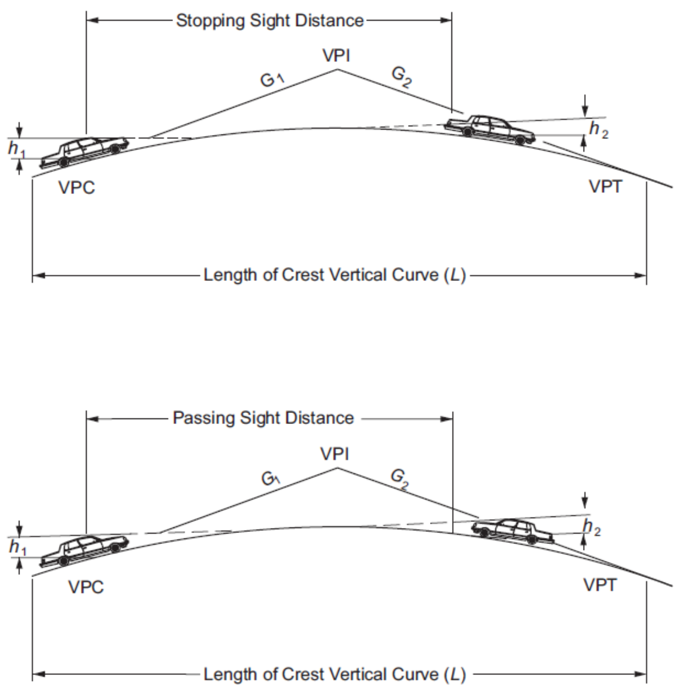


Figure 24 - Parameters Considered in Determing the Length of a Crest Vertical Curve to Provide Sight Distance

3.3.2 Sag Vertical Curves

At least four different criteria for establishing lengths of sag vertical curves are recognized to some extent. These are (1) headlight sight distance, (2) passenger comfort, (3) drainage control, and (4) general appearance.
Headlight sight distance has been used directly by some agencies and for the most part is the basis for determining the length of sag vertical curves recommended here. When a vehicle traverses a sag vertical curve at night, the portion of highway lighted ahead is dependent on the position of the headlights and the direction of the light beam. A headlight height of 0.60 m and a 1-degree upward divergence of the light beam from the longitudinal axis of the vehicle are commonly assumed. The upward spread of the light beam above the 1-degree divergence angle provides some additional visible length of roadway, but is not generally considered in design. The following equations show the relationships between S, L, and A, using S as the distance between the vehicle and point where the 1-degree upward angle of the light beam intersects the surface of the roadway:

$$L = 2 \cdot \left(S - \frac{h + S \cdot (\tan 1°)}{A} \right) \qquad \text{when S > L} \qquad (18)$$

$$L = \frac{A \cdot S^2}{2 \cdot [h + S(\tan 1°)]} \qquad \text{when S < L} \qquad (19)$$

Where:
L = length of sag vertical curve, m
A = algebraic difference in grades, percent
S = light beam distance, m

For drivers to see the roadway ahead, a sag vertical curve should be long enough that the light beam distance is approximately the same as the stopping sight distance. Accordingly, it is appropriate to use stopping sight distances for different design speeds as the value of S in the above equations.

3.3.3 General Controls for Vertical Alignment

In addition to the specific controls for vertical alignment discussed previously, there are several general controls that should be considered in design.

- A smooth grade line with gradual changes, as consistent with the type of highway, road, or street and the character of terrain, should be sought for in preference to a line with numerous breaks and short lengths of grades. Specific design criteria are the maximum grade and the critical length of grade, but the manner in which they are applied and fitted to the terrain on a continuous line determines the suitability and appearance of the finished product.
- The “roller-coaster” or the “hidden-dip” type of profile should be avoided. Such profiles generally occur on relatively straight, horizontal alignment where the roadway profile

closely follows a rolling natural ground line. Examples of such undesirable profiles are evident on many older roads and streets; they are unpleasant aesthetically and difficult to drive. Hidden dips may create difficulties for drivers who wish to pass, because the passing driver may be deceived if the view of the road or street beyond the dip is free of opposing vehicles. Even with shallow dips, this type of profile may be disconcerting, because the driver cannot be sure whether or not there is an oncoming vehicle hidden beyond the rise. This type of profile is avoided by use of horizontal curves or by more gradual grades.

- Undulating grade lines, involving substantial lengths of momentum grades, should be evaluated for their effect on traffic operation. Such profiles permit heavy trucks to operate at higher overall speeds than where an upgrade is not preceded by a downgrade, but may encourage excessive speeds of trucks with attendant conflicts with other traffic.
- A "broken-back" grade line (two vertical curves in the same direction separated by a short section of tangent grade) generally should be avoided, particularly in sags where the full view of both vertical curves is not pleasing. This effect is particularly noticeable on divided roadways with open median sections.
- On long grades, it may be preferable to place the steepest grades at the bottom and flatten the grades near the top of the ascent or to break the sustained grade by short intervals of flatter grade instead of providing a uniform sustained grade that is only slightly below the recommended maximum. This is particularly applicable to roads and streets with low design speeds.
- Where at-grade intersections occur on roadway sections with moderate to steep grades, it is desirable to reduce the grade through the intersection. Such profile changes are beneficial for vehicles making turns and serve to reduce the potential for crashes.
- Sag vertical curves should be avoided in cuts unless adequate drainage can be provided.

3.4 Combination of Horizontal and Vertical Alignment

Horizontal and vertical alignments are permanent design elements for which thorough study is warranted. It is extremely difficult and costly to correct alignment deficiencies after a highway is constructed. On freeways, there are numerous controls such as multilevel structures and costly right-of-way. On most arterial streets, heavy development takes place along the property lines, which makes it impractical to change the alignment in the future. Thus, compromises in the alignment designs should be weighed carefully because any initial savings may be more than offset by the economic loss to the public in the form of crashes and delays. Horizontal and vertical alignment should not be designed independently. They complement each other, and poorly designed combinations can spoil the good points and aggravate the deficiencies of each. Horizontal alignment and profile are among the more important of the permanent design elements of the highway. Excellence in the design of each and of their combination enhances vehicle control, ages uniform speed, and improves appearance, nearly always without additional cost (Fambro et al; AASHTO; ASCE; Cron; Leisch; SHRP, Smith and Lamm; Tunnard; USFS)

Common situation with bad combination of Horizontal and Vertical Alignment are shown in the Figures 25-32.

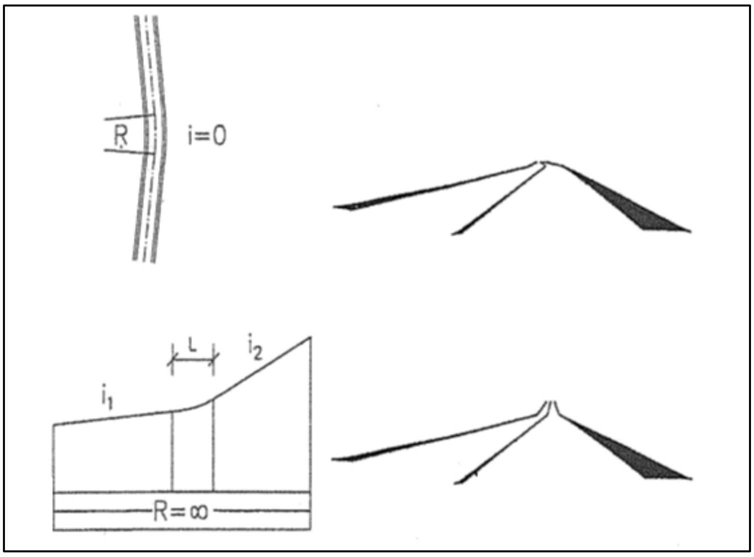


Figure 25 – Circular Radius and/or Vertical Curve too small

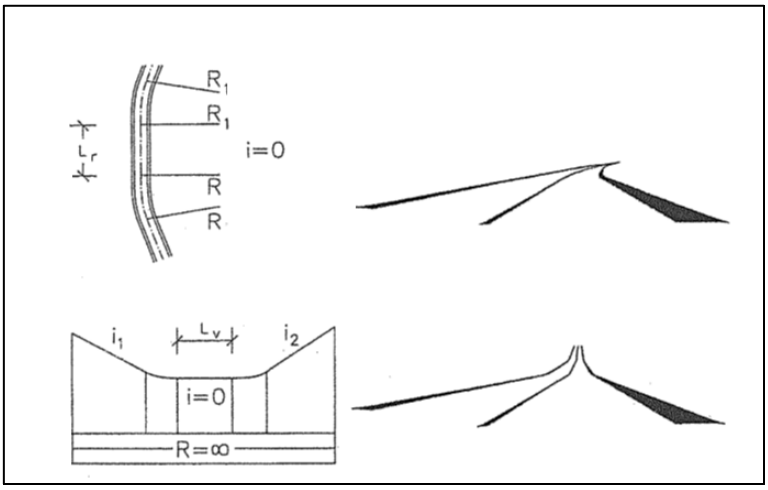


Figure 26 – Broken-back grade line

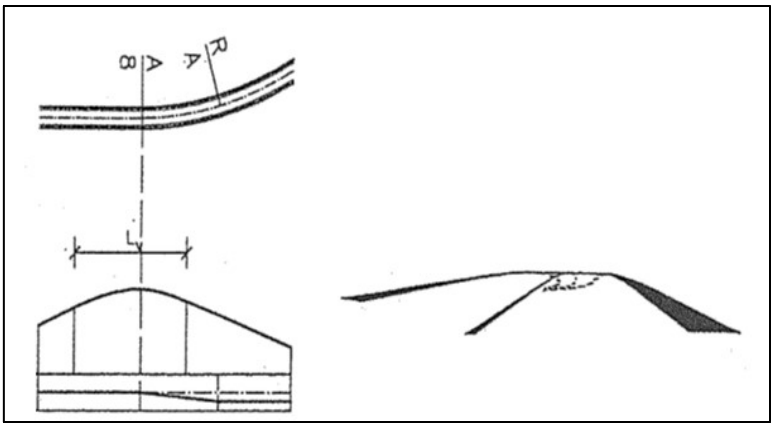


Figure 27 – Circular Curve hidden by a crest

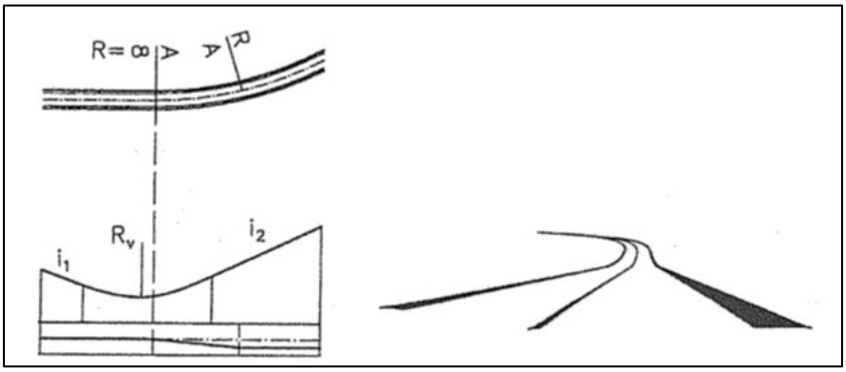


Figure 28 – Misalignment between horizontal curvature and sag vertical curve

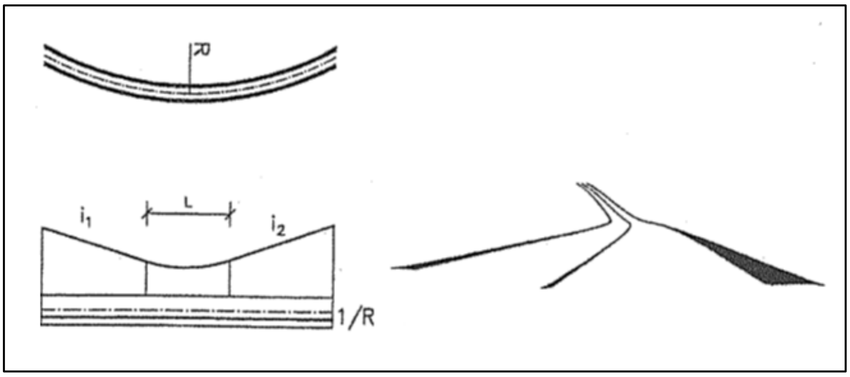


Figure 29 – Small Length vertical curvature

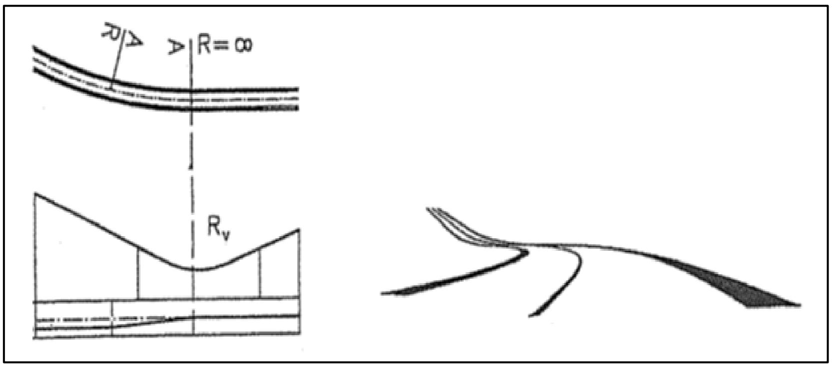


Figure 30 – Misalignment between horizontal and vertical curvature

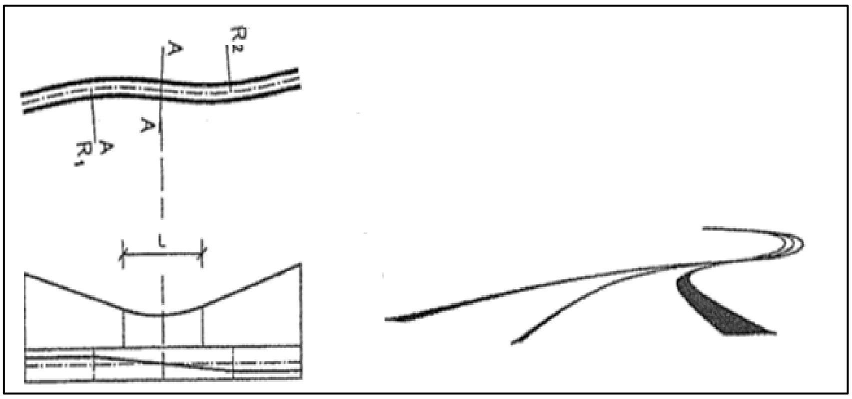


Figure 31 – Sag vertical curve near Circular Curve-to-Tangent-to-Circular Curve Transition Curve

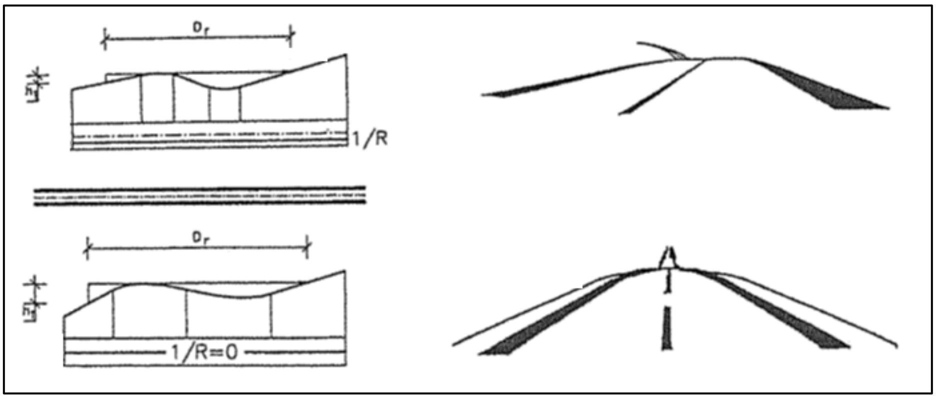


Figure 32 – Examples of distorted appearance

Appropriate combinations of horizontal alignment and profile are obtained through engineering studies and consideration to avoid situation shows in the following general guidelines:

- Curvature and grades should be in proper balance. Tangent alignment or flat curvature at the expense of steep or long grades and excessive curvature with flat grades both represent poor design. A logical design that offers the best combination of safety, capacity, ease and uniformity of operation, and pleasing appearance within the practical limits of terrain and area traversed is a compromise between these two extremes.
- Vertical curvature superimposed on horizontal curvature, or vice versa, generally results in a more pleasing facility, but such combinations should be analyzed for their effect on traffic. Successive changes in profile not in combination with horizontal curvature may result in a series of humps visible to the driver for some distance which represents an undesirable condition.
- Sharp horizontal curvature should not be introduced at or near the top of a pronounced crest vertical curve. This condition is undesirable because the driver may not perceive the horizontal change in alignment, especially at night. The disadvantages of this arrangement are avoided if the horizontal curvature leads the vertical curvature (i.e., the horizontal curve is made longer than the vertical curve). Suitable designs can also be developed by using design values well above the appropriate minimum values for the design speed.
- Somewhat related to the preceding guideline, sharp horizontal curvature should not be introduced near the bottom of a steep grade approaching or near the low point of a pronounced sag vertical curve. Because the view of the road ahead is foreshortened, any horizontal curvature other than a very flat curve assumes an undesirable distorted appearance. Further, vehicle speeds, particularly for trucks, are often high at the bottom of grades, and erratic operations may result, especially at night.

  The Swiss Standards provides diagram shows in Figure 33, for a given value V of the vehicle speed, the values of the distance Dr to which must reappear the road distorted appearance; when Dr falls in zone 2 must change the profile.

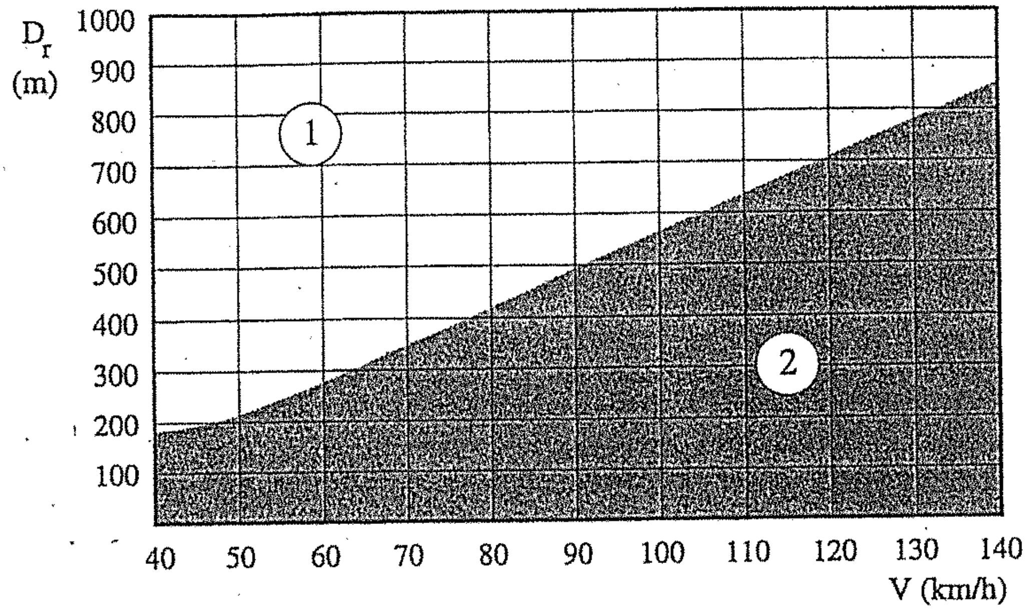


Figure 33 – Vehicle Speed and Sight distance relation

Similarly, the Italian Standard indicate, for each speed, the minimum distance Dr listed in Table 11.

Table 11 – Minimum Sight distance Dr by varying Design Speed Value

Design Speed (km/h)	25	40	50	60	70	80	90	100	110	120	130	140
Dr (m)	150	180	220	280	350	420	500	560	640	720	800	860

- On two-lane roads and streets, the need for passing sections at frequent intervals and including an appreciable percentage of the length of the roadway often supersedes the general guidelines for combinations of horizontal and vertical alignment. In such cases, it is appropriate to work toward long tangent sections to assure sufficient passing sight distance in design.
- Both horizontal curvature and profile should be made as flat as practical at intersections where sight distance along either roads or streets is important and vehicles may have to slow or stop.
- On divided highways and streets, variation in width of median and the use of independent profiles and horizontal alignments for the separate one-way roadways are sometimes desirable. Where traffic justifies provision of four lanes, a superior design without additional cost generally results from such practices.
- In residential areas, the alignment should be designed to minimize nuisance to the neighborhood. Generally, a depressed facility makes a highway less visible and less noisy to adjacent residents. Minor horizontal adjustments can sometimes be made to increase the buffer zone between the highway and clusters of homes.
- The alignment should be designed to enhance attractive scenic views of the natural and manmade environment, such as rivers, rock formations, parks, and outstanding structures. The highway should head into, rather than away from, those views that are outstanding; it

should fall toward those features of interest at a low elevation, and it should rise toward those features best seen from below or in silhouette against the sky.

3.5 Horizontal Vertical Design Specification

In according to the Italian Standard, design control for Horizontal and Horizontal-Vertical Alignment, were checked. Table 12 and 13shows the design controls checked with the associated code.

Table 12 – Horizontal Alignment Design Control Code

Design Control	Road Element	Code
Min Tangent Length (m)	Tangent	1p
Max Tangent Length (m)	Tangent	2p
R > Lr se Lr < 300 (m)	Tangent	3p
R ≥ 400 se Lr ≥ 300 (m)	Tangent	4p
Min Radius Cricular Curve (m)	Circular Curve	5p
R/3 < A < R	Transition Curve	6p
$R_1/3 < A < R_2$	Curve- to-Curve Transition	7p
$R_2 < R_1$	Curve-to-Tangent-to-Curve Transition	8p
$R_1/3 < A_1 < R_1$	Curve-to-Tangent-to-Curve Transition	9p
$R_2/3 < A_2 < R_2$	Curve-to-Tangent-to-Curve Transition	10p
$2/3 < A_1/A_2 < 3/2$	Curve-to-Tangent-to-Curve Transition	11p
$Lr \leq A_1+A_{2/}12.5$	Curve-to-Tangent-to-Curve Transition	12p
R_1 / R_2 acceptable area	Curve-to-Tangent-to-Curve Transition	13p

Table 13 – Horizontal - Vertical Alignment Design Control Code

Design Control	Code
Broken-back gradeline	1a
Crest Vertical Curve separated by small tangent grade	2a
Circular Curve hidden by Crest Vertical Curve	3a
Circular Curve after Sag Vertical Curve Dir. A-B	4a
Circular Curve after by Sag Vertical Curve Dir. B-A	5a
Circular Curve before Sag Vertical Curve Dir. A-B	6a
Circular Curve before by Sag Vertical Curve Dir. B-A	7a
Sag Vertical Circular and Curve-to-Tangent-to- Curve Transition Correspondence	8a
Difference in grades	9a
Crest Vertical Curve before Sag Vertical Circular Dir A-B	10a
Crest Vertical Curve before Sag Vertical Circular Dir B-A	11a

Table 14 and 15 show the results of test of the design control for each road element type, respectively for Horizontal and Horizontal-Vertical Alignment.

Table 14 – Test of the Horizontal Alignment Design Control

N. Element	Road Element Type	1 p	2 p	3 p	4 p	5 p	6 p	7 p	8 p	9 p	10 p	11 p	12 p	13 p
1	T	OK	OK											
2	C					OK								
3	T	OK	OK	NO	OK									
4	ST						OK							
5	C					OK								
6	ST						OK							
7	T	OK	OK	OK	NO									
8	ST						OK							
9	C					OK								
10	ST						OK							
11	T	OK	OK	OK	NO									
12	ST						OK							
13	C					OK								
14	ST						OK							
15	T	OK	OK	OK	NO									
16	C					OK								
17	T	OK	OK											
18	C					OK								
19	T	OK	OK	NO	OK									
20	ST						OK							
21	C					OK								
22	ST						OK							
23	T	v	OK											
24	C					OK								
25	T	OK	OK	OK	NO									
26	ST						OK							
27	C					OK								
28	ST						OK							
29	T	OK	OK	NO	OK									
30	C					OK								
31	T	NO	OK											
32	C					OK								
33	T	OK	OK	NO	OK									
34	ST						OK							
35	C					OK								
36	ST						OK							
37	T	NO	OK	OK	NO									
38	ST						OK							
39	C					OK								
40	ST						OK							

41	T	NO	OK	OK	NO									
42	ST						OK							
43	C					OK								
44	ST						OK							
45	T	OK	OK	OK	NO									
46	C					OK								
47	T	NO	OK	OK	NO									
48	ST						OK							
49	C					OK								
50	ST								OK	OK	OK	OK	OK	OK
51	C					OK								
52	ST								OK	OK	OK	OK	OK	OK
53	C					OK								
54	ST						OK							
55	T	NO	OK	OK	NO									
56	ST						OK							
57	C					OK								
58	ST						OK							
59	T	OK	OK	NO	OK									
60	ST						OK							
61	C					OK								
62	ST						OK							
63	T	OK	OK	NO	OK									
64	ST						OK							
65	C					OK								
66	ST						OK							
67	T	OK	OK	OK	NO									
68	C					OK								
69	T	OK	OK	OK	NO									
70	ST						OK							
71	C					OK								
72	ST						OK							
73	T	NO	OK	OK	NO									
74	C					OK								
75	T	NO	OK	OK	NO									
76	ST						OK							
77	C					OK								
78	ST						OK							
79	T	OK	OK	NO	OK									
80	ST						OK							
81	C					OK								
82	ST								NO	OK	OK	OK	OK	OK
83	C					OK								
84	ST						OK							
85	T	OK	OK	NO	OK									
86	ST						OK							

87	C					OK								
88	ST								NO	OK	OK	OK	OK	OK
89	C					OK								
90	ST						OK							
91	T	OK	OK	NO	OK									
92	C					OK								
93	T	NO	OK	OK	NO									
94	ST						NO							
95	C					OK								
96	CC							NO						
97	C					OK								
98	ST								NO	OK	OK	OK	OK	OK
99	C					OK								
100	ST								NO	OK	OK	OK	OK	OK
101	C					OK								
102	ST								NO	OK	OK	OK	OK	OK
103	C					OK								
104	ST						OK							
105	T	OK	OK	NO	OK									
106	ST						OK							
107	C					OK								
108	ST						OK							
109	T	NO	OK	OK	NO									
110	ST						OK							
111	C					OK								
112	ST						OK							
113	T	OK	OK	OK	NO									
114	ST						OK							
115	C					OK								
116	CC							NO						
117	C					OK								
118	ST						OK							
119	T	OK	OK	OK	NO									
120	ST						OK							
121	C					OK								
122	ST						OK							
123	T	OK	OK	NO	OK									
124	ST						OK							
125	C					OK								
126	ST						OK							
127	T	NO	OK	OK	NO									
128	ST						OK							
129	C					OK								
130	ST						OK							
131	T	OK	OK	OK	NO									
132	ST						OK							

133	C					OK								
134	ST						OK							
135	T	NO	OK	OK	NO									
136	ST						OK							
137	C					OK								
138	ST						OK							
139	T	NO	OK	OK	NO									
140	ST						OK							
141	C					OK								
142	ST						OK							
143	T	NO	OK	OK	NO									
144	C					OK								
145	T	NO	OK	OK	NO									
146	ST						OK							
147	C					OK								
148	ST						OK							
149	T	NO	OK	OK	NO									
150	ST						OK							
151	C					OK								
152	ST								OK	OK	OK	OK	OK	OK
153	C					OK								
154	ST								NO	OK	OK	OK	OK	OK
155	C					OK								
156	ST								OK	OK	OK	OK	OK	OK
157	C					OK								
158	ST						OK							
159	T	NO	OK	OK	NO									
160	ST						OK							
161	C					OK								
162	ST						OK							
163	T	OK	OK	OK	NO									
164	ST						OK							
165	C					OK								
166	ST						OK							
167	T	OK	OK	NO	OK									
168	ST						OK							
169	C					OK								
170	ST						OK							
171	T	OK	OK	OK	NO									
172	ST						NO							
173	C					OK								
174	ST						NO							
175	T	NO	OK	OK	NO									
176	ST						OK							
177	C					OK								
178	ST						OK							

179	T	OK	OK	OK	NO									
180	ST						OK							
181	C					OK								
182	ST								OK	OK	OK	OK	OK	OK
183	C					OK								
184	ST								NO	OK	OK	OK	OK	OK
185	C					OK								
186	ST								NO	OK	OK	OK	OK	OK
187	C					OK								
188	ST						OK							
189	T	OK	OK	NO	NO									
190	ST						OK							
191	C					OK								
192	ST						OK							
193	T	NO	OK	OK	NO									
194	ST						OK							
195	C					OK								
196	ST						OK							
197	T	NO	OK	OK	NO									
198	ST						OK							
199	C					OK								
200	ST						OK							
201	T	OK	OK	OK	NO									
202	ST						NO							
203	C					OK								
204	ST						NO							
205	T	NO	OK	OK	NO									
206	ST						OK							
207	C					OK								
208	ST						OK							
209	T	NO	OK	OK	NO									
210	ST						OK							
211	C					OK								
212	ST						OK							
213	T	OK	OK	NO	OK									
214	ST						OK							
215	C					OK								
216	ST						OK							
217	T	NO	OK	OK	NO									
218	ST						OK							
219	C					OK								
220	ST						OK							
221	T	OK	OK	NO	OK									
222	ST						OK							
223	C					OK								
224	ST						OK							

225	T	OK	OK	OK	NO									
226	ST						OK							
227	C					OK								
228	ST						OK							
229	T	NO	OK	OK	NO									
230	ST						OK							
231	C					OK								
232	ST						OK							
233	T	OK	OK	NO	OK									
234	ST						OK							
235	C					OK								
236	ST						OK							
237	T	NO	OK	OK	NO									
238	ST						OK							
239	C					OK								
240	ST						OK							
241	T	NO	OK	OK	NO									
242	ST						NO							
243	C					OK								
244	CC							NO						
245	C					OK								
246	ST						OK							
247	T	OK	OK	NO	OK									
248	ST						OK							
249	C					OK								
250	ST						OK							
251	T	NO	OK	OK	NO									
252	ST						OK							
253	C					OK								
254	ST						OK							
255	T	NO	OK	OK	NO									
256	ST						OK							
257	C					OK								
258	ST						OK							
259	T	OK	OK	NO	NO									
260	ST						OK							
261	C					OK								
262	ST								OK	OK	OK	NO	OK	OK
263	C					OK								
264	ST								OK	OK	OK	OK	OK	OK
265	C					OK								
266	ST								NO	OK	OK	OK	OK	OK
267	C					OK								
268	ST						OK							
269	T	OK	OK	OK	NO									
270	ST						OK							

271	C					OK								
272	ST						OK							
273	T	NO	OK	OK	NO									
274	ST						OK							
275	C					OK								
276	ST								NO	OK	OK	OK	OK	OK
277	C					OK								
278	ST						OK							
279	T	OK	OK	NO	NO									
280	ST						OK							
281	C					OK								
282	ST						OK							
283	T	OK	OK	OK	NO									
284	ST						OK							
285	C					OK								
286	ST								NO	OK	OK	OK	OK	OK
287	C					OK								
288	ST						OK							
289	T	OK	OK	OK	NO									
290	ST						OK							
291	C					OK								
292	ST								NO	OK	OK	OK	OK	OK
293	C					OK								
294	ST								OK	OK	OK	OK	OK	OK
295	C					OK								
296	ST								NO	OK	OK	OK	OK	OK
297	C					OK								
298	ST						OK							
299	T	NO	OK	OK	NO									
300	ST						NO							
301	C					OK								
302	CC							NO						
303	C					OK								
304	ST								OK	OK	OK	OK	OK	OK
305	C					OK								
306	ST								NO	OK	OK	OK	OK	OK
307	C					OK								
308	ST						OK							
309	T	OK	OK	NO	OK									
310	ST						OK							
311	C					OK								
312	ST						OK							
313	T	OK	OK	OK	NO									
314	T	OK	OK	OK	NO									
315	ST						OK							
316	C					OK								

317	ST						OK							
318	T	NO	OK	OK	NO									
319	ST						OK							
320	C					OK								
321	ST						OK							
322	T	NO	OK	OK	NO									
323	ST						OK							
324	C					OK								
325	ST								NO	OK	OK	OK	OK	OK
326	C					OK								
327	ST						OK							
328	T	OK	OK	NO	NO									
329	ST						OK							
330	C					OK								
331	ST						OK							
332	T	OK	OK	NO	NO									
333	ST						OK							
334	C					OK								
335	ST						OK							
336	T	OK	OK	NO	NO									
337	ST						OK							
338	C					OK								
339	ST						OK							
340	T	NO	OK	OK	NO									
341	ST						NO							
342	C					OK								
343	ST						NO							
344	T	OK	OK	NO	NO									
345	ST						OK							
346	C					OK								
347	ST						OK							
348	T	NO	OK	OK	NO									
349	ST						OK							
350	C					OK								
351	ST						OK							
352	T	NO	OK	OK	NO									
353	ST						OK							
354	C					OK								
355	ST						OK							
356	T	OK	OK	OK	NO									
357	ST						OK							
358	C					OK								
359	ST								OK	OK	OK	OK	OK	OK
360	C					OK								
361	ST								OK	OK	OK	NO	OK	OK
362	C					OK								

363	ST						OK							
364	T	NO	OK	OK	NO									
365	ST						OK							
366	C					OK								
367	ST								OK	OK	OK	OK	OK	OK
368	C					OK								
369	ST								NO	OK	OK	OK	OK	NO
370	C					OK								
371	ST						NO							
372	T	OK	OK	OK	NO									
373	ST						OK							
374	C					OK								
375	ST						OK							
376	T	NO	OK	OK	NO									
377	ST						OK							
378	C					OK								
379	ST						OK							
380	T	OK	OK	OK	NO									
381	ST						OK							
382	C					OK								
383	ST						OK							
384	T	NO	OK	OK	NO									
385	ST						OK							
386	C					OK								
387	ST						OK							
388	T	NO	OK	OK	NO									
389	ST						OK							
390	C					OK								
391	ST						OK							
392	T	NO	OK	OK	NO									
393	C					OK								
394	T	NO	OK	OK	NO									
395	ST						OK							
396	C					OK								
397	ST						OK							
398	T	NO	OK	OK	NO									

Table 15 – Test of the Horizontal – Vertical Alignment Design Control

N.	Road Element Type	Vertical Curve Type	Vertical Curve Length (m)	Vertical radius Rv (m)	1 a	2 a	3 a	4 a	5 a	6 a	7 a	8 a	9 a	10 a	11 a
1	T														
2	C														
3	T	Sag	150	15000				OK	OK	OK	OK		OK		NO
4	ST														
5	C														
6	ST														
7	T														
8	ST														
9	C														
10	ST	Crest	141.6	8000			OK							NO	NO
11	T	Crest	141.6	8000											
12	ST														
13	C														
14	ST														
15	T														
16	C														
17	T														
18	C	Sag	217.2	12000				OK	OK	OK	OK		OK	NO	NO
19	T														
20	ST														
21	C	Crest	78	6000			OK								NO
22	ST	Sag	206	20000				NO		NO	NO		OK		NO
23	T	Sag	206	20000											
24	C														
25	T	Crest	194.4	8000			NO							NO	NO
26	ST	Crest	194.4	8000											
27	C	Sag	188	8000				OK	OK	OK	OK		OK	NO	
28	ST	Sag	188	8000				OK	OK	OK	OK				
29	T					OK									
30	C					OK									
31	T					OK									
32	C					OK									
33	T	Sag	80.8	8000				OK	OK	OK	OK		OK		
34	ST					OK									
35	C	Sag	247.2	8000				NO		OK	NO		OK		
36	ST	Sag	247.2	8000						OK					
37	T	Sag	247.2	8000						OK					
38	ST	Sag	247.2	8000						OK					
39	C					OK									
40	ST					OK									
41	T					OK									

42	ST					OK									
43	C					OK									
44	ST	Sag	41.6	8000				OK	NO	NO	OK		NO		
45	T														
46	C														
47	T														
48	ST														
49	C														
50	ST	Crest	30.4	8000			OK						NO		
51	C														
52	ST														
53	C														
54	ST														
55	T	Crest	369	10000			NO								
56	ST	Crest													
57	C	Crest													
58	ST														
59	T														
60	ST														
61	C														
62	ST	Crest	284.8	8000			NO								
63	T	Crest													
64	ST														
65	C	Crest	148.8	8000			NO							NO	
66	ST	Crest													
67	T														
68	C														
69	T														
70	ST														
71	C														
72	ST														
73	T	Sag	13.6	4000				NO	OK	OK	OK		NO	NO	
74	C					OK									
75	T					OK									
76	ST					OK									
77	C					OK									
78	ST					OK									
79	T	Sag	200.4	6000				OK	OK	OK	OK		OK		
80	ST														
81	C														
82	ST														
83	C	Crest	36	8000			NO								
84	ST														
85	T														
86	ST														
87	C	Crest	103.2	8000			NO							NO	

88	ST														
89	C	Sag	55.2	8000				OK	OK	OK	OK		NO	NO	
90	ST					OK									
91	T					OK									
92	C	Sag	66.4	8000				OK	NO	OK	OK		NO		
93	T	Sag						OK		OK	OK				
94	ST														
95	C														
96	CC														
97	C	Crest	6	4000			NO								
98	ST														
99	C														
100	ST														
101	C														
102	ST	Sag	23.2	4000				NO	OK	OK	OK	OK	NO		
103	C					OK									
104	ST					OK									
105	T	Sag	53.6	8000				OK	OK	OK	OK		NO		NO
106	ST														
107	C														
108	ST														
109	T														
110	ST														
111	C	Crest	32.4	3000			NO							NO	NO
112	ST														
113	T														
114	ST														
115	C	Sag	48	20000				OK	OK	OK	OK		NO	NO	
116	CC					OK									
117	C					OK									
118	ST					OK									
119	T					OK									
120	ST					OK									
121	C	Sag	8	10000				OK	OK	OK	OK		NO		
122	ST					OK									
123	T					OK									
124	ST					OK									
125	C	Sag	90	6000				OK	OK	OK	OK		OK		NO
126	ST														
127	T														
128	ST														
129	C	Crest	261.6	8000			OK								NO
130	ST	Sag	244.8	3615.953				OK	OK	OK	OK				NO
131	T	Sag													
132	ST	Crest	816	10355.33			NO							NO	NO
133	C	Crest													

134	ST	Sag	204	5298.701				OK	OK	OK	OK		OK	NO	
135	T	Sag													
136	ST	Sag													
137	C					OK									
138	ST					OK									
139	T	Sag	71.4	10984.62				OK	OK	OK	OK		NO		
140	ST	Sag													
141	C					OK									
142	ST					OK									
143	T					OK									
144	C					OK									
145	T					OK									
146	ST	Sag	132.6	4652.632				NO	NO	OK	NO		OK		
147	C	Sag													
148	ST														
149	T														
150	ST														
151	C														
152	ST														
153	C														
154	ST														
155	C														
156	ST														
157	C														
158	ST														
159	T														
160	ST														
161	C														
162	ST														
163	T														
164	ST	Crest	102	6144.578			NO								
165	C	Crest													
166	ST														
167	T														
168	ST	Sag	153	4146.341				OK	OK	OK	OK				NO
169	C														
170	ST														
171	T														
172	ST														
173	C														
174	ST	Crest	346.8	10260.36			OK								NO
175	T						OK								
176	ST	Sag	135.8	3782.73				NO	OK	OK	OK				
177	C	Sag													
178	ST	Crest	164.9	4752.161			NO							NO	
179	T	Sag	155.2	5173.333				NO	OK	OK	OK		OK	NO	NO

180	ST	Sag													
181	C	Crest	126.1	4653.137			OK							NO	NO
182	ST	Sag	97	5418.994				NO	NO	OK	OK	NO	OK	NO	NO
183	C														
184	ST														
185	C														
186	ST	Crest	620.8	27348.02			NO								NO
187	C	Crest													
188	ST	Crest													
189	T	Crest													
190	ST														
191	C	Crest	543.2	8963.696			NO							NO	
192	ST	Crest													
193	T														
194	ST														
195	C	Sag	281.3	3677.124				OK	OK	OK	OK		OK	NO	NO
196	ST	Crest	194	4961.637			OK							NO	NO
197	T	Crest					OK								
198	ST	Crest					OK								
199	C	Sag	164.9	2960.503				OK	NO	NO	OK			NO	
200	ST	Sag													
201	T	Sag													
202	ST	Crest	358.9	17254.81			OK								
203	C	Crest					OK								
204	ST														
205	T														
206	ST														
207	C														
208	ST														
209	T														
210	ST														
211	C														
212	ST														
213	T	Crest	116.4	11757.58											
214	ST	Sag	116.4	13857.14				NO	OK	OK	OK		NO		
215	C	Sag													
216	ST	Crest	139.5	15000			NO								
217	T	Crest													
218	ST														
219	C														
220	ST	Crest	452.8	8000			OK								
221	T	Crest					OK								
222	ST	Crest	600	20000			NO							NO	
223	C	Crest													
224	ST	Crest													
225	T	Crest													

226	ST	Crest													
227	C														
228	ST	Sag	315	15000				NO	NO	NO	OK		OK	NO	
229	T	Sag													
230	ST	Sag													
231	C					OK									
232	ST					OK									
233	T	Sag	374	20000				OK	OK	OK	OK		OK		NO
234	ST														
235	C	Crest	397	10000			NO								NO
236	ST	Crest													
237	T	Crest													
238	ST	Crest													
239	C	Crest													
240	ST	Crest													
241	T														
242	ST														
243	C	Sag	425	5000				NO	NO	NO	OK		OK		NO
244	CC	Sag													
245	C	Sag													
246	ST														
247	T														
248	ST	Crest	210	10000			NO							NO	NO
249	C	Crest													
250	ST	Crest													
251	T														
252	ST	Sag	70	5000				NO	OK	OK	OK		OK	NO	NO
253	C	Sag													
254	ST	Crest	936	12000			OK							NO	NO
255	T	Crest					OK								
256	ST	Crest					OK								
257	C	Crest					OK								
258	ST	Crest					OK								
259	T	Crest					OK								
260	ST														
261	C														
262	ST														
263	C														
264	ST														
265	C														
266	ST	Sag	500	10000				NO	OK	OK	NO	NO	OK	NO	NO
267	C	Sag													
268	ST	Sag													
269	T	Sag													
270	ST	Sag													
271	C	Sag													

272	ST														
273	T	Crest	600	10000			OK							NO	NO
274	ST	Crest					OK								
275	C	Crest					OK								
276	ST	Crest					OK								
277	C	Crest					OK								
278	ST	Crest					OK								
279	T	Crest					OK								
280	ST														
281	C														
282	ST														
283	T														
284	ST														
285	C														
286	ST														
287	C														
288	ST														
289	T	Sag	60	6000				OK	NO	OK	OK		OK	NO	
290	ST														
291	C														
292	ST	Crest	80	10000			NO								
293	C	Crest													
294	ST	Crest													
295	C														
296	ST														
297	C														
298	ST														
299	T														
300	ST	Sag	75	3000				NO	NO	OK	OK				
301	C	Sag				OK									
302	CC					OK									
303	C					OK									
304	ST					OK									
305	C					OK									
306	ST					OK									
307	C	Sag	297.6	3000				OK	NO	OK	OK		OK		NO
308	ST	Sag													
309	T	Sag													
310	ST														
311	C														
312	ST														
313	T														
314	T														
315	ST														
316	C														
317	ST														

318	T														
319	ST														
320	C	Crest	389.61	11131.71			NO							NO	NO
321	ST														
322	T														
323	ST														
324	C														
325	ST	Sag	157.95	5230.132				NO	NO	OK	OK	NO	OK	NO	NO
326	C														
327	ST														
328	T														
329	ST														
330	C														
331	ST														
332	T	Crest	484.38	12986.06			OK							NO	NO
333	ST	Crest					OK								
334	C	Crest					OK								
335	ST														
336	T	Sag	84.24	3569.492				OK	OK	OK	OK		OK	NO	NO
337	ST														
338	C	Crest	494.91	13980.51			OK								NO
339	ST	Crest					OK								
340	T	Crest					OK								
341	ST	Crest					OK								
342	C	Crest					OK								
343	ST	Crest					OK								
344	T	Crest	863.46	13904.35			NO							NO	
345	ST	Crest													
346	C	Crest													
347	ST	Crest													
348	T	Crest													
349	ST	Crest													
350	C	Crest													
351	ST	Sag	136.89	5519.758				NO	OK	OK	OK		OK	NO	NO
352	T	Sag													
353	ST	Sag													
354	C														
355	ST														
356	T														
357	ST	Crest	473.85	20424.57			NO								NO
358	C	Crest													
359	ST	Crest													
360	C														
361	ST														
362	C														
363	ST														

364	T														
365	ST														
366	C														
367	ST														
368	C														
369	ST														
370	C	Crest	42.12	38290.91			NO								
371	ST														
372	T														
373	ST														
374	C														
375	ST														
376	T														
377	ST														
378	C	Sag	294.84	10345.26				OK	NO	NO	OK		OK		NO
379	ST	Sag													
380	T	Sag													
381	ST														
382	C	Crest	294.84	11001.49			NO							NO	NO
383	ST	Crest													
384	T	Crest													
385	ST														
386	C														
387	ST														
388	T														
389	ST														
390	C														
391	ST														
392	T														
393	C														
394	T														
395	ST	Sag	494.91	5761.467				OK	NO	OK			OK	NO	
396	C	Sag													
397	ST	Sag													
398	T	Sag													

Table 16 shows the total combination of horizontal-vertical design criteria not satisfied for each road element type.

Table 16 – Overview of horizontal vertical alignment Design Control not satisfied

N.	Road Element Type	N. Horizontal Design Criteria not satisfied	Combination Horizontal Design Criteria not satisfied	N. Vertical Design Criteria not satisfied	Combination Vertical Design Criteria not satisfied	N. Horizontal/ Vertical Design Criteria not satisfied	Combination Horizontal/ Vertical Design Criteria not satisfied
1	T					0	
2	C					0	
3	T	0		1	11a	1	11a
4	ST					0	
5	C					0	
6	ST					0	
7	T					0	
8	ST					0	
9	C					0	
10	ST	0		2	1011a	2	1011a
11	T					0	
12	ST					0	
13	C					0	
14	ST					0	
15	T					0	
16	C					0	
17	T					0	
18	C	0		2	1011a	2	1011a
19	T					0	
20	ST					0	
21	C	0		1	11a	1	11a
22	ST	1	1p	5	456711a	6	1p456711a
23	T					0	
24	C					0	
25	T	0		3	31011a	3	31011a
26	ST					0	
27	C	0		1	10a	1	10a
28	ST					0	
29	T					0	
30	C					0	
31	T					0	
32	C					0	
33	T	0		0		0	
34	ST					0	
35	C	1	1p	3	457a	4	1p457a
36	ST					0	

37	T					0	
38	ST					0	
39	C					0	
40	ST					0	
41	T					0	
42	ST					0	
43	C					0	
44	ST	0		3	569a	3	569a
45	T					0	
46	C					0	
47	T					0	
48	ST					0	
49	C					0	
50	ST	0		1	9a	1	9a
51	C					0	
52	ST					0	
53	C					0	
54	ST					0	
55	T	1	1p	1	3a	2	1p3a
56	ST					0	
57	C					0	
58	ST					0	
59	T					0	
60	ST					0	
61	C					0	
62	ST	0		1	3a	1	3a
63	T					0	
64	ST					0	
65	C	0		2	310a	2	310a
66	ST					0	
67	T					0	
68	C					0	
69	T					0	
70	ST					0	
71	C					0	
72	ST					0	
73	T	1	1p	3	4910a	4	1p4910a
74	C					0	
75	T					0	
76	ST					0	
77	C					0	
78	ST					0	
79	T	0		0		0	
80	ST					0	
81	C					0	
82	ST					0	

83	C	0		2	39a	2	39a
84	ST					0	
85	T					0	
86	ST					0	
87	C	0		2	310a	2	310a
88	ST					0	
89	C	0		2	910a	2	910a
90	ST					0	
91	T					0	
92	C	1	1p	2	59a	3	1p59a
93	T					0	
94	ST					0	
95	C					0	
96	CC					0	
97	C	0		2	39a	2	39a
98	ST					0	
99	C					0	
100	ST					0	
101	C					0	
102	ST	1	8p	2	49a	3	8p49a
103	C					0	
104	ST					0	
105	T	0		2	911a	2	911a
106	ST					0	
107	C					0	
108	ST					0	
109	T					0	
110	ST					0	
111	C	0		3	31011a	3	31011a
112	ST					0	
113	T					0	
114	ST					0	
115	C	0		2	910a	2	910a
116	CC					0	
117	C					0	
118	ST					0	
119	T					0	
120	ST					0	
121	C	0		1	9a	1	9a
122	ST					0	
123	T					0	
124	ST					0	
125	C	0		1	11a	1	11a
126	ST					0	
127	T					0	
128	ST					0	

129	C	0		1	11a	1	11a
130	ST	0		1	11a	1	11a
131	T					0	
132	ST	0		3	31011a	3	31011a
133	C					0	
134	ST	1	1p	1	10a	2	1p10a
135	T					0	
136	ST					0	
137	C					0	
138	ST					0	
139	T	1	1p	1	9a	2	1p9a
140	ST					0	
141	C					0	
142	ST					0	
143	T					0	
144	C					0	
145	T					0	
146	ST	0		3	457a	3	457a
147	C					0	
148	ST					0	
149	T					0	
150	ST					0	
151	C					0	
152	ST					0	
153	C					0	
154	ST					0	
155	C					0	
156	ST					0	
157	C					0	
158	ST					0	
159	T					0	
160	ST					0	
161	C					0	
162	ST					0	
163	T					0	
164	ST	0		1	3a	1	3a
165	C					0	
166	ST					0	
167	T					0	
168	ST	0		1	11a	1	11a
169	C					0	
170	ST					0	
171	T					0	
172	ST					0	
173	C					0	
174	ST	2	16p	1	11a	3	16p11a

175	T					0	
176	ST	0		1	4a	1	4a
177	C					0	
178	ST	0		2	310a	2	310a
179	T	0		3	41011a	3	41011a
180	ST					0	
181	C	0		2	1011a	2	1011a
182	ST	0		5	4581011a	5	4581011a
183	C					0	
184	ST					0	
185	C					0	
186	ST	2	48p	2	311a	4	48p311a
187	C					0	
188	ST					0	
189	T					0	
190	ST					0	
191	C	0		2	310a	2	310a
192	ST					0	
193	T					0	
194	ST					0	
195	C	0		2	1011a	2	1011a
196	ST	1	1p	2	1011a	3	1p1011a
197	T					0	
198	ST					0	
199	C	0		3	5610a	3	5610a
200	ST					0	
201	T					0	
202	ST	1	6p	0		1	6p
203	C					0	
204	ST					0	
205	T					0	
206	ST					0	
207	C					0	
208	ST					0	
209	T					0	
210	ST					0	
211	C					0	
212	ST					0	
213	T	0		2	39a	2	39a
214	ST	0		2	49a	2	49a
215	C					0	
216	ST	1	1p	2	39a	3	1p39a
217	T					0	
218	ST					0	
219	C					0	
220	ST	0		0		0	

221	T					0	
222	ST	0		2	310a	2	310a
223	C					0	
224	ST					0	
225	T					0	
226	ST					0	
227	C					0	
228	ST	1	1p	4	45610a	5	1p45610a
229	T					0	
230	ST					0	
231	C					0	
232	ST					0	
233	T	0		1	11a	1	11a
234	ST					0	
235	C	1	1p	2	311a	3	1p311a
236	ST					0	
237	T					0	
238	ST					0	
239	C					0	
240	ST					0	
241	T					0	
242	ST					0	
243	C	1	7p	4	45611a	5	7p45611a
244	CC					0	
245	C					0	
246	ST					0	
247	T					0	
248	ST	0		3	31011a	3	31011a
249	C					0	
250	ST					0	
251	T					0	
252	ST	0		3	41011a	3	41011a
253	C					0	
254	ST	2	14p	2	1011a	4	14p1011a
255	T					0	
256	ST					0	
257	C					0	
258	ST					0	
259	T					0	
260	ST					0	
261	C					0	
262	ST					0	
263	C					0	
264	ST					0	
265	C					0	
266	ST	1	8p	5	4781011a	6	8p4781011a

267	C					0	
268	ST					0	
269	T					0	
270	ST					0	
271	C					0	
272	ST					0	
273	T	3	148p	2	1011a	5	148p1011a
274	ST					0	
275	C					0	
276	ST					0	
277	C					0	
278	ST					0	
279	T					0	
280	ST					0	
281	C					0	
282	ST					0	
283	T					0	
284	ST					0	
285	C					0	
286	ST					0	
287	C					0	
288	ST					0	
289	T	0		2	510a	2	510a
290	ST					0	
291	C					0	
292	ST	1	8p	2	39a	3	8p39a
293	C					0	
294	ST					0	
295	C					0	
296	ST					0	
297	C					0	
298	ST					0	
299	T					0	
300	ST	1	6p	2	45a	3	6p45a
301	C					0	
302	CC					0	
303	C					0	
304	ST					0	
305	C					0	
306	ST					0	
307	C	0		2	511a	2	511a
308	ST					0	
309	T					0	
310	ST					0	
311	C					0	
312	ST					0	

313	T					0	
314	T					0	
315	ST					0	
316	C					0	
317	ST					0	
318	T					0	
319	ST					0	
320	C	0		3	31011a	3	31011a
321	ST					0	
322	T					0	
323	ST					0	
324	C					0	
325	ST	1	8p	5	4581011a	6	8p4581011a
326	C					0	
327	ST					0	
328	T					0	
329	ST					0	
330	C					0	
331	ST					0	
332	T	1	4p	2	1011a	3	4p1011a
333	ST					0	
334	C					0	
335	ST					0	
336	T	1	4p	2	1011a	3	4p1011a
337	ST					0	
338	C	2	16p	1	11a	3	16p11a
339	ST					0	
340	T					0	
341	ST					0	
342	C					0	
343	ST					0	
344	T	2	14p	2	310a	4	14p310a
345	ST					0	
346	C					0	
347	ST					0	
348	T					0	
349	ST					0	
350	C					0	
351	ST	1	1p	3	41011a	4	1p41011a
352	T					0	
353	ST					0	
354	C					0	
355	ST					0	
356	T					0	
357	ST	0		2	311a	2	311a
358	C					0	

359	ST					0	
360	C					0	
361	ST					0	
362	C					0	
363	ST					0	
364	T					0	
365	ST					0	
366	C					0	
367	ST					0	
368	C					0	
369	ST					0	
370	C	0		2	39a	2	39a
371	ST					0	
372	T					0	
373	ST					0	
374	C					0	
375	ST					0	
376	T					0	
377	ST					0	
378	C	0		3	5611a	3	5611a
379	ST					0	
380	T					0	
381	ST					0	
382	C	1	1p	3	31011a	4	1p31011a
383	ST					0	
384	T					0	
385	ST					0	
386	C					0	
387	ST					0	
388	T					0	
389	ST					0	
390	C					0	
391	ST					0	
392	T					0	
393	C					0	
394	T					0	
395	ST	1	1p	2	510a	3	1p510a
396	C					0	
397	ST					0	
398	T					0	

Table 17 shows the combination type of horizontal-vertical design criteria not satisfied with the indication of the size and the percentage

Table 17 – Overview of horizontal vertical alignment design criteria not satisfied on the total length road

	N. Combination Horizontal/ Vertical Design Criteria not satisfied												
	1	**%**	**2**	**%**	**3**	**%**	**4**	**%**	**5**	**%**	**6**	**%**	**Tot N. Combination Horizontal/ Vertical Design Criteria not satisfied**
1011a		0.0%	17	8.1%		0.0%		0.0%		0.0%		0.0%	17
10a	4	1.9%		0.0%		0.0%		0.0%		0.0%		0.0%	4
11a	11	5.2%		0.0%		0.0%		0.0%		0.0%		0.0%	11
11p	2	1.0%		0.0%		0.0%		0.0%		0.0%		0.0%	2
1p	23	10.9%		0.0%		0.0%		0.0%		0.0%		0.0%	23
1p1011a		0.0%		0.0%	3	1.4%		0.0%		0.0%		0.0%	3
1p10a		0.0%	1	0.5%		0.0%		0.0%		0.0%		0.0%	1
1p31011a		0.0%		0.0%		0.0%	1	0.5%		0.0%		0.0%	1
1p3a		0.0%	1	0.5%		0.0%		0.0%		0.0%		0.0%	1
1p41011a		0.0%		0.0%		0.0%	1	0.5%		0.0%		0.0%	1
1p45610a		0.0%		0.0%		0.0%		0.0%	1	0.5%		0.0%	1
1p456711a		0.0%		0.0%		0.0%		0.0%		0.0%	1	0.5%	1
1p457a		0.0%		0.0%		0.0%	1	0.5%		0.0%		0.0%	1
1p4910a		0.0%		0.0%		0.0%	1	0.5%		0.0%		0.0%	1
1p510a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
1p59a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
1p9a		0.0%	1	0.5%		0.0%		0.0%		0.0%		0.0%	1
31011a		0.0%		0.0%	11	5.2%		0.0%		0.0%		0.0%	11
310a		0.0%	16	7.6%		0.0%		0.0%		0.0%		0.0%	16
311a		0.0%	10	4.7%		0.0%		0.0%		0.0%		0.0%	10
39a		0.0%	7	3.3%		0.0%		0.0%		0.0%		0.0%	7
3a	6	2.8%		0.0%		0.0%		0.0%		0.0%		0.0%	6
41011a		0.0%		0.0%	6	2.8%		0.0%		0.0%		0.0%	6
457a		0.0%		0.0%	5	2.4%		0.0%		0.0%		0.0%	5
4581011a		0.0%		0.0%		0.0%		0.0%	1	0.5%		0.0%	1
49a		0.0%	2	1.0%		0.0%		0.0%		0.0%		0.0%	2
4a	2	1.0%		0.0%		0.0%		0.0%		0.0%		0.0%	2
4p	1	0.5%		0.0%		0.0%		0.0%		0.0%		0.0%	1
4p1011a		0.0%		0.0%	4	1.9%		0.0%		0.0%		0.0%	4
510a		0.0%	4	1.9%		0.0%		0.0%		0.0%		0.0%	4
511a		0.0%	3	1.4%		0.0%		0.0%		0.0%		0.0%	3
5610a		0.0%		0.0%	3	1.4%		0.0%		0.0%		0.0%	3

5611a		0.0%		0.0%	3	1.4%		0.0%		0.0%		0.0%	3
569a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
6p	6	2.8%		0.0%		0.0%		0.0%		0.0%		0.0%	6
6p45a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
7p	3	1.4%		0.0%		0.0%		0.0%		0.0%		0.0%	3
7p45611a		0.0%		0.0%		0.0%		0.0%	1	0.5%		0.0%	1
813p		0.0%	1	0.5%		0.0%		0.0%		0.0%		0.0%	1
8p	9	4.3%		0.0%		0.0%		0.0%		0.0%		0.0%	9
8p39a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
8p4581011a		0.0%		0.0%		0.0%		0.0%		0.0%	1	0.5%	1
8p4781011a		0.0%		0.0%		0.0%		0.0%		0.0%	1	0.5%	1
8p49a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
910a		0.0%	2	1.0%		0.0%		0.0%		0.0%		0.0%	2
911a		0.0%	1	0.5%		0.0%		0.0%		0.0%		0.0%	1
9a	3	1.4%		0.0%		0.0%		0.0%		0.0%		0.0%	3
456711a		0.0%		0.0%		0.0%		0.0%	1	0.5%		0.0%	1
59a		0.0%	1	0.5%		0.0%		0.0%		0.0%		0.0%	1
1p11a		0.0%	2	1.0%		0.0%		0.0%		0.0%		0.0%	2
8p311a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
4p311a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
45610a		0.0%		0.0%		0.0%	2	1.0%		0.0%		0.0%	2
45611a		0.0%		0.0%		0.0%	2	1.0%		0.0%		0.0%	2
4781011a		0.0%		0.0%		0.0%		0.0%	5	2.4%		0.0%	5
8p1011a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
45a		0.0%	1	0.5%		0.0%		0.0%		0.0%		0.0%	1
6p11a		0.0%	3	1.4%		0.0%		0.0%		0.0%		0.0%	3
4p310a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
1p310a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
1p39a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
1p311a		0.0%		0.0%	1	0.5%		0.0%		0.0%		0.0%	1
Tot	**70**		**73**		**48**		**8**		**9**		**3**		**211**

Figure 34 shows the overall percentage of combination of design criteria control not satisfied. In 33% of cases it was observed only one inconsistency on the geometric element, two inconsistencies in the 35% of cases and 23% of cases with three inconsistencies. Elements with combinations of four, five and six design criteria not satisfied recur rarely along the road.

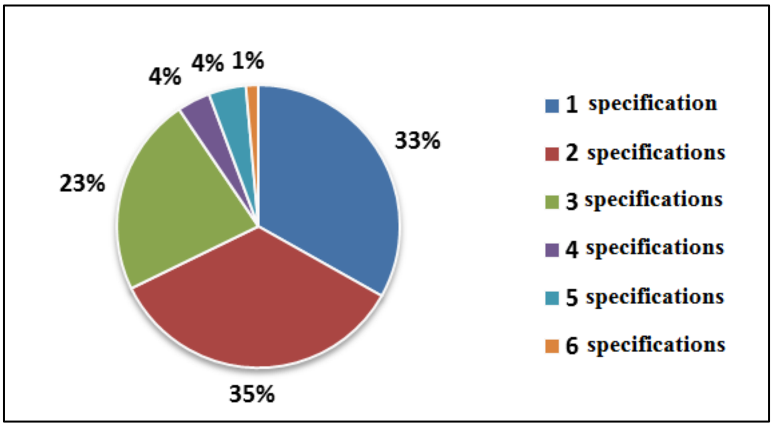


Figure 34 – Percentage of combination of design criteria not satisfied for each road element

Table 18 shows the overview of horizontal-vertical design criteria not satisfied with the associated number of crashes observed for each road element type. In particular, 211out of a total of 398 elements show problems of geometric inconsistency or horizontal and vertical alignment misalignment.

Table 18 – Overview of horizontal vertical alignment design criteria with crashes for each road element

N. Road Element	Combination Horizontal/ Vertical Design Criteria not satisfied	N. Combination of Design Criteria not satisfied	N. crashes
1	0	0	1
2	0	0	1
3	11a	1	5
4	0	0	1
5	0	0	0
6	0	0	0
7	0	0	1
8	0	0	1
9	0	0	0
10	1011a	2	0
11	1011a	2	2
12	0	0	1
13	0	0	5
14	0	0	1
15	0	0	0

16	0	0	1
17	0	0	1
18	1011a	2	0
19	0	0	5
20	0	0	3
21	11a	1	3
22	456711a	5	0
23	1p456711a	6	0
24	0	0	3
25	31011a	3	3
26	31011a	3	0
27	10a	1	1
28	10a	1	1
29	0	0	4
30	0	0	1
31	1p	1	0
32	0	0	0
33	0	0	2
34	0	0	0
35	457a	3	8
36	457a	3	1
37	1p457a	4	1
38	457a	3	2
39	0	0	3
40	0	0	0
41	1p	1	1
42	0	0	1
43	0	0	1
44	569a	3	3
45	0	0	1
46	0	0	0
47	1p	1	0
48	0	0	0
49	0	0	0
50	9a	1	3
51	0	0	1
52	0	0	0
53	0	0	1
54	0	0	0
55	1p3a	2	0
56	3a	1	0
57	3a	1	0
58	0	0	0
59	0	0	7
60	0	0	0
61	0	0	1

62	3a	1	0
63	3a	1	1
64	0	0	1
65	310a	2	0
66	310a	2	1
67	0	0	0
68	0	0	3
69	0	0	0
70	0	0	0
71	0	0	1
72	0	0	2
73	1p4910a	4	0
74	0	0	0
75	1p	1	0
76	0	0	0
77	0	0	2
78	0	0	1
79	0	0	8
80	0	0	0
81	0	0	0
82	8p	1	0
83	39a	2	0
84	0	0	0
85	0	0	0
86	0	0	0
87	310a	2	1
88	8p	1	0
89	910a	2	0
90	0	0	0
91	0	0	1
92	59a	2	3
93	1p59a	3	0
94	6p	1	0
95	0	0	0
96	7p	1	0
97	39a	2	0
98	8p	1	1
99	0	0	0
100	8p	1	1
101	0	0	0
102	8p49a	3	1
103	0	0	2
104	0	0	0
105	911a	2	3
106	0	0	0
107	0	0	0

108	0	0	0
109	1p	1	0
110	0	0	3
111	31011a	3	0
112	0	0	0
113	0	0	0
114	0	0	3
115	910a	2	2
116	7p	1	0
117	0	0	1
118	0	0	0
119	0	0	0
120	0	0	0
121	9a	1	1
122	0	0	1
123	0	0	3
124	0	0	0
125	11a	1	1
126	0	0	1
127	1p	1	0
128	0	0	0
129	11a	1	1
130	11a	1	0
131	11a	1	3
132	31011a	3	1
133	31011a	3	1
134	10a	1	1
135	1p10a	2	0
136	10a	1	1
137	0	0	0
138	0	0	1
139	1p9a	2	1
140	9a	1	2
141	0	0	1
142	0	0	7
143	1p	1	1
144	0	0	5
145	1p	1	0
146	457a	3	1
147	457a	3	1
148	0	0	0
149	1p	1	0
150	0	0	0
151	0	0	0
152	0	0	0
153	0	0	0

154	8p	1	4
155	0	0	1
156	0	0	6
157	0	0	1
158	0	0	5
159	1p	1	0
160	0	0	4
161	0	0	2
162	0	0	0
163	0	0	0
164	3a	1	0
165	3a	1	2
166	0	0	4
167	0	0	8
168	11a	1	1
169	0	0	1
170	0	0	10
171	0	0	3
172	6p	1	2
173	0	0	16
174	6p11a	2	7
175	1p11a	2	6
176	4a	1	8
177	4a	1	3
178	310a	2	1
179	41011a	3	0
180	41011a	3	0
181	1011a	2	0
182	4581011a	5	2
183	0	0	1
184	8p	1	0
185	0	0	0
186	8p311a	3	0
187	311a	2	0
188	311a	2	0
189	4p311a	3	1
190	0	0	0
191	310a	2	2
192	310a	0	0
193	1p	1	0
194	0	0	1
195	1011a	2	0
196	1011a	2	10
197	1p1011a	3	0
198	1011a	2	3
199	5610a	3	1

200	5610a	3	0
201	5610a	3	0
202	6p	1	0
203	0	0	0
204	6p	1	0
205	1p	1	0
206	0	0	0
207	0	0	0
208	0	0	0
209	1p	1	0
210	0	0	0
211	0	0	0
212	0	0	0
213	39a	2	4
214	49a	2	0
215	49a	2	1
216	39a	2	0
217	1p39a	3	0
218	0	0	1
219	0	0	2
220	0	0	4
221	0	0	8
222	310a	2	0
223	310a	2	0
224	310a	2	1
225	310a	2	0
226	310a	2	0
227	0	0	0
228	45610a	4	0
229	1p45610a	5	0
230	45610a	4	0
231	0	0	0
232	0	0	0
233	11a	1	1
234	0	0	1
235	311a	2	0
236	311a	2	0
237	1p311a	3	0
238	311a	2	0
239	311a	2	0
240	311a	2	0
241	1p	1	0
242	6p	1	0
243	45611a	4	0
244	7p45611a	5	0
245	45611a	4	1

246	0	0	0
247	0	0	0
248	31011a	3	0
249	31011a	3	0
250	31011a	3	0
251	1p	1	0
252	41011a	3	0
253	41011a	3	0
254	1011a	2	0
255	1p1011a	3	0
256	1011a	2	0
257	1011a	2	0
258	1011a	2	0
259	4p1011a	3	0
260	0	0	1
261	0	0	0
262	11p	1	0
263	0	0	0
264	0	0	0
265	0	0	0
266	8p4781011a	6	0
267	4781011a	5	0
268	4781011a	5	0
269	4781011a	5	0
270	4781011a	5	0
271	4781011a	5	0
272	0	0	0
273	1p1011a	3	0
274	1011a	2	0
275	1011a	2	0
276	8p1011a	3	0
277	1011a	2	0
278	1011a	2	0
279	4p1011a	3	1
280	0	0	0
281	0	0	1
282	0	0	0
283	0	0	0
284	0	0	0
285	0	0	0
286	8p	1	0
287	0	0	0
288	0	0	0
289	510a	2	0
290	0	0	0
291	0	0	0

292	8p39a	3	0
293	39a	2	0
294	39a	2	0
295	0	0	0
296	8p	1	0
297	0	0	0
298	0	0	0
299	1p	1	0
300	6p45a	3	0
301	45a	2	1
302	7p	1	0
303	0	0	0
304	0	0	0
305	0	0	0
306	8p	1	0
307	511a	2	0
308	511a	2	0
309	511a	2	0
310	0	0	0
311	0	0	1
312	0	0	0
313	0	0	0
314	0	0	0
315	0	0	0
316	0	0	0
317	0	0	0
318	1p	1	0
319	0	0	0
320	31011a	3	5
321	0	0	3
322	1p	1	0
323	0	0	0
324	0	0	0
325	8p4581011a	6	0
326	0	0	0
327	0	0	1
328	4p	1	1
329	0	0	0
330	0	0	0
331	0	0	3
332	4p1011a	3	0
333	1011a	2	0
334	1011a	2	0
335	0	0	0
336	4p1011a	3	0
337	0	0	1

338	11a	1	0
339	11a	1	0
340	1p11a	2	0
341	6p11a	2	0
342	11a	1	0
343	6p11a	2	0
344	4p310a	3	0
345	310a	2	0
346	310a	2	0
347	310a	2	0
348	1p310a	3	0
349	310a	2	0
350	310a	2	0
351	41011a	3	3
352	1p41011a	4	0
353	41011a	3	1
354	0	0	0
355	0	0	0
356	0	0	1
357	311a	2	0
358	311a	2	0
359	311a	2	0
360	0	0	0
361	11p	1	0
362	0	0	0
363	0	0	0
364	1p	1	0
365	0	0	0
366	0	0	0
367	0	0	1
368	0	0	1
369	813p	2	0
370	39a	2	0
371	6p	1	0
372	0	0	0
373	0	0	0
374	0	0	1
375	0	0	6
376	1p	1	0
377	0	0	0
378	5611a	3	0
379	5611a	3	0
380	5611a	3	0
381	0	0	4
382	31011a	3	0
383	31011a	3	1

384	1p31011a	4	1
385	0	0	0
386	0	0	1
387	0	0	0
388	1p	1	0
389	0	0	0
390		0	0
391		0	0
392		1	0
393		0	4
394		1	1
395		2	0
396		2	0
397		2	0
398		3	0
		Total	**344**

Table 18 shows the overview of horizontal-vertical design criteria not satisfied with the associated number of crashes observed for each road element type. In particular, 211out of a total of 398 elements show problems of geometric inconsistency or horizontal and vertical alignment misalignment.

With the use of pivot tables, were valued all the possible combinations of design criteria control not satisfied, the size and the corresponding number of crashes observed. (See Table 19).

Table 19 – Overview of horizontal vertical alignment design criteria not satisfied with crashes

Horizontal/ Vertical Design Criteria not satisfied	1	2	3	4	5	6	7	8	10	N. crashes
1011a		1	1						1	3
10a	4									4
11a	4		2		1					7
1p	3									3
1p31011a	1									1
1p457a	1									1
1p9a	1									1
31011a	3		1		1					5
310a	4	1								5
39a				1						1
3a	1	1								2
41011a	1		1							2
457a	3	1						1		5
4581011a		1								1
49a	1									1
4a			1					1		2

4p	1									1
4p1011a	1									1
5610a	1									1
569a			1							1
6p		1								1
8p	2			1						3
8p49a	1									1
910a		1								1
911a			1							1
9a	1	1	1							3
59a			1							1
1p11a						1				1
4p311a	1									1
45611a	1									1
45a	1									1
6p11a							1			1
Total	**37**	**16**	**30**	**8**	**10**	**6**	**7**	**16**	**10**	**140**

The combination 1011a was observed 17 times along the road, but only in three cases were observed crashes. Also, in presence of a single combination, the number of observed crashes varies by a minimum of one crash to a maximum of ten crashes..

Table 20 shows a summary of the results of the two previously tables, with the indication for each combination of design criteria not satisfied, the total size along the road, the frequency out of the total of the combinations and the number of times with observed crashes.

Table 20 – Overview of horizontal vertical alignment design criteria not satisfied with crashes

Combination Horizontal/ Vertical Design Criteria not satisfied	N. combination not satisfied	%. Combination of design criteria not satisfied on the total of the design criteria	N. case with combination not satisfied with crashes
1011a	17	8.06%	3
10a	4	1.90%	4
11a	11	5.21%	7
11p	2	0.95%	0
1p	23	10.90%	3
1p1011a	3	1.42%	0
1p10a	1	0.47%	0
1p11a	2	0.95%	1
1p31011a	1	0.47%	1
1p310a	1	0.47%	0
1p311a	1	0.47%	0

Combination Horizontal/ Vertical Design Criteria not satisfied	N. combination not satisfied	%. Combination of design criteria not satisfied on the total of the design criteria	N. case with combination not satisfied with crashes
1p39a	1	0.47%	0
1p3a	1	0.47%	0
1p41011a	1	0.47%	0
1p45610a	1	0.47%	0
1p456711a	1	0.47%	0
1p457a	1	0.47%	1
1p4910a	1	0.47%	0
1p510a	1	0.47%	0
1p59a	1	0.47%	0
1p9a	1	0.47%	1
31011a	11	5.21%	5
310a	16	7.58%	5
311a	10	4.74%	0
39a	7	3.32%	1
3a	6	2.84%	2
41011a	6	2.84%	2
45610a	2	0.95%	0
45611a	2	0.95%	1
456711a	1	0.47%	0
457a	5	2.37%	5
4581011a	1	0.47%	1
45a	1	0.47%	1
4781011a	5	2.37%	0
49a	2	0.95%	1
4a	2	0.95%	2
4p	1	0.47%	1
4p1011a	4	1.90%	1
4p310a	1	0.47%	0
4p311a	1	0.47%	1
510a	4	1.90%	0
511a	3	1.42%	0
5610a	3	1.42%	1
5611a	3	1.42%	0
569a	1	0.47%	1
59a	1	0.47%	1
6p	6	2.84%	1
6p11a	3	1.42%	1

Combination Horizontal/ Vertical Design Criteria not satisfied	N. combination not satisfied	%. Combination of design criteria not satisfied on the total of the design criteria	N. case with combination not satisfied with crashes
6p45a	1	0.47%	0
7p	3	1.42%	0
7p45611a	1	0.47%	0
813p	1	0.47%	0
8p	9	4.27%	3
8p1011a	1	0.47%	0
8p311a	1	0.47%	0
8p39a	1	0.47%	0
8p4581011a	1	0.47%	0
8p4781011a	1	0.47%	0
8p49a	1	0.47%	1
910a	2	0.95%	1
911a	1	0.47%	1
9a	3	1.42%	3
	211	100%	64

In conclusion, as shows in Table 21, 211 design criteria not satisfied were observed on the road, but only in 64 cases were observed crashes. On a total of 344 crashes observed from 2003-2008, only 140 are associated to design inconsistency. This was confirmed through a deep evaluation of the dynamics described in the crash report which confirmed that the majority is due to factors related to the geometry of the road, but also to user behavior, weather conditions etc., which guarantees the goodness of the analysis performed.

Table 21 – Overview of horizontal vertical alignment design criteria not satisfied with crashes

Combination Horizontal/ Vertical Design Criteria not satisfied	N. Crashes	N. Case with Combination Horizontal/Vertical Design Criteria not satisfied	N. Crashes with Design Criteria not satisfied
211	344	64	140

4. Road Design Consistency Model

4.1 Introduction

As documented in the literature review section, the traditional principles of road design even if they are based on theoretical and analytical observations of general effectiveness, are not able to represent the driver behaviour.
In the scientific community, the procedure mostly used to verify the consistency a road course, refers to the three Lamm criteria shown in Table 22.

Table 22 – Lamm Criteria

Criteria	Good	Accettable	Poor
I	$\lvert V_{85} - V_{85+1} \rvert \leq 10$	$\lvert V_{85} - V_{85+1} \rvert \leq 20$	$\lvert V_{85} - V_{85+1} \rvert > 20$
II	$\lvert V_{85} - V_{P} \rvert \leq 10$	$\lvert V_{85} - V_{P} \rvert \leq 20$	$\lvert V_{85} - V_{P} \rvert > 20$
III	$\lvert f_{td} - f_{tr} \rvert \geq 0$	$-0.02 \leq \lvert f_{td} - f_{tr} \rvert < 0$	$\lvert f_{td} - f_{tr} \rvert < -0.02$

These criteria don't give an overall road consistency evaluation of the entire road but refer only to two following elements.
The aim is the formulation of a parameter showing the global consistency that reflects the entire operating speed profile.
Nine homogenous road element, considering the distance between two following interchange, were identified (See Table 23).

Table 23 – Road homogenous element of S.P.430

	Road Element
1°	Capaccio - Prignano Km (98-110,915)
2°	Prignano - Cicerale Km (110,915-116,170)
3°	Cicerale - Omignano Km (116,170-121,825)
4°	Omignano - Vallo Scalo Km (121,825-126,623)
5°	Vallo Scalo - Vallo Luc. Km (126,623-135,936)
6°	Vallo Luc. - Futani Km (135,936-147,177)
7°	Futani - Poderia Km (147,177-158,283)
8°	Poderia - Roccagloriosa Km (158,283-163,688)
9°	Roccagloriosa - Policastro Km (163,688-170,968)

4.2 Road consistency model

The two parameters for the assessment of the road consistency are addressed to define a procedure for the calibration of a road consistency model.
The first step is the plot of operating speed profile for each road element. The final operating speed profile does not show, therefore, constant lines by varying the curvature.
To simplify the procedure and to obtain, by a sensitivity analysis, a simple and effective model for evaluate road consistency, it has been estimated the predicted average operating speeds for each road element type.
The first parameter defined as a measure of road consistency is shown symbolically in the following Equation with Ra that represents the sum of the area bounded between the profile of the operating speeds and the average operating speed (V_{85_P}) on the total length of the homogenous road element (L).
Indicating a_i, the area bounded between the profile of the operating speeds (V_{85i}) and the average operating speed (V_{85_P}), positive or negative depending if placed above or below the average operating speed, as in Figure 35, the first measure of road consistency is given by the following equation:

$$R_a = \sum \frac{a_i}{L} \qquad (14)$$

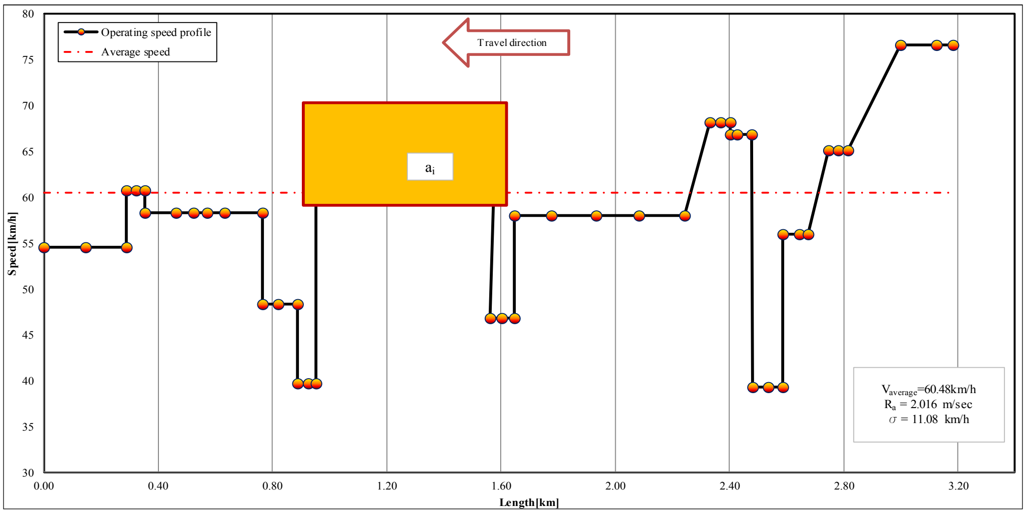


Figure 35 – Operating Speed Profile for the generic homogenous road element

The second parameter of road consistency is the standard deviation of the operating speeds along the total road length, as shown in Equation 20.

$$\sigma = \sqrt{\sum_{i=1}^{n} (\overline{V}_{85i} - \overline{V}_{85\_P}) \Big/ n} \qquad (20)$$

Where:

V_{85i} is the predicted operating speed on the i - th road element type (tangent or circular curve) in km / h

n = number of geometric elements along the homogenous road element.

Figure 36-44 show the operating speed profile for the nine homogenous road element, starting point to calculate the two consistency parameters.

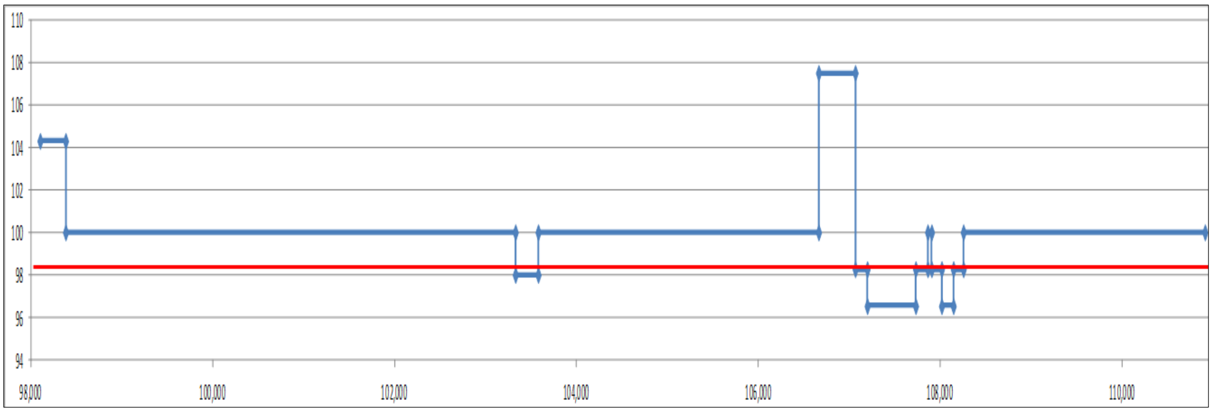


Figure 36 – Operating Speed Profile for the homogenous road element n.1

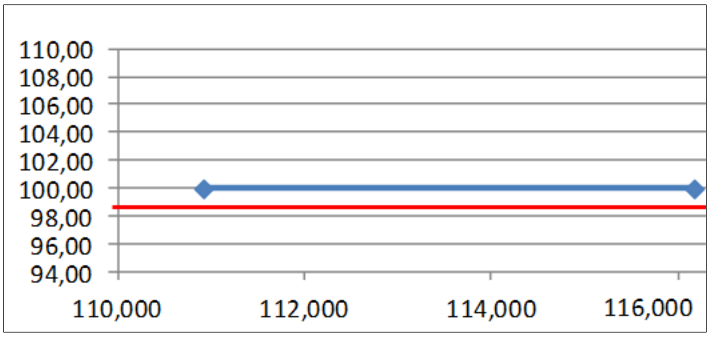


Figure 37 – Operating Speed Profile for the homogenous road element n.2

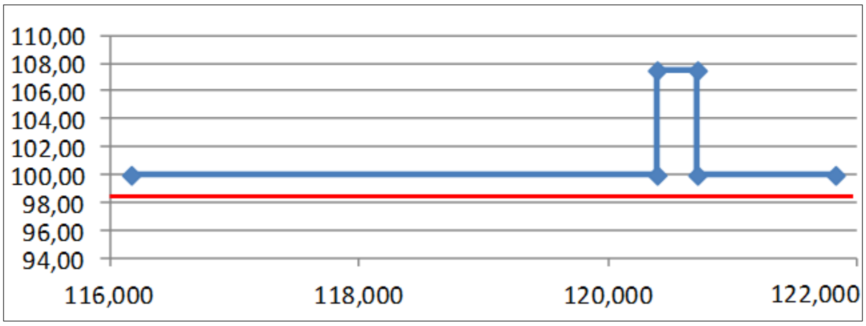


Figure 38 – Operating Speed Profile for the homogenous road element n.3

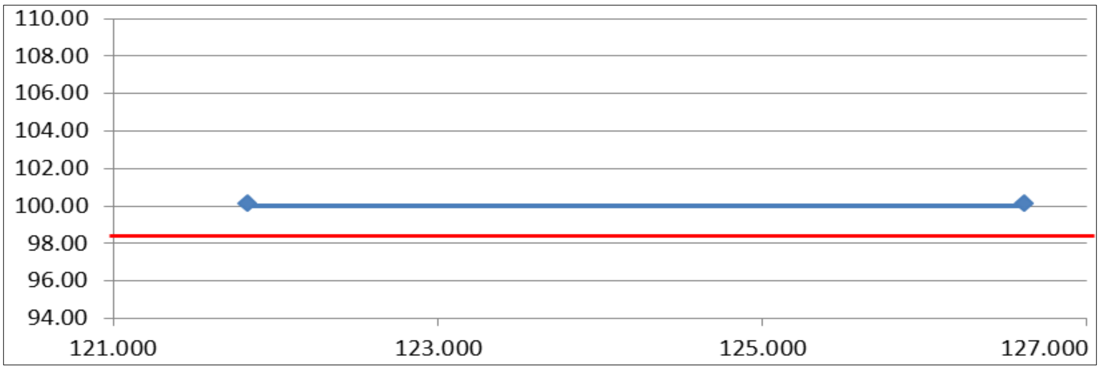


Figure 39 – Operating Speed Profile for the homogenous road element n.4

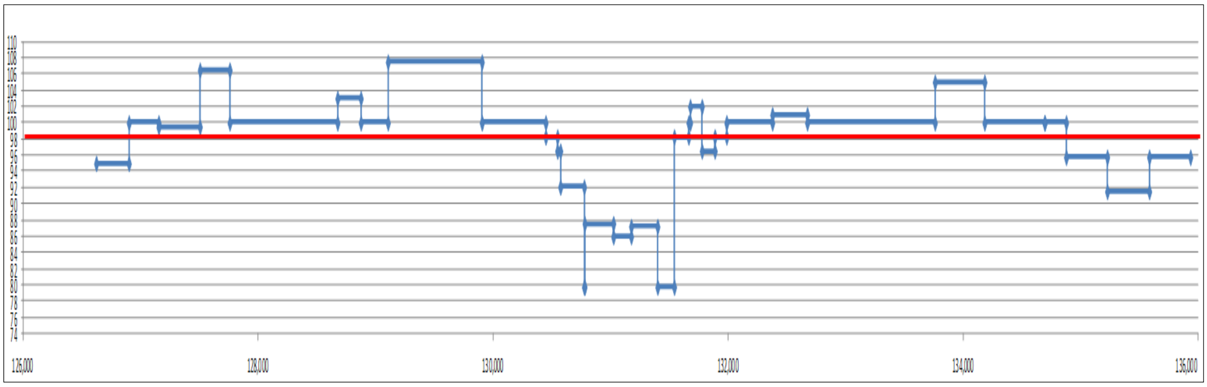


Figure 40 – Operating Speed Profile for the homogenous road element n.5

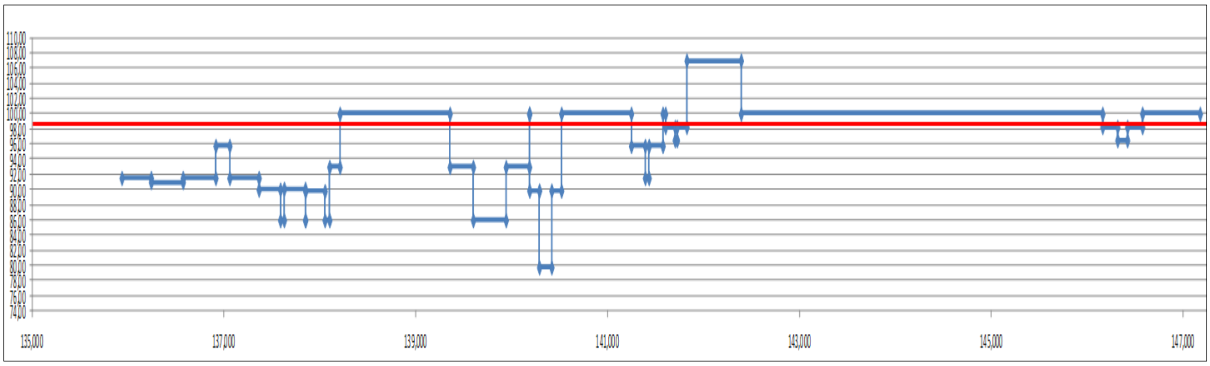


Figure 41 – Operating Speed Profile for the homogenous road element n.6

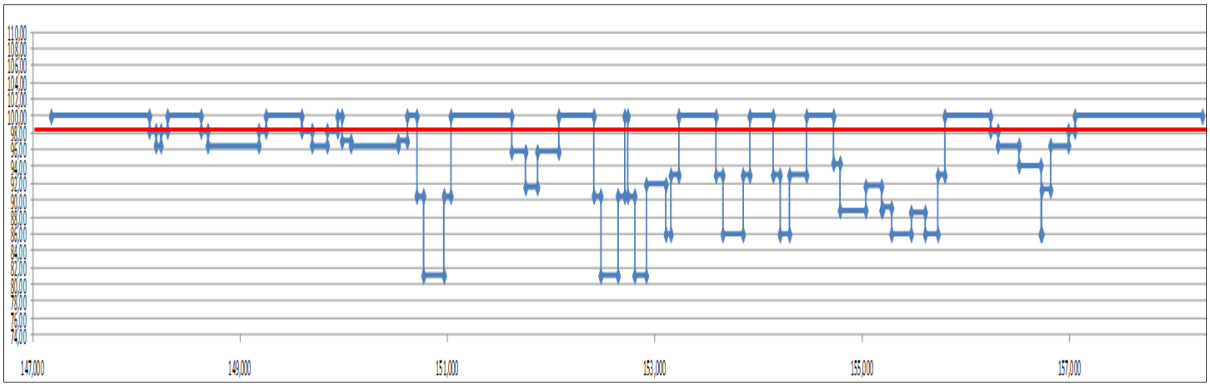


Figure 42 – Operating Speed Profile for the homogenous road element n.7

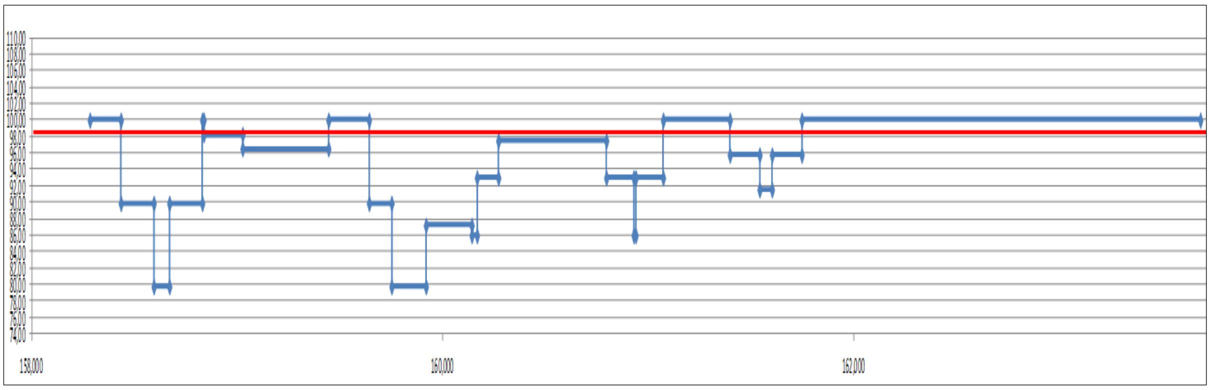


Figure 43 – Operating Speed Profile for the homogenous road element n.8

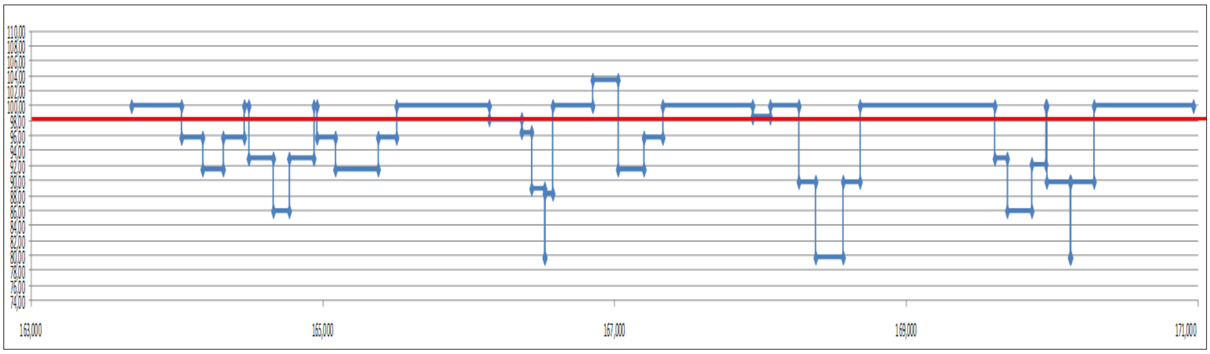


Figure 44 – Operating Speed Profile for the homogenous road element n.9

The peculiarity of these two parameters is to appreciate, a quality of the road consistency, without stopping to specific speed differences between following elements.

The parameters Ra and σ were determined on the nine homogeneous road elements identified previously as shown in Table 24.

Table 24 – Overview of Road Element Consistency

	Road Element	Ra[m/s]	σ[km/h]	**I° Lamm Criteria**	
1	Capaccio - Prignano Km (98-110.915)	0.57	2.30	Good $\|V_{85}-V_p\| \leq 10$	7.5
2	Prignano - Cicerale Km (110.915-116.170)	0.51	1.85	-	-
3	Cicerale - Omignano Km (116.170-121.825)	0.59	2.43	Good $\|V_{85}-V_p\| \leq 10$	7.5
4	Omignano - Vallo Scalo Km (121.825-126.623)	0.48	1.75	-	-
5	Vallo Scalo - Vallo Luc. Km (126.623-135.936)	1.16	5.82	Acceptable $\| V_{85}-V_p \| \leq 20$	11,5
6	Vallo Luc. - Futani Km (135.936-147.177)	1.10	5.66	Acceptable $\| V_{85}-V_p \| \leq 20$	11,0
7	Futani - Poderia Km (147.177-158.283)	1.09	5.99	-	-
8	Poderia - Roccagloriosa Km (158.283-163.688)	1.02	7.02	Acceptable $\| V_{85}-V_p \| \leq 20$	12,5
9	Roccagloriosa - Policastro Km (163.688-170.968)	1.12	6.28	Acceptable $\| V_{85}-V_p \| \leq 20$	11,7

For each homogenous road element as shown in Table 24, it was evaluate the road consistency, with the maximum difference between design speed and operating speed observed on the road element by using the I Lamm Criteria shown in Table 22.

Table 25 shows the results of the first criterion of Lamm applied to SP 430, where the maximum difference between operating speed and design speed was equal to 7.7 km/h, adequate for a good road consistency.

Table 25 – Overview I Lamm Criteria applied onSP430

N.	Road Element Type	Initial Post (Km)	Final Post (Km)	Length Element	V_P	V_{85}	ΔV I° Lamm Criteria	Quality
1	T	98.100	98.381	280.94	100.0	104.3	4.3	GOOD
20	ST	103.329	103.579	250.568	100.0	98.0	2.0	GOOD
33	T	106.664	107.067	402.912	100.0	107.5	7.5	GOOD
102	ST	120.392	120.716	323.334	100.0	107.5	7.5	GOOD
131	T	126.623	126.902	278.195	100.0	95.0	5.0	GOOD
133	C	127.155	127.506	351.44	100.0	99.5	0.5	GOOD
134	ST	127.506	127.759	253.125	100.0	106.5	6.5	GOOD
141	C	128.677	128.875	198.446	100.0	103.0	3.0	GOOD
144	C	129.106	129.906	800	100.0	107.5	7.5	GOOD
160	ST	131.679	131.779	100	98.3	102.0	3.7	GOOD
165	C	132.377	132.675	297.223	100.0	101.0	1.0	GOOD
169	C	133.761	134.184	422.502	100.0	105.0	5.0	GOOD
171	T	134.695	134.878	182.936	100.0	100.0	0.0	GOOD
177	C	136.241	136.574	332.564	91.5	91.0	0.5	GOOD
182	ST	137.364	137.588	223.818	92.5	90.0	2.5	GOOD
213	T	141.825	142.392	566.426	100.0	107.0	7.0	GOOD
321	ST	159.445	159.634	189.063	98.3	100.0	1.7	GOOD
328	T	160.272	160.797	525.322	100.0	97.5	2.5	GOOD
367	ST	166.850	167.024	173.816	95.8	103.5	7.7	GOOD
374	C	167.946	168.067	120.928	100.0	98.5	1.5	GOOD

Table 23 shows that in the presence of good consistency evaluated with I Lamm Criteria, Ra [m / s] <1 and σ [km / h] <5 km / h.

In according to this result, it was set for a good road consistency evaluation, a range of value limits (Ra; σ), with Ra [m / s] <1 σ [km / h] <5 km / h, as found in the scientific literature.

Road consistency was evaluated acceptable when 1 <Ra [m / s] <2 and 5 <σ [km / h] <10 and poor when Ra [m / s] >2 and σ [km / h] >10.

Table 26 illustrates the thresholds of value (Ra; σ) to define good, acceptable and poor road consistency.

Table 26 – Design Consistency Quality thresholds

GOOD	ACCETTABLE	POOR
Ra<1	**1<Ra<2**	**Ra>2**
σ < 5	**5< σ < 10**	**σ>10**
C>2	**1<C<2**	**C< 1**

Table 27 compares the two road consistency evaluation, the first defined according to the Lamm criteria, the second by using the innovative procedure that, through the evaluation of parameters such as R_a and σ, reflects the operating speed profile on the total homogenous road element by defines a measure of the overall consistency in according to the thresholds (R_a; σ).

Table 27 – Design Consistency Quality thresholds for the homogenous road element

	Road Element	Ra[m/s]	σ[km/h]		**I Lamm Criteria °**	
1°	Capaccio - Prignano Km (98-110,915)	0.57	2.3	C>2	Good $\lvert V_{85} - V_p\rvert \leq 10$	7,5
2°	Prignano - Cicerale Km (110,915-116,170)	0.51	1.85	C>2	-	-
3°	Cicerale - Omignano Km (116,170-121,825)	0.59	2.43	C>2	Good $\lvert V_{85} - V_p \rvert \leq 10$	7,5
4°	Omignano - Vallo Scalo Km (121,825-126,623)	0.48	1.75	C>2	-	-
5°	Vallo Scalo - Vallo Luc. Km (126,623-135,936)	1.16	5.82	1<C<2	Acceptable $\lvert V_{85} - V_p \rvert \leq 20$	11,5
6°	Vallo Luc. - Futani Km (135,936-147,177)	1.1	5.66	1<C<2	Acceptable $\lvert V_{85} - V_p \rvert \leq 20$	11,0
7°	Futani - Poderia Km (147,177-158,283)	1.09	5.99	1<C<2	-	-
8°	Poderia - Roccagloriosa Km (158,283-163,688)	1.02	7.02	1<C<2	Acceptable $\lvert V_{85} - V_p \rvert \leq 20$	12,5
9°	Roccagloriosa - Policastro Km (163,688-170,968)	1.12	6.28	1<C<2	Acceptable $\lvert V_{85} - V_p \rvert \leq 20$	11,7

The road consistency model assume the following functional form:

$$C = A \cdot e^{-B[R_a \cdot (\sigma/3,6)]} \qquad (21)$$

Where

C = Road Consistency for undivided rural roads
A and B = coefficients of the predictive model

The calibration of the model can only be implemented starting from the known values of Consistency for each homogenous road element analyzed, by defining the values of A and B through a sensitivity analysis.
In scientific community there are numerous research where specific thresholds of value assigned to the dependent variable C, are recommended for the evaluation of the road consistency; the limits assigned, in this study, were assigned in according to the most researcher works. In particular, Table 28 assign a good consistency for value of C greater than 2 , acceptable with $1<C<2$ and poor with $C<1$.

Table 28 – Design Consistency Quality thresholds

Good	**Accettable**	**Poor**
$C > 2$	$1 < C \leq 2$	$C \leq 1$

Assigning, preliminarily, at the parameters A and B the values suggested by the scientific literature, equal respectively to 10 and 1, it was determined for each homogenous road element shown in Table 26 the specific road consistency.
Through a sensitive analysis, the parameters A and B have been changed, in order to have a solution to the pair of values that would satisfy, in a univocal way, the 9 road consistency evaluations shown in Table 27. Table 29 shows the result of the sensitivity analysis.

Table 29 – Definition of Consistency parameter by sensitive analysis

	Road Element	Ra[m/s]	σ [km/h]	A	B	C
1	Capaccio - Prignano Km (98-110.915)	0.57	2.30	2.550	0.150	2.42
2	Prignano - Cicerale Km (110.915-116.170)	0.51	1.85			2.46
3	Cicerale - Omignano Km (116.170-121.825)	0.59	2.43			2.41
4	Omignano - Vallo Scalo Km (121.825-126.623)	0.48	1.75			2.47
5	Vallo Scalo - Vallo Luc. Km (126.623-135.936)	1.16	5.82			1.93
6	Vallo Luc. - Futani Km (135.936-147.177)	1.10	5.66			1.97
7	Futani - Poderia Km (147.177-158.283)	1.09	5.99			1.95
8	Poderia - Roccagloriosa Km (158.283-163.688)	1.02	7.02			1.90
9	Roccagloriosa - Policastro Km (163.688-170.968)	1.12	6.28			1.91

The final equation of the road consistency predictive model is the following:

$$C = 2.550e^{-0.150\cdot[R_a\cdot(\sigma/3,6)]} \quad (22)$$

4.3 Relation Road Consistency and crash phenomena

Next step has been the evaluation of relationship between the road consistency, design criteria not satisfied and crashes.

Each homogenous road element has been associated with the following information; parameter of congruence, design criteria not satisfied, size of the combinations not satisfied, the frequency of the combination, the number of times when in the presence of a combination were recorded crashes and the total number of accidents for combination (See Table 30-38).

Table 30 – Overview results for road homogenous element n.1

Road Homogenous Element	C	Crash Rate	N. Crashes	Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied with crashes	N. crashes
Capaccio - Prignano Km (98-110.915)	2.42	0.17	74	1011a	3	1	2
				10a	2	2	2
				11a	2	2	8
				1p	3	1	1
				1p456711a	1	0	0
				1p457a	1	1	1
				31011a	2	1	3
				456711a	1	0	0
				457a	3	2	11
				569a	1	1	3
				9a	1	1	3

Table 31 – Overview results for road homogenous element n.2

Road Homogenous Element	C	Crash Rate	N. Crashes	Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied with crashes	N. crashes
Prignano - Cicerale Km (110.915-116.170)	2.46	0.14	28	1p3a	1	0	0
				1p	1	0	0
				1p4910a	1	0	0
				310a	2	1	1
				3a	4	1	1

Table 32– Overview results for road homogenous element n.3

Road Homogenous Element	C	Crash Rate	N. Crashes	Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied with crashes	N. crashes
Cicerale - Omignano Km (116.170-121.825)	2.41	0.06	13	1p59a	1	0	0
				310a	1	1	1
				39a	2	0	0
				59a	1	1	3
				6p	1	0	0
				7p	1	0	0
				8p	4	2	2
				8p49a	1	1	1
				910a	1	0	0
				911a	1	1	3

Table 33 – Overview results for road homogenous element n.4

Road Homogenous Element	C	Crash Rate	N. Crashes	Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied with crashes	N. crashes
Omignano - Vallo Scalo Km (121.825-126.623)	2.47	0.10	17	1p	2	0	0
				11a	3	2	2
				31011a	1	0	0
				7p	1	0	0
				910a	1	1	2
				9a	1	1	1

Table 34 – Overview results for road homogenous element n.5

Road Homogenous Element	C	Crash Rate	N. Crashes	Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied with crashes	N. crashes
Vallo Scalo - Vallo Luc. Km (126.623-135.936)	1.93	0.30	104	11a	2	2	4
				10a	2	2	2
				1p	4	1	1
				1p10a	1	0	0
				1p9a	1	1	1
				31011a	2	2	2
				3a	2	1	2
				457a	2	2	2
				6p	1	1	2
				6p11a	1	1	7
				8p	1	1	4
				9a	1	1	2

Table 35 – Overview results for road homogenous element n.6

Road Homogenous Element	C	Crash Rate	N. Crashes	Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied with crashes	N. crashes
Vallo Luc. - Futani Km (135.936-147.177)	1.97	0.13	60	1p11a	1	1	6
				1011a	4	2	13
				1p	3	0	0
				1p1011a	1	0	0
				1p39a	1	0	0
				1p45610a	1	0	0
				310a	8	3	4
				311a	2	0	0
				39a	2	1	4
				41011a	2	0	0
				45610a	2	0	0
				4581011a	1	1	2
				49a	2	1	1
				4a	2	2	11
				4p311a	1	1	1
				5610a	3	1	1
				6p	2	0	0
				8p	1	0	0
				8p311a	1	0	0

Table 36 – Overview results for road homogenous element n.7

Road Homogenous Element	C	Crash Rate	N. Crashes	Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied with crashes	N. crashes
Futani - Poderia Km (147.177-158.283)	1.95	0.01	8	11a	1	1	1
				1011a	8	0	0
				11p	1	0	0
				1p	3	0	0
				1p1011a	2	0	0
				1p311a	1	0	0
				31011a	3	0	0
				311a	5	0	0
				39a	2	0	0
				41011a	2	0	0
				45611a	2	1	1
				45a	1	1	1
				4781011a	5	0	0
				4p1011a	2	1	1
				510a	1	0	0
				511a	3	0	0
				6p	1	0	0
				6p45a	1	0	0
				7p	1	0	0
				7p45611a	1	0	0
				8p	3	0	0
				8p1011a	1	0	0
				8p39a	1	0	0
				8p4781011a	1	0	0

Table 37 – Overview results for road homogenous element n.8

Road Homogenous Element	C	Crash Rate	N. Crashes	Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied with crashes	N. crashes
Poderia - Roccagloriosa Km (158.283-163.688)	1.90	0.06	14	1011a	2	0	0
				11a	3	0	0
				1p	2	0	0
				1p11a	1	0	0
				31011a	1	1	5
				4p	1	1	1
				4p1011a	2	0	0
				6p11a	2	0	0
				8p4581011a	1	0	0

Table 38 – Overview results for road homogenous element n.9

Road Homogenous Element	C	Crash Rate	N. Crashes	Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied	N. Combination Horizontal/Vertical design criteria not satisfied with crashes	N. crashes
Roccagloriosa - Policastro Km (163.688-170.968)	1.91	0.06	26	4p310a	1	0	0
				11p	1	0	0
				1p	5	1	1
				1p31011a	1	1	1
				1p310a	1	0	0
				1p41011a	1	0	0
				1p510a	1	0	0
				31011a	2	1	1
				310a	5	0	0
				311a	3	0	0
				39a	1	0	0
				41011a	2	2	4
				510a	3	0	0
				5611a	3	0	0
				6p	1	0	0
				813p	1	0	0

Subsequently the data was processed further, creating a table that shows how each specific combination of tests is not met, it is distributed on the different sections of the track. For each trunk it is associated with a different value of consistency. The same work was then done for accidents.

Table 39 shows for each homogenous road element the associated consistency value, number of combination of design criteria not satisfied when an accident occurs, and the number of crashes observed.

Table 39 – Overview of the results for each homogenous road element

	Road Element	C	N. Combination Horizontal/Vertical design criteria not satisfied with crashes	N. crashes
1	Capaccio - Prignano Km (98-110.915)	2.32	15	6
2	Prignano - Cicerale Km (110.915-116.170)	2.50	9	2
3	Cicerale - Omignano Km (116.170-121.825)	2.31	9	4
4	Omignano - Vallo Scalo Km (121.825-126.623)	2.47	14	5
5	Vallo Scalo - Vallo Luc. Km (126.623-135.936)	1.43	52	36
6	Vallo Luc. - Futani Km (135.936-147.177)	1.41	40	46
7	Futani - Poderia Km (147.177-158.283)	1.68	20	9
8	Poderia - Roccagloriosa Km (158.283-163.688)	1.67	20	10
9	Roccagloriosa - Policastro Km (163.688-170.968)	1.35	32	31

Figure 45 and 46 confirm when road consistency increases, the number of crashes decreases.

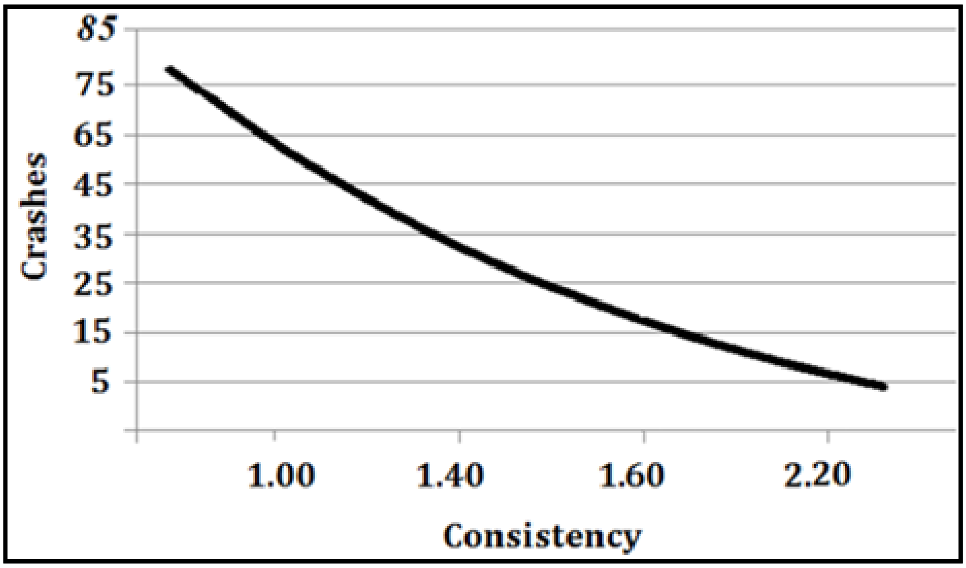


Figure 45 – Relation Consistency - Crashes

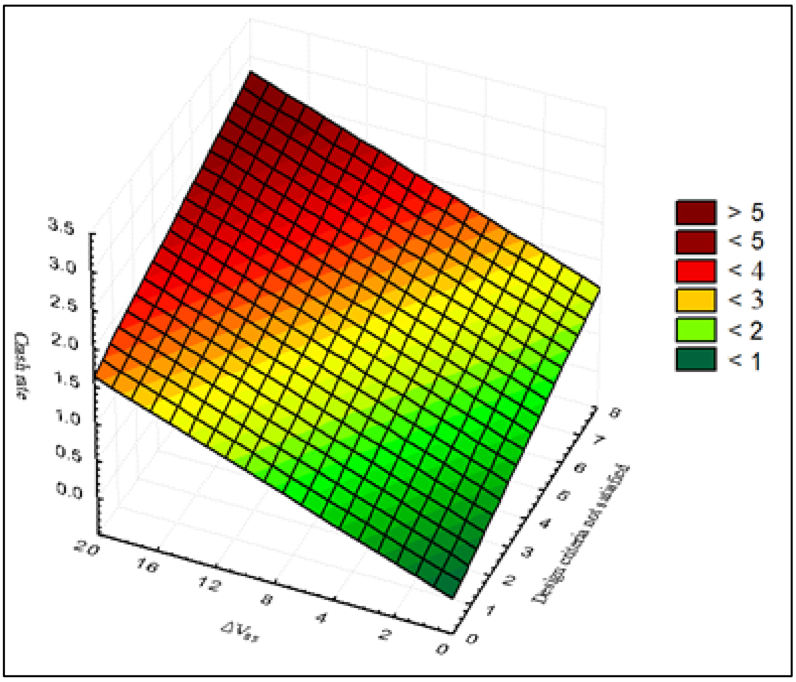


Figure 46 – Relation crashes – ΔV – horizontal/vertical combination not satisfied

4.4 Safety Effectiveness Evaluation Procedure

The Highway Safety Manual indicates an observational before/after evaluation can be conducted for a single project at a specific site to determine its effectiveness in reducing crash frequency or severity. The empirical Bayes (EB) before/after safety evaluation method is used to compare crash frequencies at a group of sites before and after a treatment is implemented. The EB method explicitly addresses the regression-to-the-mean issue by incorporating crash information from other but similar sites into the evaluation. This is done by using an SPF and weighting the observed crash frequency with the SPF-predicted average crash frequency to obtain an expected average crash frequency. Figure 47 provides a step-by-step overview of the EB before/after safety effectiveness evaluation method.

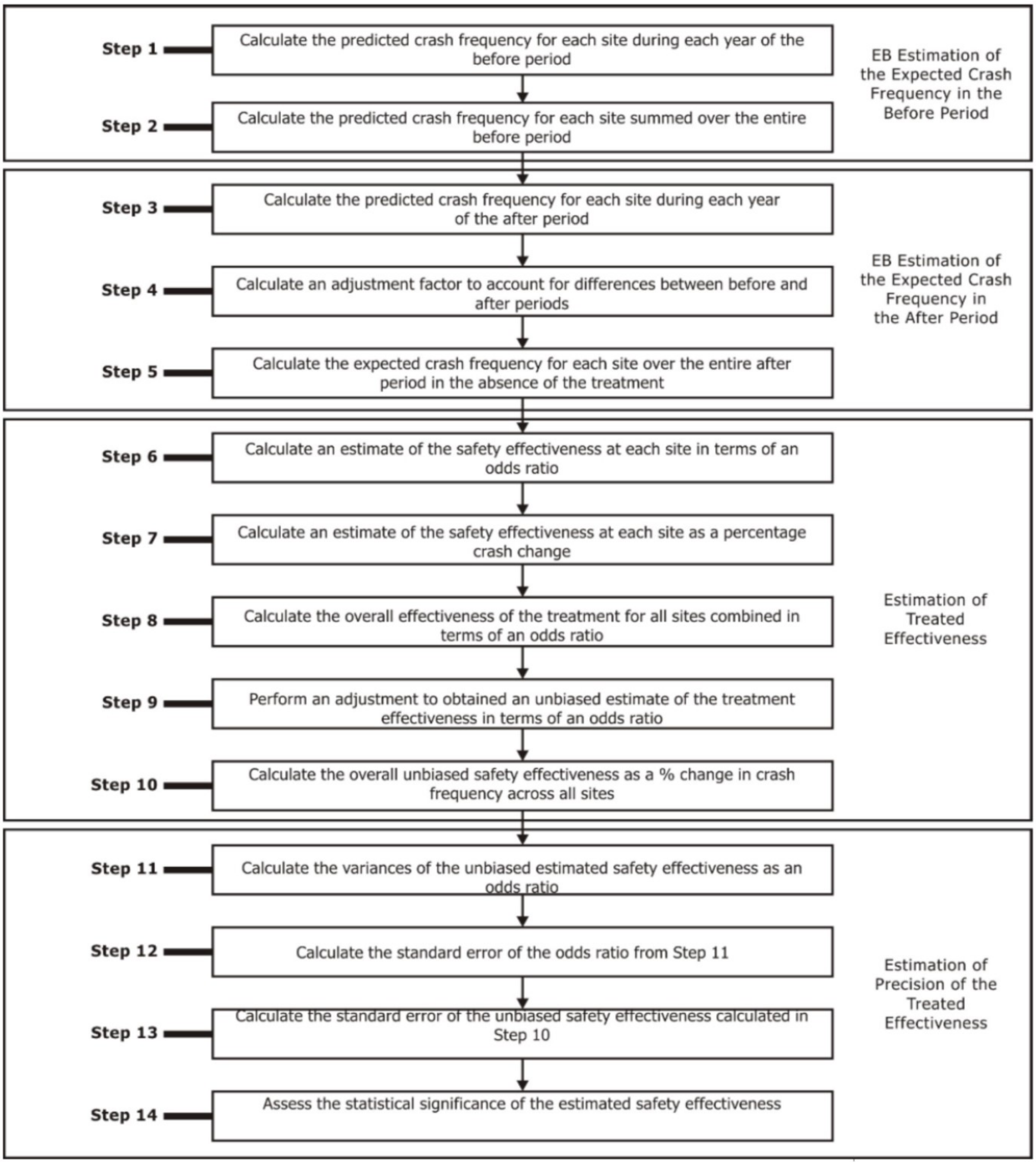


Figure 47 – Overview of EB Before/After Safety Evaluation

The data needed as input to an EB before/after evaluation include:

- At least 10 to 20 sites at which the treatment of interest has been implemented
- 3 to 5 years of crash and traffic volume data for the period before treatment implementation
- 3 to 5 years of crash and traffic volume for the period after treatment implementation
- SPF for treatment site types

An evaluation study can be performed with fewer sites and/or shorter time periods, but statistically significant results are less likely.

Step 1. The predicted crash frequency, $N_{predicted}$ for each site during each year of the before period, was calculated with equation 23:

$$N_{predicted,B=} N_{spfx} \times (AMF_{1x} \times AMF_{2x} \times \ldots \times AMF_{yx}) \times C_x \qquad (23)$$

Where:
$N_{predicted}$ = predicted average crash frequency for a specific year for site type x;
$N_{spf\,x}$ = predicted average crash frequency determined for base conditions of the SPF developed for site type x;
AMF_{yx} = Accident Modification Factors specific to site type x and specific geometric design and traffic control features y;
C_x = calibration factor to adjust SPF for local conditions for site type x.

AMFs are the ratio of the estimated average crash frequency of a site under two different conditions. Therefore, an AMF represents the relative change in estimated average crash frequency due to a change in one specific condition (when all other conditions and site characteristics remain constant).
Four AMF were included in the analysis: Lane width (AMF_1), Shoulder width and Type (AMF_2), Horizontal Curves (AMF_3), Grades (AMF_5), Driveway Density (AMF_6).

The Accident Modification Factor for the effect of lane width on total accidents was calculated using Equation 24:

$$\text{AMF}_1 = (AMF_{ra} - 1{,}0) * p_{ra} + 1{,}0 \qquad (24)$$

Where,
AMF_{ra} = Accident Modification Factor for the effect of lane width on related accidents (i.e., single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents), such as the AMF for lane width shown in Figure 48 (HSM Exhibit 10-14);
p_{ra} = proportion of total accidents constituted by related accidents. The proportion of related accidents, pra, (i.e. single-vehicle run-off-road, and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipes accidents) is estimated as 0.574 (i.e., 57.4%) based on the default distribution of crash in Minnesota.

Lane Width	AADT (veh/day)		
	< 400	400 to 2000	> 2000
9-ft or less	1.05	$1.05+2.81\times10^{-4}$(AADT-400)	1.50
10-ft	1.02	$1.02+1.75\times10^{-4}$(AADT-400)	1.30
11-ft	1.01	$1.01+2.5\times10^{-5}$(AADT-400)	1.05
12-ft or more	1.00	1.00	1.00

Figure 48 – AMF for Lane Width on Roadway Segments (AMF_{ra})

The AMF for shoulders has an AMF for shoulder width (AMF_{wra}) and an AMF for shoulder type (AMF_{tra}). The AMFs for both shoulder width and shoulder type are

$$AMF_{2r} = (AMF_{wra} * AMF_{tra} - 1{,}0) * p_{ra} + 1{,}0 \qquad (25)$$

Where,

AMF_{2r} = Accident Modification Factor for the effect of shoulder width and type on total accidents

AMF_{wra} = Accident Modification Factor for related accidents (i.e., single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents), based on shoulder width shown in Figure 49 (HSM Exhibit 10-16);

AMF_{tra} = Accident Modification Factor for related accidents based on shoulder type shown in Figure 50 (from Exhibit 10-18);

p_{ra} = proportion of total accidents constituted by related accidents.

Shoulder Width	AADT (vehicles per day)		
	< 400	400 to 2000	> 2000
0-ft	1.10	$1.10 + 2.5 \times 10^{-4}$ (AADT - 400)	1.50
2-ft	1.07	$1.07 + 1.43 \times 10^{-4}$ (AADT - 400)	1.30
4-ft	1.02	$1.02 + 8.125 \times 10^{-5}$ (AADT - 400)	1.15
6-ft	1.00	1.00	1.00
8-ft or more	0.98	$0.98 + 6.875 \times 10^{-5}$ (AADT - 400)	0.87

Figure 49 – AMF for Shoulder Width on Roadway Segments (AMF_{wra})

Shoulder Type	Shoulder width (ft)						
	0	1	2	3	4	6	8
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

Figure 50 – AMF for Shoulder Types and Shoulder Widths (AMF_{tra})

The AMF for horizontal curves was determined using the Equation 26.

$$\text{AMF}_{3r} = \left(\frac{(1{,}55*Lc) - (0{,}012*S) + \frac{80{,}2}{R}}{(1{,}55*Lc)} \right) \quad (26)$$

Where,
AMF_{3r} = Accident Modification Factor for the effect of horizontal alignment on total accidents;
Lc = length of horizontal curve (miles) which includes spiral transitions, if present;
R = radius of curvature (feet);
S = 1 if spiral transition curve is present; 0 if spiral transition curve is not present; 0.5 if a spiral transition curve is present at one but not both ends of the horizontal curve.

The AMF for Grade was evaluated in according to Figure 51 (HSM Exhibit 10-19).

Approximate Grade (%)		
Level Grade (≤ 3%)	Moderate Terrain (3%< grade ≤ 6%)	Steep Terrain (> 6%)
1.00	1.10	1.16

Figure 51 – AMF for Grade (AMF_{5r})

The AMF for driveway density was determined using Equation 27.

$$\text{AMF}_{6r} = \left(\frac{0{,}322 + DD*[0{,}05 - 0{,}005*\ln(AADT)]}{0{,}322 + 5*[0{,}05 - 0{,}005*\ln(AADT)} \right) \quad (27)$$

Where,
AMF_{6r} = Accident Modification Factor for the effect of driveway density on total accidents;
AADT = average annual daily traffic volume of the roadway being evaluated (vehicles per day);
DD = driveway density considering driveways on both sides of the highway (driveways/mile).

If driveway density is less than 5 driveways per mile, AMF_{6r} is 1.00.

Step 2. The estimate of expected average crash frequency, $N_{expected,B}$, for each site summed during each year over the before period, was calculated with equation 28:

$$N_{expected,B} = W_{i,B} N_{predicted,B} + (1 - W_{i,B}) N_{observed,B} \quad (28)$$

Where the weight, $w_{i,B}$, for each site i, is determined as:

$$W_{i,B} = \frac{1}{1 + k \sum_{Before} N_{predicted}} \quad (29)$$

And:

$N_{expected}$ = Expected average crash frequency at site i for the entire before period

$N_{spf\,x}$ = Predicted average crash frequency determined with the applicable SPF (from Step 1)

$N_{observed,B}$ = Observed crash frequency at site i for the entire before period

k = Overdispersion parameter for the applicable SPF

Step 3. Using the applicable SPF, calculate the predicted average crash frequency, $PR_{i,y,A}$,for each site i during each year y of the after period.

Step 4. Calculate an adjustment factor, ri, to account for the differences between the before and after periods in duration and traffic volume at each site i as:

$$r_i = \frac{\sum_{After} N_{predicted,A}}{\sum_{Before} N_{predicted,B}} \quad (30)$$

Step 5. Calculate the expected average crash frequency, $E_{i,A}$, for each site i, over the entire after period in the absence of the treatment as:

$$N_{expected,A} = N_{expected,B} \times r_i \quad (31)$$

Step 6. Calculate an estimate of the safety effectiveness of the treatment at each site i in the form of an odds ratio, OR_i, as:

$$OR_i = \frac{N_{observed,A}}{N_{expected,A}} \quad (32)$$

Where,

OR_i = Odd ration at site i

$N_{observed,A}$ = Observed crash frequency at site i for the entire after period

Step 7. Calculate the safety effectiveness as a percentage crash change at site i, AMFi, as:

$$AMF_i = 100 \times (1 - OR_i) \quad (33)$$

Step 8. Calculate the overall effectiveness of the treatment for all sites combined, in the form of an odds ratio, OR', as follows:

$$OR' = \frac{\sum_{All\,sites} N_{observed,A}}{\sum_{All\,sites} N_{expected,A}} \quad (34)$$

Step 9. The odds ratio, OR', calculated in Equation 34 is potentially biased; therefore, an adjustment is needed to obtain an unbiased estimate of the treatment effectiveness in terms of an adjusted odds ratio, OR. This is calculated as follows:

$$OR = \frac{OR'}{1 + \frac{Var(\sum_{All\ sites} N_{expected,A})}{(\sum_{All\ sites} N_{expected})^2}} \quad (35)$$

Where,

$$Var\left(\sum_{All\ sites} N_{expected,A}\right) = \sum_{All\ sites}\left[(r_i)^2 \times N_{expected,B} \times (1 - W_{i,B})\right] \quad (36)$$

and $w_{i,B}$ is defined in Equation 29 and ri is defined in Equation 30.

Step 10. Calculate the overall unbiased safety effectiveness as a percentage change in crash frequency across all sites, AMF, as:

$$AMF = 100 \times (1 - OR) \quad (37)$$

To assess whether the estimated safety effectiveness of the treatment, AMF, is statistically significant, one needs to determine its precision. This is done by first calculating the precision of the odds ratio, OR, in Equation 35. The following steps show how to calculate the variance of this ratio to derive a precision estimate and present criteria assessing the statistical significance of the treatment effectiveness estimate.

Step 11. Calculate the variance of the unbiased estimated safety effectiveness, expressed as an odds ratio, OR, as follows:

$$Var(OR) = \frac{(OR')^2 \left[\frac{1}{N_{observed,A}} + \frac{Var(\sum_{All\ sites} N_{expected,A})}{(\sum_{All\ sites} N_{expected,A})^2}\right]}{1 + \frac{Var(\sum_{All\ sites} N_{expected,A})}{(\sum_{All\ sites} N_{expected,A})^2}} \quad (38)$$

Step 12. To obtain a measure of the precision of the odds ratio, OR, calculate its standard error as the square root of its variance:

$$SE(OR) = \sqrt{Var\ (OR)} \quad (39)$$

Step 13. Using the relationship between OR and AMF shown in Equation 29, the standard error of AMF, SE(AMF), is calculated as:

$$SE(AMF) = 100 \times SE(OR) \quad (40)$$

Step 14. Assess the statistical significance of the estimated safety effectiveness by making comparisons with the measure Abs[AMF/SE(AMF)] and drawing conclusions based on the following criteria:

- If Abs[AMF/SE(AMF)] < 1.7, conclude that the treatment effect is not significant at the (approximate) 90-percent confidence level.
- If Abs[AMF/SE(AMF)] ≥ 1.7, conclude that the treatment effect is significant at the (approximate) 90-percent confidence level.
- If Abs[AMF/SE(AMF)] ≥ 2.0, conclude that the treatment effect is significant at the (approximate) 95-percent confidence level.

The Empirical Bayesian evaluation method was applied to estimate the average crash rate frequency on the "sites" in the "before" configuration, current configuration referring to the CNR 80 regulation, and the "after" configuration, expected configuration with the adoption of the design criteria indicated in the DM 05/11/2001. The guidelines in Section indicate that at least 10 to 20 sites generally need to be evaluated to obtain statistically significant results. The HSM procedure has been applied on 15 sites, which of 5 sites on tangent elements, 4 on circular curve and 6 on transition curves for a total length equal to 12.48 km (See Table 40).
Table 41 shows the results of the EB procedure from step 1 to 7 to evaluate the safety effectiveness of the treatment at each site i. Table 42 shows the results of the estimation of precision of the treated effectiveness for all site combined.

Table 40 – Overview of the results for homogenous road element with acceptable consistency

n.	Road element type	T Length(m)	TC Length(m)	Radius C(m)	C Length (m)	i-1	i+1	i-1 Length(m)	i+1 Length(m)	i-1 Radius(m)	i+1 Radius(m)	N. crashes	N. Injuries	N. deaths	T Length(m)	TC Length(m)	Radius C(m)	C Length (m)	i-1	i+1	i-1 Length(m)	i+1 Length(m)	i-1 Radius(m)	i+1 Radius(m)
	"BEFORE"- DESIGN CRITERIA CNR 80														*"AFTER" DESIGN CRITERIA D.M. 05/11/2001*									
1	CF		347.51			C	C	341.68	128.45	300	250	13	10	2		186.46			C	C	598.36	340.48	360	400
2	C			400	532.53	TC	TC	132.25	132.25			8	9	1			400	547.1	TC	TC	98.01	302.66		
3	R	804.62				TC	TC	88.20	107.52			8	7	0	813.66				TC	TC	88.20	73.49		
4	CL		160.00			T	C	121.33	332.56		1000	8	6	0		115.60			T	C	167.81	376.96		1000
5	R	1626.33				TC	TC	213.33	101.25			8	12	0	1691.69				TC	TC	120.00	64.80		
6	R	945.35				TC	TC	88.20	98.00			7	9	0	949.46				TC	TC	80.00	98.00		
7	CL		150.00			C	T	198.44	80.83	600		7	2	0		66.66			C	T	281.77	246.18	600	
8	CF		224.21			C	C	151.49	141.83	300	250	6	3	0		256.00			T	C	191.33	93.86		400
9	R	145.52				TC	TC	350.00	160.00			6	1	0	167.81				TC	TC	350.00	115.60		
10	CF		311.61			C	C	120.92	188.92	500	250	6	7	0		190.37			C	C	130.82	400.69	400	400
11	C			550	145.27	TC	TC	163.63	163.63			5	3	0			550	145.27	TC	TC	163.63	163.63		
12	R	530.82				C	TC	241.15	250.56	1300		5	3	0	446.92				TC	TC	161.55	227.27		
13	C			3086.49	800	T	T	80.83	11.31			5	8	0			1500	222.12	TC	TC	166.66	166.66		
14	CF		236.23			C	C	141.83	109.62	250	400	9	6	0		268.52			C	C	93.86	70.76	400	400
15	C			400	418.23	TC	TC	356.13	307.09			5	8	0			400	486.29	TC	TC	243.24	239.36		

Table 41 – Overview of the results to evaluate the safety effectiveness of the treatment at each site i

	EB Estimation of the Expected Crash Frequency in the Before Period											EB Estimation of the Expected Crash Frequency in the After Period										Safety Effectiveness at each site	
N. site	N_{spf}	C_x	AMF_{1x}	AMF_{2x}	AMF_{3x}	AMF_{5x}	AMF_{6x}	$N_{predicted,B}$	K	$W_{i,B}$	$N_{expected,B}$	$PR_{i,y,A}$	C_x	AMF_{1x}	AMF_{2x}	AMF_{3x}	AMF_{5x}	AMF_{6x}	$N_{predicted,A}$	r_i	$N_{expected,A}$	OR_i	AMF_i
1	0.216	1.10	1.00	1.08	1.10	1.00	1.00	0.280	1.093	0.765	0.596	0.117	1.1	1.00	1.08	1.17	1.00	1.00	0.162	0.578	0.344	0.000	100.000
2	0.987	1.10	1.00	1.08	1.06	1.00	1.00	1.241	0.473	0.630	1.152	1.165	1.1	1.00	1.08	1.05	1.00	1.00	1.452	1.169	1.347	0.000	100.000
3	0.894	1.10	1.00	1.08	1.00	1.00	1.00	1.057	0.472	0.667	1.038	0.904	1.1	1.00	1.08	1.00	1.00	1.00	1.069	1.011	1.050	0.952	4.751
4	0.351	1.10	1.00	1.08	1.04	1.00	1.00	0.431	0.771	0.751	0.573	0.351	1.1	1.00	1.08	1.04	1.00	1.00	0.431	1.000	0.573	0.000	100.000
5	0.963	1.10	1.00	1.08	1.00	1.00	1.00	1.139	0.234	0.790	1.110	1.002	1.1	1.00	1.08	1.00	1.00	1.00	1.185	1.040	1.154	0.866	13.379
6	1.173	1.10	1.00	1.08	1.00	1.00	1.00	1.387	0.402	0.642	1.204	1.173	1.1	1.00	1.08	1.00	1.00	1.00	1.387	1.000	1.204	0.727	27.311
7	0.306	1.10	1.00	1.08	1.10	1.00	1.00	0.399	1.090	0.697	0.544	0.306	1.1	1.00	1.08	1.10	1.00	1.00	0.399	1.000	0.544	0.230	77.006
8	0.511	1.10	1.00	1.08	1.06	1.10	1.00	0.701	0.653	0.686	0.717	0.331	1.1	1.00	1.08	1.12	1.10	1.00	0.482	0.686	0.492	0.000	100.000
9	0.104	1.10	1.00	1.08	1.00	1.10	1.00	0.135	2.610	0.740	0.295	0.119	1.1	1.00	1.08	1.00	1.10	1.00	0.155	1.153	0.340	0.000	100.000
10	0.118	1.10	1.00	1.08	1.08	1.10	1.00	0.167	1.219	0.831	0.265	0.064	1.1	1.00	1.08	1.11	1.10	1.00	0.092	0.552	0.146	0.000	100.000
11	0.581	1.10	1.00	1.08	1.07	1.00	1.00	0.736	0.804	0.628	0.695	0.581	1.1	1.00	1.08	1.07	1.00	1.00	0.736	1.000	0.695	0.900	10.026
12	0.653	1.10	1.00	1.08	1.00	1.00	1.00	0.772	0.716	0.644	0.719	0.549	1.1	1.00	1.08	1.00	1.00	1.00	0.650	0.842	0.606	0.206	79.364
13	0.703	1.10	1.00	1.08	1.01	1.00	1.00	0.839	0.475	0.715	0.778	0.488	1.1	1.00	1.08	1.01	1.00	1.00	0.582	0.693	0.539	0.000	100.000
14	0.168	1.10	1.00	1.08	1.11	1.10	1.00	0.243	1.608	0.719	0.491	0.191	1.1	1.00	1.08	1.08	1.10	1.00	0.269	1.104	0.543	0.000	100.000
15	0.348	1.10	1.00	1.08	1.05	1.00	1.00	0.432	0.368	0.863	0.459	0.327	1.1	1.00	1.08	1.05	1.00	1.00	0.407	0.941	0.432	0.290	71.046

Table 42 – Overview of the results to evaluate the treated effectiveness for all site combined

OR'	OR	AMF	Var(OR)	SE(OR)	SE(AMF)	AMF/SE(AMF)
0.064	0.061	93.940	0.010	0.246	24.616	3.820

Table 42 shows the Abs[AMF/SE(AMF)] ≥ 2.0, concluding that the treatment effect is significant at the (approximate) 95-percent confidence level.

Lastly, in order to check the improvements in terms of consistency on the road element with acceptable consistency before the treatments, the road consistency model was re-applied. The values of operating speed have been calculated referring to operating speed prediction models carried out by Russo et al (2015). The HSM procedure has been re-applied to check the safety improvements in terms of reduction of expected crashes. The result are shown in Table 43.

Table 43 – Overview of the results to evaluate the treated effectiveness for all site combined

	Before				After			
Homogenous road element	**C**	**ΔV_{85} [km/h]**	**N. crashes**	**N. Design criteria not satisfied**	**C**	**ΔV_{85} [km/h]**	**N. predicted crashes**	**N. Design criteria not satisfied**
5	1.43	**14**	36	52	2.33	**5**	**2**	**0**
6	1.41	**15**	46	40	2.35	**5**	**2**	**0**
7	1.68	**11**	9	20	2.38	**2**	**1**	**0**
8	1.67	**11**	10	20	2.37	**2**	**1**	**0**
9	1.35	**17**	31	32	2.35	**7**	**1**	**0**

5. Conclusions and future development

The Directive 2008/96/EC of the European Parliament and of the Council on Road infrastructure Safety Management pointed up the need to carry out safety impact assessments and road safety audits, in order to identify and manage high accident concentration sections within the Community. This Directive required the establishment and implementation of procedures relating to road safety impact assessments, road safety audits, the management of road network safety and safety inspections by the Member States that are essential tool for preventing possible dangers for all road users and also in case of road works.
One way to accommodate for human information processing limitations is to design roadway environments in accordance with driver expectations: a road alignment that it's easy to be predicted by drivers, it's characterized by a good consistency.
The importance and seriousness of the accident phenomenon has also been implemented by the Italian regulation, in fact, the recent D.M. n.35 / 11 (Ministero delle Infrastrutture e dei Trasporti, 2012) developed the "Guidelines for the safety management of road infrastructures". Criteria and procedures are defined for the execution of road safety checks on projects, for safety inspections of existing infrastructure and for the implementation of the process for the classification of the safety of the road network.
Other regulation focuses on adaption treatments on existing roads (Ministero delle Infrastrutture e dei Trasporti, 2005), in particular providing useful tools to develop probabilistic analysis on the effects of adaptation treatments, which may vary by data available, the design level of detail and specific characteristics of each project.
In this scenario, the research work has focused on, first of all, a meticulous study of S.P. 430, a variant of the state highway S.S. 18, the "Tirrenia Inferiore", which is the major road, after freeway A3, and is also one of the most important and long in Southern Italy. The road project dates back to 1973, and was carried out prior to the development and introduction of the D.M. 5/11/2001, having been subject during the years to a series of interventions that have changed the geometric regularity. By using project cartographies and information collected onsite and the help of Civil Design software, the horizontal-vertical alignment was drawn with the definition of the exact succession of the road elements, including information on the progressive start and end of the road element, the length, the angle of deviation in grads, the radius of curvature etc. Based on the geometric layout output, S.P. 430 is composed by 398 geometric elements; of which 91 tangent elements, 121 circular curves and 186 spiral transition curves, which are divided into 154 tangent-curve-tangent spiral transitions, 28 curve-tangent-curve spiral transitions and 4 curve-curve spiral transitions, for a total road length equal to 72.65 km.
Speed data collection was carried out in environmental and traffic conditions using a laser. The conditions were the following: dry roads, free flow conditions, daylight hours and good weather conditions. Speed data collection includes 40 sections, which of 25 sections on tangent element and 15 sections on the middle circular curve.
Crash data analysis from 2003 to 2010. was carried out to identify the possible relationships existing between the geometric and functional characteristics of the road analyzed and the crash types and numbers of accidents. Totally, 344 accidents were observed on the S.P. 430

from 2003 to 2010, which of 167 PDO, and 177 that have registered at least one injured or dead. In according to the current regulation, design control for Horizontal and Horizontal-Vertical Alignment, were checked. These included sight distance, super elevation, traveled way widening, grades, horizontal and vertical alignments, and other elements of geometric design. The horizontal-vertical design criteria not satisfied were correlated with the associated number of crashes observed for each road element type. In particular, 211out of a total of 398 elements show problems of geometric inconsistency or horizontal and vertical alignment misalignment. On a total of 344 crashes observed from 2003-2008, only 140 are associated to design inconsistency. This was confirmed through a deep evaluation of the dynamics described in the crash report which confirmed that the majority is due to factors related to the geometry of the road, but also to user behavior, weather conditions etc., which guarantees the goodness of the analysis performed.
Road alignment consistency was evaluated and a prediction model was calibrated by a sensitive analysis to match the road with one only global measure of consistency for the entire development, and no with speed reductions between two following elements.
Nine homogeneous road elements identified. The starting point of the analysis was the operating speed profiles and the assessment of two parameters for each investigated road: a) the area bounded by the speed profile and the average weighted speed lines, and b) the standard deviation of speeds along a road horizontal alignment. Negative exponential function will be adopted to calibrate the model. Four homogeneous road elements were associated with good road consistency, and the remaining with acceptable road consistency.
Next step has been the evaluation of relationship between the road consistency, design criteria not satisfied and crashes. The results shown on the first four homogenous road element with good consistency, the number of combinations of design criteria not satisfied is equal to 18 for a total of 59 crashes, less than the 26 combinations of design criteria not satisfied for a total of 89 accidents observed on the remaining five homogenous road elements with acceptable consistency. Lastly, an observational before/after evaluation was to determine treatments effectiveness in reducing crash frequency or severity, by changing the current roadway layout in according to the current regulation D.M. 5/11/2001. The Empirical Bayesian evaluation method was applied to estimate the average crash rate frequency on the "sites" in the "before" configuration, current configuration referring to the CNR 80 regulation, and the "after" configuration, expected configuration with the adoption of the design criteria indicated in the DM 05/11/2001. The HSM procedure has been applied on 15 sites, which of 5 sites on tangent elements, 4 on circular curve and 6 on transition curves for a total length equal to 12.48 km. The results show that the treatment effect is significant at the (approximate) 95-percent confidence level. The work presented can be an useful tool for body government to identify hot spot of the road network and evaluate the effective treatments to improve road safety.
Possible future development are oriented to include several roadway in the analysis, considering also the urban context. Also, is suggested an evaluation of relationship between the road consistency and safety data by changing the crash type to identify the common factors effecting a specific crash types. In addition, is suggested the use of operating speed models, in conjunction with micro traffic simulations. The information can be used in the design of devices for the traffic management for the analyzed infrastructures.

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