Università degli Studi di Catania   European Union   Provincia Regionale di Catania

PROJECT TREN-03-ST-S07.31286

Identification of Hazard Location and Ranking of Measures to Improve Safety on Local Rural Roads:

Identificazione e Adeguamento delle Strade Pericolose

Final Research Report

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University of Catania

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Identification of Hazard Location and Ranking of Measures to Improve Safety on Local Rural Roads

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PROJECT TREN-03-ST-S07.31286

Identification of Hazard Location and Ranking of Measures to Improve Safety on Local Rural Roads

PROJECT START DATE: April 2004

DURATION: 36 months

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1 INTRODUCTION

PROJECT TREN-03-ST-S07.31286 entitled 'Identification of Hazard Location and Ranking of Measures to Improve Safety on Local Rural Roads IASP' is promoted by the Province of Catania, co-financed by the European Union and with the scientific partnership of the Department of Civil and Environmental Engineering (DICA) of the University of Catania. The project, which began in April 2004, assumes the form of a 'pilot project' to define methods and procedures for the analysis of the actual safety conditions of two lane local rural roads.

The Province of Catania contributes to Regional programming and co-ordination with various functions and services of social and cultural nature, regarding economic and tourist development, territorial organisation and planning, and environmental protection.

Safety of the existing road network has become an high priority for road management agencies, both in the light of what was established by the New Highway Code and in relation to the objective gravity of the phenomenon in terms of losses of human lives.

Road management agencies play a fundamental role within a Safety Management System (SMS), identifying the actual conditions of risk of the road infrastructure. Moreover, the Provinces, in their function as Public Authorities, can carry out an important role in co-ordinating and stimulating other areas of intervention (Education, Enforcement and Emergency).

As far as the road network is concerned, the Province of Catania owns a network of about 2,000 km of rural roads (provincial roads and other local roads). In this field the Province is, essentially, involved with:

- road network construction and maintenance;
- Traffic Police activities;
- road accident studies;
- administrative and logistical support activities.

The local road network of the Province consists in that part of the network which provides mobility and connections between the secondary and primary rural road system with the provincial towns. Therefore, the provincial local roads are a part of the rural road network characterized by low volume and short distance travel. They are composed by one carriage with two lanes and by a design speed normally in the range of 40 ÷ 80 km/h.

From the safety point of view, at national level, 25% of the total number of accidents on two lane rural roads take place on provincial roads, leading to about 30% of the total number of fatalities. In particular, in 2003, on 1,350 km of provincial roads (SP) in the province of Catania, there were 96 injury accidents with 6 deaths and 142 people injured (Source: ISTAT, 1999-2003).

As highlighted also in the Italian National Road Safety Plan [Italian Ministry of Infrastructures and Transports, 2002], for such roads there is a remarkable lack of reliable information referring both to the real state of the road and to accident situation. The former aspect is connected to the delay in the development of the National Roads Register [Italian Ministry of Infrastructures and Transports, 2001 a]. The latter aspect is connected with the general deficiency of reliable data on road crashes on rural local roads with low traffic flow.

For such reasons on this type of roads it is difficult to carry out the usual methodologies of identification of the hazard locations based on the statistical analysis on accident data. Based on these considerations, in the IASP project, a methodological approach for the safety evaluation of two lane rural local roads which use both analytical procedures referring to alignment design consistency models and the "Safety Inspection" process was suggested [Cafiso et al., 2004].

The deficiency of information related to the road and to the accident situation and the low cost of the procedure respect to the available limited budget are factors that evidence the particular usefulness of Safety Inspection method in the verification of safety conditions on provincial local roads. To such aim, the inspection methodologies proper of the Road Safety Inspection (RSI) were applied, adapting them to the specificity of the application, as support and completion of the analyses conducted through the theoretical-experimental models.

Considering that at present an Italian guideline on Safety Inspection doesn’t exist, while different procedures are adopted both in some EU countries and no EU ones, an RSI operative procedure was defined as part of the IASP project [Cafiso et al., 2005 a].

On the other hand the models based on the evaluation of the safety factors related to the horizontal alignment, supply a greater degree of efficiency and objectivity with special emphasis to the analysis of alignment design consistency and design standards agreement. Such problems often exist on this type of roads which were built in years ‘50/'80 using obsolete design criteria. Moreover, the simple comparison between site characteristics and road design standard can highlight the existing defects, but this type of comparison is inadequate in order to completely characterize the dangerousness of roads sections.

Since the potentialities and the limits of the two approaches are complementary, it is useful to integrate the results of the analyses based on the theoretical-experimental models with those deriving from the judgments collected during the Road Safety Inspection.

In Figure 1 the methodological approach proposed in the IASP project was reported.

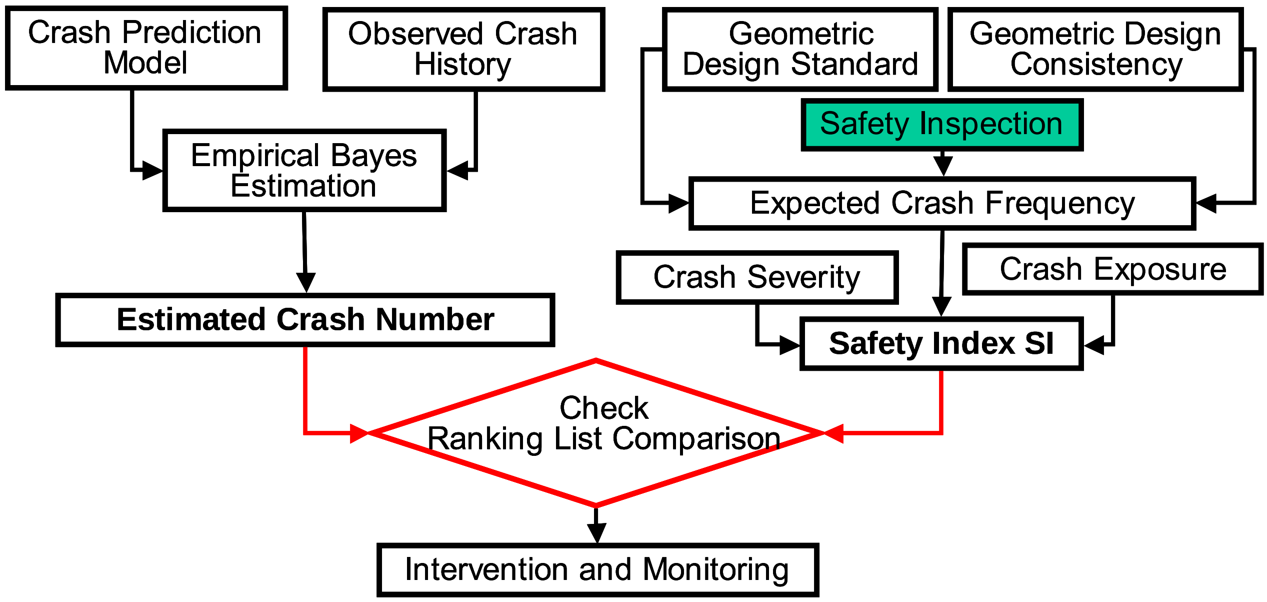


Figure 1 Flow-chart of the methodological approach proposed in the IASP project.

Using the information derived from the safety analysis of road characteristics, a Safety Index (SI) of the level of risk in different homogenous stretches of the road was defined.

The SI is formulated by combining three components of risk: the Exposure of road users to road hazards, the Probability of becoming involved in an accident and the resulting Consequences when an accident occurs:

Risk = Vulnerability x Exposure x Magnitude

where:

Vulnerability = accident probability defined on the basis of the integrated Safety Inspection + theoretical-experimental model system;

Exposure = number of vehicles x km;

Magnitude = possible consequences of an accident based on the vehicle speed and the roadside safety conditions.

The proposed methodology was tested on about 100 km of provincial roads in order to propose a suitable model for the safety evaluation of local two lane rural roads.

2 MACROSCOPIC ANALYSIS OF ACCIDENT DATA

2.1 The ISTAT data base on road accidents

The analyses on road accident data at a provincial level were taken and then elaborated from National ISTAT data base.

For each accident which has taken place in Italy, in which at least one person died and/or was injured, the ISTAT data base contains a record subdivided into fields with information relating both to the infrastructure (but only at a qualitative level) and the accident itself. Despite the fact that each accident record contains a large number of fields (153), each of which can be given different values (up to 77), the quality and completeness of the data is poor. Moreover, in the case of the provincial road network almost all the accidents classified by the ISTAT appear with 'no location' and therefore it is not possible to obtain differentiated data for single roads.

2.2 The Regional Context

With the aim of evaluating how critical the specific conditions of the local two lane rural roads are in the Province of Catania, it is useful to define some accident indicators both on a national and a regional scale. In this way, it is possible to obtain comparative data which allow to evaluate anomalies and, therefore, highlight the specific aspects of the situation under examination.

In relation to the whole Regional road network, the data for the five-year period 1999 – 2003 show a slight tendency towards an increase in the accident frequency (Figure 2).

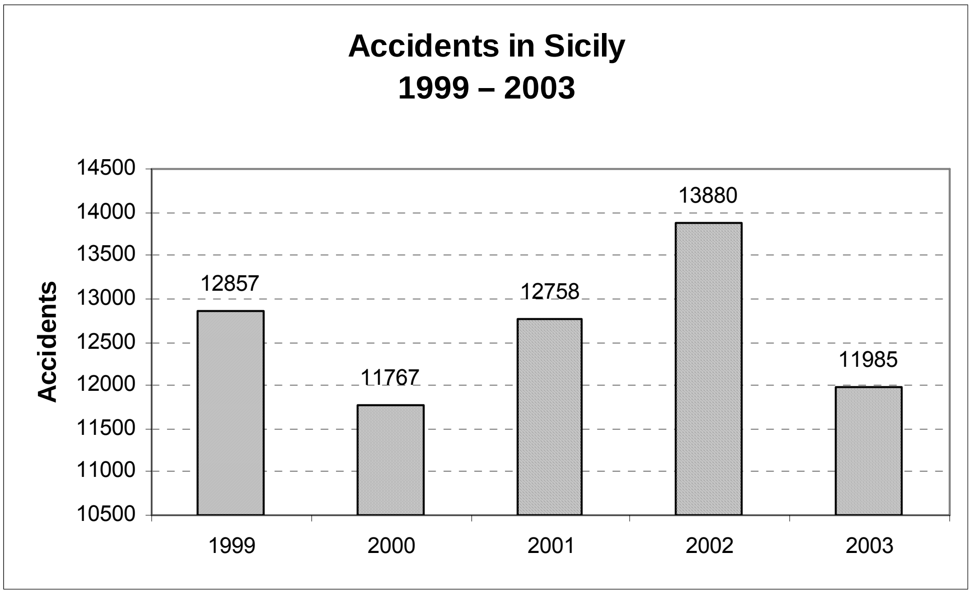


Figure 2 Sicily Road Network (Source: ISTAT).

Instead, the data referring only to the local two lane rural roads, classified as provincial roads (SP), (Figure 3, Figure 4) show that the numbers of accidents, fatalities and injuries over the five-year analysis period remained substantially constant.

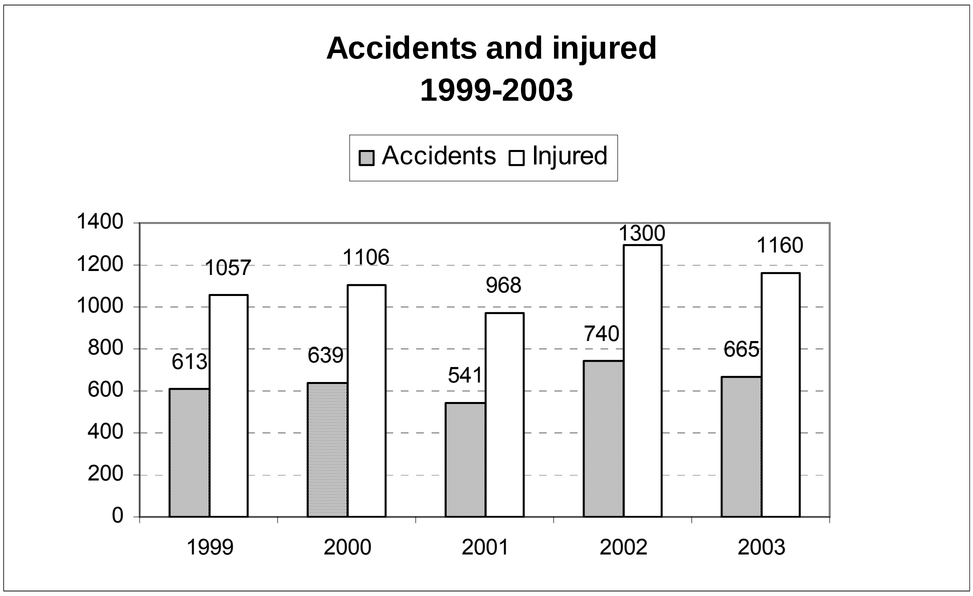


Figure 3 Provincial roads - Sicily (Source: ISTAT).

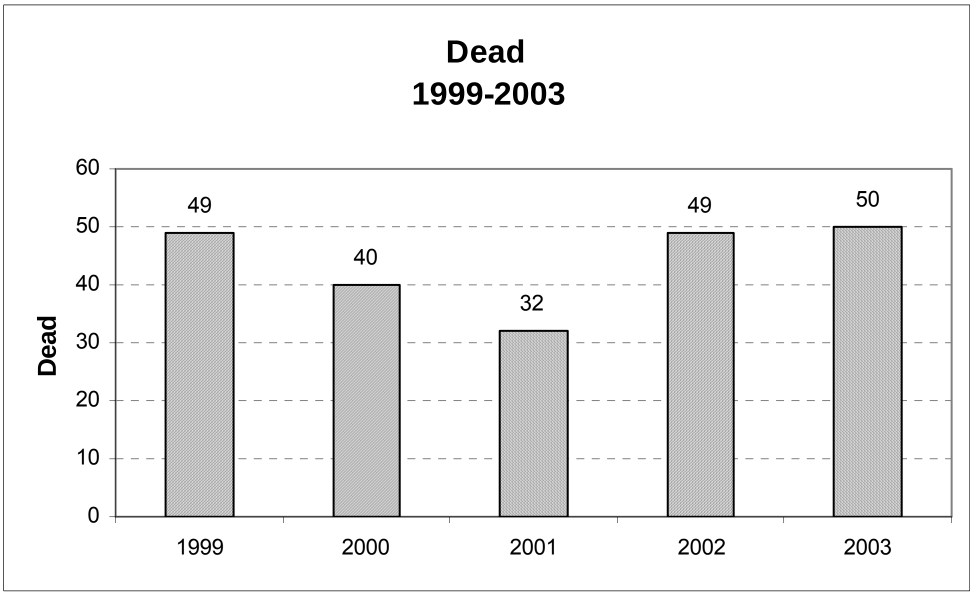


Figure 4 Provincial roads – Sicily (Source: ISTAT).

Figure 5 shows the accident frequency (accidents/km) with reference to the provincial network of the nine Sicilian provinces. An analysis of this diagram reveals an unequivocal disparity of values in the rates of the nine contexts analysed and that the Province of Catania has a value (5.66 accidents/100 km) that close to the regional mean (6.18 accidents/100 km). A probable difference in traffic volume on provincial roads has to be considered to explain these differences.

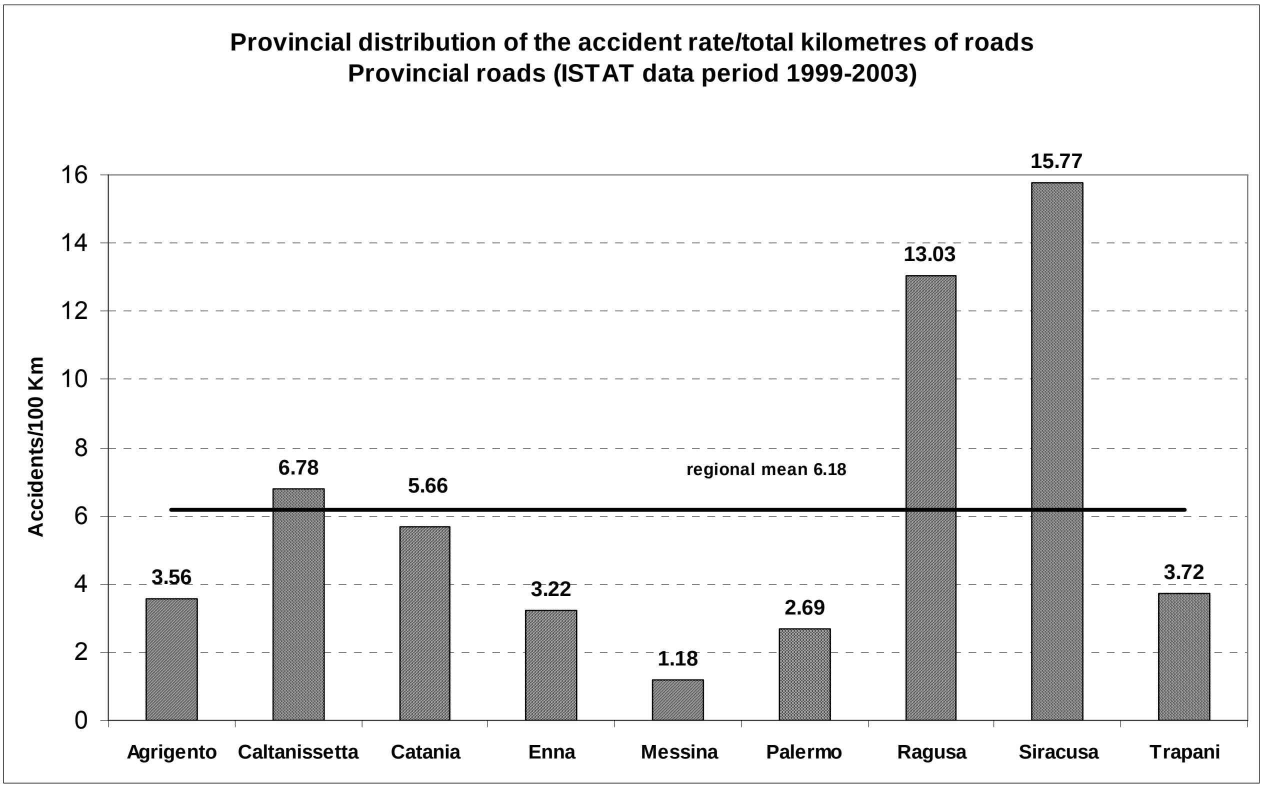


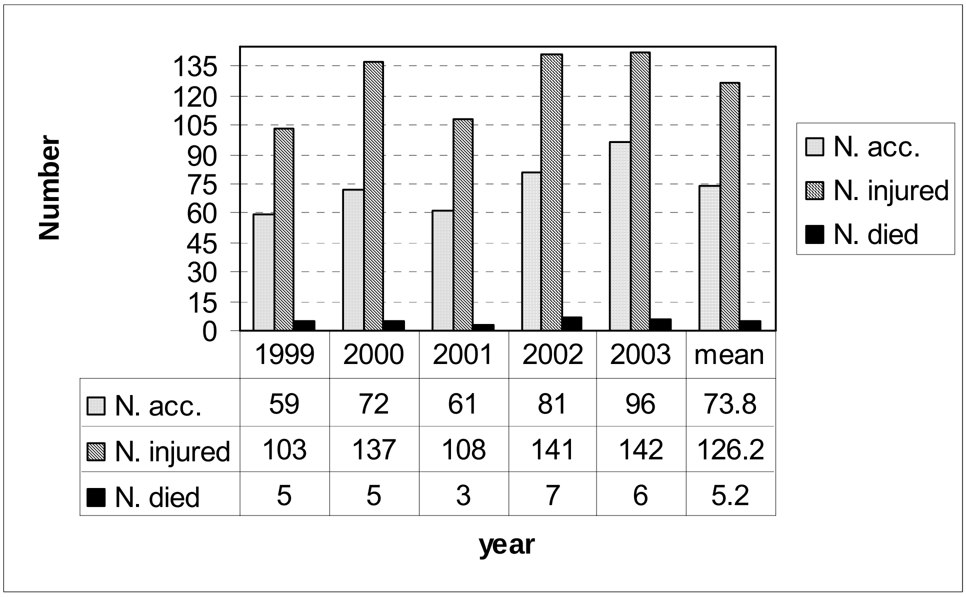
Figure 5 Accident frequency (accidents/km) on provincial roads (Source: ISTAT 1999-2003).

2.3 The Province of Catania Context

Figure 6 shows the evolution of accidents on Catania provincial roads in terms of number of crashes, number of people and number of deaths, which highlights a certain stationeries, with a tendency to increase in 2003.

The accident data relating to the whole provincial road network (SP) coming under the authority of the Regional Province of Catania were elaborated and compared to the corresponding values relating to the provincial road networks of the Sicilian Region, which certainly constitute a representative sample for comparison purpose.

Various detailed analyses were carried out on accident distribution with reference both to seasonal variations and as regards the type and the location of the accidents [Cafiso et al., 2005, Report 1].



	1999	2000	2001	2002	2003	mean
N. acc.	59	72	61	81	96	73.8
N. injured	103	137	108	141	142	126.2
N. died	5	5	3	7	6	5.2

Figure 6 Accident data in Province of Catania (Source: ISTAT).

In the following the more interesting results are shown. Figure 7 shows the data distribution for the five-year period 1999 –2003 relating to the percentage of accident type on SP in the province of Catania. In particular, from the analyses of accident type distribution it emerged that those accidents involving only one vehicle are about one third of those involving more than one vehicle. The high percentage of single vehicle accidents underlines road alignment problems as compared to driving speed.

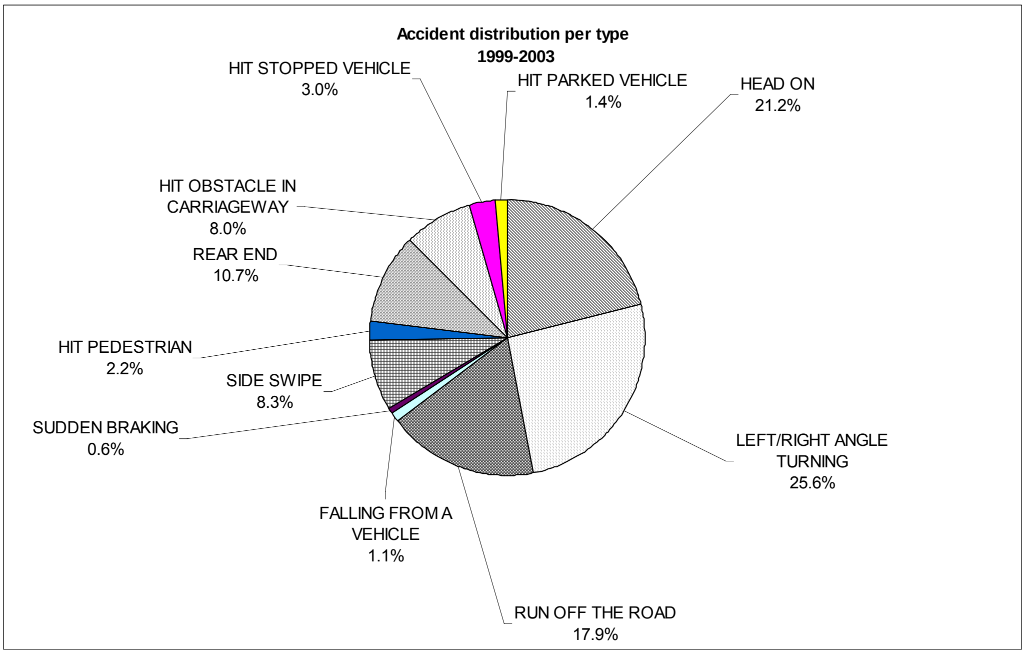


Figure 7 Accident distribution per type (Source: ISTAT).

The accident analysis by type and location highlighted high number of accidents related to the presence of intersections and connected to alignment defects (accident on curves).

For a statistical analysis, the properties of the binomial distribution have been used to calculate the probability of observing a number of accidents of a given type compared to the proportions taken from a reference population. In this way it is possible to identify significant differences in the accident distribution of Catania provincial road network compared to the Sicilian provincial road network.

This analysis showed a greater specificity for roads in the Province of Catania as regards to head-on collisions (98.6 % level of confidence) and to accidents on curves (97.3 % level of confidence). Therefore, problems linked to axis alignment, to paved section width and to road-side hazards seem to be aspects in particular evidence on the provincial network.

2.4 Province of Catania Territorial Disaggregation

The territory of the Province of Catania was subdivided into 7 homogenous zones in terms of population and road network distribution (Figure 8). Therefore, it can be considered that, at a macroscopic level, each area has specific mobility and road network conditions.

Comune	Zona
ACI BONACCORSI	7
ACI CASTELLO	7
ACI CATENA	7
ACI SANT`ANTONIO	5
ACIREALE	6
ADRANO	3
BELPASSO	3
BIANCAVILLA	3
BRONTE	4
CALATABIANO	6
CALTAGIRONE	1
CAMPOROTONDO ETNEO	7
CASTEL DI IUDICA	2
CASTIGLIONE DI SICILIA	5
CATANIA	7
FIUMEFREDDO DI SICILIA	6
GIARRE	6
GRAMMICHELE	1
GRAVINA DI CATANIA	7
LICODIA EUBEA	1
LINGUAGLOSSA	5
MALETTO	4
MANIACE	4
MASCALI	6
MASCALUCIA	7
MAZZARRONE	1
MILITELLO IN VAL DI CATANIA	2
MILO	5
MINEO	1
MIRABELLA IMBACCARI	1
MISTERBIANCO	3
MOTTA SANT`ANASTASIA	3
NICOLOSI	5
PALAGONIA	2
PATERNO`	3
PEDARA	5
PIEDIMONTE ETNEO	5
RADDUSA	2
RAGALNA	3
RAMACCA	2
RANDAZZO	4
RIPOSTO	6
SAN CONO	1
SAN GIOVANNI LA PUNTA	7
SAN GREGORIO DI CATANIA	7
SAN MICHELE DI GANZARIA	1
SAN PIETRO CLARENZA	7
SANT`AGATA LI BATTIATI	7
SANT`ALFIO	5
SANTA MARIA DI LICODIA	3
SANTA VENERINA	5
SCORDIA	2
TRECASTAGNI	5
TREMESTIERI ETNEO	7
VALVERDE CT	7
VIAGRANDE	5
VIZZINI	1
ZAFFERANA ETNEA	5

Figure 8 Subdivision of the Catania Province into homogeneous territorial zones.

Table 1 shows data relating to the resident population, the area and the total number of kilometres of provincial roads for the seven territorial homogenous zones.

Table 1 Subdivision of the homogeneous territorial zones by area, population and total number of kilometres of provincial roads.

	Resident population 2001	Area	Total number of kilometres of roads
Zone 1	84346	977.29	401.51
Zone 2	60482	575.48	232.25
Zone 3	187152	600.38	290.43
Zone 4	37310	531.71	76.43
Zone 5	78084	447.04	173.79
Zone 6	116437	156.35	76.96
Zone 7	490967	265.08	52.63

Accident distribution by zone on provincial roads in terms both of the number of accidents and of number of injuries, shown in Figure 9 and Figure 10, highlights very high values, equal to about double the provincial average, in zones 1, 3 and 7.

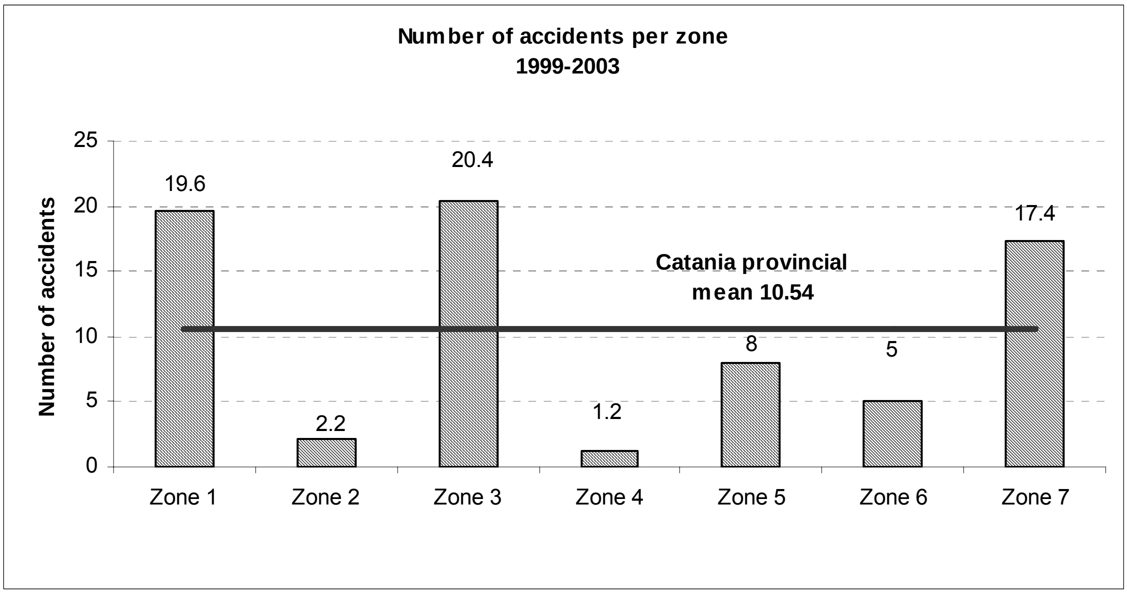


Figure 9 Number of accidents per zone (Source: ISTAT).

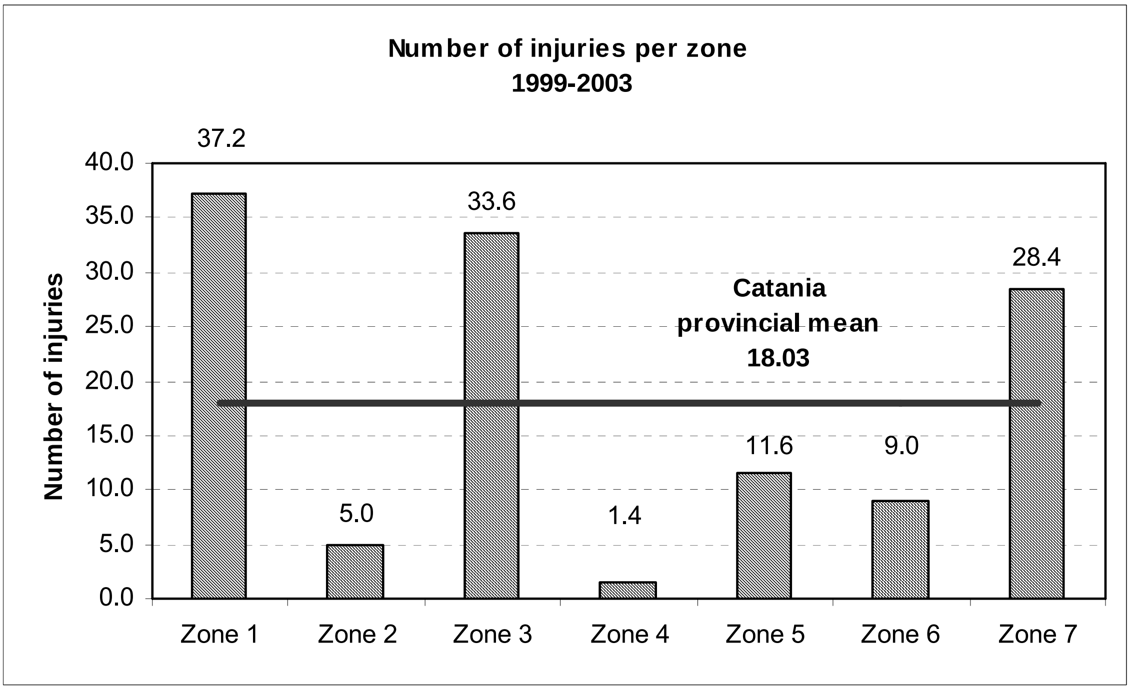


Figure 10 Number of injuries per zone (Source: ISTAT).

Due to the lack of data regarding traffic flows, the only information in terms of accident rates can be referred to the roads extension (accidents/100 km – Figure 11) and to the resident population (accidents/100,000 inhabitants – Figure 12).

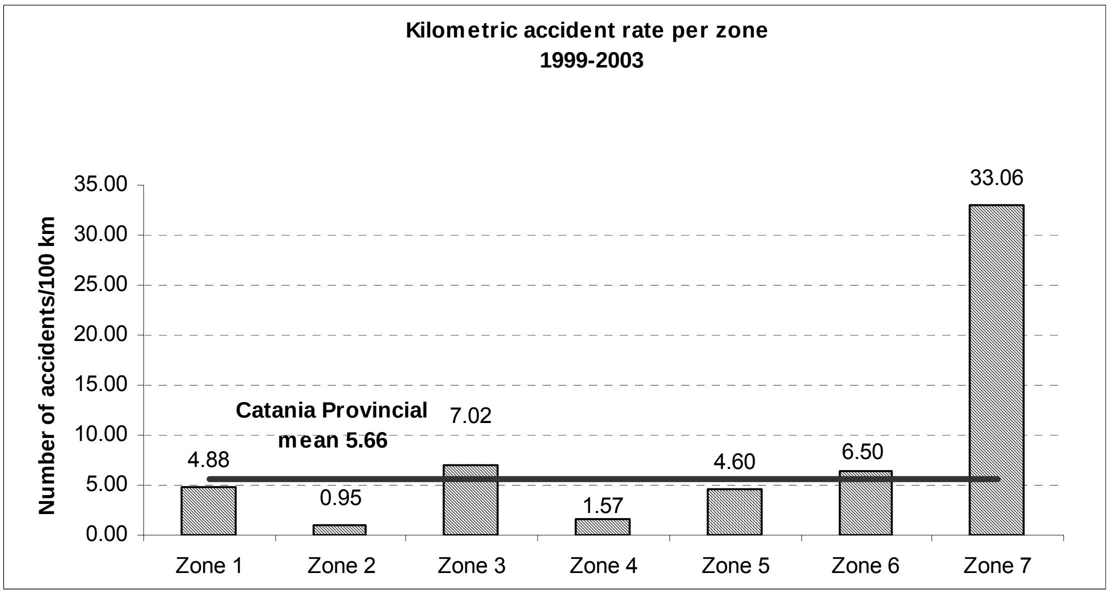


Figure 11 Kilometric accident rate per zone (Source: ISTAT).

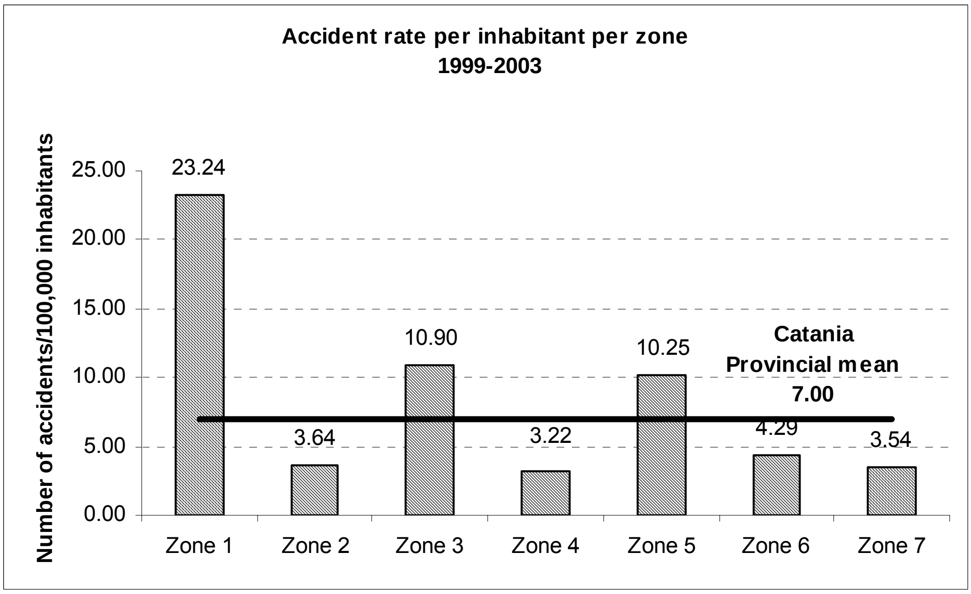


Figure 12 Accident rate per inhabitants per zone (Source: ISTAT).

On the whole, the territorial disaggregation from a road safety point of view highlights the most critical situations in zones 1, 3 and 7 wit respect to the number of acc., zones 7 and partially 3 with respect to the acc./km rate and zones 1, 3, 5 with respect to the acc./inhab. rate.

As the ISTAT official data base does not contain specific information regarding accidents taking place on the various provincial roads, an initial selection of roads to be studied under the IASP project was made concentrating on the provincial roads in zones 1, 3 and 7 and partially in zones 2 and 4 as comparison group. Within these zones the final choice of roads was made on the basis of consensus with the people of the Technical Offices of the Province of Catania. The final list of the roads studied by the IASP project is shown in Table 2 and Figure 12.

Table 2 List of the roads studied by the IASP project.

N.	S.P.	Length [Km]	Width [m]	Municipalities	Zone
9	4/II	13+920	6,50	Trecastagni, Pedara, Mascalcia, Nicolosi, Belpasso, Paterno'	7-3
33	28/II	15+879	5,50	Militello Val Di Catania, Vizzini	1-2
61	57	12+195	5,00	Paterno' , Ragalna, Belpasso	3
75	69/II	23+883	7,50	Catania, Ramacca, Lentini (Sr)	7-2
102	94	18+141	7,00	Bronte, Adrano	4-3
110	104	16+100	6,00	Catania, Lentini (Sr)	7
228	231	4+600	7,00	Adrano	3
	SC4	6+300	7,00	Catania, Lentini (Sr)	7
Total		**111,018**			

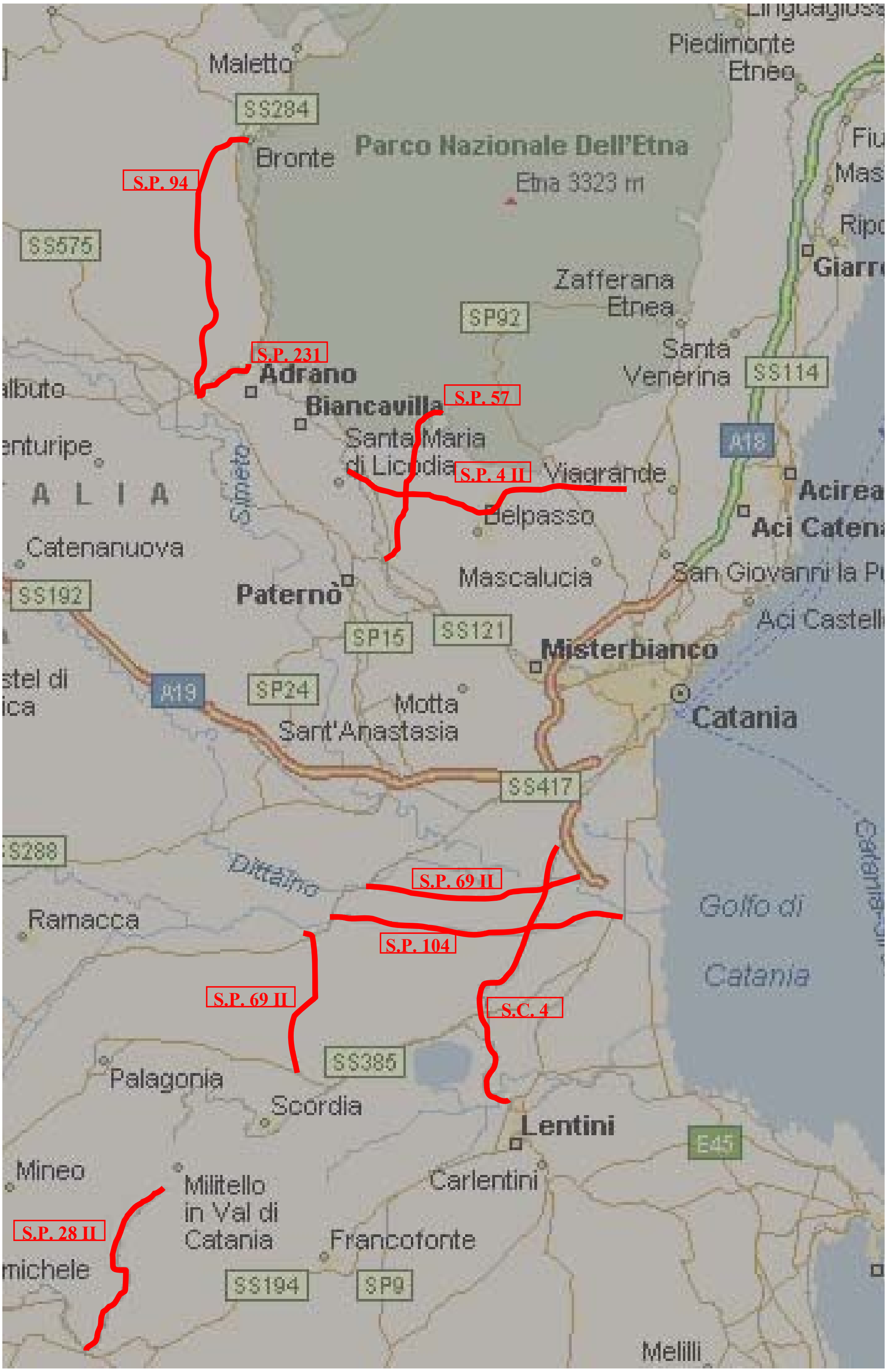


Figure 13 Provincial Roads in the IASP Project

3 ROAD AND ACCIDENT DATA

3.1 Road data

Efficient management of a road network greatly depends on the availability of adequate and reliable information that allows the state of the road network system infrastructure to be controlled. Therefore, a partial or total lack of such information represents the first obstacle that must be faced in an optimised road management.

To overcome this problem the Department of Civil and Environmental Engineering of the University of Catania has set up a multi-function Mobile Laboratory for high-performance surveys of the road network infrastructure (Figure 14) [Cafiso et al., 2003].

The Laboratory has been used to collect useful data for the horizontal and vertical road alignment reconstruction, as well as other fundamental information as section width, road markings, pavement conditions, etc..

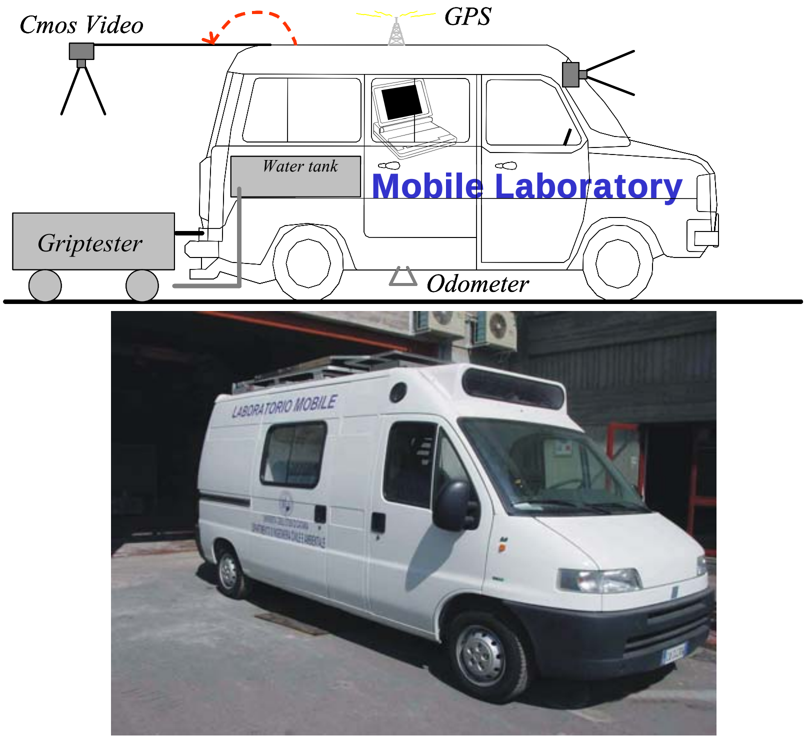


Figure 14 The DICA Mobile Laboratory

The hardware system of the mobile laboratory is run by a software for the synchronous acquisition and post-elaboration of both analogue and digital information coming from the various instruments. Figure 15 shows layout of the instruments connections.

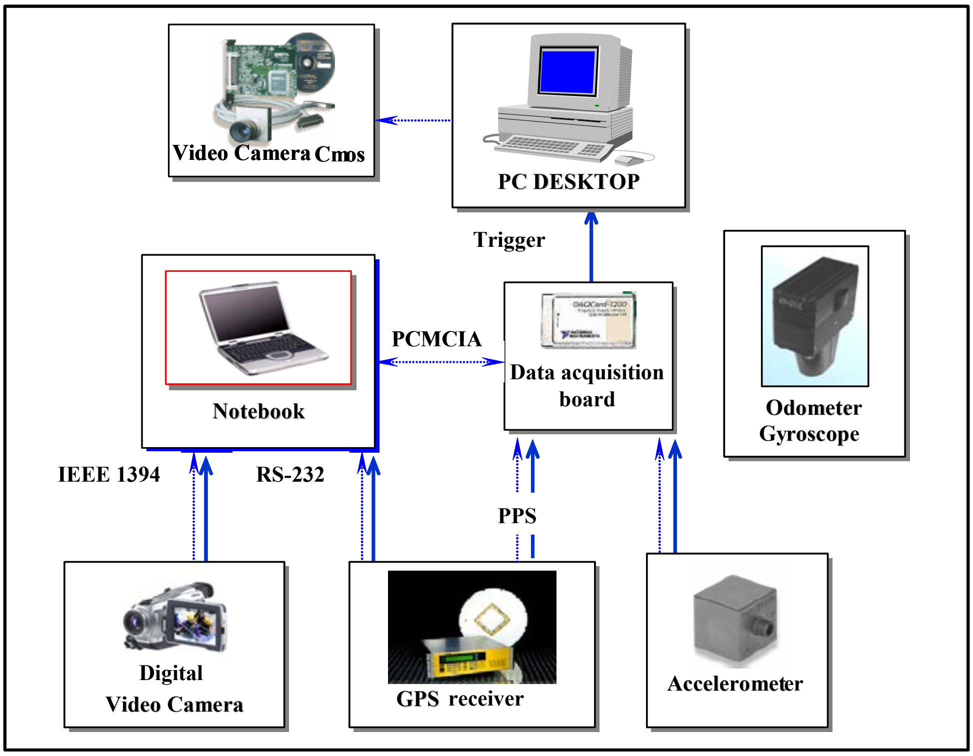


Figure 15 Instrument connection chart.

The GPS survey is performed using a cinematic-differential method (DGPS), so as to obtain a precision of ± 2 cm + 1 ppm.

The GPS survey allows a series of points to be identified along the trajectory of the vehicle. Although this information makes it possible to produce an efficient representation of the stretch, it is not enough for the parameters of the alignment design to be identified. Therefore, the next phase of the survey consists in elaborating the data so as to identify the single element of the axis (tangents, circular curves, transition curves) and determine their geometric parameters (length, radius, angular extension).

The set up model uses regression splines with the aid of suitable smoothing factors to correct the inevitable axis survey errors due to the actual trajectory followed by the vehicle or to measurement inaccuracies [D'Andrea et al., 1990; Cafiso et al., 2002].

In particular, smoothing functions are used on the spline to correct the curvature locally by means of a P parameter whose value varies between 0 and 1.

In particular for:

P = 0, the spline represents a minimum squared linear regression;

P = 1, the spline represents an interpolation spline passing exactly through the points.

Operationally, a parameter P < 1 is defined limiting the smoothing error to 1 m, or rather, the spline carried out (Figure 16) has a maximum of 1 m distance from the surveyed GPS points.

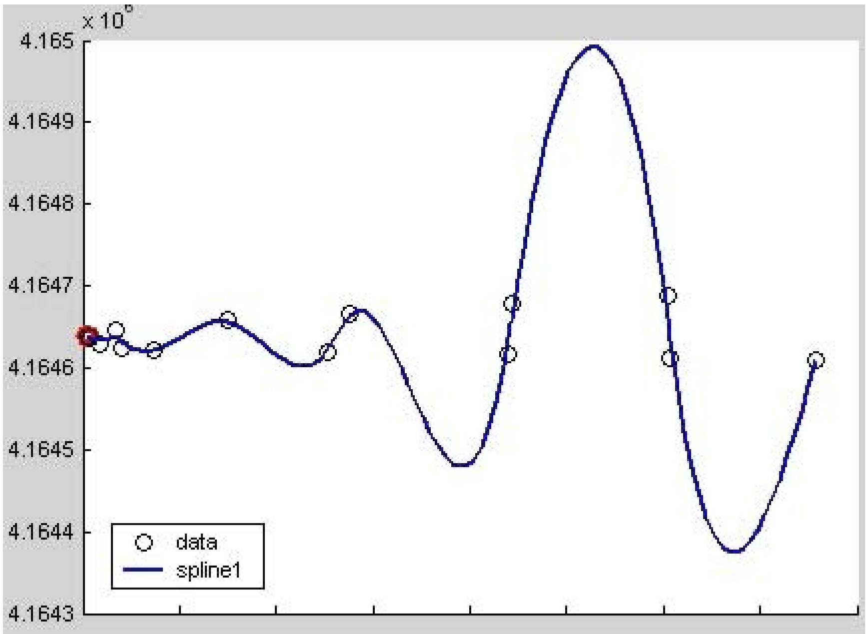


Figure 16 Spline carried out by the smoothing routine.

The coefficients of the cubic spline being defined as *f*i(x)=ai x3 + bi x2 + ci x + di, the curvilinear extension (S) of the spline from the point of origin of co-ordinate (x0, *f*(x0)) to the point of the co-ordinate (x, *f*(x)) is calculated according to the expression:

$$s = \sum_i \int_{x_0}^{x} \sqrt{1 + f_i'(x)}\,dx$$

where *f*i′(x) represents the first derivative of the spline function *f*i(x).

While, according to the first and second spline derivative *f*”(x) it is possible to calculate the 1/ρ curvature by means of the expression:

$$\frac{1}{\rho} = \frac{f''(x)}{\left(1 + f'(x)^2\right)^{3/2}}$$

When the curvature function (S,1/ρ) is carried out, a definition of the actual geometrical elements of the alignment is obtained by looking for the succession of defined geometrical elements (straight stretches, transition curves, circumferences) that guarantee the same angular and linear extension of the spline curvature.

Having imposed equality on the angular development, is equivalent to having imposed equality between the areas of the spline curvature and the curvature of the desired element. Therefore, the numerical values of the radius R of the curve and the parameter A of the transition curve are calculated imposing equality between the area subtended by the curve function of the spline and that of the trapezium, between the beginning and end points of the element under consideration, establishing that the mean square variation of the error is minimal (Figure 17).

Figure 17 Error between the imposed curvature and that of the spline.

In this way it is possible to carry out the reconstruction of the alignment design of the stretch as shown in Figure 18.

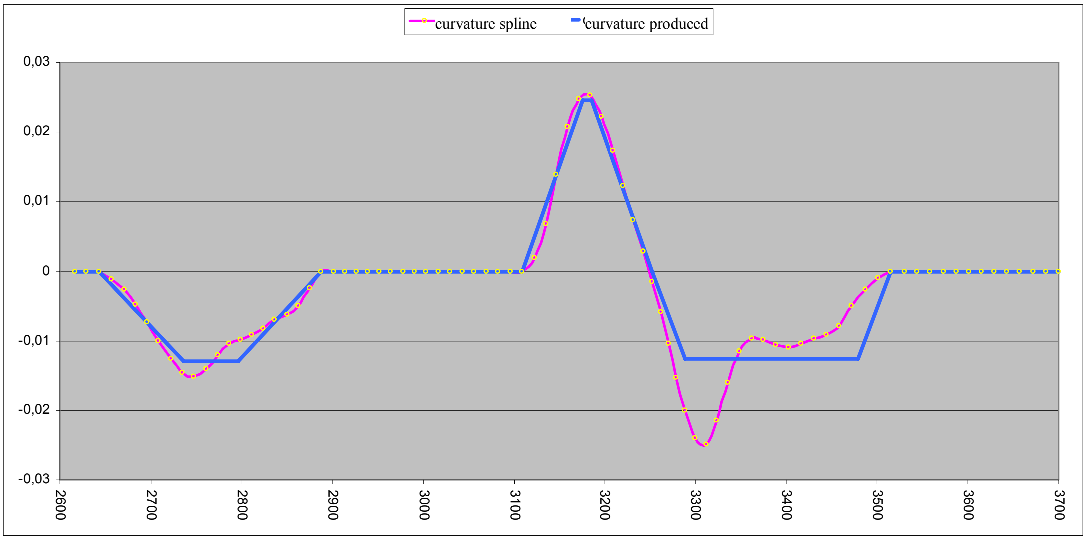


Figure 18 Comparison between the spline and reconstructed curvature.

For old roads constructed without the use of transition curves, like those in the IASP project, constant curve elements (rectangular shape) are identified having the same angular development as the trapeziums (Figure 19).

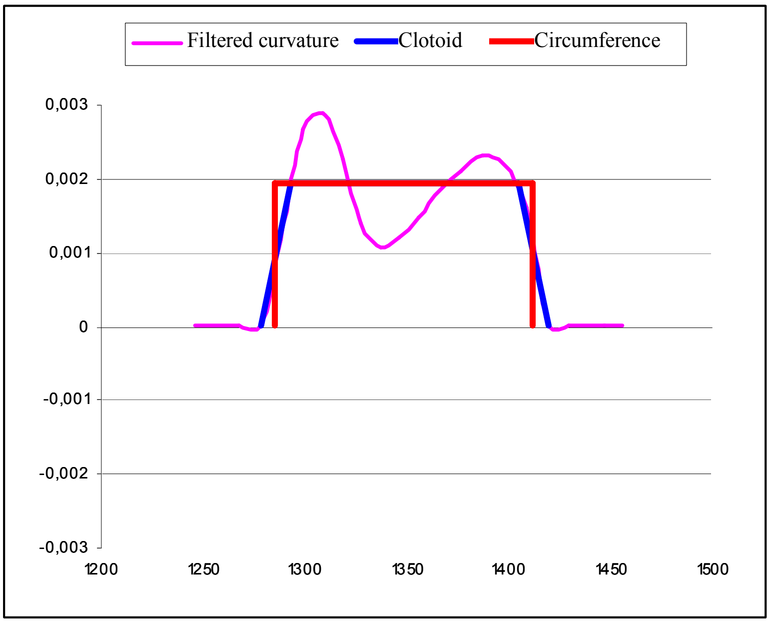


Figure 19 Constant curvature elements survey.

The alignment design, obtained using the above method, corresponds well to the survey points (Figure 20) highlighting the correct identification of the geometrical elements forming the stretch.

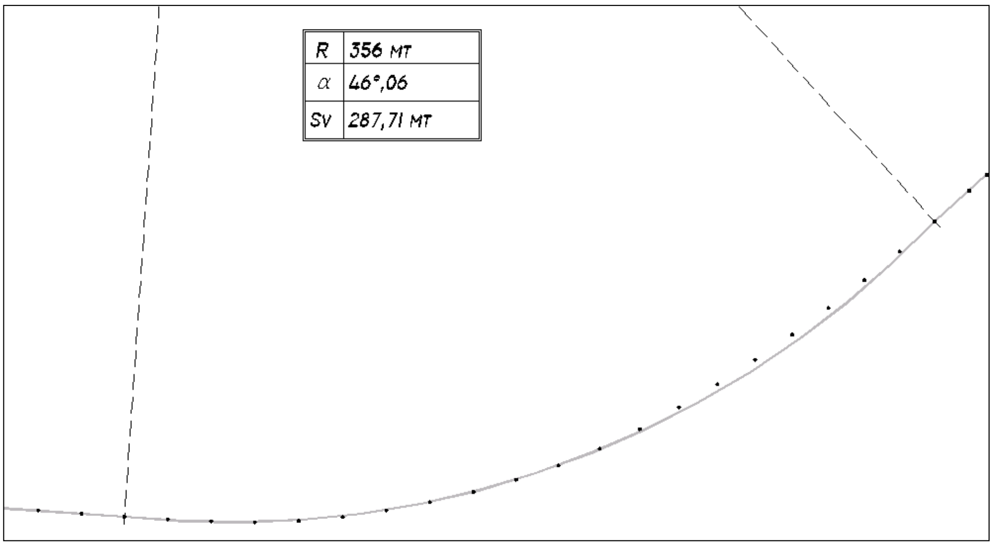


Figure 20 Survey points and horizontal alignment reconstruction.

3.2 Accident Data

Due to the lack of ISTAT data mentioned in the previous chapter, a survey was carried out to directly collect from of Traffic Police and Carabinieri reports, with the aim of acquiring accident data for five-year period 1999-2003 for all the IASP road sample .

The data for a correct identification and classification of accidents was deduced from police reports. More specifically, for each accident information relating to the following items were identified:

- where the accident took place;
- when the accident took place;
- number and type of vehicles involved in the accident;
- what consequences of the accident were;
- what the weather and road pavement conditions were when the accident occurs;
- how the accident happened.

A synthetic form was prepared to carry this information in digital records as shown in Table 3 and Table 4.

Table 3 Synthetic list for accident survey (first part).

Accident ID	YEAR	MONTH	DAY	TIME	REPORTING AUTHORITY	PAVEMENT CONDITIONS	WEATHER CONDITIONS

Table 4 Synthetic list for accident survey (second part).

LOCATION	ACCIDENT TYPE	VEHICLE A	VEHICLE B	VEHICLE C	VEHICLE D	DEAD	INJURED	NOTES

Each section of the accident record must be completed using codings that are directly linked to those defined by ISTAT. Table 5 shows the codes used for the accident record.

Table 5 Crash data coding sheet.

PAVEMENT CONDITIONS	WEATHER CONDITIONS	ACCIDENT TYPE	LOCATION	VEHICLE TYPE
Dry	Fair	Head-on	Intersection	Motorcar (ATV)
Wet	Fog	Left/Right angle turning	Roundabout	Bus
Slippery	Rain	Side swipe	Straight stretch	Lorry
Icy	Hail	Rear-end	Curve	Lorry with trailer
Snowy	Snow	Hit pedestrian	Crest, bottleneck	Articulated vehicle
	Strong wind	Hit stopped vehicle	Gradient	Road tractor
	Other	Hit parked vehicle	Tunnel	Agricultural vehicle
		Hit obstacle in carriageway		Bicycle
		Collision with a train		Moped
		Run off the road		Motorbike
		Sudden braking		Three-wheeler
		Falling from a vehicle		Animal or human drawn vehicle
				Unknown vehicle (did not stop)

During the reference period (1999 – 2003) 85 fatal or with injuries accidents were identified and classified on roads under examination.

The location of the accident was effected on the basis of the indications given in the accident report and with the aid of the Province's technical staff who carried out detailed site inspections indicating the position on the map and obtaining the GPS co-ordinates of the accident site.

4 SAFETY INDEX

The Safety Index (SI) measures the relative safety performance of a road segment. It does not take into account junctions and it refers to two lane rural roads.
The SI is formulated by combining three components of risk: the exposure of road users to road hazards, the probability of becoming involved in a accident and the resulting consequences should an accident occur.
General formulation of the SI is as follows:

$$SI = \text{Exposure factor} \times \text{Accident Frequency factor} \times \text{Accident Severity factor} \quad (1)$$

4.1 Exposure Factor

Exposure factor measures the exposure of road users to road hazards, and is assessed by equation 2 as follows:

$$\textit{Exposure factor} = L \times AADT^{a} \quad (2)$$

where:

AADT : average annual daily traffic [(veh/day)/1000];

L : length of the segment under consideration (km).

a : $a \leq 1$ exponent of AADT in the pertinent accident predictive model to consider non linearity between crashes and traffic volume (1 if pertinent accident predictive model is not available).

4.2 Accident Frequency Factor

Accident Frequency factor depends on the safety features of the segment, which are assessed by two analysis methodologies:

- Road Safety Inspections;
- Design Consistency evaluations and Design Standards check.

The Accident Frequency factor is assessed by the formula:

$$\textit{Accident Frequency factor} = RSI\ AF \times DC\ AF \quad (3)$$

where:

RSI AF = Road Safety Inspection Accident Frequency factor;

DC AF = Design Consistency Accident Frequency factor.

4.2.1 Road Safety Inspections

Road Safety Inspections (RSI) aim to identify potential hazards, which are assessed by measuring risk in relation to road features which may lead to future crashes, so that remedial treatments may be implemented before crashes happen [Cafiso et al., 2004].

RSI procedures defined by the IASP research program, which are better described in the next chapter, have improved the effectiveness and reliability of the methodology [Cafiso et al., 2005 a]. Indeed, even though safety evaluations based on inspections are subjective in nature, the definition of a precise procedure and evaluation criteria allows an acceptable agreement between the inspectors' evaluations.

IASP general inspection checklists are related to the main safety features which may be present with continuity along two lane rural roads. Checklists are filled in both directions of the road, with a step of 200 m (inspection unit). Criteria for identifying and ranking safety issues have been defined [Cafiso et al., 2005a, Cafiso et al., 2005 b, Cafiso at al,. 2006a, Cafiso et al., 2007a]. Safety issues are ranked as high level problem (score equal to 1), low level problem (score equal to 0.5) and no problem (score equal to 0).

The following safety issues are assessed: accesses, cross section, delineation, markings, pavement, roadside, sight distance, signs.

In order to improve safety issues evaluation, each item is divided in more detailed concerns (Table 6).

Table 6 Safety Issues of RSI.

Safety issues	Detailed safety issues
Accesses	Dangerous accesses Presence of accesses
Cross section	Lane width Shoulder width
Delineation	Chevrons Guideposts and barrier reflectors
Markings	Edge lines Center line
Pavement	Friction Unevenness
Roadside	Embankments Bridges Dangerous terminals and transitions Trees, utility poles and rigid obstacles Ditches
Sight distance	Inadequate sight distance on horizontal curve Inadequate sight distance on vertical curve
Signs	Warning signs, regulation signs

For each issue, a Weighted Score of the safety issue j (WS_j), ranging from 0 to 1, is assessed by the formula:

$$WS_j = \frac{1}{2 \times n \times m_j} \times \sum_{i=1}^{m_j} \sum_{k=1}^{2\times n} S_{ik} \tag{4}$$

where:

S_{ik} = Score of the detailed safety issue i in the inspection unit k;

n = number of inspection units which form the segment under consideration;

m_j = number of detailed issues which make up the issue j.

The Accident Frequency factor of the safety issue j (AF_j) is assessed by the formula:

$$AF_j = 1 + WS_j \times \Delta AF_j \times P_j \tag{5}$$

where:

WS_j = Weighted Score of the safety issue j;

ΔAF_j = estimated relative increase in injury accidents risk due to the issue j;

P_j = proportion of accidents affected by the issue j.

From the National accident database (ISTAT) the accidents types distribution on two lane local rural roads in Sicily and in Italy were defined and they are reported in Table 7and Table 8.

Table 7 Accident percentages on road segments and Junctions (Local roads Province of Catania, Italy - reference years 1999-2003).

Accident type	Percentage in Sicily	Percentage in Italy
Head on	21.2 %	12.1 %
Left/Right angle/turning	25.6 %	31.6 %
Side swipe	8.3 %	7.7 %
Rear end	10.7 %	14.7 %
Hit pedestrian	2.2 %	1.6 %
Hit stopped/ parked vehicle	4.4 %	2.7 %
Collision with train	0.0 %	0.0 %
Run off the road	25.9 %	28.9 %
Sudden braking	0.6 %	0.2 %
Falling from a vehicle	1.1 %	0.6 %
Total	**100.0 %**	**100.0 %**

Table 8 Accident percentages on road segments without junctions (Local roads Province of Catania - reference years 1999-2003).

Types	Percentage (without junctions)
Head on	20.2 %
Left/Right angle/turning	17.3 %
Side swipe	8.9 %
Rear end	11.6 %
Hit pedestrian	2.7 %
Hit stopped/ parked vehicle	5.4 %
Collision with train	0 %
Run off the road	30.3 %
Sudden braking	0.9%
Falling from a vehicle	1.2 %
Total	**100.0 %**

The cumulative influence of the different Accident Frequency factors is assessed by the formula of the “RSI Accident Frequency factor”:

$$\mathrm{RSI\,AF} = \prod_{j=1}^{\ell} \mathrm{AF}_j \tag{6}$$

where:

AF_j = Accident Frequency factor of the safety issue j;

ℓ = number of safety issues, equal to 8.

Basing on existing literature, relative increase in accident risk due to each issue has been estimated (Table 9).

Table 9 Safety effects of the Issues.

Safety issue	**Related accidents**	**ΔAF_j (%)**
Accesses	All	135
Cross section	Run off the road Head-on Sideswipe	15 - 100 f(AADT)
Delineation	All	30
Markings	All	20
Pavement	All	10
Roadside	Run off the road	-
Sight distance	All	50
Signs	All	20

Change in accident risk (ΔAF_j) is related to the Accident Modification Factor (AMFj) of the safety issue by the formula:

$$\Delta AF_j = AMF_j - 1 \tag{7}$$

Many studies have been performed for estimating the safety impacts of various types of engineering improvements. Many existing AMFs are derived from before–after analysis of actual countermeasure implementation. Indeed, such before–after studies, as opposed to cross-sectional/regression-type analysis, will produce the best AMF estimates, but only if conducted properly [TRB, 2005]. Unfortunately, many current studies reflect changes in crash experience resulting from improvements at sites that had experienced unusually high accident rates in the before-treatment period. The selection bias inherent in this approach often results in significantly exaggerated AMF estimates due to the phenomenon of regression to the mean. The most accurate AMFs have been developed in rigorous before–after studies that incorporated the current best study

design and statistical analysis methods. At this time, the Empirical Bayes (EB) methodology represents the best available approach [Hauer, 1997; Hauer et al., 2002; Persaud et al., 2005].
Below, explanations of the relative increase in accident risk estimates for each safety issue are briefly reported.

Accesses Direct accesses to roads can significantly increase accidents. Location (e.g., accesses on horizontal curves) and layout (e.g., too narrow accesses) of access points can be very dangerous. AMFs that take into account driveway density have been developed [Harwood et al., 2000]: they show a dramatic effect of accesses on road safety. ΔAF relative to high frequency of dangerous accesses (40 accesses/km) is equal to 135%.
Cross section Cross section affects single vehicle run-off-the-road and multiple vehicle head-on, opposite-direction sideswipe and same-direction sideswipe accidents [Harwood et al., 2000; Hauer et al., 1997]. The greater the lane and shoulder widths, the lesser the accidents. A bottom value in the lane width exists: too wide lanes may be counter-productive [Hauer, 2005; Lamm et al., 1999].
The effect of cross section width is more pronounced for high traffic volumes and is assessed basing on AMFs reported in [Harwood et al., 2000]. If AADT is greater than 2'000 vpd, very narrow lanes and shoulders, compared with ideal lanes and shoulders, increase related accident probability of 100%. If AADT is less than 400 vpd, the increase in related accident probability is 15%. With intermediate AADT values, the ΔAF varies linearly between these extreme values.
Delineation Daytime delineation of the road generally can be accomplished effectively with pavement markings. Night time and rainy conditions, however, often require a different approach to provide long-range delineation of the roadway alignment [Migletz at al., 1994]. Supplementary delineation is an important safety factors in any condition; on horizontal curves, especially isolated curves with a short radius, it is critical. Chevron missing or ineffective and guideposts or barrier reflectors damaged or missing can lead to an accident risk increase equal to 30% [TNZ, 2003].
Markings Much literature has investigated the effect of road marking on accidents, showing that road markings improvements are likely to be cost-effective. Relative increase in injury accidents risk has been assumed equal to 20% for edge lines and center line missing or ineffective [TNZ, 2003].
Pavement The pavement factor which more impacts road safety is friction. The skid resistance of the road surface is an important safety factor, specially when the surface is wet. Several studies [Elvik et al., 2004] show a dramatic increase in accident risk when the friction decreases below certain threshold values. Also unevenness affects road safety, although friction effect has been

proved by more studies. ΔAF relative to inadequate unevenness and friction has been selected equal to 10%.

Roadside Main effect of roadside safety issues is not on accident probability but on accident severity. Therefore roadside will be computed in the consequence factor of the risk model.

Sight distance Inadequate sight distance on horizontal and vertical curves is a common accident contributory factor. Literature reports widely different values related to the effect of sight distance improvement measures [Agent at al., 2003; Elvik et al., 2004; Hassan et al., 1996]. Taking into account this variability, ΔAF relative to inadequate sight distance on both horizontal and vertical curves has been selected equal to 50%.

Signs Road signs which have greatest effect on traffic safety are the warning signs [Road Directorate, 1999]. They call attention to unexpected conditions and to situations that might not be readily apparent to road users, giving suggestions about the safe behavior. Regulatory signs, such as speed limits, can affect road safety by conveying essential information on safe behavior. For signs missing or ineffective, the relative risk factor has been assumed equal to 20% [Shen et al., 2004].

4.2.2 Design Consistency Evaluations and Design Standards Check

A consistent highway design is one which ensures successive elements coordinated in such a way as to produce harmonious and homogeneous driver performances along the road. Practice highlights that an alignment with inconsistencies requires drivers to handle speed gradients in order to drive safely on certain alignment elements. On this basis, the importance of identifying inconsistencies on highways and its significant contribution to road safety is emerging as an important feature in highway design.

The Design Consistency and Standard accident frequency score (DCS AFS) is assessed by the formula:

$$\text{DCS AFS} = 1 + WS_{DC} \times \Delta AF_{DC} \times P_{DC} \tag{8}$$

where:

WS_{DC} = Weighted Score of the safety issue DC;

ΔAF_{DC} = Estimated relative increase in injury accidents risk due to the issue DCS;

P_{DC} = proportion of accidents affected by the issue DC.

WS_{DC} is computed through single Weighted average Score (WS_ℓ) of geometrical elements as follows:

$$WS_{DC} = \frac{\sum_{\ell=1}^{\nu} WS_\ell \times L_\ell}{\sum_{\ell=1}^{\nu} L_\ell} \qquad (9)$$

where:

ν = number of geometrical elements which form the section under consideration;

L_ℓ = Length of single geometrical element.

Each Weighted Score (ranging from 0 to 1) has been estimated by analysing the increase of the accident rate with respect to poor, fair and good curved elements according to Table 10.
For tangents which failed design standards check in terms of minimum or maximum length [Italian Ministry of Infrastructures and Transports, 2001b] the relative increase was assessed equal to 0.1, considering that a good curved segment anyway affects safety more than tangents. The DCS weighted scores are reported in Table 10.
A more detailed explanation about the procedure used to carry out the WS_{DC} values is presented in chapter 5.

Table 10 Design Consistency and Standards Check Weighted Scores (WS_{DC}) proportion of accidents (P_{DC}).

Curved elements		**Tangents**		**Related Accidents**
Good	0.2	Overall Standards Check	0.0	Run off the road Partially: Head-on Sideswipe
Fair	0.5	Minimum Length	0.1	
Poor	1.0	Maximum length	0.1	

State of the art indicates increase of AR related to the effect of horizontal alignment defects equal to 800 % as shown in Table 11 [Lamm et al., 2002] and with particular regards to the manner in which accident experience of curved alignments (e.g., for radius and super elevation) differs from that of tangents [Harwood et al., 2000]. Accordingly, ΔAF_{DC} has been assumed equal to 7.0.

Table 11 Results of Mean Accident Rates for Different CCR_S-Classes.

Design/ CCR_S-classes	Mean AR	$t_{calc.}$ $t_{crit.}$	Significance; Remarks
Database 1:United States of America (261 Two-Lane Rural Test Sites), 1987 All Accidents			
			Considered as
tangent (0)	1.17		--- Good Design
		4.00 > 1.96	Yes
35 – 180	2.29		--- Good design
		7.03 > 1.96	Yes
> 180 – 360	5.03		--- Fair design
		6.06 > 1.99	Yes
> 360 – 550	10.97		--- Poor design
		3.44 > 1.99	Yes
> 550 – 990	16.51		--- Poor design
Database 3:Germany (2726 Two-Lane Rural Test Sites), 2001 Run-Off and Deer Accidents			
			Considered as
0 - 180	0.22		--- Good design
		27.92 > 1.65	Yes
> 180 - 360	0.87		--- Fair design
		15.69 > 1.65	Yes
> 360	2.27		---Poor design
Database 3:Germany (2726 Two-Lane Rural Test Sites), 2001 Run-Off, Head-on and Deer Accidents			
			Considered as
0 - 180	0.33		--- Good design
		28.04 > 1.65	Yes
> 180 - 360	1.12		--- Fair design
		14.09 > 1.65	Yes
> 360	2.52		--- Poor design

Legend: AR = accident rate (acc. per 10^6 veh.-km); Deer = animal

The significant results of Table11 indicate for three databases and different accident types:

1. gentle curvilinear horizontal alignments consisting of tangents or transition curves, combined with curves up to CCR_S-values of 180 gon/km (that corresponds roughly to radii of curves greater than or equal to 350 m) classified as “good design”, experienced the lowest average accident risk;

2. the accident rate on sections with CCR_S-values between 180 and 360 gon/km (that means roughly radii of curve between 175 and 350 m) classified as "fair (tolerable) design", was at least twice to three times as high as that on sections with CCR_S-values of up to 180 gon/km;
3. the accident rate on sections with CCR_S-values between 360 and 550 gon/km (databases 1 and 2) classified as "poor design", was about eight times higher than that on sections with CCR_S-values of up to 180 gon/km;
4. for CCR_S-values greater than 550 gon/km (roughly radii of curve of less than 115 m), the average accident rate was even higher.

4.3 Accident Severity Factor

Accident Severity is intended as a measure of the ratio between the number of injured people and the number of accidents. In the IASP project two factors were considered significant:

1) Operating speed;

2) Roadside Hazard.

Accident Severity factor for the segment is computed with the following formula:

$$\text{Accident Severity factor} = (V_{85}/V_{base}) \times \text{RSI AS} \qquad (10)$$

where:

V_{85}	=	85^{th} percentile of speed distribution weighted along the segment;
V_{base}	=	base operating speed for two lane local rural roads (assumed equal to 90 km/h, that is equal to the legal speed limit for two lane rural roads in Italy);
RSI AS	=	Road Safety Inspection Accident Severity factor of the segment, equal to the Accident Severity factor of the safety issue roadside (see Table 12).

4.3.1 Operating Speed

For the assessment of the operating speed of the segment a weighted V_{85} of the expected speeds along the different geometrical elements of the whole segment can be used.

Expected operating speed was carried out using two experimental regression models developed for the roads of the IASP Project (Figure 21):

$$V_{85} = 99.31 - 0.51\ CD \qquad (11)$$

$V_{85} = 82.76 - 0.45\ CD$ (12)

where:

CD = curvature degree [°/100 m] = $\frac{360 \times 100}{2 \times \pi \times R}$;

R = radius of the curve [m].

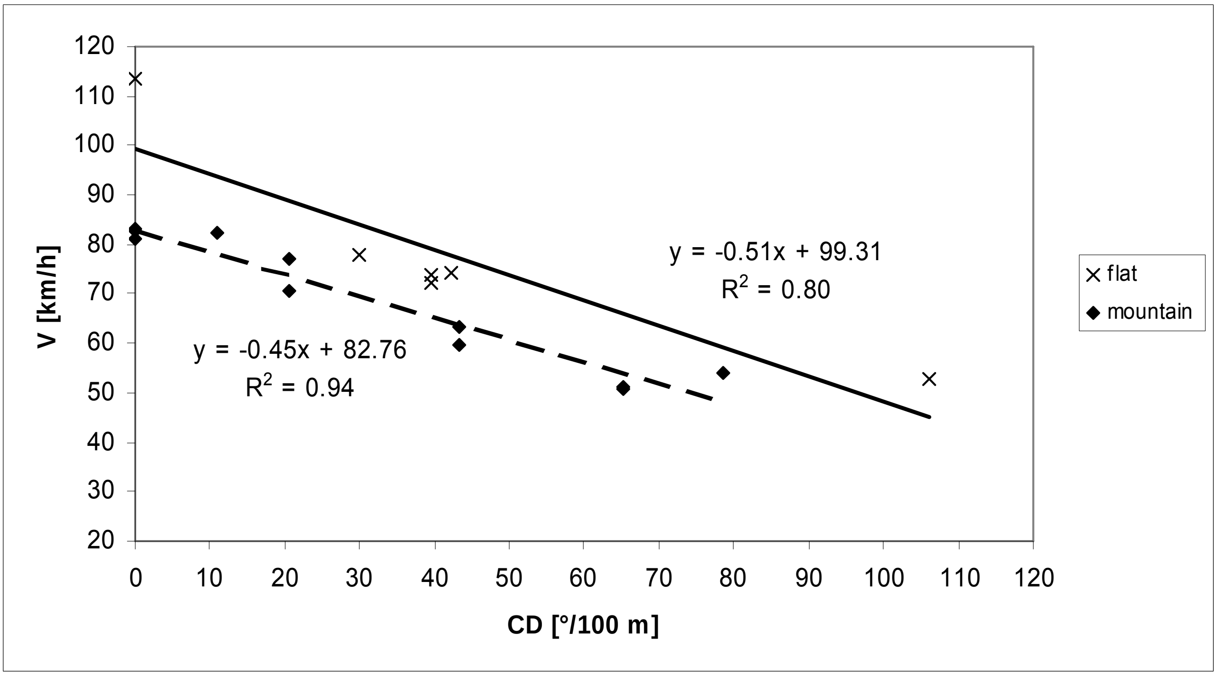


Figure 21 Regression Model for operating speed.

Equation (11) is valid for local two lane rural roads in flat environment (SP 69 II, 104, S.C. 4) instead equation (12) can be used to estimate V_{85} for roads in mountain environment (SP 94, 57, 4 II, 28 II, 231).

Equations (11) and (12) were obtained from a survey of vehicle operating speeds. The measurements were carried out with a dual-beam laser instrument located transversely across the road. In order to achieve a precision of 1.5 km/h in the estimation of the average speed, at a confidence level of 95% for each section, at least three hundred "isolated" vehicles were measured in good weather and daylight conditions. The measurements were carried out at the midpoint of the curves and at the midpoint of the long tangent between curves.

4.3.2 Roadside Hazard

Road Safety Inspection Accident Severity factor is equal to:

$$RSI\ AS = RSI\ AS_{roadside} = 1 + WS_{roadside} \times P_{roadside} \times \Delta AS_{roadside} \quad (13)$$

where:

$RSI\ AS_{roadside}$ = Road Safety Inspection Accident Severity factor of the safety issue roadside;

$WS_{roadside}$ = Weighted Score of the safety issue roadside;

$P_{roadside}$ = proportion of accidents related to the issue roadside, equal to the proportion of run off the road accidents (0.30 for Catania province).

$\Delta AS_{roadside}$ = estimated relative increase in accident severity due to the issue j. This value was assumed equal to 2 considering the maximum increase in proportion of injury accidents due to roadside hazard [AASHTO, 1996; Elvik et al,. 2004].

Weighted Score of the safety issue roadside is computed as follows:

$$WS_{roadside} = \frac{\sum_{k=1}^{2\times n} \max_i (Score_{ik} \times Weight_i)}{2 \times n \times 5} \quad (14)$$

where:

$Score_{ik}$ = Score of the roadside safety issue i in the section k (0, 0.5 or 1);

$Weight_i$ = relative Weight of the roadside safety issue i (see Table 12).

RSI AS evaluate the following roadside items: embankments, bridges, dangerous terminals and transitions, trees, utility poles and rigid obstacles, ditches. Relative increase in accident severity has been calculated by using the AASHTO severity indices and accident cost values [AASHTO, 1996]. In relation to design speed, which has been selected equal to 90 km/h, severity indices for each roadside feature define the probability of injuries and fatalities, given a collision. The greater the severity index, the greater the accident cost. As safety issues representing high risk problems, the following scenarios have been considered:

- unshielded embankments with great slope (h > 3 m and i ≥ 2/3);
- bridges shielded with ineffective barriers (90% of vehicles contained by the barriers);

- not breakaway terminals (fish tails, buried in the ground, etc.);
- trees with diameter greater than 300 mm close to the carriageway;
- rectangular or trapezoidal ditches close to the carriageway.

Basing on accident costs corresponding to the afore mentioned scenarios, different weights of the roadside issues have been established (Table 12) [AASHTO, 1996].

Table 12 Relative Weights of the Roadside Safety Issues.

Detailed safety issue	Related weight
Embankments	**3**
Bridges	**5**
Dangerous terminals and transitions	**2**
Trees, utility poles and rigid obstacles	**2**
Ditches	**1**

5 DESIGN ALIGNMENT EVALUATION

The evaluation of the safety factors linked to the horizontal alignment is related to the analysis of alignment design consistency and design standards agreement.

5.1 Design consistency of horizontal curves

Design consistency is evaluated through an overall Safety Module, based on quantitative criteria for the evaluation of the endangerment of two-lane rural roads [Lamm et al., 1999; Lamm et al., 2002, Lamm et al, 2006] proposed by prof. Lamm of the University of Karlsruhe which define three different levels of judgment (good, fair, poor) for different degree of safety respect to horizontal alignment consistency.

The safety evaluation process used is based on quantitative consistency measurements according to Good (sound), Fair (tolerable), and Poor (dangerous) design practices, which allow the quantified measurements of the following:

- design consistency, related to the difference between the operating speed, represented by the 85th-percentile speed (V_{85}), and the design speed (V_d) of the observed roadway section (Safety Criterion I);
- operating speed consistency, related to the difference in V_{85}, between two successive geometric elements (Safety Criterion II);
- driving dynamic consistency, determined by the difference between side friction assumed (f_{RA}) and demanded (f_{RD}), (Safety Criterion III).

As the differences between the two factors that characterize the various safety criteria increase there is a progressive decrease in the degree of consistency and thus a probable increase in dangerous situations. All factors ($V_{d,}$ $V_{85,}$ $f_{RA,}$ f_{RD}) are related to the curvature change rate of the single curve (CCR_{si}) which results the most important parameter to explain most of the variability in alignment design.

The formula for determining CCR_{si} is given by the following equation:

$$CCR_S = \frac{\left(\frac{L_{Cl1}}{2R} + \frac{L_{Cr}}{R} + \frac{L_{Cl2}}{2R}\right)}{L} \times \frac{200}{\pi} \times 10^3 = \frac{\left(\frac{L_{Cl1}}{2R} + \frac{L_{Cr}}{R} + \frac{L_{Cl2}}{2R}\right)}{L} \times 63{,}700 \qquad (15)$$

where:

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

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

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

R = radius of circular curve [m],

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

In comparison with accident investigation based on six large international databases, it could be shown that increasing CCRs-classes correspond to increasing mean accident rates (AR) and mean accident cost rates (ACR). Thus, based on accident research, it can be assumed that the proposed CCR_S-ranges ($CCR_S \leq 180$; $180 < CCR_S \leq 360$; $CCR_S > 360$ gon/km) represent a sound classification system for the arrangement of good, fair and poor design practices in modern highway geometric design (Table 13).

Table 13 Quantitative Ranges for Safety Criteria I to III for Good, Fair, and Poor Design Classes.

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

Legend:

CCR_S = curvature change rate of the single curve [gon/km] ,

V_d = design speed [km/h] ,

$V85_i$ = expected 85th-percentile speed of design element “i” [km/h] ,

f_{RA} = side friction “assumed” [-] ,

f_{RD} = side friction “demanded” [-] .

Notes:

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

As shown, all three criteria are evaluated in terms of three ranges, described as "good", "fair (tolerable)", and "poor", with cut-off values between the ranges.

Finally, for a simplified general overview of the safety evaluation process for network investigations, the three safety criteria were combined in an overall safety module.

Based on comparative analyses of the actual accident situation, it was proved [Lamm et al., 1999; Lamm et al., 2002, Lamm et al, 2006] that the three individual safety criteria can be equally weighted. A specific weighting factor is assigned to each design level. Good design is classified by the weighting factor of "+1.0", fair (tolerable) design is described by the factor "0.0" and for poor design the factor "-1.0" becomes relevant. Summing up the weighting factors for the individual safety criteria, the calculated average value x represents, in combination with the given limiting ranges, an evaluation for the safety module as shown in the following:

$x \geq 0.5 \rightarrow$ good (+);

$-0.5 < x < 0.5 \rightarrow$ fair (o);

$x \leq -0.5 \rightarrow$ poor (-).

5.2 Design standard check

Referring to Italian Design Standard Guidelines [Italian Ministry of Infrastructure and Transport, 2001c] two checks were carried out with respect to tangent length TL:

A) Maximum length of tangents (TL_{max})

B) Minimum length of tangents (TL_{min})

The Italian Guidelines for check A) in order to avoid fatigue and dazzle during night driving establish that tangents must have a length less than 22 times the speed design (km/h) of stretch under analysis:

$(TL_{max}) < 22\ V_d$

Respect to ceck B) Italian Guidelines assess that a straight element to be perceived as a tangent needs a minimum length in function of the design speed, as reported in Table 14 [Italian Ministry of Infrastructures and Transports, 2001c].

Table 14 Tangents minimum length vs Design Speed (rural two lane roads) .

Design Speed [km/h]	40	50	60	70	80	90	100
TL_{min} [m]	30	40	50	65	90	115	150

In the case that at least one of the two checks are not verified the score for Safety Index Evaluation is 0.1, vice versa it is equal to 0.

An example real-world application of the procedure is presented in Table 15 [Cafiso et al, 2007 b].

Table 15 Example Real-World Application of Procedure (Road SP4II, Section 1)

	Accesses	Cross Section	Delineation	Markings	Pavement	Sight Distance	Signs
L (km)	3.463						
AADT [(1,000 vehicles per day)]	4.10						
Exposure factor = L × AADT	**14.197**						
WS_j	0.287	0.147	0.618	1.000	0.037	0.066	0.015
ΔAF_j	1.350	1.000	0.300	0.200	0.100	0.500	0.200
P_j	1.000	0.600	1.000	1.000	1.000	1.000	1.000
$AF_j=1+WS_j\times\Delta AF_j\times P_j$	1.387	1.088	1.185	1.200	1.004	1.033	1.003
$RSIAF=\prod AF_j$	2.233						
WS_{GD}	0.064						
ΔAF_{GD}	7.000						
P_{GD}	0.450						
$GDAF=1+WS_{GD}\times\Delta AF_{GD}\times P_{GD}$	1.202						
Accident Frequency factor = RSI AF × GD AF	**2.683**						
V_{85} (km/h)	76.94						
V_{base} (km/h)	90						
$WS_{roadside}$	0.253						
$P_{roadside}$	0.300						
$\Delta AS_{roadside}$	2.000						
$RSIAS_{roadside} = 1+WS_{roadside}\times P_{roadside}\times\Delta AS_{roadside}$	1.152						
Accident Severity factor = V_{85}/V_{base} × RSI $AS_{roadside}$	**0.985**						
SI = Exposure × Accident Frequency × Accident Severity	**37.505**						

6 ROAD SAFETY INSPECTIONS

Nowadays, Road Safety Inspections (RSI) are recognized as an effective tool for identifying safety deficiencies of road infrastructures. They represent a low cost process for the evaluation of the network safety performance. Its applicability in rural local roads, where accident data generally do not give enough information for the safety analysis, make the procedure very attractive. However, due to the subjective nature of the process RSI may give rise to disagreements which limit their effectiveness. Various countries adopted RSI procedures but, in the main, they are not operational in nature. Basing both on the international experience [Austroads, 2001; EU DG_TREN, 2003; EU Road Federation, 2002; Italian Ministry of Public Work, 2001b; Montella A. et al., 2002; Montella A., 2005; PIARC Committee, 2004; Road Directorate, 1997; TAC 2004] and on the project experience [Cafiso et al., 2004], a safety inspection operative manual has been written [Cafiso et al., 2005 b, Cafiso et al., 2007 a].

6.1 Road safety inspections international current practice

6.1.1 Australasia

6.1.1.1 New Zealand

In New Zealand, safety reviews, which are defined safety audits of existing roads, are part of the national road safety strategy. In 1990, Transit New Zealand, which is responsible for managing the national road network (state highways), began examining the Road Safety Audit (RSA). Safety audit of existing roads started in 1995, essentially as a tool to determine whether a road controlling authority is doing a good job in respect of road safety. Draft procedures were produced in 1996 and revised in 1998 [Transfund, 1998].

The audits aim to discover the general themes and trends. They do not aim to audit every road, nor do they aim to identify every deficiency on every road audited. The audits are more like global overviews than detailed inspections.

Approximately 6 audits of existing roads are conducted each year. A central record of existing road safety audits (approximately 35) are retained on a central database. The database has a number of uses [Appleton I. 2001]:

- it enables authorities' performances to be monitored over time – hopefully they will improve;
- it can record the implementation of the audit teams' recommendations;
- it can be interrogated for common recurring themes. Transfund has started a series of articles that describe these recurring themes and offer advice on how they may be addressed.

6.1.1.2 Australia

In 1994, Austroads released a broad set of guidelines for a national road safety audit program [Austroads, 1994] , which has been revised in 2001 [Austroads, 2001]

The guidelines specifically address the safety review of the existing roads. The aim is to ensure that the safety features of a road are comparable with the functional classification of the road, and to identify any feature which may develop over time into safety concern [Jordan p., 2002] Regular audits of existing roads allow road safety hazards to be identified before they result in accidents.

Two levels of inspection are defined: the preliminary level and the detailed level. The first level involves a broad assessment of the route, highlighting what major problems exist and where they are located. The second level follows, with an inspection of the selected problem locations in more detail, highlighting specific issues and making specific recommendations.

Austroads states that ideally a program of safety reviews that covers every road in the network should be developed. Individual states are incorporating road safety audits at different rates throughout Australia. In New South Wales twenty percent of existing roadways within all regions are to be audited to identify deficiencies in existing roads and identify priorities for action.

In Australia, a formal auditor accreditation exists. An auditor has to meet the following criteria:

- have a minimum of five years experience in road design, traffic engineering; or closely related road safety discipline;
- have successfully competed a training course approved and recognized by the State Road Authority;
- certify that he has maintained current knowledge and experience in road safety auditing.

To be a designated audit team leader or a senior auditor, an individual has to also satisfy the following criterion:

- have participated in at least five road safety audits under the guidance of a senior road safety auditor.

6.1.2 North America

6.1.2.1 Canada

In Canada, road safety audits have been introduced in different form across the country. In 1998, the Insurance Corporation of British Columbia released a Draft Discussion Document to raise awareness and stimulate a discussion on audits [Halmiton Associates Consulting, 1998]

In 1999, the University of New Brunswick issued the Road Safety Audit Guidelines document [University of Brunswick TG, 1999], drawing on the audit experiences in New Brunswick. In 2001, the Canadian Road Safety Audit Guide [TAC, 2001] has been released.

Existing roads safety reviews are intended as a mean to address potential collision risks before collisions start occurring. To date, both in urban and rural area, numerous reviews of existing facilities have been undertaken and the Canadian Guide to In-Service Road Safety Reviews was edited for the Transportation Association of Canada [TAC, 2004].

6.1.2.2 USA

In 1996, the Federal Highway Administration (FHWA) dispatched a scanning team to evaluate the road safety audit process in Australia and New Zealand to investigate their applications of RSAs and to determine if that tool would have added value in advancing U.S. safety practices. [FHWA, 1997a] The proactive RSA practice and its wide acceptance were recognized by the team as adding value to road safety practices.[FHWA, 1997b]

The program participants recommended that a United States pilot study be conducted. Subsequently, the FHWA started a Road Safety Audit Pilot Project in 1998. The project began by auditing road projects. The application of RSAs and RSARs is in its infancy in the United States, with only a few states having safety pro-grams that include either an RSA or RSAR component. However, as a result of training, more states appear to be willing to try these approaches to enhance safety. In particular, thirteen states indicated the Road Safety Audit Reviews were part of their state's safety program.[TRB, 2004]

6.1.3 EU

6.1.3.1 Euro RAP and other activities

In 2002 The AA Foundation for Road Safety Research launched its "European Road Assessment Program", an European wide program whose core objectives are

- to reduce deaths and life-treating injuries on Europe's roads by systematically assessing risk and identifying safety shortcomings that can be addressed with practical road-improvements measures
- to put assessment of risk at the heart of strategic decisions on route improvements, crash protection and standards of route management.

It is a sister program to the European New Car Assessment Program (EuroNCAP) which awards stars to roads for safety and produces maps describing risk of traffic accidents on routes of states involved in the project, as the starting point for a series of demonstration assessments or reviews. These reviews are check-list based assessments of existing roads, concentrating on Safety Audit techniques rather than historical accident data. Part of the EuroRAP program is the development of a procedure for "drive through" inspections of routes carried out in specially equipped vehicles, in

which inspectors assess and score each road's major safety features and hazards– the Road Protection Score (RPS).
The RPS describes the protection from accidents that a road provides (elements of primary safety) and the protection from injury when collisions do occur (secondary safety). The results show where safety gains can be obtained and, where this is not cost effective, how some improvement can be made by reducing traffic speed [Lynam D. et al., 2004].
The results of the project co-funded by the EU "Guidelines to Black Spot management: Identification and Handling" [ERF, 2002] Road Safety Inspections are indicated like accidents preventive measures. The main objectives of the development of the inspections are to diminish accident frequency and severity, to reduce the accident costs, to guarantee that every road have optimal safety conditions.
The European Commission of the Directorate General' on Energy and Transport [EU DG_TREN, 2003] highlights the role of the RSI as part of a systematic approach to road safety, evidencing as expected benefits from RSI application: the removal of road defects, the coordination of structures and paving operations maintenance, the safety improvement for all road users, the implementation of low costs interventions. The Directive aims to establish infrastructure safety as an objective in its own right at all stages of the planning, design and use of roads [EU Parliament, 2007]. A uniformly high level of safety should prevail on the roads of all the EU member States. Care must be taken to ensure that limited resources are targeted to improving road safety. To achieve these aims, the Directive proposes four procedures:

1. Impact assessment of the effect of road building on safety;
2. Safety Audits;
3. Improving safety in existing road network;
4. Safety Inspections, defined as regular inspections of road infrastructure by trained staff that are a binding requirement.

To date, the Directive was not still approved.
In quantitative terms the European Road Federation (ERF) assesses that 30 % of the problems identified during RSI could transform itself in an accident cause in the following 5 years [Papì J., 2005].

6.1.3.2 UK

In the UK the 1988 Road Traffic Act places a statutory duty on local authorities to "carry out studies into accidents on roads", and "to take such measures as are appropriate to prevent such accidents".

Since the early 1970's many local authorities have therefore undertaken work to identify high risk sites, and implement "low-cost" improvement schemes. Much of this work has been monitored, and can therefore be shown to be highly cost-effective.

The UK government has set targets in terms of casualty reduction since the 1980's. In 1987 a target of a one-third reduction in road accident casualties was set for the year 2000. This was met for killed and serious (KSI) casualties but not for slights. In 2000 new targets of a 40% reduction in KSI, a 50% reduction in KSI for children and a 10% reduction in slights expressed as a flow based accident rate were established for 2010. A 2001 U.K. publication entitled *Practical Road Safety Auditing* was edited [Proctor S. et al., 2001]

6.1.3.3 Denmark

Since 1997 Denmark applies road safety audit on new road project for systematic prevention of road accidents, according to the procedures described in the Danish Manual of Road Safety Audit [Road Directorate, 1997].

In October 2000 the Danish Road Directorate launched the project "Road Safety Audit of Existing Roads" [Langer K.A., 2001]. Such an audit is to be seen as a supplement, and not as an alternative, to other safety measures on existing roads, e.g. black spots treatment.

The project concerns a road safety audit of a road section in Denmark of about 35 km on the island Lolland. The stretch of road represents different types of roads: motorway, expressway, and highway with small villages along the route.

In the fall of 2000, the road section was systematically inspected for all the matters that might be of importance to the traffic safety. After the inspection, an audit report listing all commentaries and offering recommendations for possible solutions has been prepared. The comments have been given priority according to the seriousness of the relevant traffic safety problems at three levels.

6.1.3.4 Italy

In Italy, guidelines on road safety audits have been edited in 2001 [Italian Ministry of Public Works, 2001b] .The guidelines are based on pilot road safety audits and a research job carried out by the Universities of Naples, Palermo and Florence.

The pilot road safety audits have been carried out in September 2000 by road safety specialists of the Universities of Naples, Palermo and Florence (Italy) with the partnership of TMS Consultancy (UK). On existing roads, three pilot safety reviews have been carried out comprising a stretch of motorway, a stretch of rural two-lane single carriageway highway and a small portion of an urban network.

Italian guidelines are divided in two sections: road safety audits of highway schemes and safety reviews of existing roads, that is, special emphasis on safety review is given.

Their goal is road safety improvement using a specific approach able to integrate several aspects (technical, behavioral, physiological).

In such field, the implementation of safety measures represent an important tool for the evaluation of road risk conditions. Actually a renewal of the guidelines could be favorable for several reasons:

- they have been written in 2000 and they have not endured any review;
- they have been written having no basis on national experience (apart the pilot project);
- as first version of a extremely innovative guidelines they have a mainly scientific character, rather than practical;
- they are lacking in specificity since they deal with every types of new and existing roads.

To date, some administrations carry out safety reviews of part of their network. In the last years several provinces have defined safety reviews as part of their planning on existing roads, in both rural and urban area.

6.1.3.5 Germany

In Germany, the Federal Ministry for Traffic and Buildings
(BMVBW) has recommended in 1999 to reunite, the relative jobs of "Road Safety Audits" into the Committee of research for Roads and Transports (FGSV), which has instituted 2.0.2 Group "Road Safety Verification" (SAS). The target of this research group is the elaboration of an appropriate instrument for administrative procedure of road safety verification. In the 2002 FGSV has published the "Directives for road safety verification" [ESAS, 2002]. Although it has been highlighted that road safety requirements are already contained in the technical guidelines, the norms of the 2002 come understandings like instrument of support, the above mentioned directives are an integration and optimization in the process of planning and design of the roads, as part of the quality management of road network.

6.1.3.6 Spain

The Spanish Authorities have thought that the checklists of the other Countries were too much general and have proceeded to the definition of own checklists. In any case the structure of the RSA has maintained a such shape in order to not have restrictions to the contribution of the safety inspectors. Moreover, to the aim to simplify the operating procedures and put together the safety criteria, the checklists must on one side comprise all the aspects that are necessary to identify, to estimate and to classify respect to safety and on the other they must allow the formulation of homogenous results in terms of assessments between various groups of inspection.. They are divided in four main sections [Javer et al. 2001]: 1) dual carriageway 2) single carriageway roads, 3) urban roads, 4) intersections.

6.1.3.7 Norway

Experience from completed road safety inspections in Norway shows that many roads have design faults that can lead to serious accidents. Undertaking road safety audits that can reveal such faults will be a central measure in the Vision Zero effort. In 2003 the Directorate of Public Roads made an evaluation of results and experiences with undertaking road safety inspections of a total of 56 road sections. Moreover, the Action Program for 2006 – 2015 stated that the Public Roads Administration will intensify its work on road safety inspections on national roads with high injury severity density. In October 2006 the Norwegian Public Roads Administration published the guidelines handbook "Road Safety Audit and Inspections" [NPRA, 2006] based on the "Preliminary guide for road safety audit of existing road and traffic projects" and additional material has been taken from "Development of road safety inspection methods for existing roads". The handbook contains procedures, checklists and other information on how road safety inspections of existing road shall be carried out.

6.1.3.8 Austria

Road Safety Inspections in Austria are regarded as a periodical controlling instrument of the existing road network (including roadsides), independently of number of accidents, which allows the implementation of remedial measures before accidents occur. However, selection of inspection sites depends on the actual number of occurred accidents, priority given to sections with an accident rate above average. In Austria, Road Safety Inspection of motorways and expressways started in July 2003, with a total of 21 inspected sections at the end of 2006. The Austrian Road Safety Board is a partner in RIPCORD-ISEREST European project with particular respect to WP 5 "Best practice guidelines on Safety Inspection", whose goals are:

- Standardized approach for RSI in Europe
- Setting up of implementation plan
- Developing of checklists
- Carrying out of practicability tests

RSI includes accident analysis – accident map, analysis of the traffic conditions, analysis of the constructional elements, inspection – on-site visit, meetings and interviews with motorway maintenance unit and traffic police, analysis of road surface (pavement rating - ruts, friction, …), analysis of road maintenance measures, analysis of road environment, in order to define remedial measures (short-, medium-, long term) [Fessl 2006].

6.2 Operative procedures for road safety inspections

The IASP safety inspection procedures reflect the scope of the project and give some quantitative safety evaluation, to the best extent compatible with a methodology mainly based on subjective evaluations. The research was aimed at defining a RSI operative procedure able to improve the effectiveness and reliability of the methodology. For this purpose, the research was focused on the review framework, on the reviewers and client roles and, with special emphasis, on the methodologies used for identifying and ranking the safety problems. Phases of the inspection procedures have been defined: preliminary inspection, general inspection, detailed inspection and night time inspection. For each phase, objectives of the inspection, needed equipments, inspection methodology and roles of each team member have been defined and described. General inspection checklists, relative to the main safety features which may be present with continuity along two lane rural roads, and detailed inspection modules, differentiated for segments and intersections, have been defined. Moreover, criteria for identifying and ranking safety issues have been briefly reported. Last, the review report contents and format have been described.

The procedure has proved to be effective to identify most safety issues. As far as alignment geometric defects and design consistency evaluation is concerned, RSI are not as valuable such as the quantitative methods, that may usefully integrate the inspection results.

As a research outcome, a RSI operative manual has been edited. It allows to transfer to other road agencies the acquired knowledge and to obtain a greater objectivity in the inspection process.

6.2.1 Actors involved in the process

Actors involved in the process are the inspection team and the client.

The team must comprise three or more people because: 1) the road inspections, due to operative reasons, require at least three inspectors; 2) diverse backgrounds and different approaches of different people create cross-fertilization of ideas and are beneficial in problems identification and analysis. Main requisites of the safety inspection team are independence and qualification. Independence from the design, maintenance and operation of the road to be inspected is needed since the team has to look only at safety problems applying "fresh eyes" to the task. Qualification is vital for the process to be effective, given that addressing the safety problems and providing recommendations to eliminate or mitigate them doesn't give any real benefit in terms of accident reduction if the task is not based on sound road safety engineering experience and practice. Qualification requires both deep knowledge of the road safety principles and the familiarization with the IASP procedures.

The client is the road agency. Before the inspection starts, the client selects the roads to be inspected and the team. After the inspection, the client decides upon implementation of safety measures recommended by the team. An innovative aspect of the IASP procedures is the active participation of the client in the inspection phase. The client participates as an observer to the site inspections and to the preliminary in office discussion about general safety problems. The team has advantage from discussion with the client because obtains in depth information about site history, and maintenance and rehabilitation procedures and practices. The client has advantage arising from interaction with the inspection team and has a better understanding of the procedure and the technical reasons relating to the problems identification.

6.2.2 Road inspections and problems identification

6.2.2.2 General Aspects

More site inspections are required:

- preliminary inspection, in daytime, aimed at understanding the general road safety conditions and its relationship with surrounding land use, terrain and road network;
- general inspection, in daytime, aimed at examining the general safety concerns along the road segments;
- detailed inspection, in daytime, aimed at examining in detail safety concerns of specific sites;
- night time inspection, aimed at analyzing the road perception without natural lighting.

6.2.2.3 Preliminary Inspections

Objective

Main objective of the preliminary inspections is trying to investigate how the road environment is perceived, and ultimately utilized by different road users. The analysis has to look not only the road, but also the environment which can interact with the road and the road users.

Length of inspection

Any preliminary inspection should interest not more than three-four different roads of the same network, with a total length not greater than 100 km.

Recommended team composition and equipments

At least three team members are needed: the driver, the inspector in front seat and the inspector in back seat. Recommended equipments are GPS receiver and digital video camera.

Procedure

Each road is ran in both directions at normal speed, that is the prevailing traffic speed. During the inspection a video recording is performed and inspectors comments are recorded in the same video-tape. Driver calls traveled distance and refers about corrective maneuvers and driving perception of the road. Inspectors on front seat and back seat make safety comments. GPS receiver is used to locate useful points of the road such as mile stones and intersections.

6.2.2.4 General Inspections

Objective

Main objective of the general inspections is to obtain most important information about the safety issues and their location along the route.

Length of inspection

Any general inspection can interest not more than 30 km.

Recommended team composition and equipments

At least three inspectors are needed: the driver, the inspector in front seat and the inspector in back seat. Recommended equipments are GPS receiver, digital video camera and checklists (see Table 15 and Table 16).

Procedure

The road is ran in both directions at very low speed (about 30 km/h): 1) video recording is performed, 2) the driver calls travelled distance any 100 m, 3) inspectors in front and back seats compile the checklists. GPS receiver is used to locate the starting and the ending points of inspection.

6.2.2.4.1 Checklists Format

IASP checklists are very synthetic, since they relate only to main safety features which usually are present with continuity along two lane rural roads. Features which concern design consistency are not considered because in the IASP project design consistency is performed as a separate quantitative procedure [Harwood D. et al.,2000; Lamm et al., 1999; Lamm et al., 2002, Lamm et al., 2006].

Checklists must be filled in both directions. Front seat and back seat reviewers, which have different views of the road, compile different checklists (Table 16 and Table 17) with a step of 200 m (24 s at 30 km/h). In order to simplify the reviewers task, any checklist is split in two parts: part A has to be compiled on site, part B can be compiled during the video examination performed in the office. Safety issues are ranked as high level problem and low level problem. If an high level problem occurs, the reviewer fills the gray box, if a low level problem occurs, the reviewer fills the blank box. Since a good friction evaluation requires instrumented measures, the friction problems are not ranked. Ranking of safety issues can be used both as an aid for the prioritization of the safety measures and as an aid to road agencies in measuring the effectiveness over time of their safety improvement programs.

Table 16 Checklist for General Inspection: Module for Front Seat Reviewer.

	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
PART A										
Roadside										
Embankments										
Bridges										
Dangerous terminals and transitions										
Trees, utility poles and rigid obstacles										
Ditches										
Alignment										
Inadequate sight distance on horizontal curve										
Inadequate sight distance on vertical curve										
PART B										
Accesses										
Dangerous accesses										
Presence of accesses										

Table 17 Checklist for General Inspection: Module for Back Seat Reviewer.

	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
PART A										
Cross section										
Lane width										
Shoulder width										
Pavement										
Friction										
Unevenness										
Delineation										
Chevrons										
Guideposts and barrier reflectors										
PART B										
Signs										
Warning signs, regulation signs										
Markings										
Edge lines										
Center line										

Checklists Compilation Criteria

Criteria for identifying and ranking safety issues are briefly reported in Table 18 to Table 25. In the main report [Cafiso et al., 2005 b] detailed explanations and reference photographs are reported [Cafiso et al., 2007a].

Table 18 Criteria for assessing safety problems related to roadside.

Safety issues	Criteria for assessing high level problems	Criteria for assessing low level problems
Embankments	Unshielded or shielded with ineffective barriers embankments (h > 5 m) Unshielded or shielded with ineffective barriers embankments with great slope (h > 3 m) Embankments shielded with low containment safety barrier with great slope (h > 3 m) if dangerous obstacles in the bottom are present	Unshielded or shielded with ineffective safety barriers embankments with great slope (1 < h ≤ 3 m) Embankments shielded with low containment safety barrier (h > 3 m) if high commercial vehicles traffic is present Embankments shielded with discontinuous barriers (h > 3 m)
Bridges	Ineffective barriers Low containment barriers if high commercial vehicles traffic is present	Not correct installation conditions Medium containment barriers if the bridge overpasses roads or railways
Dangerous terminals and transitions	Not breakaway terminals (fish tails, buried in the ground, etc.) Not connected barriers and walls Not connected roadside barriers and bridge rails Not connected roadside barriers Barriers and walls connected without transition Roadside barriers and bridge rails connected without transition Roadside barriers connected without transition	Inadequate transition between steel barriers
Trees, utility poles and rigid obstacles	High diameter trees located at distance less than 3 m from carriageway Concrete utility poles located at distance less than 3 m from carriageway High diameter steel utility poles located at distance less than 3 m from carriageway Rigid obstacle with exposed front face or corner located at distance less than 3 m from carriageway	Low diameter trees located at distance less than 3 m from carriageway High diameter trees located at distance between 3 and 8 m from carriageway Concrete utility poles located at distance between 3 and 8 m from carriageway Low diameter steel utility poles located at distance less than 3 m from carriageway High diameter steel utility poles at distance between 3 and 8 m from carriageway Rigid obstacle with exposed front face or corner located at distance between 3 and 8 m from carriageway
Ditches	Rectangular or trapezoidal ditches located at distance less than 3 m from carriageway	Rectangular or trapezoidal ditches located at distance between 3 and 5 m from carriageway

Table 19 Criteria for assessing safety problems related to alignment.

Safety issues	Criteria for assessing high level problems	Criteria for assessing low level problems
Inadequate sight distance on horizontal curve	Available sight distance less than 50 m caused by continuous visibility obstructions inside the curve	Available sight distance greater than 50 m but smaller than SSD or inadequate to give the correct road perception Discontinuous visibility obstructions inside curve
Inadequate sight distance on vertical curve	Available sight distance less than 50 m	Available sight distance greater than 50 m but smaller than SSD or inadequate to give the correct road perception

Table 20 Criteria for assessing safety problems related to accesses

Safety issues	Criteria for assessing high level problems	Criteria for assessing low level problems
Dangerous accesses	Accesses located on horizontal curves Accesses located on crests Accesses located on sites with poor visibility Accesses located close to intersections	Narrow accesses Accesses without markings Accesses without delineators Unpaved accesses
Presence of accesses	Three or more accesses in one stretch 200 m long	One or two accesses in one stretch 200 m long

Table 21 Criteria for assessing safety problems related to cross section.

Safety issues	Criteria for assessing high level problems	Criteria for assessing low level problems
Lane width	Width < 2.75 m Width > 4.50 m	2.75 ≤ Width < 3.25 m 3.75 < Width ≤ 4.50 m
Shoulder width	Width < 0.30 m	0.30 ≤ Width < 1.00 m

Table 22 Criteria for assessing safety problems related to pavement.

Safety issues	Criteria for assessing high level problems	Criteria for assessing low level problems
Friction	Polished aggregate Bleeding Raveling Low macro texture	
Unevenness	Steel drains on carriageway Disrupted joints Potholes on curves or close to intersections Deep potholes on tangent Shoving on curves, approach to curves or close to intersections High shoving on tangent Rutting on curve Patches on curve	Low shoving on tangent Low potholes on tangent Rutting on tangent Patches on tangent

Table 23 Criteria for assessing safety problems related to delineation.

Safety issues	Criteria for assessing high level problems	Criteria for assessing low level problems
Chevrons	Missing chevrons on severe curves Chevrons placement inadequate to give correct perception of the total length of the curve Chevrons placed only in one direction Ineffective chevrons since high deterioration Not reflective chevrons Chevrons with directional arrows in the wrong direction Chevrons obscured by vegetation	Missing chevrons on moderate curves Chevrons spacing inadequate to give correct perception of the curve Low reflective chevrons Local discontinuity of chevrons Partially obscured chevrons
Guideposts	Missing guideposts Missing reflectors on guideposts Missing reflectors on roadside safety barriers Missing reflectors on roadside walls Ineffective reflectors Guideposts with dangerous placement (e.g., inside ditches)	Variable height of reflectors along the road Low reflective guideposts Local discontinuity of guideposts

Table 24 Criteria for assessing safety problems related to signs.

Safety issues	Criteria for assessing high level problems	Criteria for assessing low level problems
Warning signs, regulation signs	Missing curve warning sign Missing crest warning sign Not visible curve warning sign Not visible crest warning sign Missing warning sign in dangerous situations	Curve warning sign faded or with low visibility Crest warning sign faded or with low visibility Yield sign missing, faded or with low visibility Advertisement located so as to disturb road users Indication signs incomplete or with low legibility Not consistent speed limit Unclear signs Wrong height signs

Table 25 Criteria for assessing safety problems related to markings.

Safety issues	Criteria for assessing high level problems	Criteria for assessing low level problems
Edge lines	Missing edge lines Very faded edge lines	Low faded edge lines Edge lines partially obscured by the vegetation
Center line	Missing center line Very faded center line	Low faded center line

General Problems and Recommendations

After the preliminary inspection, in the office, the team analyzes videos and (if wasn't done on site) compiles part B of the checklists. Checklists are compiled in both directions referring in particular to the right side. By brainstorming among the team members checklist results are examined and the final version of the checklists is edited.

In the problem analysis it is valuable to take into account both sides of the road. General problems not contained in the checklists can arise since checklists are an aid but must not limit the flexibility of the procedure.

Safety issues are classified as general problem if they are present along a substantial portion of the road (e.g., more than 30%). General problems require mass action safety programs. The manual [Cafiso et al., 2005 b, Cafiso et al., 2007a] suggests for each general problem the recommendation typologies. The checklists results, the safety comments recorded during the preliminary inspection and the manual suggestions are a valid support to formulate recommendations for general safety problems. Recommendations are engineering solutions to the reported problems. They indicate the type of measures, without specifying detailed technical issues.

Problems and recommendations are disaggregated in order to highlight the safety issues of each road feature, but road safety improvement requires an integrated approach where interaction between different measures must be taken into account.

As final result of the meeting, a preliminary report containing general problems and recommendations is edited. Moreover, some sites requiring specific inspection might be identified.

6.2.2.5 Site Detailed Inspections

Objective

The detailed inspection is aimed at a closer examination of sites which present specific safety issues.

Length of inspection

The inspection is focused on specific sites. The number of the sites for each inspection is limited only by the available time.

Recommended team composition and equipments

At least two inspectors are needed. Recommended equipments are: protective clothes with high retro reflectivity, GPS receiver, digital video camera, digital photo camera, measuring wheel or laser measurer, inclinometer, inspection modules with rigid support, stopwatch, laser gun (optional) and traffic counters (optional).

Procedure for road segments

The road is ran in both direction at low speed, stopping the car in sites which show the greatest safety problems or specific features which require investigation deepening. Other than those selected during the general analysis, more sites can be identified during the drive through. During the driving through photos related to general problems are taken. These photos can be added to the final report.

In the selected sites, the team performs the inspection by walking and observing both the road features and the road users behavior. Photos of identified problems and videos of dangerous behaviors are helpful both in the problem analysis and in the report writing.

Compilation of the site inspection module (Table 26) is strongly recommend since it gives the following benefits:

- focuses the identified safety issues;
- gives a chance to record the concerns raised during the inspection;
- synthesizes observation results simplifying the report writing.

Inspection module has some similarities with general checklists but contains more information which are acquired by detailed observations and are integrated by further information, such as:

- available sight distance;
- lane and shoulder widths;
- road users behaviors (speed, queues, braking, overtaking, traffic volume and composition, etc.);
- accident signs (damaged barriers, braking marks, etc.).

Procedure for intersections

Each intersection is ran both by car and by walking. The intersection inspection module (Table 27) is an aid for the inspectors but must not limit their task. Indeed, inspectors' task is very flexible and can comprise also integrative surveys that seem more appropriate in relation to the site conditions.

Road users' behavior analysis is one of the main task in the investigation. If critical traffic conditions occur, traffic counts (in the rush hour) and speed measurements can be acquired. If speed measurement are not carried out, sight distance adequacy evaluation can be performed by the stopwatch method [SETRA, 1998].

Table 26 Road Segments Inspection Module.

Site general description	
Street name:	Problem number:
ID GPS waypoint:	ID first and last photo:
– Curve: ☐ – Tangent: ☐ – Longitudinal grade: level ☐ slope ☐ – Embankment: ☐ Cut: ☐ Cut and fill: ☐ Bridge: ☐ Tunnel: ☐	
Problems description	
Horizontal alignment problems – Curve preceded by long tangent : ☐ – Series of curves: ☐ – Inadequate super elevation: ☐ – Super elevation measure: right lane ______ left lane ______ – Visibility obstructions: ☐ – Available sight distance: __________ Notes:	Vertical alignment problems – Crest: ☐ – Inadequate visibility: ☐ – Available sight distance: – Sag: ☐ – High longitudinal grade: ☐ Notes:
Cross section – Lane width: – Shoulder width: Notes:	Roadsides – Embankment inadequately shielded: ☐ – Bridge inadequately shielded: ☐ – Dangerous terminals and transitions: ☐ – Trees, utility poles, rigid obstacles: ☐ – Unrecoverable ditches: ☐ – Others: __________________________________ Notes:
Presence of accesses: ☐	Notes:
Inadequate friction: ☐	Notes:
Pavement unevenness: ☐	Notes:
Inadequate markings: ☐	Notes:
Inadequate signs: ☐	Notes:
Inadequate delineation: ☐	Notes:
Road users dangerous behaviors – High operating speeds: ☐ – Queues: ☐ – Wrong maneuvers o Late braking: ☐ o Dangerous passing: ☐ o Invasion of opposite lanes: ☐ Notes:	
Accident signs (damaged barriers, glasses on the pavement, braking marks, etc.): ☐	Notes:
Sheet 2 (not to scale)	
Site condition diagram:	Sketch of potential accidents:
Notes	Description of potential accident scenarios:

Table 27 Intersections Inspection Module.

Intersection general description	
Intersection type: ☐ T ☐ X ☐ Y ☐ Roundabout ☐ Other (specify)	
Name of intersecting streets:	
ID GPS waypoint:	ID first and last photo:
Problems description	
Horizontal alignment – Intersection located inside a curve: ☐ yes ☐ no – Intersection located outside a curve: ☐ yes ☐ no – Curve in one of the approach legs: ☐ yes ☐ no Notes:	Vertical alignment – Intersection located on a crest: ☐ yes ☐ no – Crest in one of the approach legs: ☐ yes ☐ no – High longitudinal grade: ☐ yes ☐ no – Intersection located on a sag: ☐ yes ☐ no – Continuity of the secondary road profile: ☐ yes ☐ no Notes:
Left turn and right turn lanes – Left turn lane: ☐ yes ☐ no – Too high left turn volume: ☐ yes ☐ no – Left turn volume count: – Right turn lane.: ☐ yes ☐ no – Too high right turn volume: ☐ yes ☐ no – Right turn volume count: Notes:	Channeling – Ghost island on secondary road: ☐ yes ☐ no – Curbed left turn lane: ☐ yes ☐ no – Inadequate canalization islands: ☐ yes ☐ no Notes:
Visibility obstructions: ☐ yes ☐ no	Notes:
Presence of accesses: ☐ yes ☐ no	Notes:
Roadside obstacles: ☐ yes ☐ no	Notes:
Inadequate friction: ☐ yes ☐ no	Notes:
Inadequate notice signs: ☐ yes ☐ no	Notes:
Inadequate direction signs: ☐ yes ☐ no	Notes:
Inadequate regulatory and warning signs ☐ yes ☐ no	Notes:
Inadequate markings: ☐ yes ☐ no	Notes:
Inadequate delineation: ☐ yes ☐ no	Note:
Road users dangerous behaviors – High approach speeds: ☐ yes ☐ no – Long queues: ☐ yes ☐ no – Wrong maneuvers o Late braking: ☐ yes ☐ no o Poor compliance of traffic regulations: ☐ yes ☐ no o Invasion of opposite lanes: ☐ yes ☐ no o Short gap acceptance : ☐ yes ☐ no	
Accident signs (damaged barriers, glasses on the pavement, braking marks, etc.): ☐ yes ☐ no	Notes:
Sheet 2 (not to scale)	
Intersection condition diagram:	Sketch of potential accidents:
Notes	Description of potential accident scenarios:

6.2.2.6 Night Time Inspections

Objective

Night time inspections are focused at understanding how the road is perceived in the night. Consequently, main focus is on markings, delineation and legibility of the road alignment.

Length of inspection

Any night time inspection should interest not more than 100 km.

Recommended team composition and equipments

At least three team members are needed: the driver, the inspector in front seat and the inspector in back seat. Recommended equipments are GPS receiver and digital video camera.

Procedure

Each road is ran at normal speed in both direction. Videos of the road and comments of the inspectors are recorded. Location of specific night time problems may be carried out by using the GPS receiver in cinematic modality.

The day after the inspection, a meeting in the office is carried out. Videos are examined and identified problems are annotated in the report.

6.2.2.7 Final Report

For each road, a specific inspection report is written [Cafiso et al. 2005 c]. The report is written in “problem/recommendation” format, where the problem is described in terms of safety issues and accident risk to a road user, and the recommendations are engineering solutions to the reported problem. After discussion among the inspectors, the final report is edited and signed. The report describes the analysis procedure and contains the study results, which are detailed and explained. It contains the following sections: 1) introduction (road name and location, dates of road inspections and other phases of the inspection process, team members and qualifications, information on meetings, information on data provided by the client, description of the procedure used to conduct the inspection); 2) segment general problems (graphs relative to nature, severity and extension of the safety issues, detailed description of the safety problems, identification of the potential accident scenarios, photos exemplifying the problems, description of recommendations aimed at eliminating or alleviating the safety problems); 3) segment specific problems (detailed description of the safety problems, identification of the potential accident scenarios, photos exemplifying the problems, description of the recommendations); 4) intersection problems (description of the general safety problems and recommendations, for each intersection: detailed description of the specific safety problems, identification of the potential accident scenarios, photos exemplifying the problems, description of the recommendations); 5) synthesis, in tabular format, of problems and recommendations; 6) concluding statement and signatures of the inspectors.

7 ESTIMATES FROM HISTORICAL ACCIDENT DATA

Introduction

Accident record systems have been developed and maintained by highway agencies to monitor the safety performance of their roadways, but they provide historical or retrospective data. An effective Road Management System needs not only the knowledge of the safety performance of a roadway in the past, but also the actual and the future ones. Moreover, historical accident data are an important indicator of the safety performance of a roadway, but they suffer from the weakness of being highly variable. Due to this high variability, it is difficult to estimate the long-term expected accident rate using a relatively short- time period sample of 1 to 3 years of accident data. This is especially true for rural roadway sections where accidents are very rare events and many locations experience no accidents, or at most one accident, over a period of several years. If a location has experienced no accidents in the past several years, it is certainly not correct to think that it will never experience an accident.

7.1 Data collection and road segmentation

A sample of about 100 km of two lane local rural roads was used in order to perform the IASP APM. On these roads a segmentation into homogeneous sections was carried out on the basis of their geometric alignment characteristics. Specifically, the homogeneous sections were chosen basing on cumulative curvature change rate of the single curve respect to the total length of the road and on presence of major junctions and railway crossings. In Figure 22 an example of road segmentation is shown and in Table 28 the beginning and final reference points of road sections for IASP sample are reported.

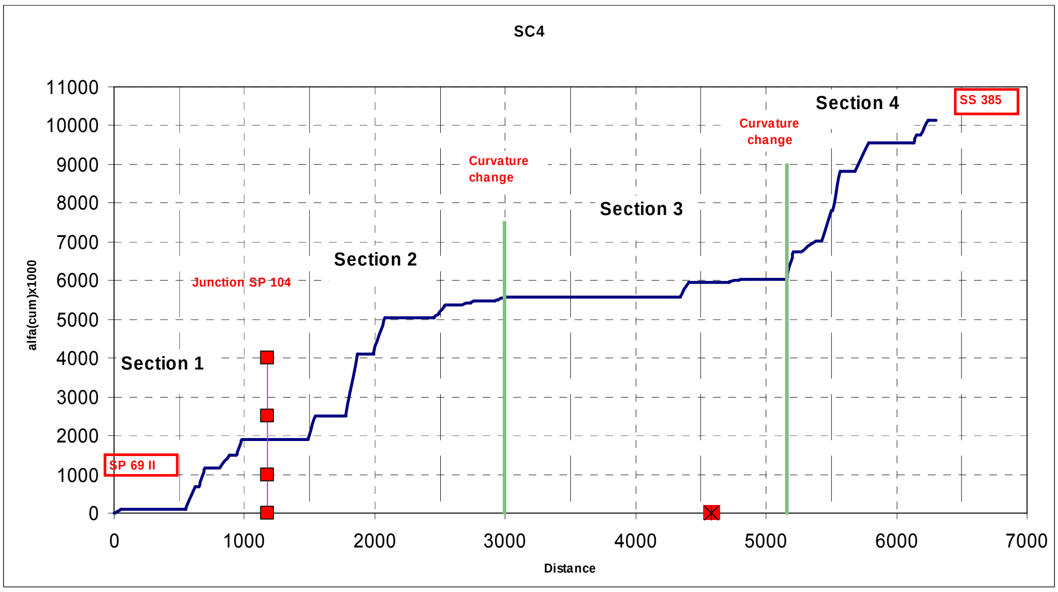


Figure 22 Example of segmentation into homogeneous Sections.

Table 28 Homogeneous Sections for IASP Road Sample.

Section	Road Name	Start section	End section
1	SP 4II	0	3463
2	SP 4II	3463	6245
3	SP 4II	6245	6884
4	SP 4II	6884	**9624**
5	SP 57	0	4505
6	SP 57	4505	5904
7	SP 69II	0	3084
8	SP 69II	3084	9510
9	SP 69II	9510	12625
10	SP 69II	12625	17953
11	SP 69II	17953	18991
12	SP 69II	18991	**20447**
13	SP94	0	5628
14	SP94	5628	13264
15	SP94	13264	15081
16	SP94	15081	**18069**
17	SP104	0	6854
18	SP104	6854	9263
19	SP104	9263	11483
20	SP104	11483	14357
21	SP104	14357	**16451**
22	SP231	0	**3887**
23	SC4	0	1175
24	SC4	1175	2990
25	SC4	2990	5155
26	SC4	5155	**6300**
27	SP 28II	0	1260
28	SP 28II	1260	4607
29	SP 28II	4607	7186
30	SP 28II	7186	**12460**

Furthermore, for each stretch the following information were collected:

- cross section data (type, lanes and shoulders width);
- geometric elements type (tangent, circular curve, transition curve);
- bending radius value;
- curvature angle deviation;
- length of geometric elements;
- location and typology of junctions;
- type and location of all fatal and/or accidents, occurred in the time period 1999 – 2003.

7.2 Generalized Linear Model and Empirical Bayes Estimate

The Accident Prediction Models (APMs) are an important instrument for evaluating road safety performance. These models explain accident occurrence as a function of traffic and geometric characteristics of road. For the IASP project, the Generalized Linear Model approach (GLIM) is used to calibrate an APM using as explanatory variables traffic and length of road segments. The procedure based on GLIM has the advantage of overcoming the limitations due to conventional linear regression in accident frequency modelling.

Many studies [Hauer et al., 1998; Jovanis P.P. et al,. 1986] have demonstrated the inappropriateness of conventional linear regression in modelling discrete, non-negative, and rare events such as traffic accident occurrence due to the non linear relationship with traffic volume and road length. The assumption of a Poisson or negative binomial error structure is recommended [Sawala Z. et al,. 2001]. Considering that accident data are typically over-dispersed negative-binomial distribution are more appropriate.

The development of the model was carried out using the Generalised Linear Model (GLIM) with a basic formula of two independent variables (L, ADT):

$$\hat{E}(Y) = e^{a_0} \times L^{a_1} \times ADT^{a_2} \qquad (16)$$

where:

$\hat{E}(Y)$ = Predicted accident frequency / 5 years;

L = segment length (km);

ADT = Average annual Daily Traffic (veh/day);

a_0, a_1, a_2 = model parameters.

The regression analyses were performed by use of the software packages GenStat 7.2 and SAS 8.2 (GENMOD procedure). The GLIM model obtained from the data is the following:

$$\hat{E}(Y) = e^{-5.861} \times L^{0.601} \times TGM^{0.747} \qquad (17)$$

Consideration of site-specific accident history data in the accident modification algorithm increases the accuracy of the predicted accident frequency.

The Empirical Bayes procedure provides a method to combine predictions from the APM ($\hat{E}(Y_i)$) with observed site-specific history data (O_i).

Using the APM based on negative binomial the Empirical Bayes estimate of the expected accident frequency (EBi) considering both the predicted and the observed accident frequencies is computed as [Harwood et al, 2000]:

$$EB_i = w\,\hat{E}(Y_i) + (1\text{-}w)\,O_i \tag{18}$$

where:

EBi = expected accident frequency based on a weighted average of $\hat{E}(Y_i)$ and Oi;

$\hat{E}(Y_i)$ = number of accident predicted by APM;

Oi = number of accidents observed during the specified period of time;

w = weight to be placed on the accident frequency.

The weight w is determined in the EB procedure as:

$$\mathbf{w} = \frac{\mathbf{k}}{\mathbf{k} + \hat{\mathbf{E}}(\mathbf{Y_i})} \tag{19}$$

Where:

k = negative binomial parameter of the accident prediction model.

7.3 Model Goodness of fit

Using the GLIM approach, several measurements are usually used to assess the goodness of fit of the model and the significance of the model parameters.

It can be possible to assess how well the model fits by doing an analysis of scaled deviance SD. The SD is defined as the likelihood ratio test statistic measuring twice the difference between the log likelihoods of the studied model and the full or saturated model. The full model has as many parameters as there are observations so that the model fits the data perfectly. Therefore, the full model, which possesses the maximum log likelihood achievable under the given data, provides a baseline for assessing the goodness of fit of an intermediate model with parameters. McCullagh and Nelder [McCullagh et al,. 1989] have shown that for negative binomial error structure the scaled deviance is as follows:

$$\mathbf{SD} = 2\sum_{i=1}^{n}\left[\mathbf{O_i}\ln\left(\frac{\mathbf{O_i}}{\hat{\mathbf{E}}(\mathbf{Y_i})}\right) + (\mathbf{O_i} + \mathbf{k})\ln\left(\frac{\hat{\mathbf{E}}(\mathbf{Y_i}) + \mathbf{k}}{\mathbf{O_i} + \mathbf{k}}\right)\right] \tag{20}$$

where:

O_i = observed number of accidents on site I;

k = negative binomial parameter.

The scaled deviance has approximately a χ^2_d distribution, d being the number of residual degrees of freedom.

The Pearson χ^2 statistics is calculated as follow:

$$\textbf{Pearson} \quad \chi^2 = \sum_{i=1}^{n} \frac{\left(O_i - \hat{E}(Y_i)\right)^2}{\text{var}\left(O_i\right)} \tag{21}$$

where:

$\text{var}(O_i)$= variance of observed number of accidents on site i, estimated from the variance equation of the negative binomial distribution.

Both the scaled deviance and the *Pearson* χ^2 have exact χ^2 distributions for Normal theory linear models, but are asymptotically χ^2 distributed with $n - p$ degrees of freedom for other distributions of the exponential family [Aitkin et al., 1989]. The asymptotic results may not be relevant to statistics calculated from a small sample size. Therefore, the generalized Pearson χ^2 statistics sometimes can not be used as an absolute measure for assessing the goodness of fit of a model.

In order to verify the goodness of fit of the model, these two measures must be compared with the value obtained from χ^2 table of the sample degrees of freedom (27). For the model to be considered significant, the two measures should be less than χ^2 critical value.

Another measure of model goodness of fit is the dispersion parameter Φ :

$$\Phi = \frac{\text{Pearson}\chi^2}{n - p} \tag{22}$$

where:

n = number of observations (30);

p = number of model parameters (3).

As above shown, Φ can be obtained by dividing the Pearson χ^2 by n-p, and it is a useful measure for assessing the fit of model. A value near 1.0 means that the error assumption of the model is equivalent to that found in the observed data. If the value of dispersion parameter is greater than 1.0, the observed data has greater dispersion than in the model.

The regression analysis was carried out considering number of crashes in the road section minus crashes at minor junctions. Results obtained for the road sample of IASP project are reported in Table 29.

Table 29 Model parameters and indicators for models goodness of fit.

DOF	variable	Coefficient	t-ratio	p-value	k	Φ	SD	Pearson χ^2	$X^2_{0.05, 27}$
27	Constant L ADT	-5.861 0.601 0.747	-2.48 1.85 2.59	0.019 0.076 0.015	3.56	0.98	34.09	26.44	40.11
Log Likelihood		-18.84							
Model form GLIM		$\hat{E}(Y) = e^{-5.861} \times L^{0.601} \times TGM^{0.747}$							

Results show an acceptable goodness of fit for the IASP APM. Therefore the expected number of accident EB_i for the homogenous section i can be calculated (Table 30).

Table 30 Accident History, Empirical Bayes expected number of accidents and Safety Index factor (SI) for the road sections of the IASP project.

Section	Road Name	Length [km]	AADT [v/d]	O_i	$\hat{E}(Y_i)$	EB_i	SI
1	SP 4II	3.463	4100	5	3.01	3.92	37.50
2	SP 4II	2.782	4100	2	2.64	2.37	31.89
3	SP 4II	639	4100	3	1.09	1.54	11.32
4	SP 4II	2.740	5200	5	3.13	4.00	39.02
5	SP 57	4.505	1800	5	1.91	2.99	22.73
6	SP 57	1.399	1800	0	0.94	0.75	6.71
7	SP 69II	3.084	5500	1	3.50	2.26	33.57
8	SP 69II	6.425	1800	5	2.36	3.41	33.86
9	SP 69II	3.115	1800	3	1.53	1.97	18.78
10	SP 69II	5.328	600	1	0.93	0.94	7.71
11	SP 69II	1.038	600	0	0.35	0.32	1.05
12	SP 69II	1.456	600	0	0.43	0.38	1.66
13	SP94	5.628	900	2	1.30	1.49	11.71
14	SP94	7.636	900	0	1.56	1.09	17.99
15	SP94	1.817	900	1	0.66	0.71	4.33
16	SP94	2.988	900	0	0.89	0.71	8.32
17	SP104	6.854	1200	1	1.81	1.54	20.89
18	SP104	2.409	1200	0	0.97	0.76	8.88
19	SP104	2.220	1200	0	0.92	0.73	9.09
20	SP104	2.874	2900	0	2.08	1.31	22.78
21	SP104	2.094	2900	4	1.72	2.46	16.98
22	SP231	3.887	3500	1	2.87	2.04	32.65
23	SC4	1.175	4500	2	1.69	1.79	13.91
24	SC4	1.814	4000	0	2.01	1.28	19.27
25	SC4	2.165	4000	1	2.23	1.76	21.61
26	SC4	1.146	4000	0	1.52	1.07	16.53
27	SP 28II	1.260	1100	2	0.61	0.82	2.93
28	SP 28II	3.347	1100	2	1.10	1.32	12.25
29	SP 28II	2.580	1100	1	0.94	0.96	5.87
30	SP 28II	5.273	1100	1	1.45	1.32	10.46

8 IASP Geographic Information Systems

Introduction

Geographic Information Systems (GIS) can be seen as complex sets of hardware and software which can acquire, process, analyse, store and reproduce data referring to a particular territory in graphical and alphanumerical form. Moreover, a GIS is an integrated, organic, multidisciplinary tool which can elaborate spatial data transforming it into information and bring together different forms of data. In this way the territory can be studied, not as a set of 'distinct' objects, but as a single whole.

One of the special characteristics that distinguishes GIS software from graphic software (in particular CAD) is this ability to use graphic and descriptive data together, or rather, to carry out analyses of various types and complexity on spatial databases.

A GIS consists of various parts, a fundamental numerical cartography base, a series of alphanumerical archives holding descriptions of objects and phenomena and a series of application packages for analyses and queries whose results up-date the main archive, consequently increasing the amount of information available. The cartographic base and functions, are organised in a structure of interconnected data, from which it is possible to obtain information on a single or whole group of objects and on the ways in which they are linked. This is possible because all the data are geo-referenced: each territorial object is associated to its co-ordinates (latitude and longitude, Gauss-Boaga, Cassini-Soldner, UTM, etc). In this way, different kinds of data can be found within the same model: geometrical, alphanumerical, sketches, cross-sections, diagrams, digital models of the area, photographic and remotely sensed image data, economic and demographic statistical data, all united by the spatial factor.

A GIS is set up according to the information that one wishes to obtain from the territorial situation. The development process has various phases:

1. acquiring the cartographic base;
2. developing the database;
3. maintenance and up-dating of information at the same time as the system develops so as to avoid information becoming obsolete as the system grows.

8.1 Description of the IASP GIS

ArcView® GIS software, produced by ESRI Inc, was used for the implementation of the 'IASP' GIS, which made it possible to organise the geographical information by means of 'Themes' and therefore to attach tables managed by a DBMS in the software to topologically referenced geographical entities created by means of AUTOCAD ®.

As regards the fundamental cartography, the themes regarding the provincial road network were taken into consideration, in this particular case those of the eight roads analysed in the IASP project. For the cartographic base the provincial topographic map at scale 1:10,00 was used.

All the themes contained in a view are listed on the left of the map in the view *Summary* (Figure 23). The Summary also shows the symbols used to draw the elements in each theme.

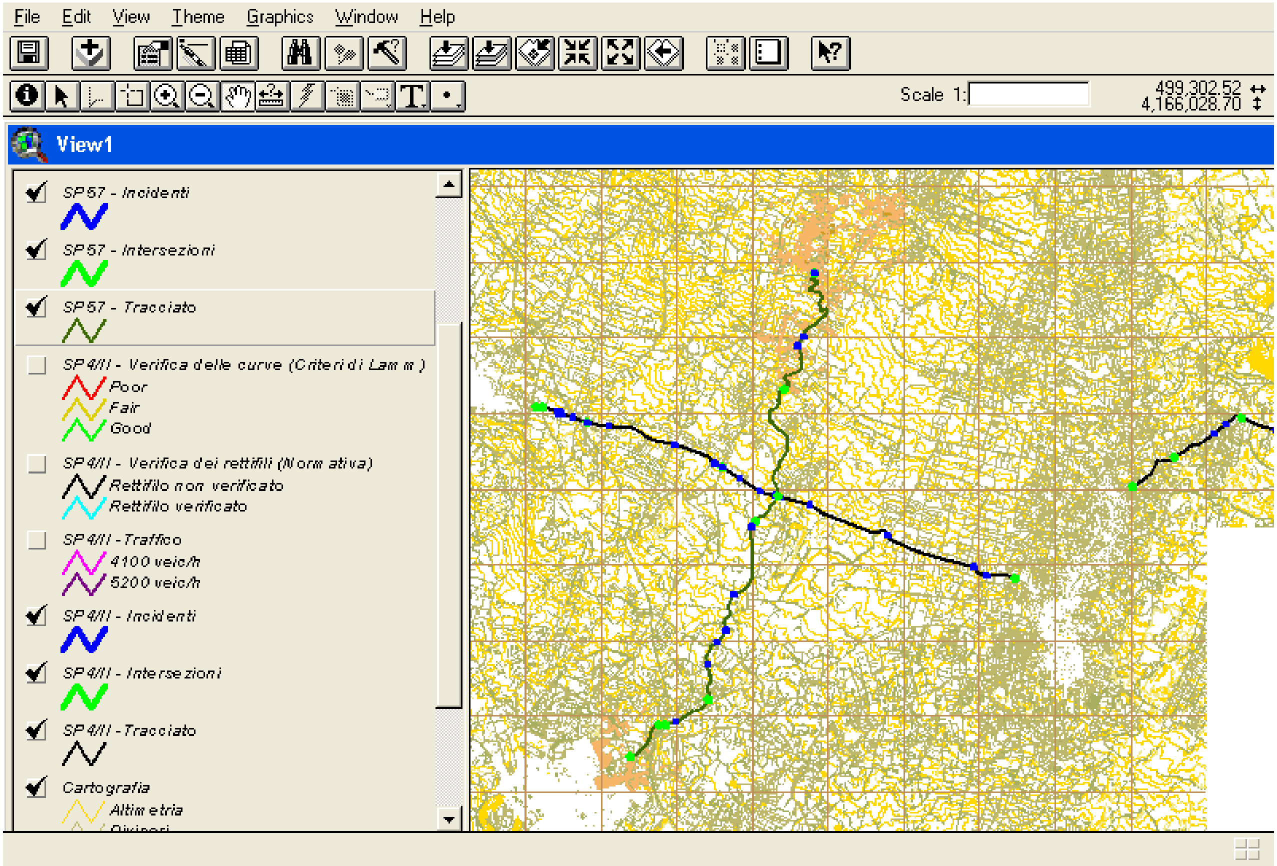


Figure 23 View of the SP4/II and the SP57 in the topographic map.

A table of attributes was created for each geographical entity. For each stretch of road (Figure 24), in addition to the identification code, the first and last milestones, the length of the stretch, the alignment features (tangent or curve, specifying the bending radius of the latter), traffic data (in terms of ADT) and check results according to the Lamm Safety Criteria and Italian Design Standards, were archived.

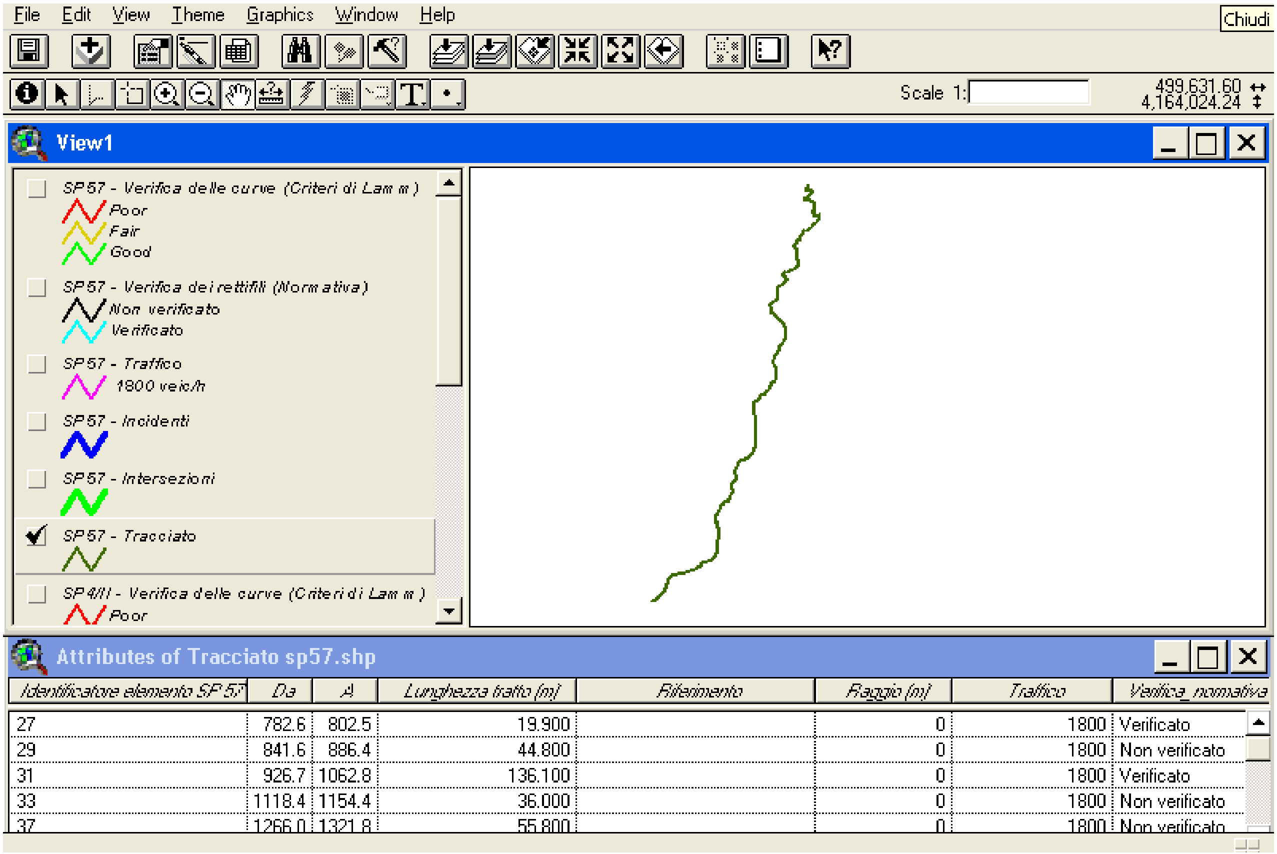


Figure 24 Example of road feature table (SP57).

The accidents table (Figure 25 and Figure 26) shows data coming from the reports of Police forces (Carabinieri, Road Police) and specifically data relating to:

1. location;
2. day, month, year;
3. intervening force;
4. pavement condition;
5. weather conditions;
6. accident type;
7. site;
8. vehicle type;
9. number of fatalities;
10. number of injuries.

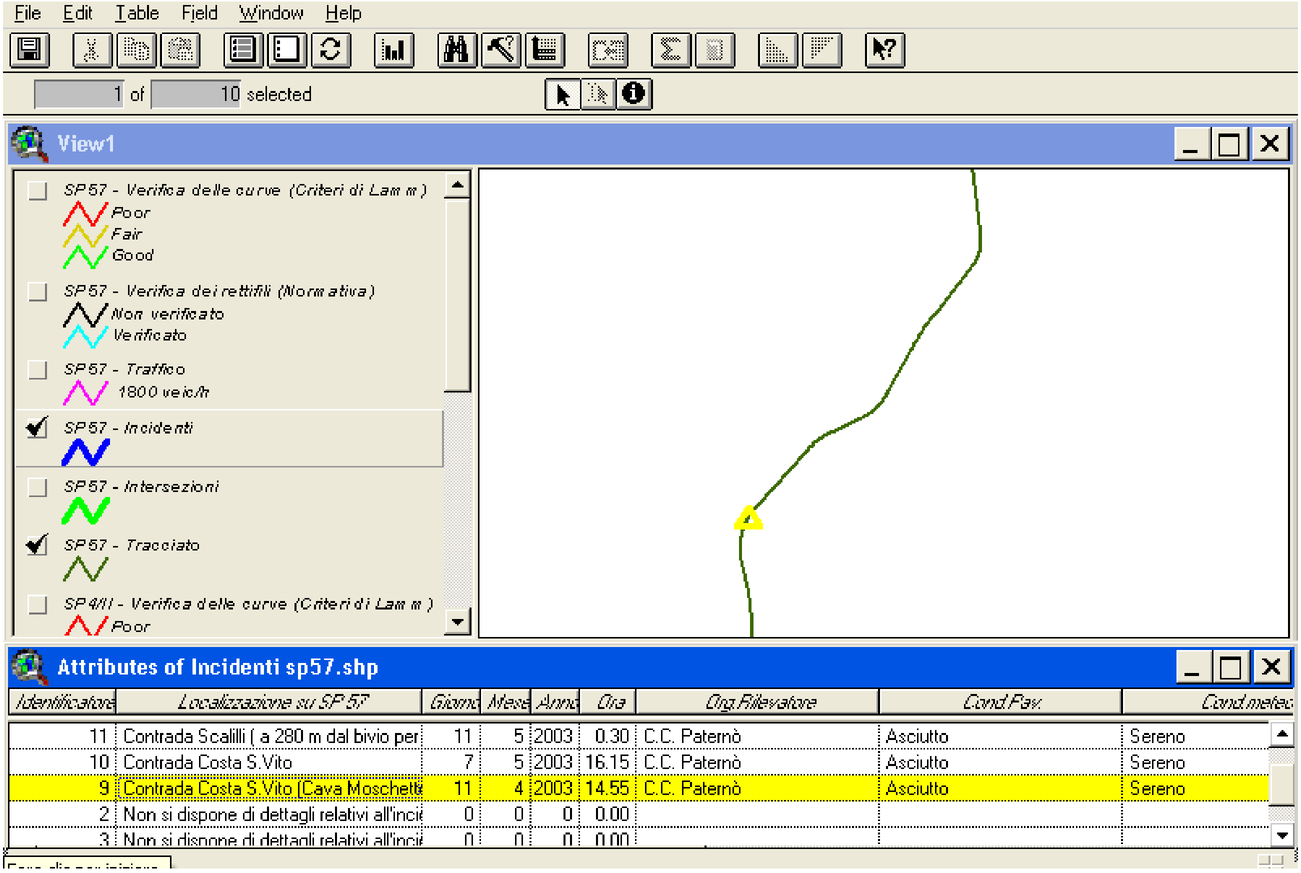


Figure 25 Example of accident table (SP57).

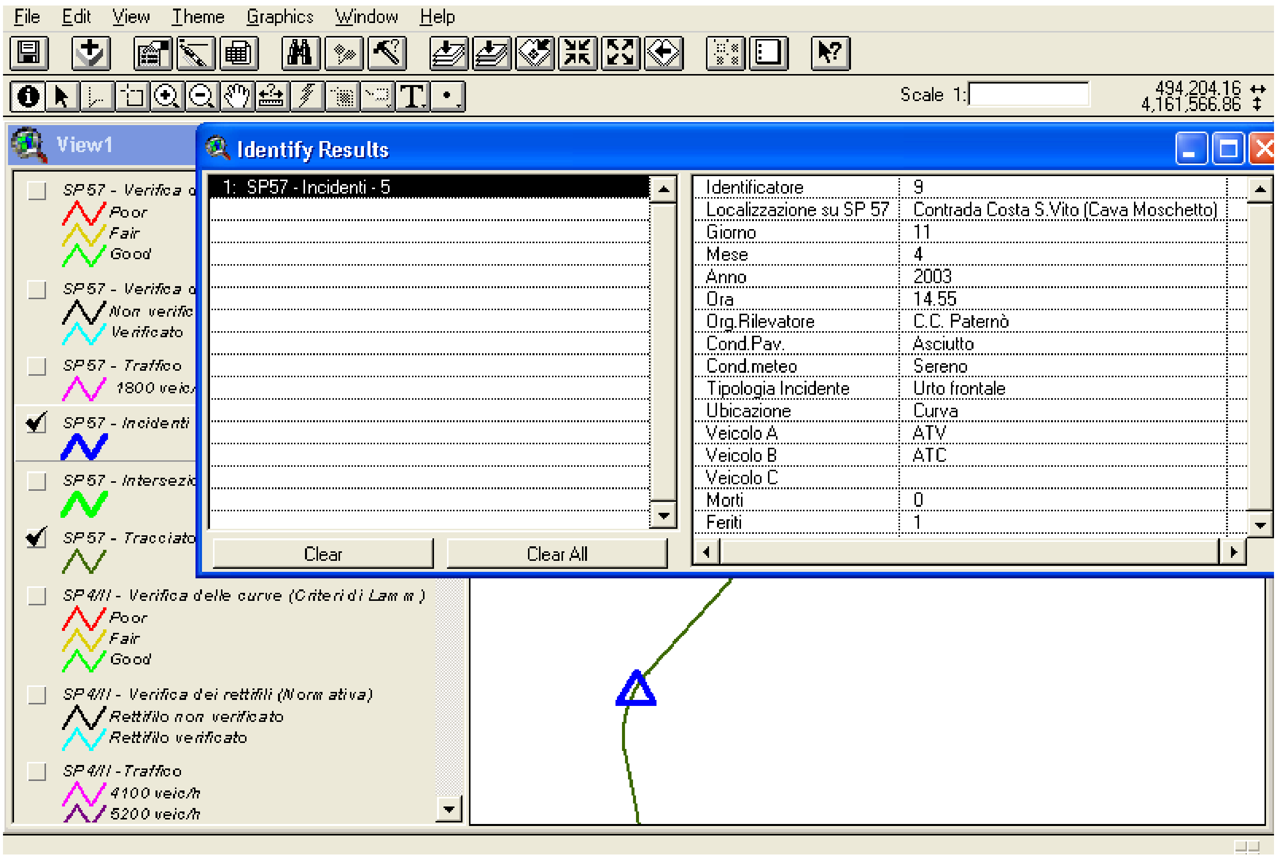


Figure 26 Identification of an accident using 'Identify' tool.

As the GIS allows the use of lines, with a thickness or colour varying according to the importance of each feature contained in the associated table visualised on the monitor, it is possible to get an immediate and effective representation of the general traffic situation in terms of ADT (Figure 27).

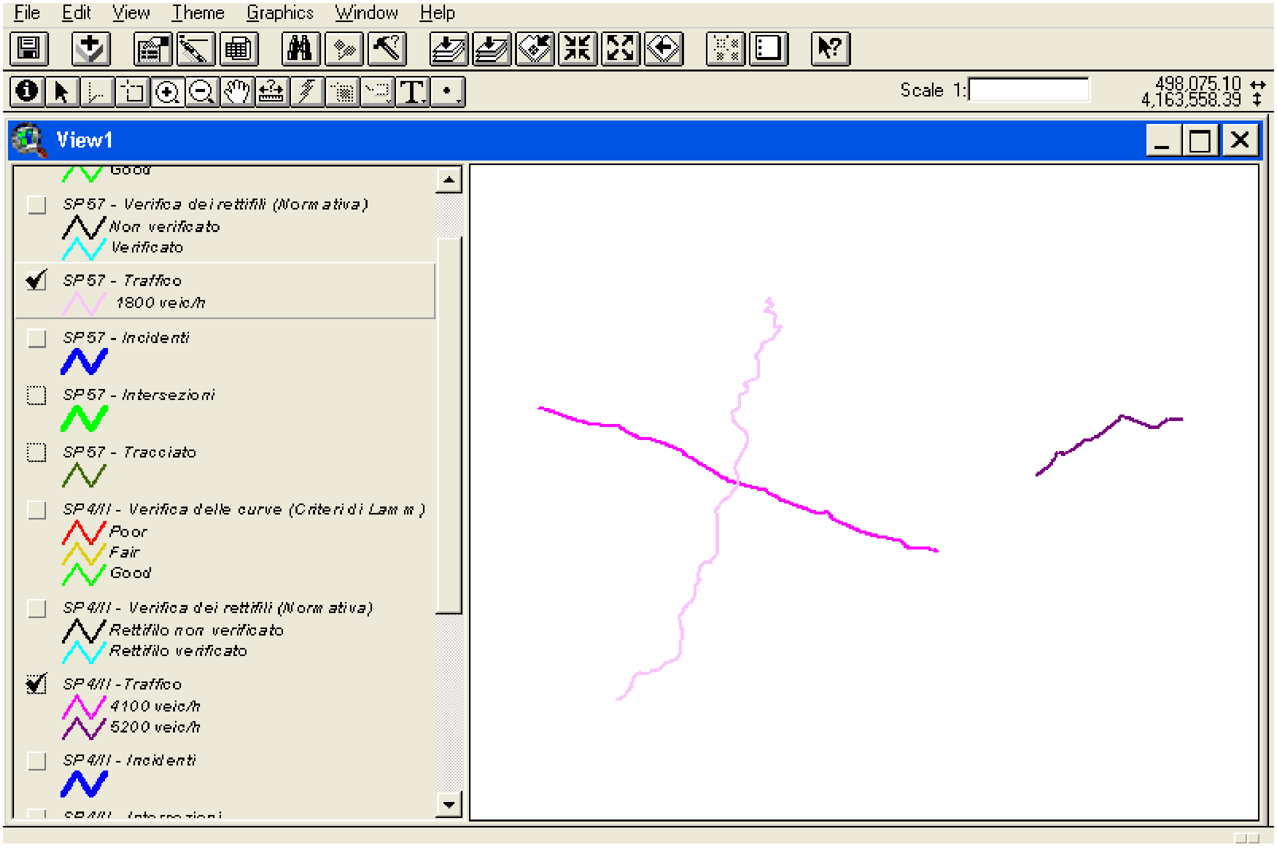


Figure 27 Traffic situation in terms of ADT of SP57 and SP4/II.

Furthermore, it is possible to make a graphical check of the stretch according to both Lamm's criteria and those laid down by and Italian Design Standards (Figure 28, Figure 29).

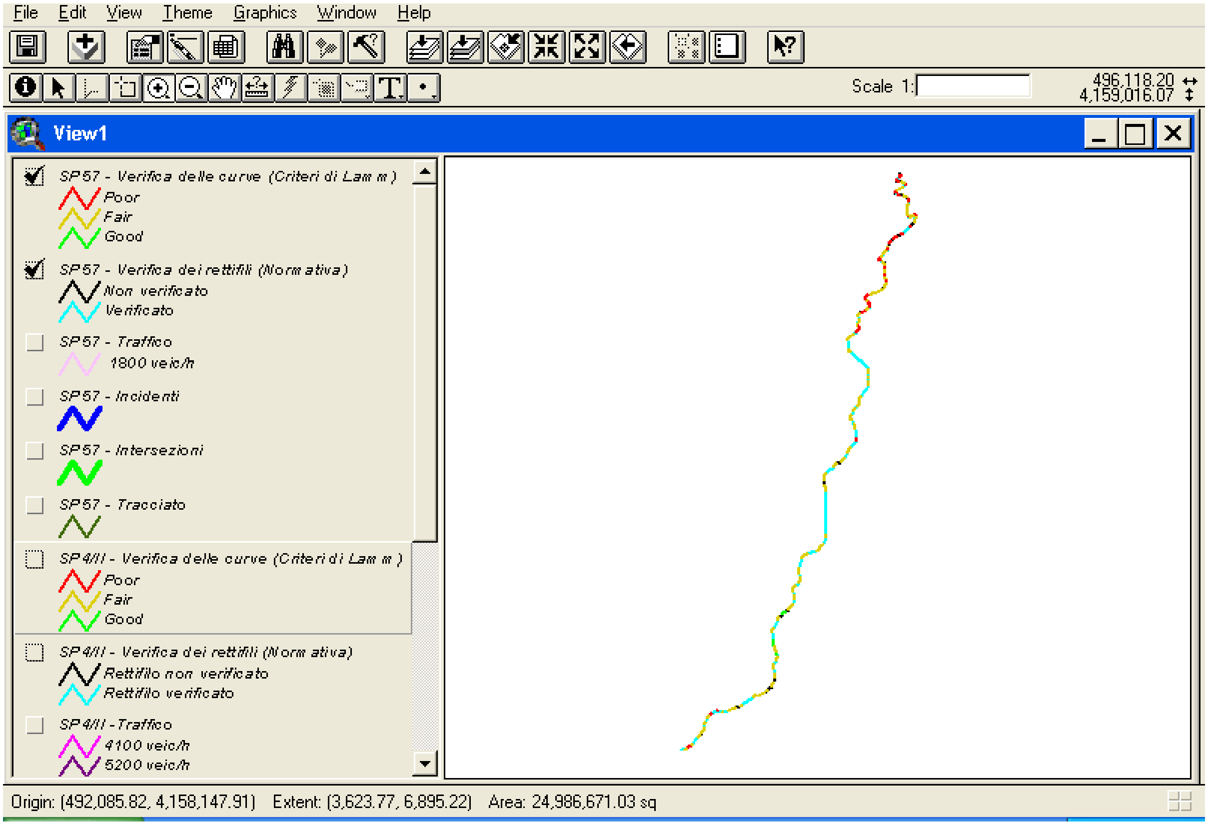


Figure 28 Design Consistency (Lamm Criteria) and Design Guidelines Standard Check of SP57.

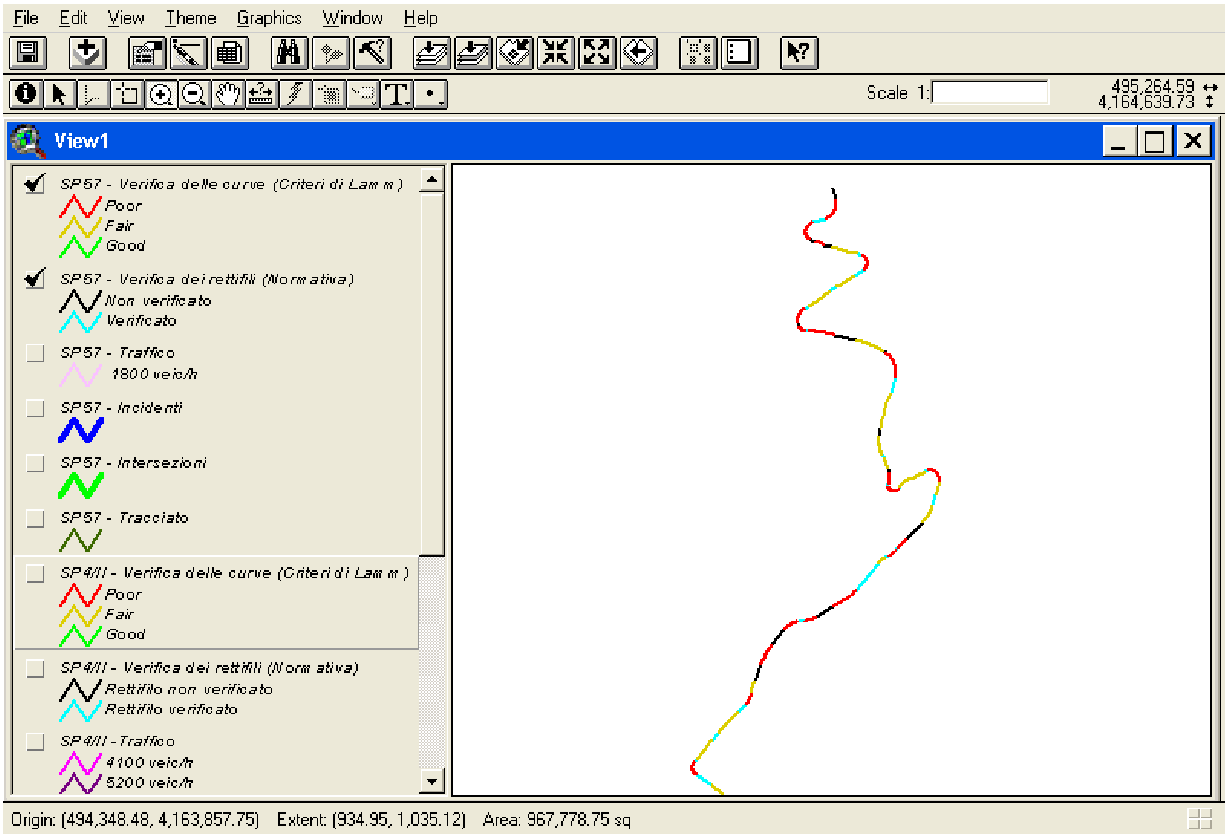


Figure 29 Particular view of Design Consistency and Standard Check of SP57.

Finally, for the different homogenous sections into which each road was divided, it is possible to show in Figure 30, Figure 31, Figure 32, Figure 33 the Safety Index (SI) level obtained using the IASP procedures (Chapter 4).

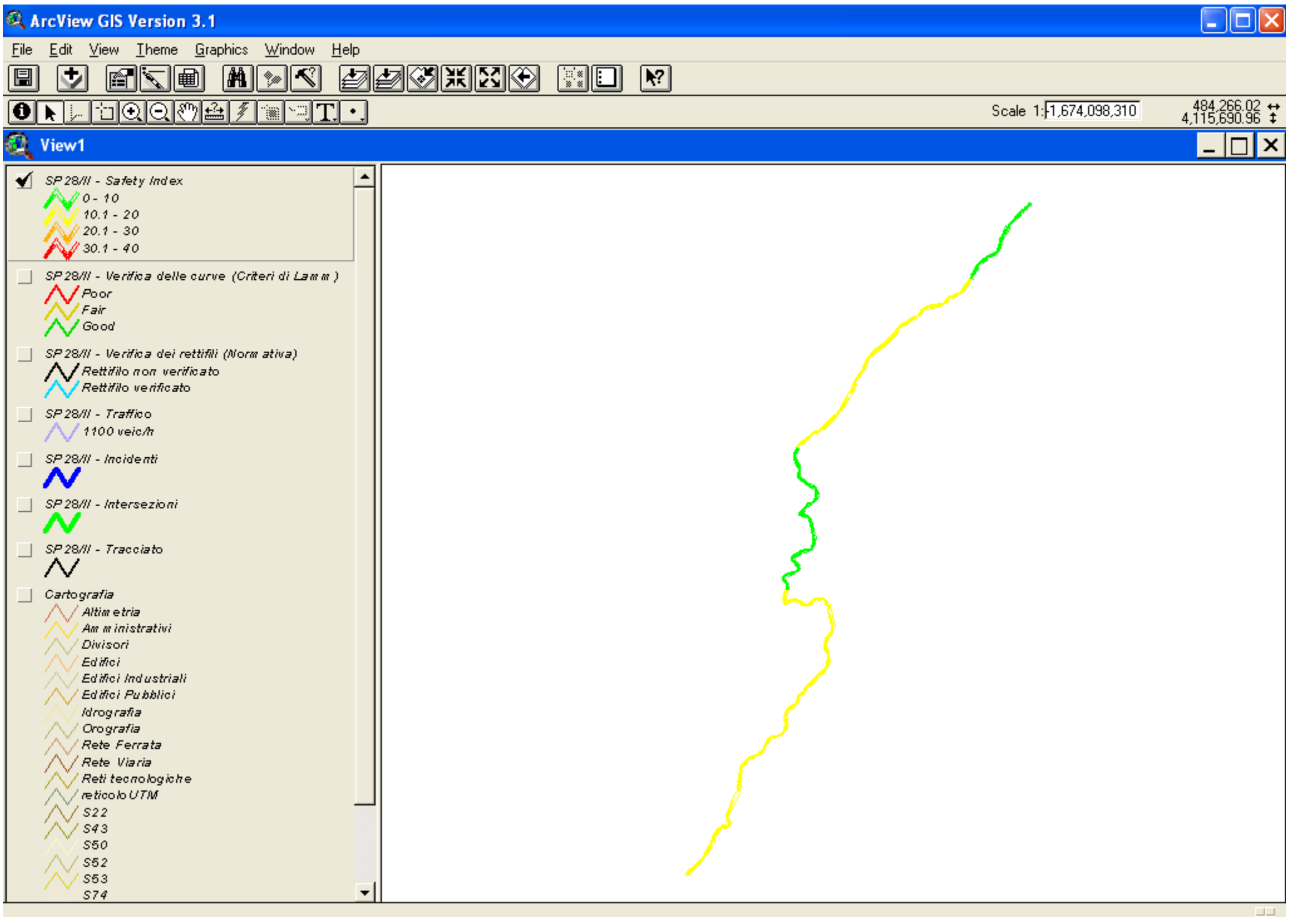


Figure 30 Safety Index levels of SP 28II

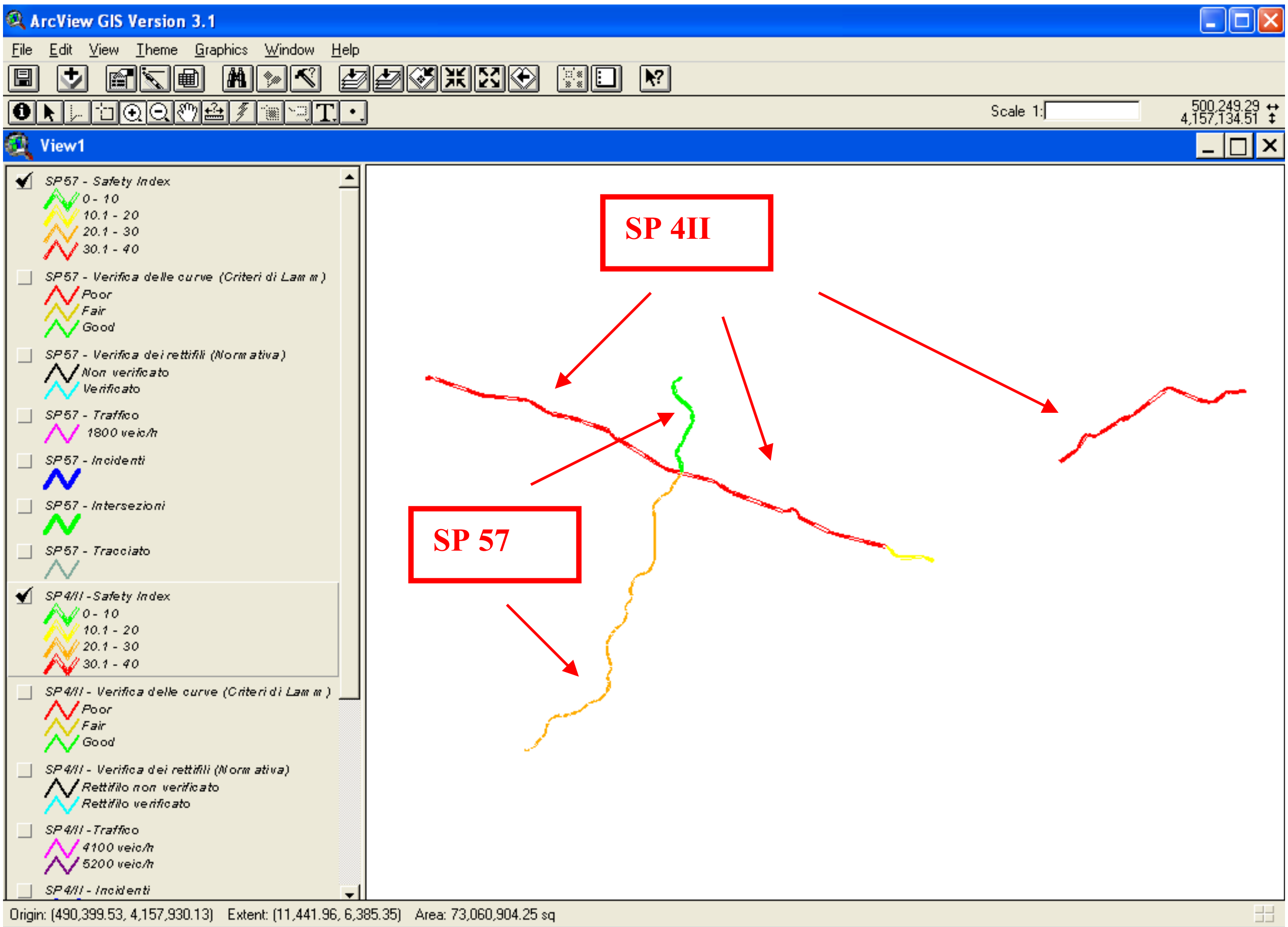


Figure 31 Safety Index levels of SP 4II and SP 57

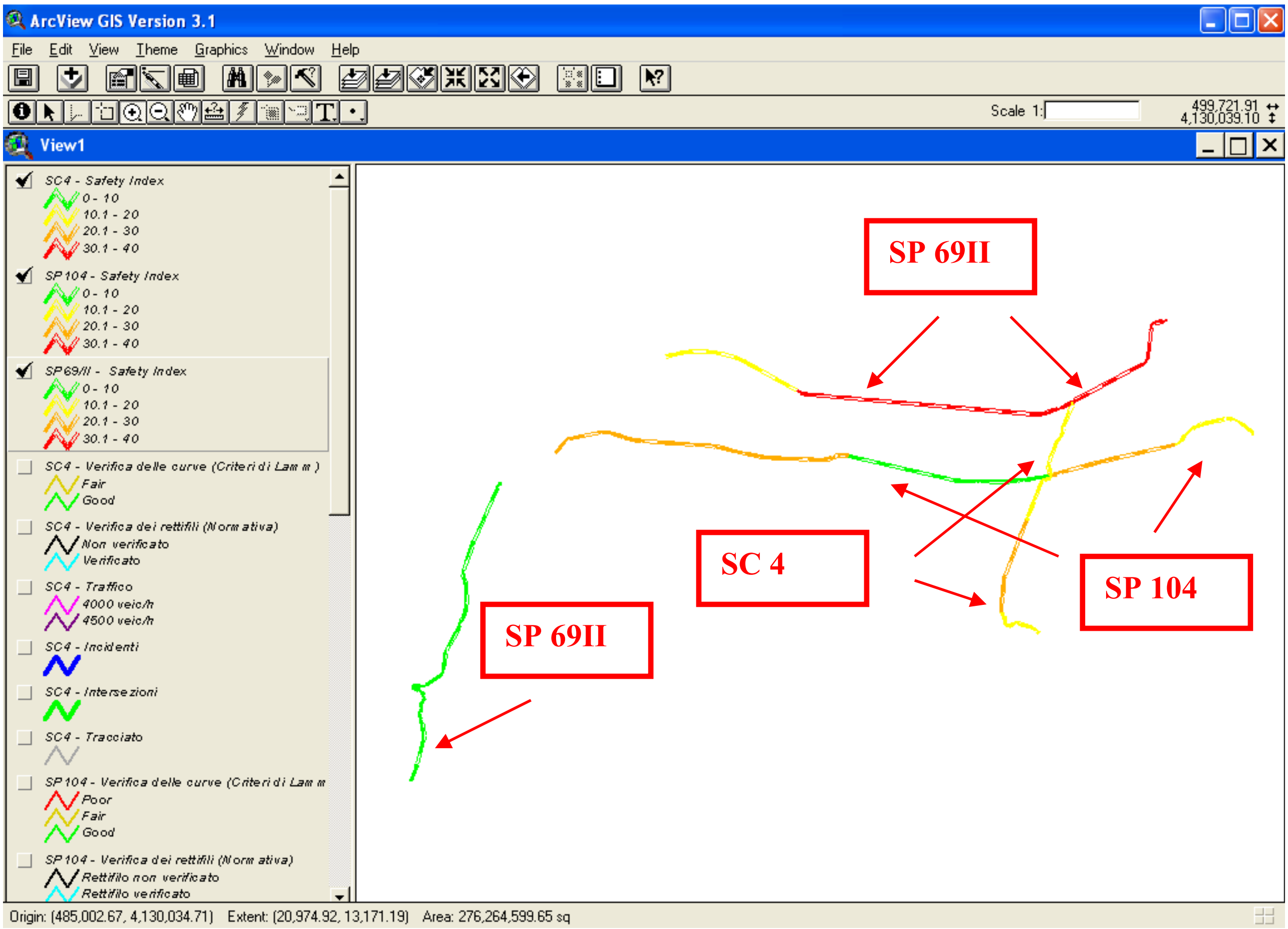


Figure 32 Safety Index levels of SP 69II, SP 104 and SC 4

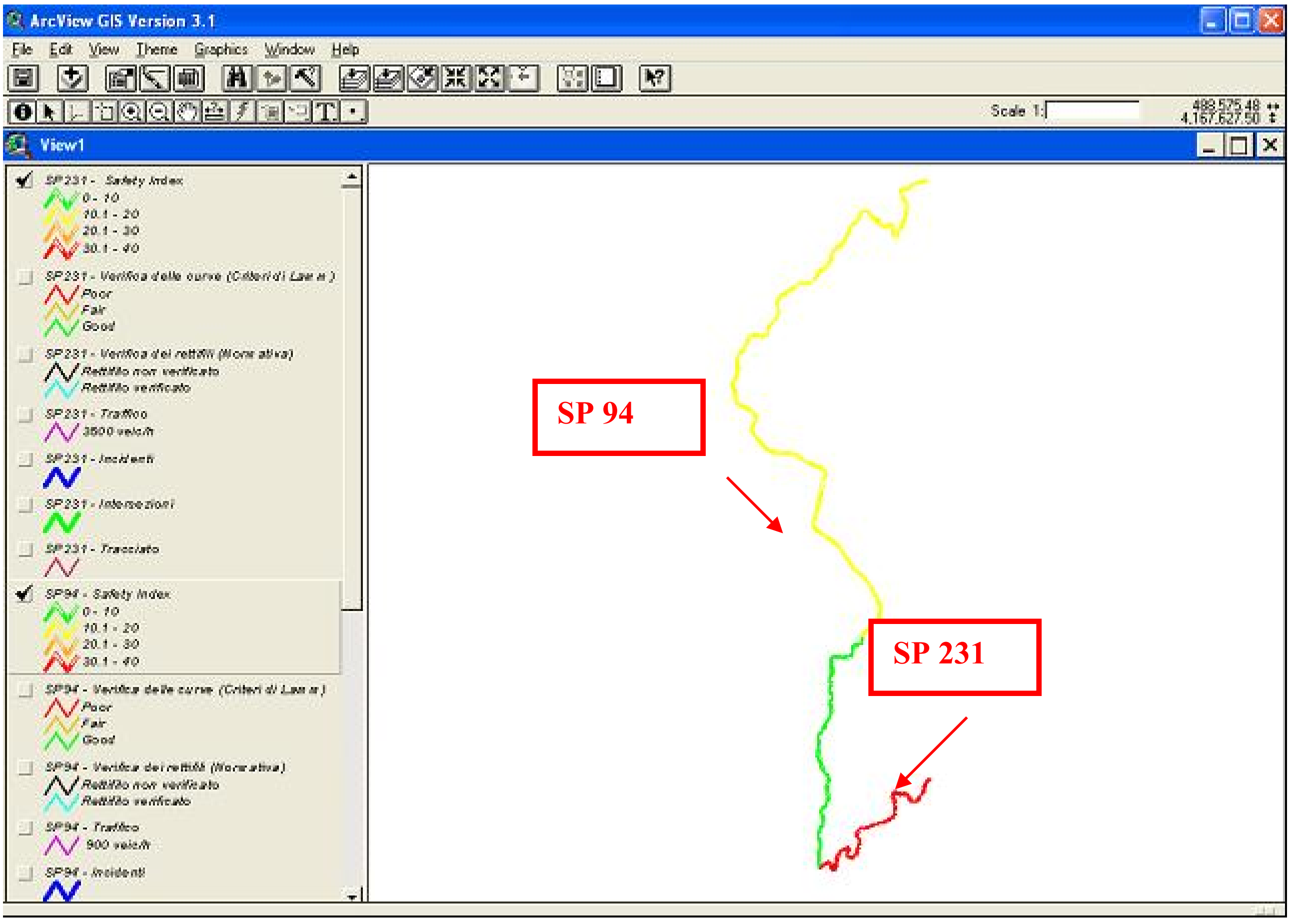


Figure 33 Safety Index levels of SP 231 and SP 94

9 RELIABILITY AND VERIFICATION OF THE PROCEDURE

9.1 Safety Inspection

In order to test the reliability of the Safety Inspection methodology, the agreement of the results of the general safety issues ranks produced by different inspectors for the road segments has been addressed. Specifically, with the aim of checking the consistency of the risk assignment between different inspectors, the statistic kappa has been used [De Leur, P. et al, 2002, Cafiso et al., 2006b].
The kappa coefficient (k) provides a measure of agreement among a set of inspectors, who have rated a set of N objects using a nominal scale with M different category judgments, correcting for expected chance agreement:

$$k = \frac{P - P_e}{1 - P_e} \tag{21}$$

where:

P = proportion of times that the inspectors agree (0.00 ÷ 1.00);

P_e = proportion of times that agreement by chance is expected (0.00 ÷ 1.00).

If there is total agreement k is equal to 1. If there is no agreement other than that which would be expected by chance k is equal to 0. A negative kappa value indicates disagreement between inspectors.
There are several variants of the kappa coefficient in the literature, the multirater kappa for category data proposed by Siegel [Siegel et al., 1988] provides an adjustment for bias and was applied. The values of the k statistic were calculated by using the GenStat 7.2 software.
Moreover, it is possible to test whether the level of agreement is statistically significant. When N is large (> 30), the sampling distribution of kappa is approximately Normal. Therefore, under a test hypothesis of no agreement beyond chance, the level of significance α of the agreement can be determined evaluating the probability of $k/\sqrt{var(k)}$ for a standard Normal distribution. An α of 10% can be used as level of significance.
The k statistics have been performed with reference to different combination of inspectors and different category judgments with the aim of testing the reliability of the procedure.
First, the comparison of checklists filled by two groups of safety specialists has been carried out. The checklists were compiled with respect to three different two lane rural roads with a total length of 40 km (200 segments). Each group was composed by two inspectors: one in front seat and the

other one in back seat. Safety issues have been ranked with three categories of judgment: high level problem, low level problem and no problem.

Results reported in Table 31 show that there is a significant level of agreement for the majority of the safety issues. For some issues (terminals and transitions, presence of accesses, unevenness, chevrons and markings) the level of agreement is very satisfactory (α ≤ 0.1%).

Table 31 K Statistics and Level of Agreement Between Two Inspectors with a Nominal Scale of Three Judgments.

Safety issues / Calculated values	P	P_e	k	Var(k)	Significance Level (%)	Significance (α= 10%)
Roadside						
Embankments	0.753	0.721	0.117	0.0177	18.8	**No**
Bridges	1.000	1.000	-	-	-	Not significant data
Dangerous terminals and transitions	0.623	0.478	0.278	0.0063	<0.1	**Yes**
Trees, utility poles and rigid obstacles	0.324	0.368	-0.041	0.0040	74.2	**No**
Ditches	1.000	1.000	-	-	-	Not significant data
Sight distance						
Sight distance on horizontal curve	0.630	0.552	0.174	0.0062	1.3	**Yes**
Sight distance on vertical curve	0.955	0.951	-	-	-	Not significant data
Accesses						
Dangerous accesses	0.515	0.482	0.063	0.0047	17.7	**No**
Presence of accesses	0.595	0.360	0.367	0.0028	<0.1	**Yes**
Cross section						
Lane width	0.603	0.524	0.165	0.0075	2.9	**Yes**
Shoulder width	0.534	0.456	0.144	0.0057	2.9	**Yes**
Pavement						
Friction	0.905	0.909	-	-	-	Not significant data
Unevenness	0.675	0.542	0.291	0.0059	<0.1	**Yes**
Delineation						
Chevrons	0.655	0.519	0.283	0.0054	<0.1	**Yes**
Guideposts and barrier reflectors	0.890	0.895	-	-	-	Not significant data
Signs						
Warning signs, regulation signs	0.835	0.791	0.212	0.0189	6.2	**Yes**
Markings						
Edge lines	0.570	0.421	0.258	0.0036	<0.1	**Yes**
Center line	0.735	0.401	0.558	0.0034	<0.1	**Yes**

For bridges, ditches, sight distance on vertical curves, delineation guideposts and friction the collected data were not significant for the test because the judgment expressed by both the groups assumed an almost constant value along the entire roads. This circumstance, generally, derives from a substantial homogeneity of road features (both for good and bad conditions). When this condition occurs, both P and P_e assume a value equal or very close to one. It means that the proportion of times that the inspectors agree is very high, even if the agreement is not statistically significant.

A specific consideration can be made with respect to friction. Both the observers rarely filled the relevant boxes in the checklist assigning a value equal to good for almost the entire roads. Instead, during site inspections, poor friction conditions were often identified. These results stem in the main from the inspectors inability in recognizing the friction state when running the road at normal speed.

Safety issues where there is not a statistically significant level of agreement are embankments, roadside obstacles and dangerousness of accesses. As far as embankments is concerned, there is indication of a slight level of agreement, since k is greater than 0 and inspectors' ranks agree in 75% of the evaluations (P = 0.753). A good evaluation of embankments dangerousness is not an easy task without stopping the car. As far as dangerousness of accesses ($k > 0$) and roadside obstacles is concerned, it must be remembered that they are isolated elements.

Really, there is not general agreement about the minimum order of k to speak of an acceptable level of agreement [Landis et al., 1977] because the correct interpretation of the k values depends entirely on what one intends to do with the coding [Krippendorff, 1980]. Anyway, the k values are useful in order to compare the level of agreement across different studies.

In order to check if the disagreement can be reduced considering a simpler identification of the safety issues, the checklists were compiled using a nominal scale of two categories of judgment: problem (which includes low level and high level problems) and no problem.

The results are listed in Table 32.

Table 32 K Statistics and Level of Agreement Between Two Inspectors with a Nominal Scale of Two Judgments.

Safety issues / Calculated values	P	P_e	k	Var(k)	Significance Level (%)	Significance (α= 10%)
Roadside						
Embankments	0.774	0.730	0.163	0.0185	11.5	**No**
Bridges	1.000	1.000	-	-	-	Not significant data
Dangerous terminals and transitions	0.733	0.539	0.420	0.0080	<0.1	**Yes**
Trees, utility poles and rigid obstacles	0.562	0.502	0.121	0.0069	7.3	**Yes**
Ditches	1.000	1.000	-	-	-	Not significant data
Sight distance						
Sight distance on horizontal curve	0.730	0.592	0.338	0.0076	<0.1	**Yes**
Sight distance on vertical curve	0.960	0.951	-	-	-	Not significant data
Accesses						
Dangerous accesses	0.555	0.538	0.037	0.0058	31.3	**No**
Presence of accesses	0.730	0.524	0.433	0.0055	<0.1	**Yes**
Cross section						
Lane width	0.973	0.973	-	-	-	Not significant data
Shoulder width	0.801	0.821	-	-	-	Not significant data
Pavement						
Friction	0.905	0.910	-	-	-	Not significant data
Unevenness	0.745	0.582	0.390	0.0070	<0.1	**Yes**
Delineation						
Chevrons	0.690	0.548	0.314	0.0061	<0.1	**Yes**
Guideposts and barrier reflectors	1.000	1.000	-	-	-	Not significant data
Signs						
Warning signs, regulation signs	0.850	0.796	0.263	0.0196	3.0	**Yes**
Markings						
Edge lines	0.875	0.800	0.374	0.0200	0.4	**Yes**
Center line	0.870	0.781	0.406	0.0179	0.1	**Yes**

A general improvement of the agreement is highlighted by higher values of both the k coefficients and the significance levels. A particular case is represented by the identification of roadside obstacles (trees, utility poles and rigid obstacles), which shows a poor agreement when a nominal

scale of three judgments is used while an acceptable level of agreement when two judgments are used. In the latter case, the judgment is limited only to the identification of the presence of a dangerous obstacle; obviously this is an easier task.
On the whole, it appears that the advantage arising from the greater level of detail reached by the three level judgment overcomes the reduced level of agreement in comparison with the two level judgment procedure.

The RSI carried out according to the defined procedures showed that there is a statistically significant level of agreement (k test) of the safety issues ranks produced by different inspectors for the majority of the safety issues. As a result, the reliability of the procedure is satisfactory, specially if it is considered that the identification of the safety issues is a very complex task based on human evaluations and expertise not supported by instrumental measures [Cafiso et al., 2006b].
The proposed procedure has shown positive features. It is very operational in nature and gives a detailed inspection framework, an innovative definition of team and client relationships and a clear definition of objectives, team composition, required equipments and procedures of each phase of the process, thus improving the global effectiveness of the safety inspection process. Proposed checklists can result helpful since they are not overwhelming and at the same time they give constructive support to the inspectors.
The ranking of the safety issues is performed according explicit criteria and is useful to allow the inspection results to be used in a comprehensive road safety program. Indeed, the defined ranking criteria take into account the road safety effects of the identified issues.
Training of the inspectors is crucial in order to obtain reliable safety ranks and, more in general, an effective and objective procedure.

9.2 Safety Index

In order to check the results obtained using the Safety Index (SI) risk factor proposed in chapter 4, the Spearman rank-correlation was used to determine the level of agreement between the rankings obtained by the Safety Index procedure and by the EB technique [De Leur, P. et al., 2002].
Spearman's Rank Correlation Coefficient is a measure of association between the rankings of two variables measured on N individuals.
To calculate the Spearman’s rank-correlation coefficient, it is necessary to segment the data sets and then rank the paired data sets in ascending or descending order. The Spearman’s rank-correlation coefficient is often used as a non-parametric alternative to a traditional coefficient of correlation and can be applied under general conditions [Freund, 1982]. An advantage of using (ρ) is that when

testing for correlation between two sets of data, it is not necessary to make assumptions about the nature of the populations sampled.

The correlation coefficient is calculated from the two vectors of ranks for the samples: let { Xi ; i=1...N } and { Yi ; i=1...N } be the vectors of ranks for sample 1 and sample 2 respectively, then the coefficient r is based on the vector of differences between ranks: { Di = Xi - Yi ; i=1...N } and is calculated by:

$$\rho = 1 - 6\times\Sigma D_i^2/[N\times (N^2-1)] \quad (23)$$

where:
D = differences between ranks;
N = number of paired sets.

A score of 1.0 represents perfect correlation and a score of zero indicates no correlation.
The t-approximation for this statistic, T, is valid for samples of size 8 upwards, and is calculated by:

$$T = \rho \times \sqrt{[(N-2)/(1- r^2)]} \quad (24)$$

It has approximately a t-distribution on N-2 degrees of freedom, and can be used for a test of the null hypothesis of independence between samples (see for example Siegel 1956, pages 202-213.)
The Spearman rank-correlation coefficient was used to determine the level of agreement between the SI and the GLIM EB refined prediction. Moreover, since segments are usually ranked in terms of accidents per unity of length, level of agreement was evaluated also comparing SI and EB safety estimate divided for the length of the segment (SI/L, EB/L).
A summary of the SI scores and the EB estimates for each of the 30 sites is shown in Table 33 and in Table 34. Also included in the table is the ranking established for each of the 30 sites based on both the SI and the GLIM with EB estimation. In Figure 34 and Figure 35 ranking deviations between the two criteria are reported.

Table 33- Ranking agreements: SI versus EB.

Segments	SI	SI rank	EB estimate	EB rank	Rank difference
1	37.50	2	3.92	2	0
2	31.89	6	2.37	6	0
3	11.32	19	1.54	13	6
4	39.02	1	4.00	1	0
5	22.73	8	2.99	4	4
6	6.71	25	0.75	25	0
7	33.57	4	2.26	7	-3
8	33.86	3	3.41	3	0
9	18.78	12	1.97	9	3
10	7.71	24	0.94	22	2
11	1.05	30	0.32	30	0
12	1.66	29	0.38	29	0
13	11.71	18	1.49	14	4
14	17.99	13	1.09	19	-6
15	4.33	27	0.71	27	0
16	8.32	23	0.71	28	-5
17	20.89	10	1.54	12	-2
18	8.88	22	0.76	24	-2
19	9.09	21	0.73	26	-5
20	22.78	7	1.31	17	-10
21	16.98	14	2.46	5	9
22	32.65	5	2.04	8	-3
23	13.91	16	1.79	10	6
24	19.27	11	1.28	18	-7
25	21.61	9	1.76	11	-2
26	16.53	15	1.07	20	-5
27	2.93	28	0.82	23	5
28	12.25	17	1.32	16	1
29	5.87	26	0.96	21	5
30	10.46	20	1.32	15	5
				ρ_s	**0.87**
				T	**9.54**
				p-value	**< 0.001**

Table 34 Ranking agreements: SI/L versus EB/L.

Segments	SI/L	SI/L rank	EB/L estimate	EB/L rank	Rank difference
1	10.83	7	1.13	5	2
2	11.46	5	0.85	7	-2
3	17.72	1	2.41	1	0
4	14.24	3	1.46	3	0
5	5.05	15	0.66	11	4
6	4.79	16	0.53	14	2
7	10.88	6	0.73	9	-3
8	5.27	14	0.53	15	-1
9	6.03	13	0.63	13	0
10	1.45	28	0.18	29	-1
11	1.01	30	0.30	23	7
12	1.14	29	0.26	25	4
13	2.08	26	0.26	24	2
14	2.36	23	0.14	30	-7
15	2.39	22	0.39	19	3
16	2.78	21	0.24	27	-6
17	3.05	20	0.22	28	-8
18	3.68	18	0.32	22	-4
19	4.10	17	0.33	21	-4
20	7.93	12	0.46	17	-5
21	8.11	11	1.18	4	7
22	8.40	10	0.52	16	-6
23	11.84	4	1.52	2	2
24	10.62	8	0.71	10	-2
25	9.98	9	0.81	8	1
26	14.43	2	0.93	6	-4
27	2.33	24	0.65	12	12
28	3.66	19	0.39	18	1
29	2.27	25	0.37	20	5
30	1.98	27	0.25	26	1
				ρ_s	**0.87**
				T	**9.15**
				p-value	**< 0.001**

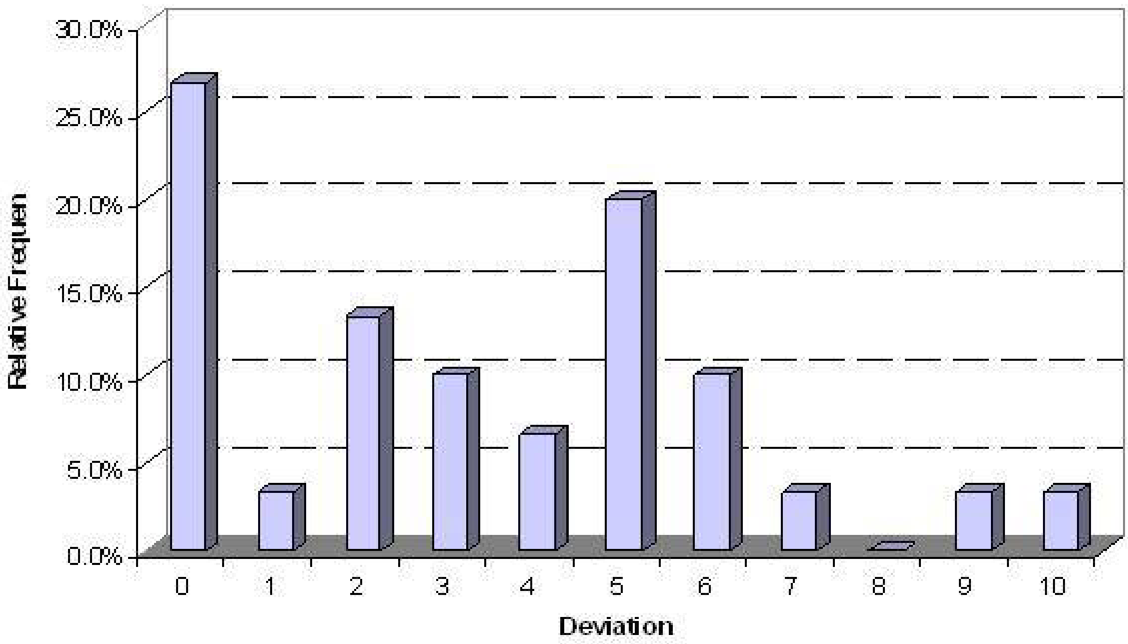


Figure 34 Ranking deviations: SI versus EB.

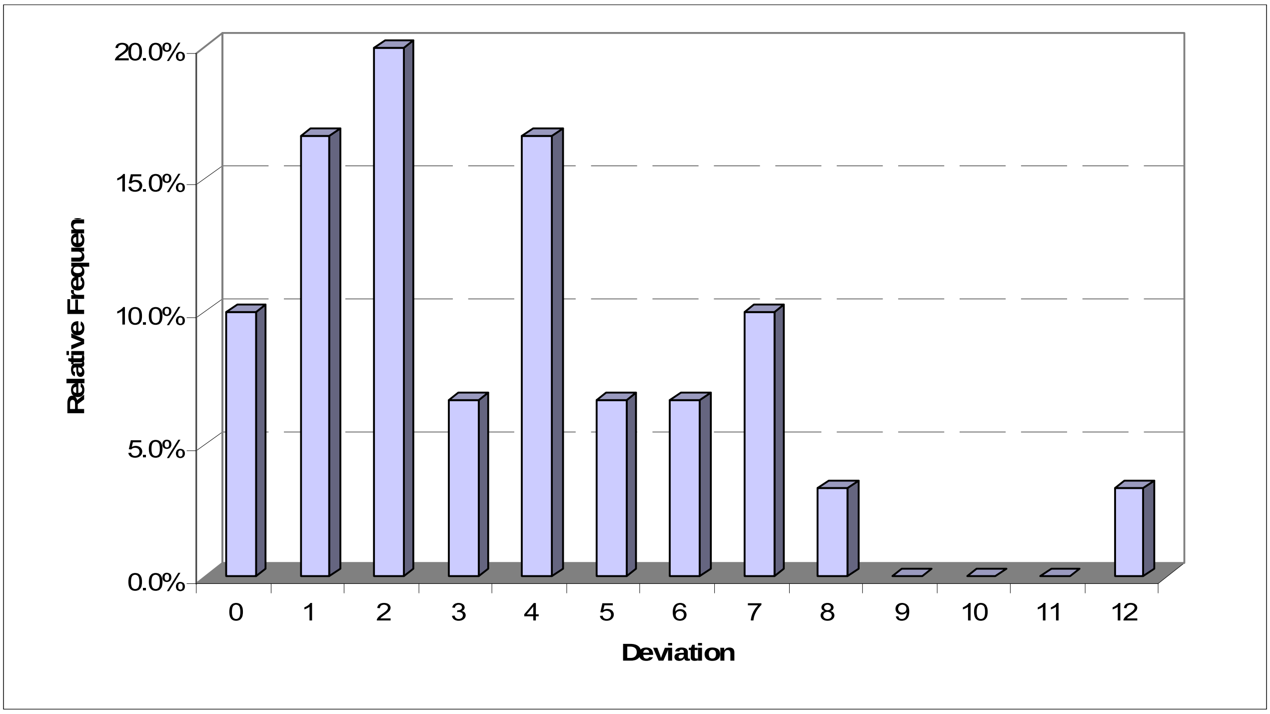


Figure 35 Ranking deviations: SI/L versus EB/L.

With N equal to 30, the Spearman rank-correlation coefficient (ρ) was estimated to be 0.87. The calculated T-value was 9.22 (9.42 when SI/L versus EB/L is considered), with p-value < 0.001, thus indicating agreement at a 99.9% confidence level.

The results from the Spearman's Rank correlation analysis provide further validation for the SI indicating that the ranking from the subjective SI and the objective EB estimate do agree at the 99.9% level of significance with a correlation coefficient of 0.87. The same level of agreement is obtained if ranking from SI/L and from EB/L are compared.

To test furthermore the procedure, comparisons between SI scores and EB safety estimates have been carried out (see Table 33 and Figure 36). The correlation between EB safety estimates and SI values is highly significant ($t = 9.64$, p-value < 0.001), with 77 % of the variation in the estimated number of accidents explained by the value of SI. This means that the relationship between EB estimates and SI scores had less than 0.1% chance of occurring by accident.
Comparisons between SI/L scores and EB/L safety estimates give similar results (see Table 34 and Figure 37). The correlation between EB/L safety estimates and SI/L values is highly significant ($t = 9.05$, p-value < 0.001), with 75 % of the variation in the estimated number of accidents per kilometer explained by the value of SI/L value.

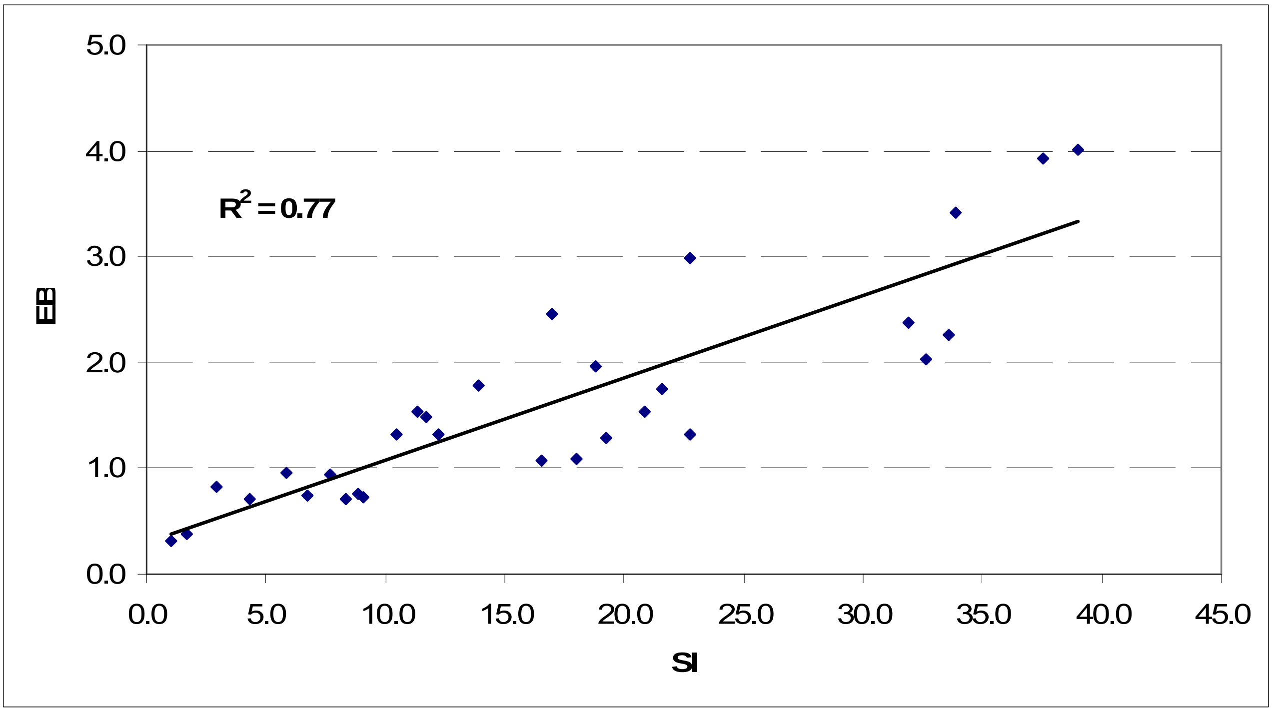


Figure 36 Correlation between EB and SI.

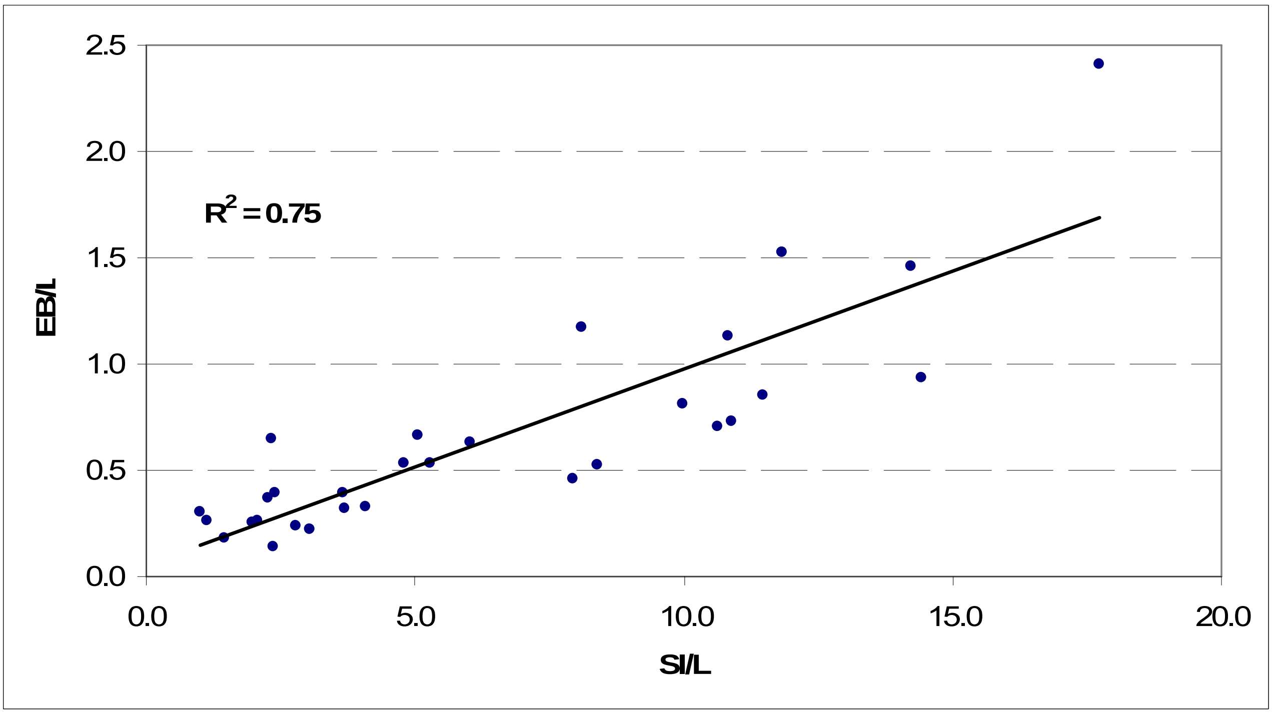


Figure 37 Correlation between EB/L and SI/L.

10 IMPROVEMENT INTERVENTIONS AND MONITORING

The type of works proposed involved three basic areas:

1. Improvement interventions on a stretch of road. Monitoring by means of Before-After Accident Analyses.
2. Interventions to reduce traffic speed. Monitoring by means of Before-After Speed Analyses.
3. Improvement interventions on a curve. Monitoring by means of Before-After Vehicle Trajectory Analyses.

There follows a description of the interventions carried out, specifying the project details with respect to the prior situation, as well as the monitoring phase.

10.1 Improvement interventions on a stretch of road.

10.1.1 Description of the interventions

The type of road safety interventions carried out involved principally the improvement interventions described here:

1. Road widening from a variable width of between 6-7 m to a constant width of 9.50 m (lane width 3.50 m, shoulder 1.25 m) so as to improve the cross-section, bearing in mind the requisites of D.M. 5/11/01 “Functional and Geometric Norms for Road Building”, which establishes a C2 class road for secondary roads in rural areas with low traffic (Figure 38);

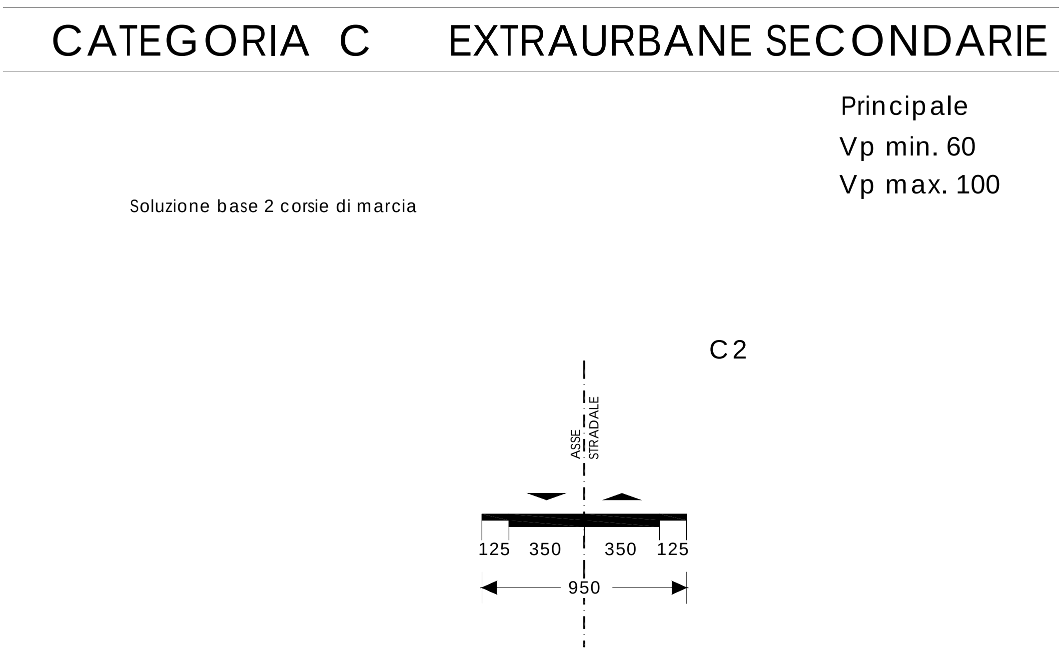


Figure 38 C2 type secondary road for rural areas

2. Repainting of road markings, installation of new danger and regulation signs, installation of reflectors and chevrons on curves with reduced sight distance;
3. Construction of concrete walls to partially replace the existing stone walls (Figure 39, Figure 40, Figure 41, Figure 42) covered with lava stone ashlars facing;
4. Installation of lamp posts/utility poles along the stretch (Figure 43);
5. Resurfacing and installation of anti-skid Stone Mastic Asphalt for the wearing course (Figure 43).

Figure 39 stone walls

Figure 40 stone walls

Figure 41 Walls after interventions

Figure 42 Retaining walls

Figure 43 Lighting and anti-skid surfacing

As regards the horizontal design the most important interventions in terms of road safety improvement were the following:

- Construction of a tangent to eliminate two narrow curves (Sections 32 and 37) (Figure 44);

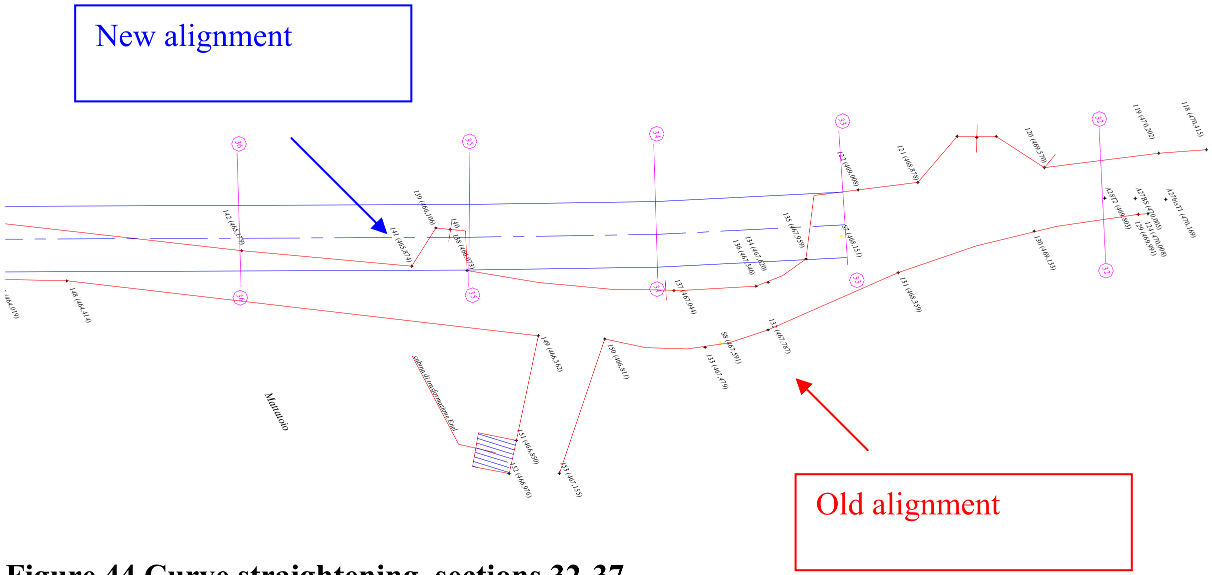


Figure 44 Curve straightening, sections 32-37

- Substitution of a narrow curve with one having a radius of 146 m (sections39T1 and 41T2) (Figure 45).

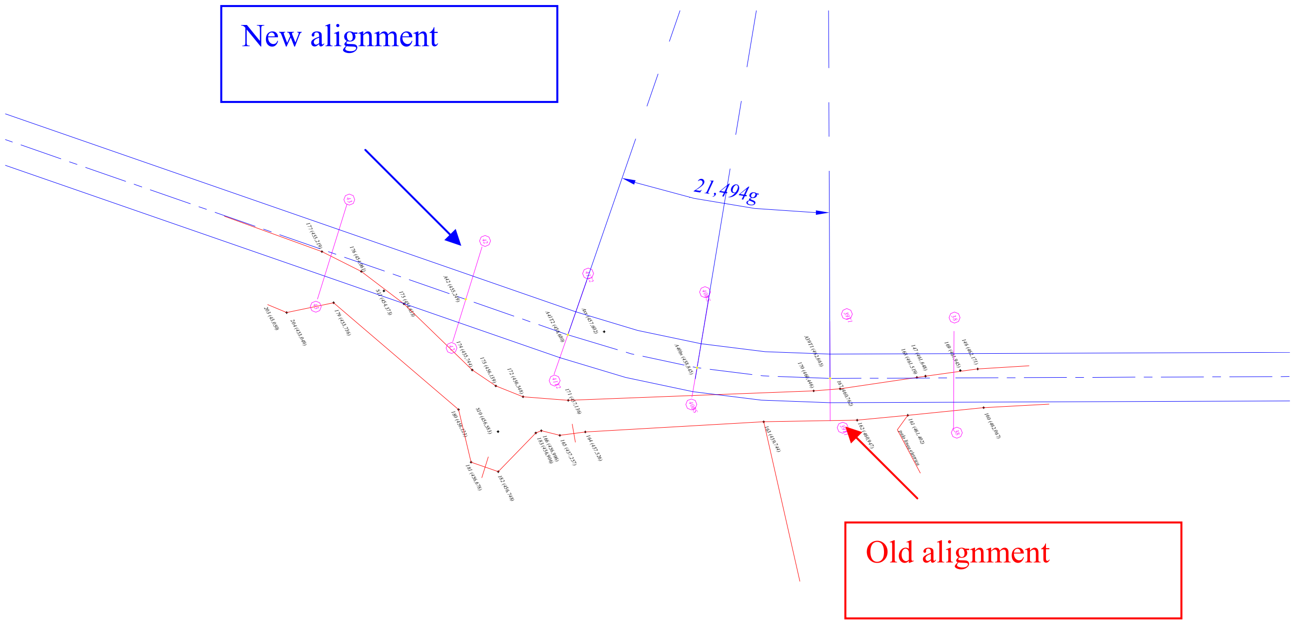


Figure 45 Curve straightening, sections 39-43

- The elimination of a series of narrow curves with irregular design between sections 72T2 and 79 (Figure 46, Figure 47)

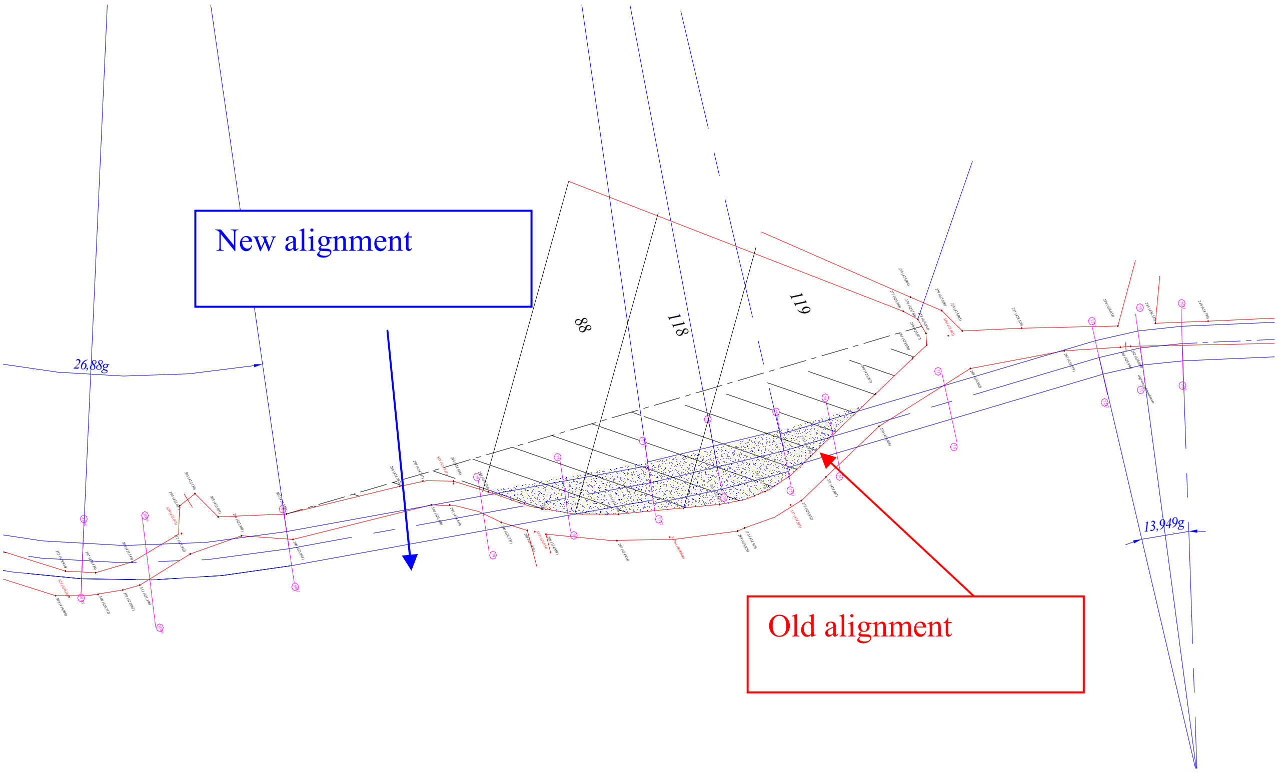


Figure 46 Straightening of a series of curves, sections 72-79

Figure 47 Straightening of a series of curves, sections 72-79

- The previously existing curve between sections 84 and 86 having a radius of about 48 m was replaced with one having a radius of about 136 m (Figure 48).

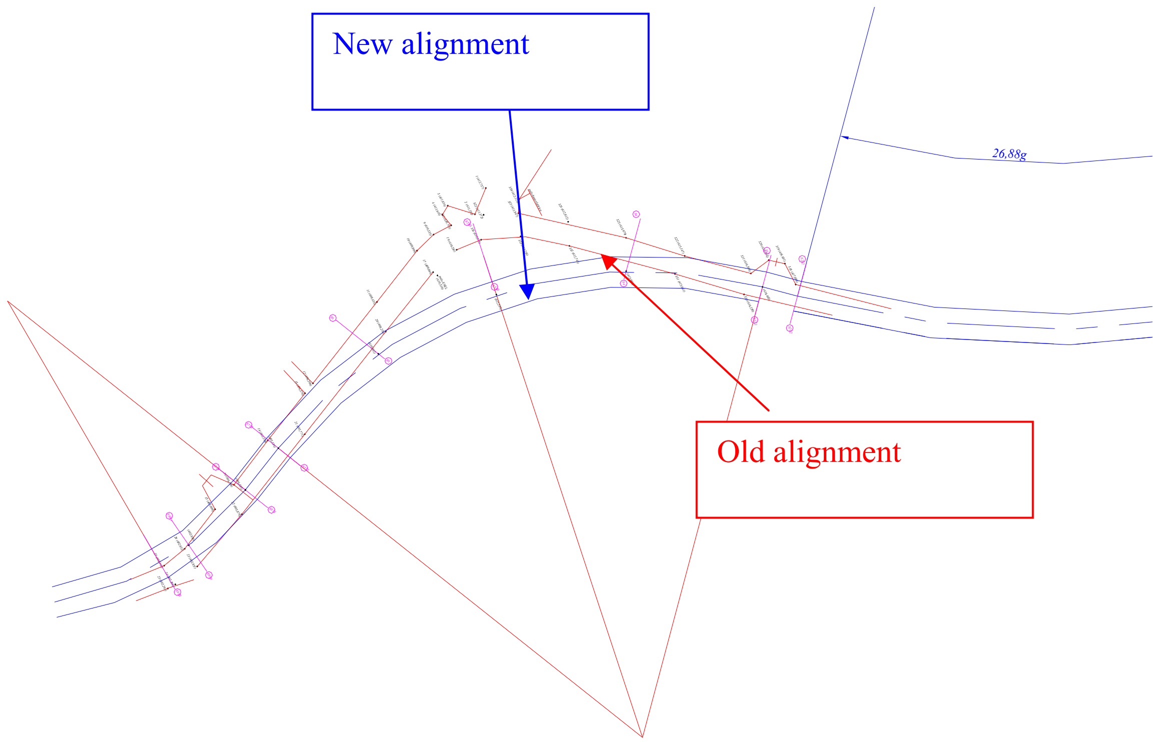


Figure 48 Straightening of a series of curves, sections 83-87

The project did not include any plans for improvement interventions on vertical design.

10.1.2 Monitoring of the interventions using Before-After Accident Analyses

The aim of Before-and-After studies is to evaluate the effectiveness of an intervention comparing the conditions observed before and after the carrying out of the interventions. In effect, it is more correct to say that the situation observed in the after period must be compared with the number of accidents that would have been expected for that site if interventions had not been carried out.

As regards the 'after' situation, the most useful parameter is the number of accidents taking place in a significant observation period once the interventions have been completed. Instead, it is more complicated to evaluate the situation hypothesising an absence of interventions. The simplest method would be to assume that the number of accidents observed in a significant period of time before the interventions were effected, would have remained unchanged in the period immediately following if the interventions had not been carried out.

However, this value is not a good estimate of the long term situation at the site. Usually, the sites where it is decided to carry out interventions are those having a higher number of accidents compared to the average number for road networks with similar characteristics.

In the ‘after’ period on these sites the number of accidents tends to go down, even in the absence of any intervention, due to the effect of regression to the mean. Therefore, the evaluations performed with reference to this parameter could lead to an overestimation of the effectiveness of the interventions (Hauer, 1997; Elvik 2000; Shen 2003).

For this reason, the problem of estimating the expected number of accidents at a site, in the absence of interventions, must be undertaken with great care, choosing the most suitable methods in order to reduce possible evaluation errors deriving from random fluctuations linked to the particular nature of the phenomenon.

Before looking in detail at the methods of analysis used for the estimation of the variables, it is necessary to define the most suitable indicators for the evaluation of the efficacy of treatments in terms of a reduction in the number of accidents:

$\delta = \pi - \lambda$ reduction in the expected accident frequency

$\theta = \lambda / \pi$ index of effectiveness

AMF= $100*(1 - \theta)$ Accident Modification Factor (percentage reduction in accident frequency)

where:

π represents the value of the number of expected accidents in the *after* period if the treatment had not been made (estimated value), and is a random variable with Poisson probability density function;

λ represents the value of the number of accidents in the period following on from the carrying out of treatment (observed value), and is also a Poisson random variable.

Due to the fact that π and λ represent random variables of unknown populations, it is necessary to proceed with estimations of the distribution parameters and the same is true for all the variables deriving from them (d, θ and ARF) (Hauer,1997):

$\delta = \pi - \lambda$ mean value

$VAR(\delta) = VAR(\pi) + VAR(\lambda)$ variance

$\bar{\theta} = (\bar{\lambda}/\bar{\pi}) / \left[1 + VAR(\pi)/\bar{\pi}^2\right]$ mean value

$VAR(\theta) = \bar{\theta}^2 \cdot \left[\left(VAR(\lambda)/\bar{\lambda}^2\right) + \left(VAR(\pi)/\bar{\pi}^2\right)\right] / \left[1 + VAR(\pi)/\bar{\pi}^2\right]^2$ variance

Where mean $(\bar{\pi}, \bar{\lambda})$ and variance (VAR(π), VAR(λ)) are estimated values and [1+VAR(π)/ π^2] is a correction factor to make the estimator unbiased.

As the exact calculation of the θ parameter strictly depends on the correct estimation of π and its variance, literature proposes various solutions offering different degrees of reliability and complexity of calculation.

Four types of before-and-after methods are commonly used in literature (Hauer,1997; Shen, 2003).

1. The simple before-and-after study method;
2. The before-and-after study with control sites method;
3. The before-and-after study with Empirical Bayes method;
4. The before-and-after study with Empirical Bayes and control sites method.

The first is easy to use but it does not consider the variability linked to the accident phenomenon and the effects of the regression to the mean.

The other methods for a correct estimation of π tend to correct the previous mistakes using control sites (control sites method) or considering the accident rate as a random variable (Bayesian method). Finally, there is also the possibility of combining the control sites method with the Bayesian method (Bayesian method with control sites).

In the before-and-after study with control sites method, accident data from the comparison group of sites are used to estimate the accidents that would have occurred at the treated sites if the treatment had not been made. The control sites can be defined as a group of sites similar to the treated sites as regards traffic and geometric characteristics. This method can provide an accurate estimate of π, but its use is very complicated since it is difficult to find a suitable sample of control sites (Cafiso, 2001; Yuan, 1999).

For this reason, in this research it was decided to adopt Methods 1 and 3 that will be described in detail in the following paragraphs.

10.1.2.1 Simple Before-and-After study method

This is one of the simplest methods for checking the safety benefits of an intervention through a direct comparison of the number of accidents taking place in the ‘before’ and ‘after’ periods.

It is assumed, therefore that:

$$\bar{\lambda}_i = L_i \qquad VAR(\lambda_i) = L_i$$

$$\bar{\pi}_i = R_{Ei} \cdot K_i \qquad VAR(\pi_i) = R_{Ei}^2 \cdot K_i$$

where:

L_i : number of accidents observed in the *after* period at site i;

K_i : number of accidents observed in the *before* period at site i;

$R_{Ei} = E_A / E_B$: exposure ratio;

$E_{Ai} = n_{Ai} \times (365\ AADT_{Bi}) \times Length_i$: exposure during *after* period at site i (10^6 vehicle per kilometre);

$E_{Bi} = n_{Bi} \times (365\ AADT_{Ai}) \times Length_i$: exposure during *before* period at site i (10^6 vehicle per kilometre);

n_{Bi} : number of years of *before* period,

n_{Ai} : number of years of *after* period,

AADT : Annual Average Daily Traffic.

This method has the advantage of being simple to use, but it does not take into account some important elements such as the regression to the mean and the possibility of changes in the accident phenomenon due to external factors such as traffic characteristics and composition, rules of the road (Hauer,1997; Elvik, 2000).

Table 35 shows for the site: length of the treated stretch, exposure and number of accidents in before (January 1999, March 2003) and after (January 2005, December 2006) periods.

Table 35 Treated stretch data

BEFORE				AFTER			
L	Months	AADT (v/day)	L [km]	K	Months	AADT (v/day)	L [km]
3	51	4000	2.55	1	24	4500	2.35

The database of accidents includes crashes from January 1999 to December 2006.

They were collected from the Italian Police and Carabinieri reports. Accident variables included date, location, time, collision type, weather conditions, number of fatalities and injuries and pavement condition.

In this way a sufficient number of years of accident data for before and after periods were available.

Accidents occurring during the construction period were excluded from the analysis.

In the first approach the comparison included all accidents which occurred in the before and after periods.

Using the simple Before-After method the following results reported in Table 36 can be obtained :

Table 36 Results of simple Before-After method

BEFORE		AFTER			Results			
π	VAR(π)	λ	VAR(λ)	R_{Ei}	δ	VAR(δ)	θ	VAR(θ)
1.46	0.71	1	1	0.49	0.46	1.71	0.51	0.20

The results in terms of δ and θ show an apparent reduction (AMF = 49 %) in the accident frequency after the intervention. However, the height values of variance gives a low level of significance to these results.

10.1.2.2 Empirical Bayes Before-and-After study method

In general, the Bayesian method is the most widely used for estimating accident rate. With the Bayesian method the accident rate is considered as a random variable having its own probability distribution.

Such an approach uses all the information available relating to the phenomenon, in order to build up a prior distribution of the accident frequency $\hat{E}$ (Y) which is later modified according to the data recorded for each single site, so as to arrive at a posterior distribution of EB_i for the site (i) from which to obtain the estimation (π_i).

For the IASP project, the Generalised Linear Model approach (GLIM) was used to calibrate an Accident Prediction Model to estimate E(Y) using traffic and length of road segments as explanatory variables. The GLIM-based procedure has the advantage of overcoming the limitations of conventional linear regression in accident frequency modelling.

The regression analyses were performed using the GenStat 7.2 and SAS 8.2 software packages (GENMOD procedure). The GLIM model obtained from the data was the following:

$$\hat{E}(Y) = e^{-5.861} \times L^{0.601} \times AADT^{0.747}$$

where:

$\hat{E}(Y)$ = Predicted accident frequency / 5 years;

L = segment length (km);

AADT = Average annual Daily Traffic (veh/day);

The Empirical Bayes procedure provides a method to combine predictions from the APM ($\hat{E}(Y_i)$) with observed site-specific history data (O_i).

Using the APM based on negative binomial the Empirical Bayes estimate of the expected accident frequency (EBi) considering both the predicted and the observed accident frequencies was computed as [Harwood et al, 2000]:

$EB_i = w\,\hat{E}(Y_i) + (1\text{-}w)\,O_i$

$VAR(EB_i) = (1\text{-}w) \times EB_i$

where:

EBi = expected accident frequency based on a weighted average of $\hat{E}(Y_i)$ and Oi;

$\hat{E}(Y_i)$ = number of accidents predicted by APM;

Oi = number of accidents observed during the specified period of time;

w = weight to be placed on the accident frequency.

The weight w is determined in the EB procedure as:

$$\mathbf{w = \frac{k}{k + \hat{E}(Y_i)}} \qquad (19)$$

where:

k = 3.56 : negative binomial parameter of the accident prediction model.

The values of $\bar{\pi}_i$ and VAR (π □) relating to site i can be determined using the following relation (Hauer,1997):

$\pi_i = R_{Ei} \times EB_i$

$VAR(\pi_i) = R_{Ei}^2 \times VAR(EB_i)$

Using the Empirical Bayes APM the following results reported in Table 37 can be obtained:

Table 37 Empirical Bayes APM

$\hat{E}(Y_i)$	w	EBi	$EB_i^{(corrected)}$	$VAR(EB_i)^{(corrected)}$
2.45	0.59	2.68	2.27	0.88

To take into account the different reference period between the APM (60 months) and the 'before' observation (51 months), the expected number of accidents in 5 years were related to a period of 51 months:

$EB_i^{(corrected)} = 51/60 \times EBi$;

$VAR(EBi) = (51/60)^2 \times VAR\,(EB_i)^{(corrected)}$

Using the Empirical Bayes Before-After method the following results reported in Table 38 can be obtained:

Table 38 Empirical Bayes Before-After method

BEFORE		AFTER			Results			
π	VAR(π)	λ	VAR(λ)	R_{Ei}	δ	VAR(d)	θ	VAR(θ)
1.31	0.21	1	1	0.49	0.31	1.21	0.68	0.41

The results in terms of δ and θ show a reduction (AMF=32 %) in the accident frequency after the intervention. However, the high variance values make these results relatively insignificant.

A comparison between the simple and the Bayesian methods shows how the former tends to overestimate the efficiency of treatments as compared to the latter. In general, this can be attributed to the regression to the mean phenomenon.

10.2 Intervention to reduce traffic speeds.

As far as overall road safety is concerned driver behaviour, and above all speeding, certainly plays an important part both in the causing of accidents and in aggravating the seriousness of their consequences. To this end enforcement procedures to control speeding were set up. Three different methods of speed control were investigated:

- Positioning of speed limit signs
- Presence of police patrols with electronic speed measuring instruments (Autovelox).
- Presence of variable message signs, in particular the Driver Feedback Sign

10.2.1 Description of intervention

The infrastructure taken into consideration for the carrying out of the experimental investigations was:

- Two long tangents on secondary rural roads to test the effects of speed limit signs and police patrols.
- A very dangerous curve and an area near the intersection of two different secondary rural roads to test the DFS.

The speed controls were effected using hidden Autovelox speed sampling equipment (Figure 49)

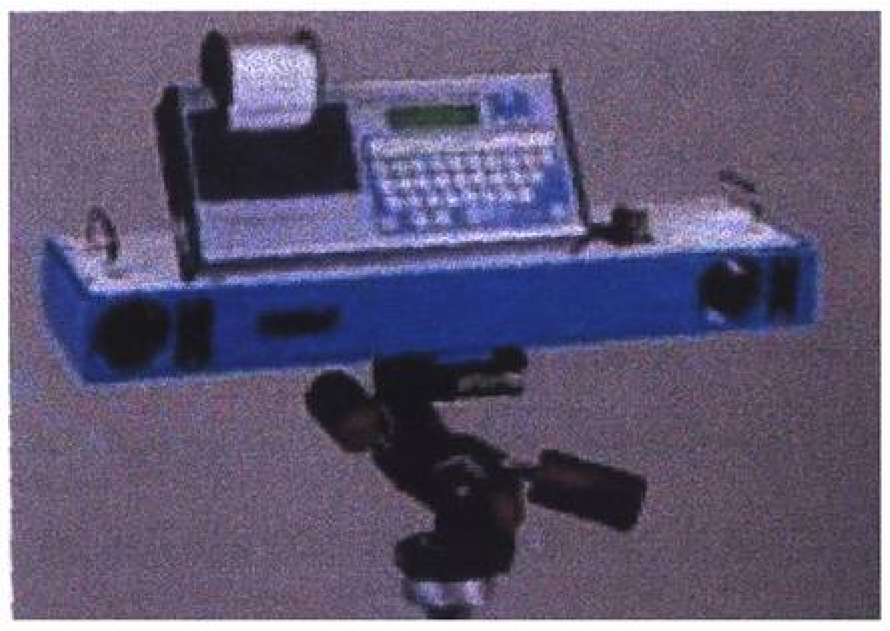


Figure 49 Autovelox

The equipment works on the basis of two photocells which emit and receive two laser beams. The beams emitted cross the selected stretch of road in an orthogonal direction. The first and then the second beam are interrupted in quick succession by the passage of a vehicle. Knowing the distance between the two photocells and the time it has taken the car to cover the distance, the computer easily calculates the speed and length of the vehicle which has passed.

During the speed controls the Autovelox was set up on the front window of a private car parked on the right side of the road in order to conceal it, as far as possible, from road users (Figure 50).

In this way the Autovelox equipment was completely invisible to approaching drivers. The vehicle, apparently parked on the roadside, did not make drivers suspicious and, therefore, did not influence travelling speed (Figure 51).

Figure 50 Autovelox set up on a car.

Figure 51 Parked vehicle with Autovelox installed.

10.2.1.1 Police patrols

The same kind of Autovelox was used at the police patrol posts. In this case, given that the aim was that of simulating a speed control, the Autovelox was installed on a tripod in full view near the traffic police vehicle. The Traffic Police officers set everything up as if the speed controls were actually being effected with the aim of catching transgressors (Figure 52).

Figure 52 Autovelox positioned by the police patrol.

10.2.1.2 Road signs

The road signs used, in addition to those already *in situ*, were mainly of two types: speed limit signs and electronic speed control devices. As regards the speed limits, the normal speed limit signs were used. These were panels in the shape, size and colour laid down by the highway code for the kind of road under examination and ANAS positioned them as established in the regulations (Figure 53).

Instead, the electronic speed control panel is compulsory when the police carry out speed controls. It is positioned before the control point so as to avoid road-users protesting about any eventual transgressions. During the experiment it was used on those days in which police controls were simulated (Figure 54).

Figure 53 70 km/h speed limit

Figure 54 Electronic speed control panel

<u>10.2.1.3 Variable message sign (DFS)</u>

The electronic speed deterrent, or Driver Feedback Sign® (DFS), is a panel with a variable display which can show the driver of an approaching vehicle his/her actual speed. The aim of this device is to act as a psychological deterrent against speeding. The panel is composed of a fixed display and a variable message display formed by two or three numbers indicating the speed measured. The fixed display is covered with a white, reflective film and allows two lines of written characters to be inserted. During the experiment it read 'SPEED MEASURED' (Figure 55).

Figure 55 DFS Panel

During the daytime the speed measured is always shown while the LED flash only if the speed limit is exceeded. During the night the LED are always on and flash if the speed limit is exceeded.

The DFS works by means of a Doppler effect radar device. The electronic deterrent used in the survey was a mobile model (DFS-230 ® supplied on free loan for the duration of the experiment by 3M). The radar has a frequency of 24.125 GHz and emits over an angle of 12° to a maximum distance of 150-180 m. To avoid errors in the speed measured by the radar it is necessary for the DFS to be in a perfectly orthogonal position with respect to the direction of traffic (Figure 56). However, in the case of inclinations of less than 5° the error is in the order of 0.3% while for inclinations of 10° the error reaches 1.5%. Greater inclinations are not advised.

Besides its normal functions the DFS can store survey data, being suitably equipped to memorise the speed and the number of vehicles passing in pre-established speed intervals at intervals of 10 minutes, without any distinction regarding the type of vehicle. In order to improve the precision of the data, Autovelox equipment was used to directly measure speed, as previously illustrated.

Figure 56 Positioning of the DFS with combined speed limit signal.

10.2.2 Description of the sites

<u>*10.2.2.1 Tangents*</u>

The enforcement area surveyed forms part of a rural road having a two-lane carriageway, each lane being 3.75 m wide. The two lanes are flanked by 1.50 m wide shoulders.

The road can be classified as a C1 type secondary rural road with a speed limit, where not otherwise specified, of 90 Km/h. The sites studied were two successive tangents, forming part of a series of three.

The first tangent, called tangent A, was 2649 m long (Figure 57, Table 39).

The second tangent, called tangent B, was 1891 m long.

Both tangents are preceded and followed by curves having a radius of about 350 m which can create safety problems due to the high speed reached on the long tangents preceding them.

Moreover, the problem of excess speed constitutes a critical safety factor also due to the number of lateral private accesses in both traffic directions.

Figure 57 shows the geometric succession of the survey site in detail.

Table 39 Geometric characteristics of the site studied

Element	Radius (m)	Length (m)	Km
Right curve	285	130	17
Tangent		74	17
Left curve	544	355	17
Tangent A		2649	17-18-19-20
Right curve	356	141	20
Tangent		96	20
Left curve	364	226	20
Tangent B		1891	20-21-22
Right curve	357	205	22
Tangent		235	22-23
Left curve	350	259	23

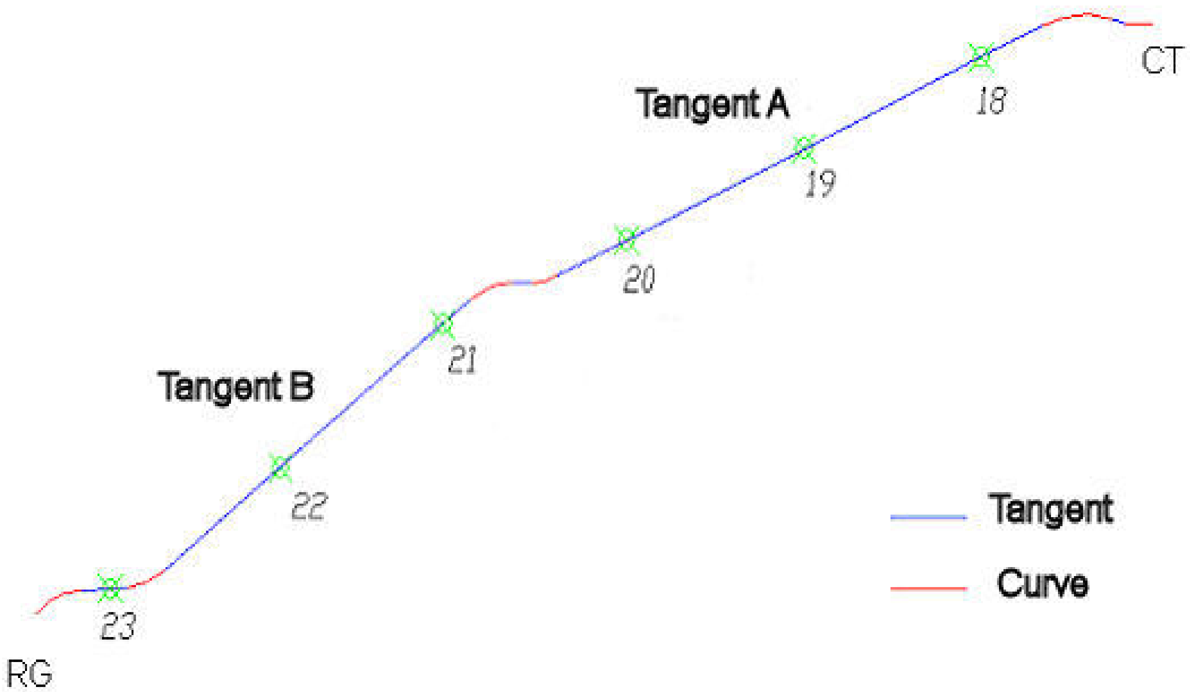


Figure 57 Survey site

The choice of the speed survey points along the two long tangents was made so as to be able to study the speed profiles in high speed zones, where this is not influenced by the curvature of the geometrical elements. The gradient slopes can be considered as having no effect on speed given that they have values of less than 1%.

The speed limit in the 'before' phase of the experiment was 90 Km/h on the two long tangents and 70 Km/h (with appropriate road sign) on the curves at the beginning and end of each tangent (including the short transition tangents). Later, in the 'after' phase of the experiment the speed limit for tangent B was set at 70 Km/h by means of appropriate road signs showing the beginning and end of the limit.

It should be mentioned that the area examined is a zone which is often subject to police speed controls for the reasons described above. However, the normal controls were suspended during the survey period.

10.2.2.2 The polycentric curve and intersection

In order to evaluate the effect of the presence of the DFS a speed survey was carried out on the stretch of road immediately after the point where the DFS was positioned, both when the DFS signal was working and when it was off.

The first site examined (Site 1) has a two-lane carriageway, one 3.75 m wide lane in each direction with 1.50 m wide shoulders. The road can be classified as a C1 class secondary rural road with a speed limit, where not otherwise specified, of 90 Km/h. The site examined was a very long polycentric curve.

In the traffic direction studied, the geometry of the stretch is shown in Table 40 and in Figure 58.

Table 40 Geometric elements of the stretch at the investigated site.

Element	Radius (m)	Length (m)	Km
Tangent			29
Right curve (1° T)	166	270	29
Right curve (2° T)	210	190	29-30
Right curve (3° T)	110	100	30
Tangent			30

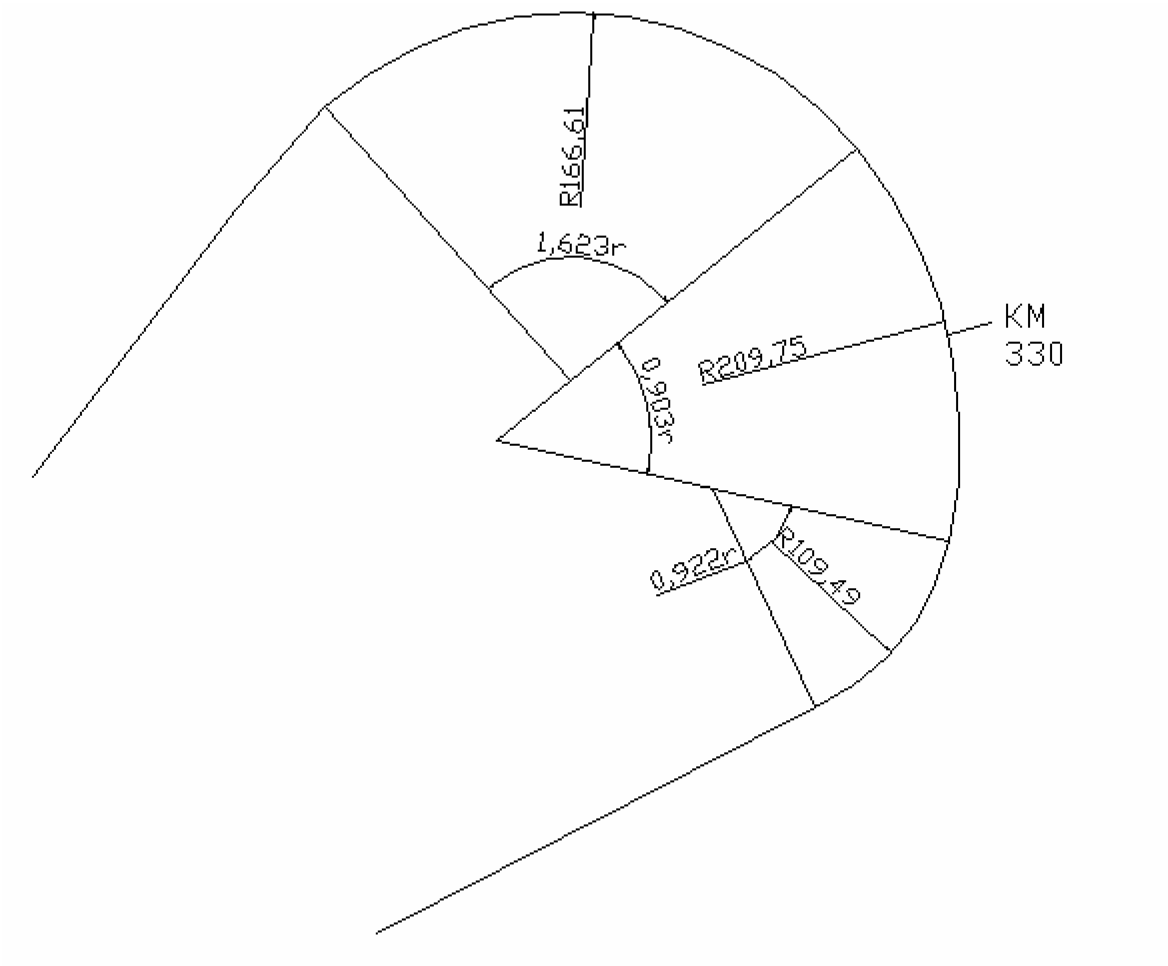


Figure 58 Horizontal design of the polycentric curve.

From a vertical point of view the curve is positioned on a steeply-sloping, downward gradient.

The speed limit is 90 Km/h both before and after the curve, while the road sign on the curve indicates a speed of 60 Km/h.

At the second site examined (Site 2) the carriageway is composed of two lanes, one 3.75 m wide lane in each direction with 1.50 m wide shoulders.

The road can be classified as a C1 class secondary rural road with a speed limit, where not otherwise specified, of 90 Km/h. the site examined was a short tangent between two curves in which there is an intersection with reduced sight distance.

Only one direction of traffic was examined with the succession of elements shown in Table 41 and Figure 59.

Table 41 Geometric elements of the stretch at the intersection.

Element	Radius (m)	Length (m)	Km
Tangent		542	2
Left curve	295	183	2-3
Tangent 1p		85	3
Intersection SP9			3
Tangent 2p		101	3
Right curve	285	110	3
Tangent		583	3

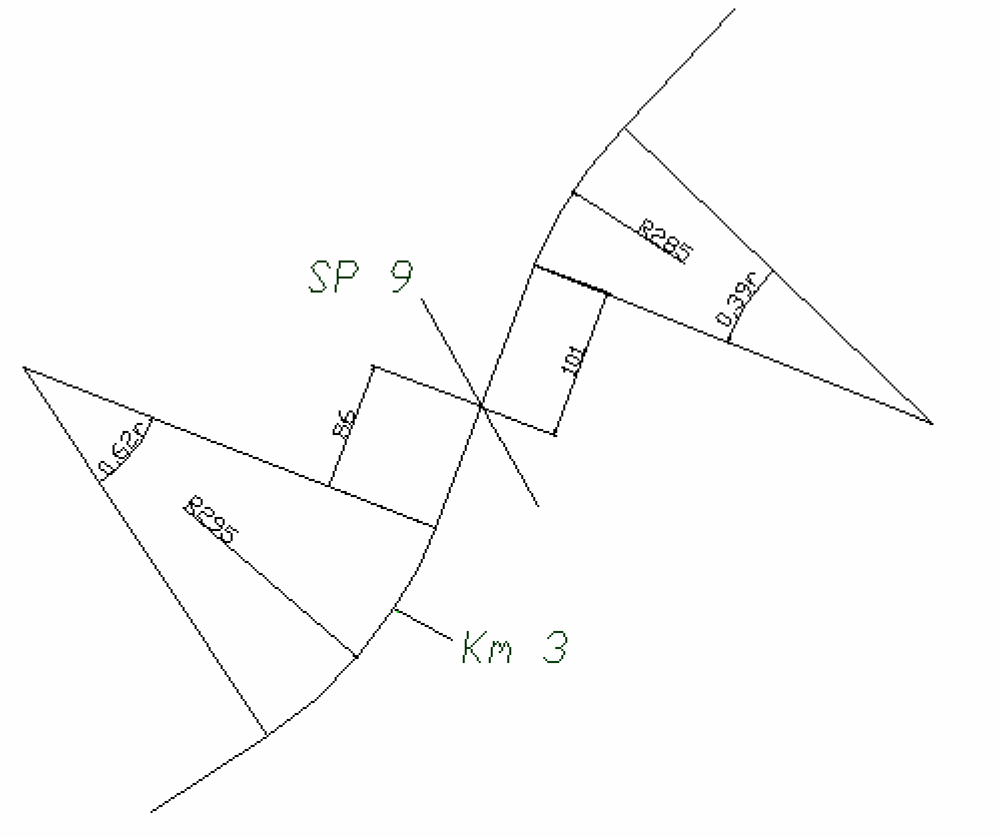


Figure 59 Horizontal design of the stretch at the intersection.

The speed limit is 90 Km/h before and after the curves, while it is 70 Km/h on the curves and the tangent in between them (the speed limit sign is positioned just before the curves).

10.2.3 Speed measurement survey

The speed survey was carried out using Autovelox equipment. The section on which to measure speed was located in the final part of each tangent, so that the police patrol could be positioned at some point along the whole of the preceding stretch. However, to avoid any influence by the curve that followed, the survey point was placed at a distance of at least 150 m from the end of the tangent. This distance was estimated by the relation of uniformly accelerated movement working on the strict hypothesis that the speed limits would be respected both on the curve (70 Km/h) and on the tangent (90 Km/h):

$D_t = (V_{max} – V_{min})^2/(26*a) = 154$ m

where:

D_t= transition distance in m.

V_{max} = maximum speed on tangent (equal to 90 Km/h).

V_{min}= speed on the curve (equal to 70 Km/h).

a= acceleration/deceleration equal to 0.8m/s^2.

Apart from these values, the survey point was also chosen on the basis of an off-the-road space where the parked vehicle could be positioned so as to carry out the survey without affecting the normal traffic flow.

For each of the days on which the surveys were conducted about 300 isolated vehicles were sampled. The expression isolated vehicle means a vehicle travelling freely, not a vehicle in a line of cars which is therefore conditioned by the presence of other, slower vehicles. This condition can be considered valid if the vehicle is separated from the preceding vehicle by a time distance of at least six seconds [Cafiso S., 2000].

Lastly, reference was made to a sample which included at least 300 isolated vehicles so as to render the estimate of the characteristic values of the speed probability distribution (mean, standard deviation) statistically reliable.

The length of the survey period depended on the traffic flow, the kind of flow (percentage of vehicles queued) and the measurements cancelled by the Autovelox.

An approximate period of about two and a half hours for each survey could be considered sufficient. The surveys were carried out between 08.30 and 12.00 depending on the availability of the police patrol.

Survey of tangent A

Tangent A was 2,649 m long and the speed survey point was positioned 390 m before the end of the tangent. The days of the week and procedures for the various surveys carried out on the tangent are reported as follows with reference to Figure 60.

- Survey 1A (Monday): speeds in normal conditions were surveyed with no police presence before the survey point (RA). It should be remembered that the speed limit is 90 Km/h.
- Survey 2A (Tuesday): speeds were measured in the survey section with the presence of a police patrol simulating speed checks 1600 m before the survey point (S1A). At about 400 m from the beginning of the tangent (CA) a notice was placed saying ‘Electronic speed checks’ in accordance with the regulations.
- Survey 3A (Wednesday): speeds were surveyed in the survey section with the presence of a police patrol simulating speed checks 890 m before the survey point (S2A). The same notice as previously described was positioned at the same point.
- Survey 4A (Thursday): speeds were surveyed in normal conditions with no police presence before the survey point (RA) to evaluate the residual effects of the checks simulated on the previous days. The time of the survey was more or less the same for each day of the survey.
- Survey 5A (Monday, the following week): speeds were surveyed in normal conditions with no police presence before the survey point (RA) to evaluate any eventual, residual effects of the simulated checks on the previous days.

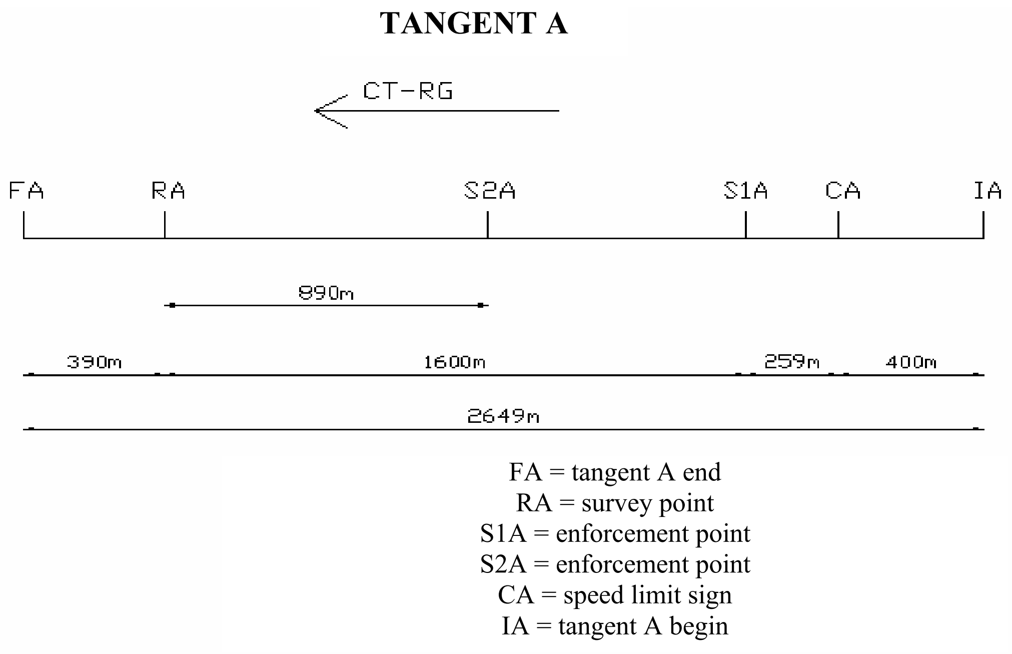


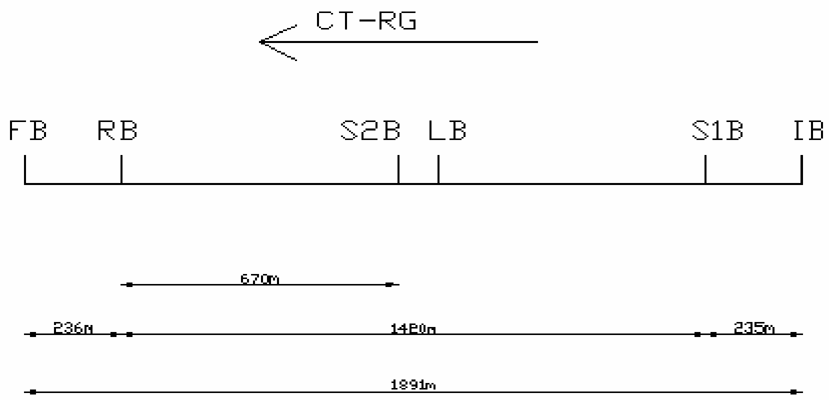
Figure 60 Survey position tangent A

Survey of tangent B

Tangent B was 1,891 m long; the speed survey section was placed 236 m from the end of the tangent. There follow the data and procedures of the various surveys carried out on the tangent with reference to Figure 61.

- Survey 1B (Thursday): speeds were surveyed in normal conditions with no police presence before the survey point (PR). It should be remembered that the speed limit was 90 Km/h.
- Survey 2B (Monday): speeds were surveyed in normal conditions but with the speed limit lowered to 70 Km/h using suitable road signs. A speed limit sign was positioned 985 m from the beginning of the tangent, 770 m before the survey point. The surveys began about one month after the change in speed limit.
- Survey 3B (Tuesday): speeds were surveyed along the survey section with the presence of a police patrol simulating checks 1,420 m before the survey point (PS1). Where the tangent begins a notice was placed saying 'Electronic speed checks' in accordance with the regulations. The notice was present for the whole survey period as it had been placed there by the traffic wardens a long time before the experiment began (speed limit 70 Km/h).
- Survey 4B (Wednesday): speeds were surveyed along the survey section with the presence of a police patrol simulating checks 670 m before the survey point (PS2).
- Survey 5B (Thursday): speeds were surveyed in normal conditions with no police presence before the survey point (PR), to evaluate the residual effects of the simulated checks on the previous days. As for the former tangent, the time of the survey was more or less the same for each day of the survey (speed limit 70 Km/h).
- Survey 6B (Monday, following week): speeds were surveyed in normal conditions with no police presence before the survey point (PR), to evaluate any eventual, residual effects of the simulated checks on the previous days (speed limit 70 Km/h).

TANGENT B



FB = tangent B end
RB = survey point
S1B = enforcement point
S2B = enforcement point
IB = tangent A begin and speed limit sign
LB = speed limit of 70 Km/h

Figure 61 Survey position tangent B

<u>Survey of polycentric curve and intersection</u>

As already described, the speed surveys were carried out using Autovelox equipment. At the first site (polycentric curve) the point where the curve reduces from a radius of 210 m to 110m was chosen as the survey position. At the second site (intersection), a section was chosen at the end of the right-to-left curve (the first in the direction studied) 95 m from the crossroads, being a point at which drivers should already slow down in order to approach the crossroads safely.

The surveys for each site were all carried out on one day at different times, all in daylight conditions and with identical atmospheric conditions. During each survey period about 300 isolated vehicles were surveyed at the first site and about 200 isolated vehicles at the second. Apart from this, all the considerations made for the previous surveys are valid.

At Site 1 the speed survey point was positioned on the polycentric curve at the critical point where the radius reduces from 210 m to 110 m. The times and conditions of the different surveys carried out at the site follow:

- Survey 1 Tuesday 10.15 – 11.50: speeds were surveyed in normal conditions without the influence of the DFS positioned prior to the survey point (R1). In reality, the DFS was present in the same position as for the successive survey, but the display of measured speed was obscured. It should be remembered that the speed limit is 60 Km/h.

- Survey 2 Tuesday 12.15 – 13.31: speeds were surveyed along the survey section with the DFS positioned 100 m before the survey point (DFS1). In this position the DFS with combined speed limit notice was visible from a distance of about 80 m prior to the curve (PV). The DFS was set with a 60 Km/h limit (using flashing lights) and signalling a maximum speed of 130 Km/h.

The characteristics of the survey position as well as the survey points are shown in Figure 62 and Figure 63.

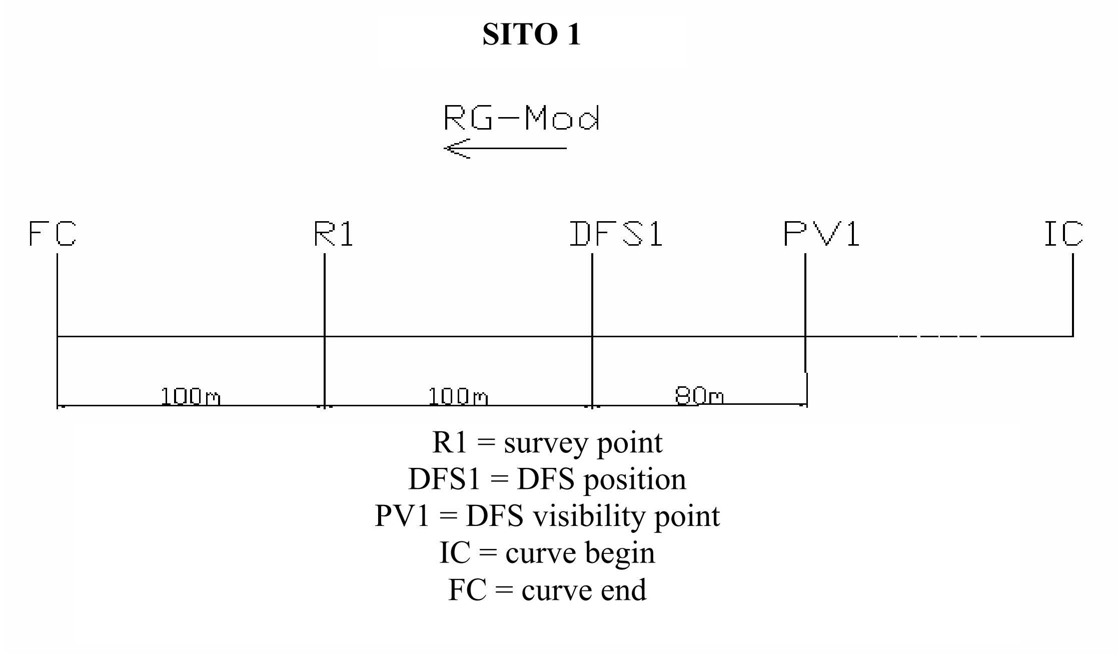


Figure 62 Characteristics of the survey position at Site 1.

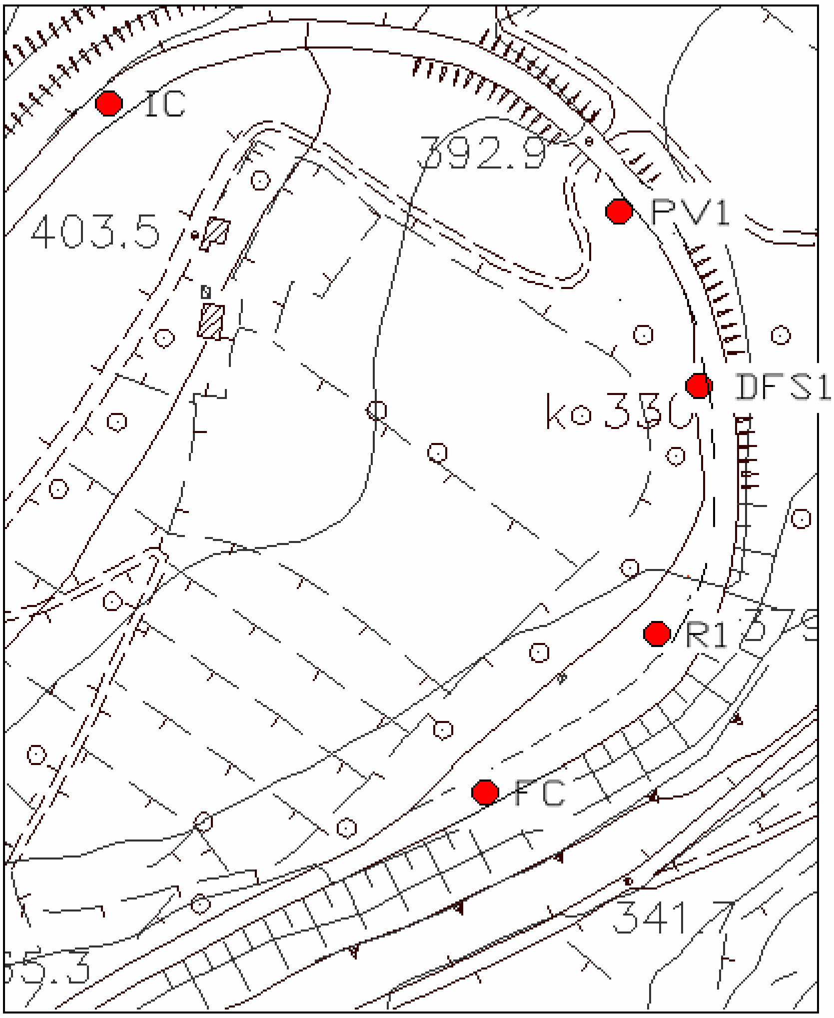


Figure 63 Identification of Site 1 survey points on the map

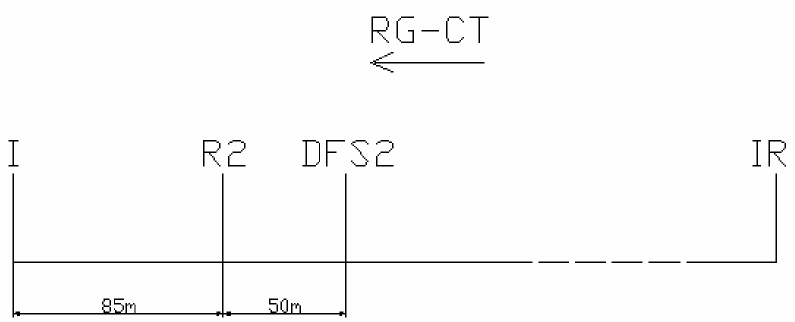
At Site 2, the speed survey section was positioned on the final part of the curve before the crossroads. There follow the details of the survey carried out at the site with reference to Figure 64 and Figure 65.

- Survey 1 Tuesday 09.10 – 10.22: speeds were surveyed in normal conditions without the influence of the DFS positioned prior to the survey section (R2). In reality, the DFS was present in the same position as for the successive survey, but the display of measured speed was obscured. It should be remembered that the speed limit is 70 Km/h.
- Survey 2 Tuesday 10.45 – 12.03: speeds were surveyed along the survey section with the DFS positioned 50 m before the survey point (DFS2). The DFS with combined speed limit sign was placed at the end of the tangent so as not to create problems of visibility for drivers approaching the curve. The DFS was set with a 70 Km/h limit (using flashing lights) and signalling a maximum speed of 140 Km/h.

- Survey 3 Tuesday 12.20 – 13.24: speeds were surveyed along the survey section with the DFS placed in correspondence to the survey point itself. There were visibility problems with the DFS given its position on the curve. The other conditions were the same as those of the previous survey.

The characteristics of the survey position as well as the survey points are shown in Figure 64 and Figure 65.

SITO 2



R2 = survey point
DFS1 = DFS position
I = SP9 intersection
IC = tangent begin

Figure 64 Survey position Site 2

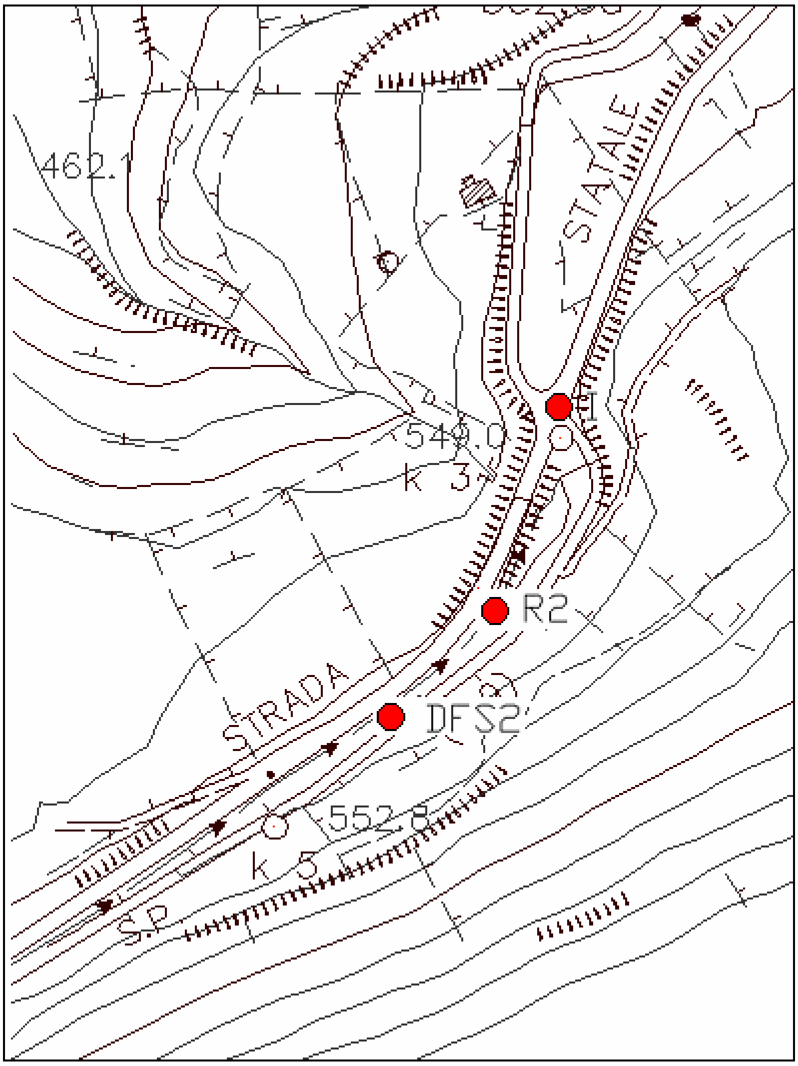


Figure 65 Map showing the survey positions at Site 2.

10.2.4 Monitoring of speed control procedures

10.2.4.1 Processing of speed limit data and police enforcement (tangent)

For each day of the survey the data collected was sub-divided into three categories:

1. isolated vehicles
2. isolated heavy vehicles
3. vehicles queued

All three categories were statistically analysed separately, even if particular attention was paid to the isolated vehicles. The first step was to verify the fit of the sample to the normal distribution. Then, for each day of the survey, all the descriptive values were calculated from the population analysed. There follow the descriptive data of the sample and the results of the fitness test.

10.2.4.1.1 Description of the sample and goodness-of fit test.

Once the vehicle categories for each day of the survey were differentiated three different data samples were obtained. For each of these we calculated:

- Mean: m
- standard deviation: s
- estimated error of the effective mean ε
- Asymmetry γ
- Kurtosis δ

Therefore, each sample underwent goodness-of-fit χ^2 and Kolmogorv-Smirnov (K-S) tests. For both tests the results are given as the value of the level of confidence α of acceptance of the null hypothesis H_o: "the random variable V is distributed according to a norm".

The significant value for judging that a sample can be considered as fitting a normal distribution is $\alpha \geq 0.05$. Table 42 and Table 43 which follow show the predicted values calculated for each sample, in two tables relating to the two tangents. In each table the data are separated according to the category of vehicle analysed.

The goodness-of-fit to the norm test highlights that, in general, all the vehicle data fit a Gauss distribution, and the same applies for the heavy vehicles. However, in some cases for vehicles queued there are problems of goodness of fit to the Gauss distribution.

It can be seen that the data of vehicles queued are also different from the others because almost all have a negative asymmetry.

The same considerations apply to the data referring to tangent B as for tangent A, with the exception that, in this case, the χ^2 test demonstrates that the series of vehicle data collected over two days does not fit, but that here too the K-S test highlights acceptable values.

Table 42 Goodness of fit to Gauss distribution for the data referring to tangent A

TANGENT A								
ISOLATED VEHICLES								
Enforcement	N° of data	Mean m	Standard deviation s	estimated error of the effective mean ε	Asymmetry γ	Kurtosis δ	α of χ^2	α of K-S
-	234	92.4	16.1	2.06	0.21	0.17	0.32	0.39
1600 m before the survey point	247	81.4	14.3	1.78	0.24	-0.48	0.17	0.19
890 m before the survey point	252	78.9	14.4	1.78	0.54	0.72	0.05	0.60
-	243	88.8	16.7	2.10	0.26	0.09	0.89	0.87
-	237	92.0	16.0	2.04	0.12	-0.02	0.79	0.81
HEAVY VEHICLES								
Enforcement	N° of data	Mean m	Standard deviation s	estimated error of the effective mean ε	Asymmetry γ	Kurtosis δ	α of χ^2	α of K-S
-	66	70.4	11.0	2.64	0.31	0.07	0.76	0.96
1600 m before the survey point	53	66.8	13.7	3.69	0.67	1.11	0.77	0.90
890 m before the survey point	48	61.3	14.9	4.21	0.52	0.54	0.70	0.94
-	57	64.2	11.8	3.06	-0.18	0.40	0.09	0.54
-	63	68.3	12.3	3.06	0.14	1.27	0.00	0.14
QUEUED VEHICLES								
Enforcement	N° of data	Mean m	Standard deviation s	estimated error of the effective mean ε	Asymmetry γ	Kurtosis δ	α of χ^2	α of K-S
-	224	65.1	12.3	1.62	-0.16	0.33	0.11	0.53
1600 m before the survey point	210	59.2	14.6	1.97	-0.20	-0.31	0.00	0.07
890 m before the survey point	216	63.9	14.6	1.95	-0.10	-0.34	0.01	0.20
-	203	69.0	13.9	1.91	0.49	0.54	0.00	0.08
-	240	71.2	14.0	1.77	0.15	-0.26	0.03	0.65

Table 43 Goodness of fit to Gauss distribution for the data referring to tangent B.

TANGENT B								
ISOLATED VEHICLES								
Enforcement	N° of data	Mean m	Standard deviation s	estimated error of the effective mean ε	Asymmetry γ	Kurtosis δ	α of χ^2	α of K-S
-	244	89.8	15.6	1.95	-0.08	0.23	0.28	0.84
Speed limit	247	84.8	16.6	2.07	0.14	-0.14	0.91	0.78
1420 m before the survey point	247	79.9	14.6	1.82	0.39	-0.11	0.20	0.43
670 m before the survey point	250	73.4	13.4	1.66	0.33	-0.34	0.00	0.06
-	252	81.4	14.2	1.75	0.19	-0.55	0.00	0.16
-	245	82.4	14.8	1.86	0.21	-0.25	0.66	0.49
HEAVY VEHICLES								
Enforcement	N° of data	Mean m	Standard deviation s	estimated error of the effective mean ε	Asymmetry γ	Kurtosis δ	α of χ^2	α of K-S
-	56	69.1	11.6	3.03	0.11	0.40	0.64	0.8
Speed limit	53	64.5	10.6	2.87	1.61	6.66	0.13	0.3
1420 m before the survey point	53	57.4	8.2	2.21	-0.17	-0.42	0.34	0.85
670 m before the survey point	50	55.6	9.7	2.68	0.19	-0.76	0.43	0.84
-	52	61.8	8.9	2.51	-0.48	-0.27	0.10	0.49
-	55	62.3	9.7	2.55	-0.54	-0.83	0.01	0.13
QUEUED VEHICLES								
Enforcement	N° of data	Mean m	Standard deviation s	estimated error of the effective mean ε	Asymmetry γ	Kurtosis δ	α of χ^2	α of K-S
-	266	62.7	13.0	1.56	0.06	-0.38	0.34	0.61
Speed limit	131	65.1	14.1	2.42	0.06	0.30	0.35	0.32
1420 m before the survey point	139	61.6	13.1	2.17	0.03	-0.68	0.33	0.77
670 m before the survey point	142	57.2	12.5	2.06	0.41	-0.24	0.03	0.43
-	125	62.3	13.1	2.29	0.69	0.82	0.03	0.30
-	147	63.0	13.0	2.09	0.77	0.23	0.02	0.12

Therefore, exploiting the normal distribution properties for each category we calculated the following parameters:

- Mean speed
- 85th percentile speed
- Percentage of vehicles breaking the speed limit

- Percentage of vehicles breaking the limit by 10 Km/h
- Percentage of vehicles breaking the limit by 20 Km/h
- Percentage of vehicles breaking the limit by 30 Km/h
- Percentage of vehicles breaking the limit by 40 Km/h

Tables 44 to 54 show the values calculated, subdivided for each day of the survey.

Data tangent A

Data collected with no police presence.

Table 44 Surveys with no police presence

Total vehicles survey		
	N°	%
Total vehicles	524	/
Isolated vehicles	300	57,3
Queued vehicles	224	42,7

Isolated vehicles survey		
	N°	%
Isolated vehicles	300	/
Vehicles	234	78
Heavy vehicles	66	22

	Mean	85° %	% of speeding	% of speeding (10 Km/h)	% of speeding (20 Km/h)	% of speeding (30 Km/h)	% of speeding (40 Km/h)
Isolated vehicles	92,4	109	55,8	31,7	13,6	4,3	1
Isolated heavy vehicles	70,4	81,7	3,7	0,3	0	0	0
Queued vehicles	65,1	77,9	2,2	0,2	0	0	0

Data collected with a police patrol stationed 1600 m before the survey point.

Table 45 Survey with a police patrol stationed 1600 m before the survey point.

Total vehicles survey		
	N°	%
Total vehicles	510	/
Isolated vehicles	300	58,8
Queued vehicles	247	41,2

Isolated vehicles survey		
	N°	%
Isolated vehicles	300	/
Vehicles	247	82,3
Heavy vehicles	53	17,7

	Mean	85° %	% of speeding	% of speeding (10 Km/h)	% of speeding (20 Km/h)	% of speeding (30 Km/h)	% of speeding (40 Km/h)
Isolated vehicles	81,4	96,2	27,3	9,6	2,3	0,3	0
Isolated heavy vehicles	66,8	81	4,5	0,8	0,1	0	0
Queued vehicles	59,2	74,3	1,7	0,3	0	0	0

Data collected with a police patrol stationed 890 m before the survey point.

Table 46 Survey with a police patrol stationed 890 m before the survey point

Total vehicles survey		
	N°	%
Total vehicles	516	/
Isolated vehicles	300	58,1
Queued vehicles	252	41,9

Isolated vehicles survey		
	N°	%
Isolated vehicles	300	/
Vehicles	252	84
Heavy vehicles	48	16

	Mean	85° %	% of speeding	% of speeding (10 Km/h)	% of speeding (20 Km/h)	% of speeding (30 Km/h)	% of speeding (40 Km/h)
Isolated vehicles	78,9	93,8	22,1	7,2	1,6	0,2	0
Isolated heavy vehicles	61,3	76,7	2,7	0,5	0,1	0	0
Queued vehicles	63,9	79	3,7	0,7	0,1	0	0

Data collected with no police presence, one day after enforcement procedure

Table 47 Survey with no police presence, one day after enforcement

Total vehicles survey		
	N°	%
Total vehicles	503	/
Isolated vehicles	300	59,6
Queued vehicles	243	40,4

Isolated vehicles survey		
	N°	%
Isolated vehicles	300	/
Vehicles	243	81
Heavy vehicles	57	19

	Mean	85° %	% of speeding	% of speeding (10 Km/h)	% of speeding (20 Km/h)	% of speeding (30 Km/h)	% of speeding (40 Km/h)
Isolated vehicles	88,8	106,1	47,1	25,1	10,2	3,1	0,7
Isolated heavy vehicles	64,2	76,4	1,4	0,1	0	0	0
Queued vehicles	69	83,4	6,6	1,3	0,2	0	0

Data collected with no police presence, five days after enforcement procedure

Table 48 Survey with no police presence, five days after enforcement

Total vehicles survey		
	N°	%
Total vehicles	540	/
Isolated vehicles	300	55,6
Queued vehicles	237	44,4

Isolated vehicles survey		
	N°	%
Isolated vehicles	300	/
Vehicles	237	79,3
Heavy vehicles	62	20,7

	Mean	85° %	% of speeding	% of speeding (10 Km/h)	% of speeding (20 Km/h)	% of speeding (30 Km/h)	% of speeding (40 Km/h)
Isolated vehicles	92	108,6	54,9	30,8	13	4	0,9
Isolated heavy vehicles	68,3	81	3,8	0,5	0	0	0
Queued vehicles	71,2	85,8	9	2	0,3	0	0

<u>Data tangent B</u>

Data collected with no police presence and a speed limit of 90 Km/h

Table 49 Survey with no police presence and a speed limit of 90 Km/h

Total vehicles survey		
	N°	%
Total vehicles	566	/
Isolated vehicles	300	53
Queued vehicles	244	47

Isolated vehicles survey		
	N°	%
Isolated vehicles	300	/
Vehicles	244	81,3
Heavy vehicles	56	18,7

	Mean	85° %	% of speeding	% of speeding (10 Km/h)	% of speeding (20 Km/h)	% of speeding (30 Km/h)	% of speeding (40 Km/h)
Isolated vehicles	89,8	105,9	49,4	25,6	9,7	2,6	0,5
Isolated heavy vehicles	69,1	81,1	3,5	0,4	0	0	0
Queued vehicles	62,7	76,1	1,8	0,2	0	0	0

Data collected with no police presence and a speed limit of 70 Km/h

Table 50 Survey with no police presence and a speed limit of 70 Km/h

Total vehicles survey		
	N°	%
Total vehicles	431	/
Isolated vehicles	300	69,6
Queued vehicles	247	30,4

Isolated vehicles survey		
	N°	%
Isolated vehicles	300	/
Vehicles	247	82,3
Heavy vehicles	53	17,7

	Mean	85° %	% of speeding	% of speeding (10 Km/h)	% of speeding (20 Km/h)	% of speeding (30 Km/h)	% of speeding (40 Km/h)
Isolated vehicles	84,8	102	81,5	61,5	37,8	18	6,5
Isolated heavy vehicles	64,5	75,5	30,3	7,3	0,8	0	0
Queued vehicles	65,1	79,8	36,5	14,6	3,9	0,7	0,1

Data collected with a police patrol stationed 1420 m before the survey point

Table 51 Survey with a police patrol stationed 1420 m before the survey point

Total vehicles survey		
	N°	%
Total vehicles	439	/
Isolated vehicles	300	68,3
Queued vehicles	247	31,7

Isolated vehicles survey		
	N°	%
Isolated vehicles	300	/
Vehicles	247	82,3
Heavy vehicles	53	17,7

	Mean	85° %	% of speeding	% of speeding (10 Km/h)	% of speeding (20 Km/h)	% of speeding (30 Km/h)	% of speeding (40 Km/h)
Isolated vehicles	79,9	95	75,1	49,7	24,4	8,4	2
Isolated heavy vehicles	57,4	66	6,3	0,3	0	0	0
Queued vehicles	61,6	75,1	25,9	7,9	1,5	0,2	0

Data collected with a police patrol stationed 670 m before the survey point

Table 52 Survey with a police patrol stationed 670 m before the survey point

Total vehicles survey		
	N°	%
Total vehicles	442	/
Isolated vehicles	300	67,9
Queued vehicles	250	32,1

Isolated vehicles survey		
	N°	%
Isolated vehicles	300	/
Vehicles	250	83,3
Heavy vehicles	50	16,7

	Mean	85° %	% of speeding	% of speeding (10 Km/h)	% of speeding (20 Km/h)	% of speeding (30 Km/h)	% of speeding (40 Km/h)
Isolated vehicles	73,4	87,3	60,1	31,1	10,8	2,3	0,3
Isolated heavy vehicles	55,6	65,6	6,8	0,6	0	0	0
Queued vehicles	57,2	70,2	15,3	3,4	0,4	0	0

Data collected with no police presence, one day after enforcement procedure

Table 53 Survey with no police presence, one day after enforcement procedure

Total vehicles survey		
	N°	%
Total vehicles	425	/
Isolated vehicles	300	70,6
Queued vehicles	252	29,4

Isolated vehicles survey		
	N°	%
Isolated vehicles	300	/
Vehicles	252	84
Heavy vehicles	48	16

	Mean	85° %	% of speeding	% of speeding (10 Km/h)	% of speeding (20 Km/h)	% of speeding (30 Km/h)	% of speeding (40 Km/h)
Isolated vehicles	81,4	96,1	78,9	53,9	27,2	9,5	2,2
Isolated heavy vehicles	61,8	70,9	17,6	2	0,1	0	0
Queued vehicles	62,3	75,9	27,8	8,8	1,7	0,2	0

Data collected with no police presence, five days after enforcement procedure

Table 54 Survey with no police presence, five days after enforcement procedure

Total vehicles survey		
	N°	%
Total vehicles	447	/
Isolated vehicles	300	67,1
Queued vehicles	245	32,9

Isolated vehicles survey		
	N°	%
Isolated vehicles	300	/
Vehicles	245	81,7
Heavy vehicles	55	18,3

	Mean	85° %	% of speeding	% of speeding (10 Km/h)	% of speeding (20 Km/h)	% of speeding (30 Km/h)	% of speeding (40 Km/h)
Isolated vehicles	82,4	97,7	79,8	56,3	30,3	11,7	3,1
Isolated heavy vehicles	62,3	72,4	21,4	3,4	0,2	0	0
Queued vehicles	63	76,4	29,4	9,4	1,9	0,2	0

As can be seen the percentage of heavy vehicles is more or less constant even if there are some small variations depending on the day of the week. The percentage of vehicles queued is to a certain degree connected to the percentage of heavy vehicles. In fact, in most cases the vehicles are queued behind a heavy vehicle. The variation in the values surveyed are analysed in the next paragraph.

10.2.4.1.2. Speed variations for tangent A

Table 55 shows the variations in the mean speed and the 85th percentile speed for isolated vehicles along tangent A.

Table 55 Speed variations along tangent A for vehicles.

	Without enforcement (1)	Enforcement 1600 m before the survey point (2)	Enforcement 890 m before the survey point (3)	One day after enforcement procedure (4)	Five days after enforcement procedure (5)
Average speed (Km/h)	92.4	81.4	78.9	88.8	92
85° speed (%)	109	96.2	93.8	106.1	108.6

It can be understood from Table 55 that when the police are present there is a reduction in mean speed of more than 10 Km/h, going down from a value above the speed limit to one decidedly below it, while moving the police post nearer to the survey point does not have a significant effect, reducing the mean speed only by about 3 Km/h. Immediately after enforcement there is a decided increase in mean speeds, while it can be seen that five days after the controls speeds return to the values which were measured before enforcement. In a similar way the 85th percentile speed goes from almost 20 Km/h above the limit to a value near, if still greater than, the limit itself.

As can be seen from Figure 66 the variations in mean speed and 85th percentile speed follow the same trend.

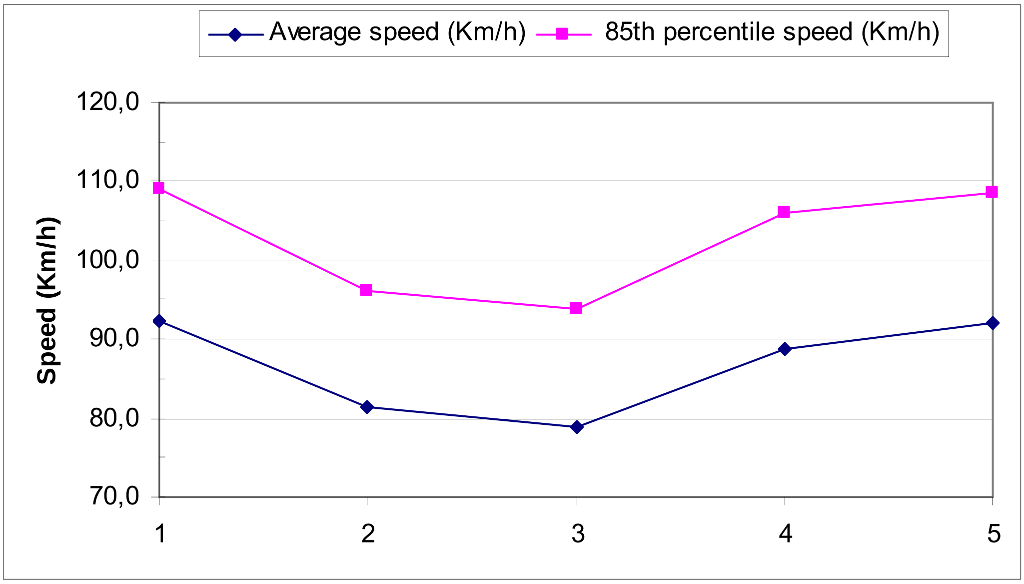


Figure 66 Speed trend for vehicles along tangent A

Heavy vehicles speeds, even if already below the speed limit, go down still further although not to the same extent as those of vehicles.

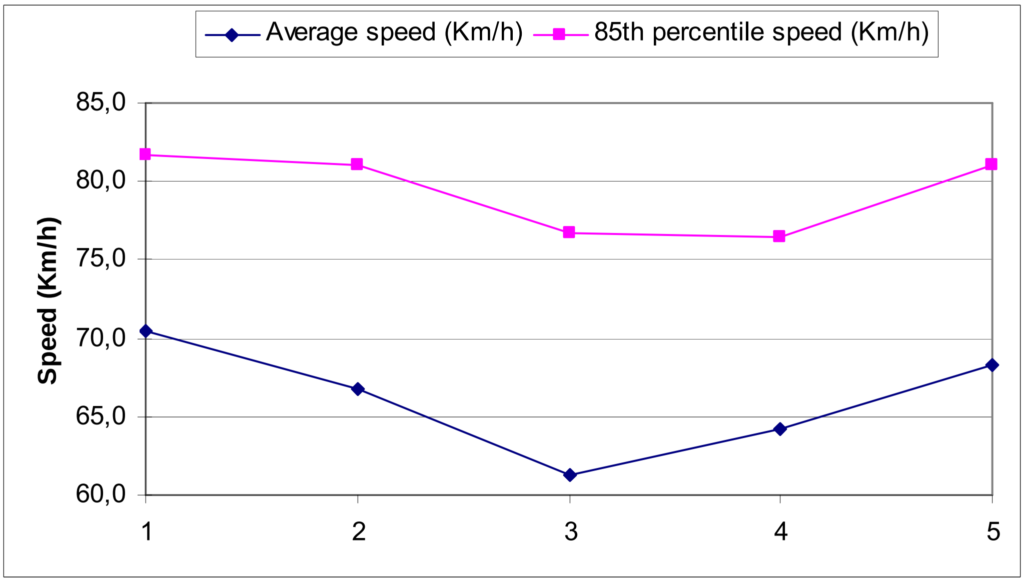


Figure 67 Speed trend for heavy vehicles along tangent A

10.2.4.1.3 Speed variations for tangent B

The analyses in Figure 68 show a reduction in speed of about 5 Km/h after the lowering of the speed limit to 70 Km/h; however, it should be noted that, while before the change the speed was below the limit (90 Km/h) after the change, although speeds reduce, they are greatly above the new limit (70 Km/h). The police presence leads to a reduction in mean speed of another 5 Km/h and stationing the police patrol nearer the survey point results in a further reduction of 6 Km/h. Therefore, in this case unlike tangent A, the positioning of the police patrol has a considerable influence on the mean speed. Once removed the enforcement procedure produces a small, although almost irrelevant, residual effect. The 85th percentile speed follows the same trend as the mean speed, but in any case remains abundantly above the speed limit.

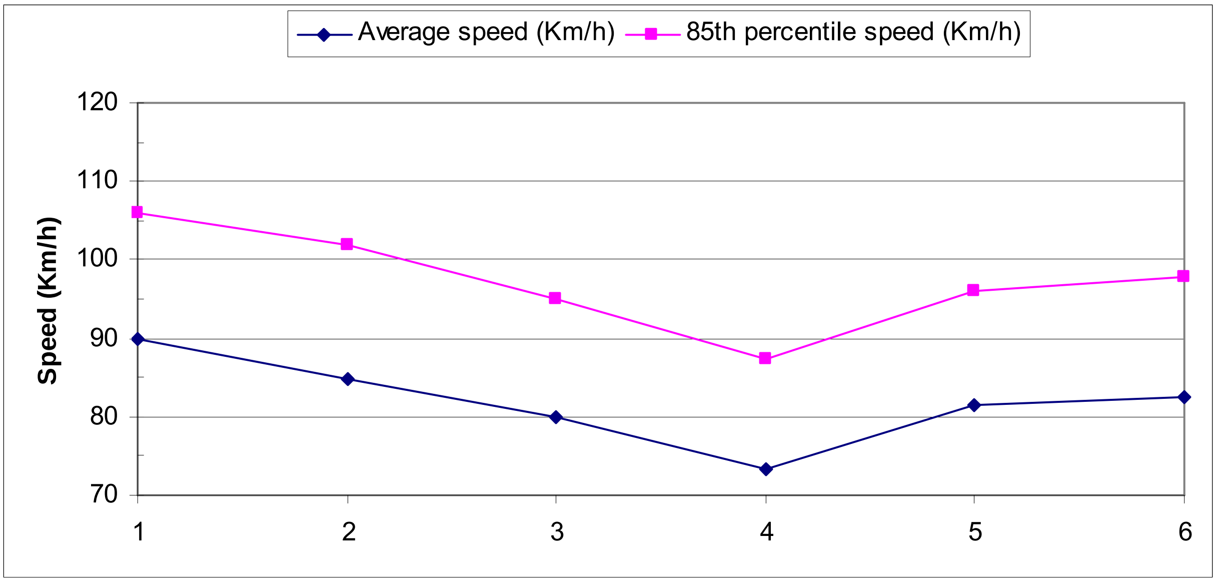


Figure 68 Speed trend for vehicles along tangent B

Figure 69 shows that heavy vehicles also undergo a reduction in mean speed of about 5 Km/h with the lowering of the speed limit. A further reduction occurs with the police patrol in position, while moving the patrol nearer to the survey point is less influential, a factor which is even more evident if we consider the 85th percentile speed. The after-effects are more evident than for vehicles, in particular for the first day after enforcement procedures when a mean speed, 3 Km/h lower than the first day of the survey, can be seen. This effect is slightly more evident taking the 85th percentile speed into consideration. It can be seen in Figure 69 that the 85th percentile speed curve is much flatter after the first day of the survey than that of the mean speed. This shows that enforcement procedures produce a constant effect on these parameters as far as heavy vehicles are concerned.

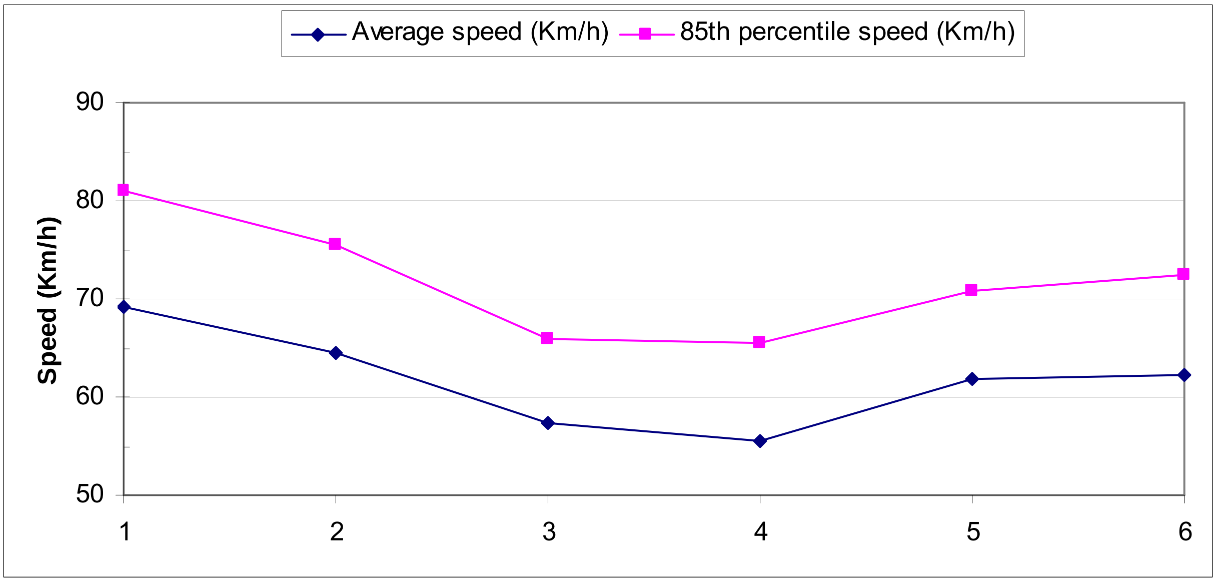


Figure 69 Speed trend for heavy vehicles along tangent B

10.2.4.1.4 Variations in the number of speeding violations on tangent A

Table 56 shows the speeding violations for vehicles on tangent A with regard to violations of different gravity (10 Km/h, 20 Km/h, 30 Km/h).

Table 56 Variations in speeding violations for vehicles on tangent A.

	Without enforcement (1)	Enforcement 1600 m before the survey point (2)	Enforcement 890 m before the survey point (3)	One day after enforcement procedure (4)	Five days after enforcement procedure (5)
% of speeding	55.8	27.3	22.1	47.1	54.9
% of speeding (10 Km/h)	31.7	9.6	7.2	25.1	30.8
% of speeding (20 Km/h)	13.6	2.3	1.6	10.2	13
% of speeding (30 Km/h)	4.3	0.3	0.2	3.1	4
% of speeding (40 Km/h)	1	0	0	0.7	0.9

An analysis of the graph in Figure 70 makes it possible to highlight a reduction by half of speeding violations when the police are present.

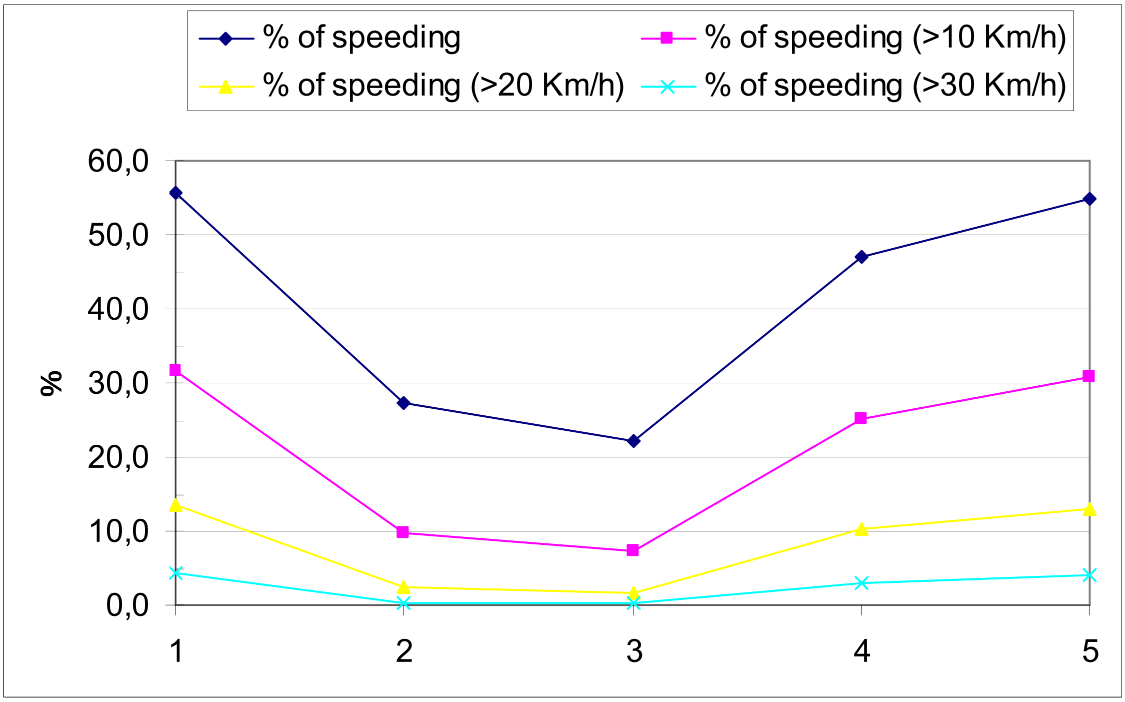


Figure 70 Speeding violations for vehicles on tangent A

Speeding violations of more than 10 Km/h reduce to less than one third when the police are present, while those of more than 20 Km/h reduce to less than one-fifth. Those drivers breaking the limit by more than 30 Km/h go down to less than one-tenth when the police are present, while those breaking the limit by more than 40 Km/h disappear completely. Stationing the police patrol nearer to the survey point produces a further reduction, but not comparable to the effect of introducing enforcement, while at the end of the enforcement period the values return to the initial figure, in particular on the last day of the survey.

Table 57 shows the variations in speeding violations for heavy vehicles but only considers the percentages of these, given that the other distinctions of gravity are not significant for these vehicles.

Table 57 Variations in speeding violations for heavy vehicles on tangent A

	Without enforcement (1)	Enforcement 1600 m before the survey point (2)	Enforcement 890 m before the survey point (3)	One day after enforcement procedure (4)	Five days after enforcement procedure (5)
% of speeding	3.7	4.5	2.7	1.4	3.8

Neither is the trend of the variations in speeding violations for heavy vehicles very significant, given that there are few cases of the 90 Km/h limit being broken and that these cases depend more on external causes than on the presence of enforcement.

10.2.4.1.5 Variations in the number of speeding violations for tangent B

All six days of the survey are analysed together in Table 58 bearing in mind, however, that although the limit of 90 Km/h still existed on the first day of the survey (while on the days that followed this was lowered to 70 Km/h) the speed limit of 70 Km/h is taken as the value for analysis for all the days of the survey.

Table 58 Variations in speeding violations for vehicles on tangent B

	Without speed limit (SL)	Speed limit without enforcement (1)	Enforcement 1420 m before the survey point (2)	Enforcement 670 m before the survey point (3)	One day after enforcement procedure (4)	Five days after enforcement procedure (5)
% of speeding	89.8	81.5	75.1	60.1	78.9	79.8
% of speeding (10 Km/h)	73.5	61.5	49.7	31.1	53.9	56.3
% of speeding (20 Km/h)	49.4	37.8	24.4	10.8	27.2	30.3
% of speeding (30 Km/h)	25.6	18.0	8.4	2.3	9.5	11.7
% of speeding (40 Km/h)	9.7	6.5	2.0	0.3	2.2	3.1

After the lowering of the speed limit there is a small reduction in speeding violations. The number of violations goes down when the police are stationed on the road, even if to a decidedly lesser degree than for tangent A. Instead, the reduction resulting from moving the police patrol nearer to the survey point is more relevant. It can be seen that even with the police at 670 m it is not possible to eliminate vehicles passing at speeds of more than 40 Km/h above the limit. Considering that similar values are seen for both tangents with regard to a reduction in speeds, it can be deduced that the new limit is either not accepted or perhaps not understood by road users. As regards residual effects after enforcement procedures it can be seen that these are practically irrelevant five days after enforcement, while there is still some effect the day after, especially as far as the higher speeds are concerned.

The trend of speeding violations is shown in the graph in Figure 71.

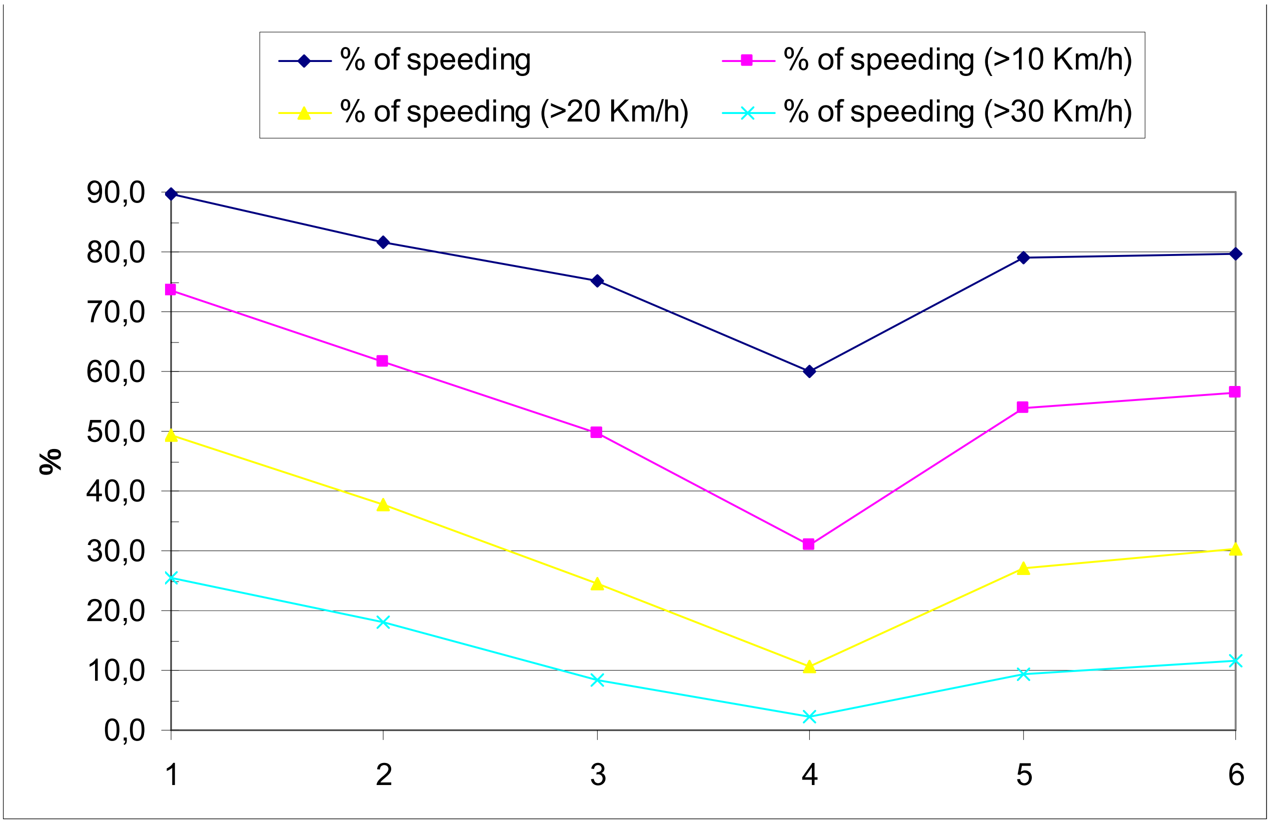


Figure 71 Speeding violations for vehicles on tangent B

The results for heavy vehicles will now be reported considering only violations up to 20 Km/h, given that above this figure there is not a relevant number of violations.

The same considerations already made regarding the speed limits are valid here. However, it can be noted that the reduction due to the positioning of the speed limit sign is more relevant than for vehicles while, unlike what happened for the latter, there is a decided reduction in the number of violations when the police patrol is in position although there is no significant difference between the two positions of the patrol (which was also true for speed variations). The residual effects are significant both for the following day and five days after (Figure 72).

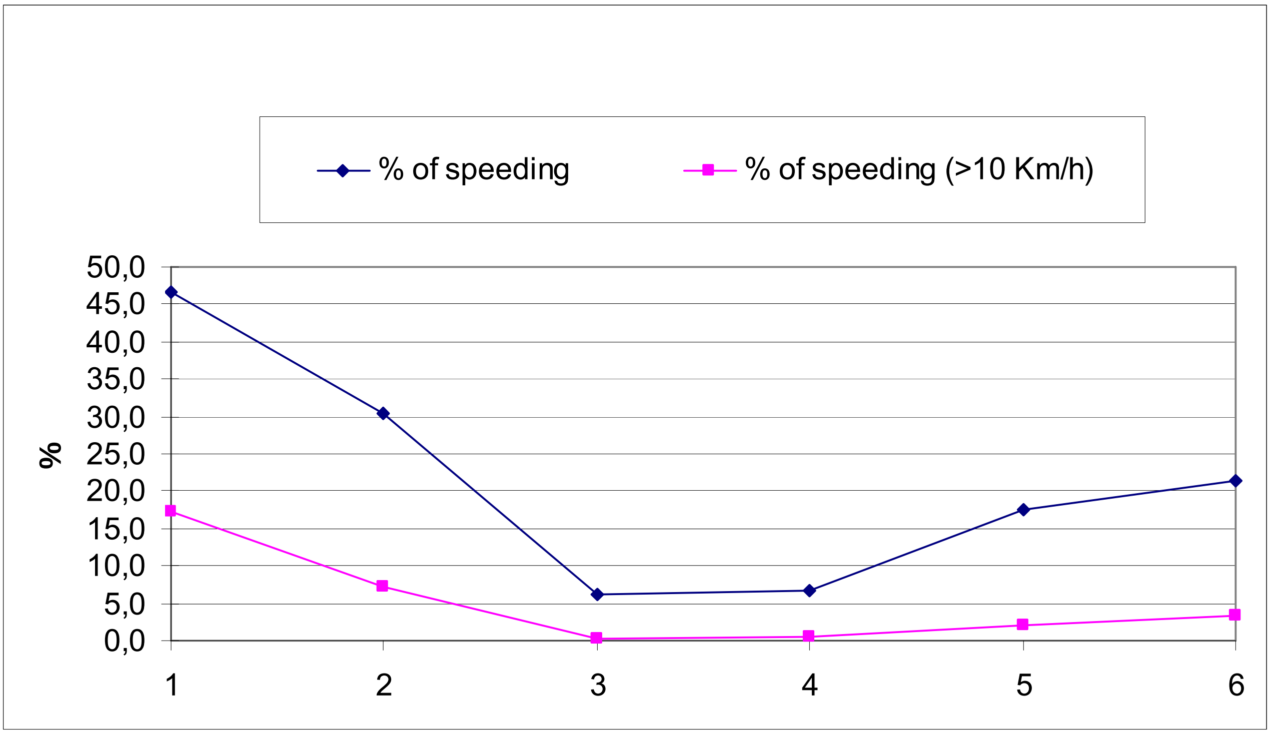


Figure 72 Speeding violations for heavy vehicles on tangent B.

10.2.4.2. Data processing using the DFS system (curve, intersection)

The data collected during each period of the survey was analysed and sub-divided into three categories:

1. isolated vehicles
2. isolated heavy vehicles
3. vehicles queued

All three categories were statistically analysed separately with particular attention to the behaviour of isolated vehicles. As in the study on the tangents, in this case too, the first step was to analyse the sample and its normal distribution trend. Then all the descriptive parameters were calculated from the analysed population for each day of the survey.

Site 1data

Table 59 shows all the data collected in the two survey periods by the Autovelox with no sub-division into classes.

Table 59 Data collected with the Autovelox in two survey periods for Site 1

Survey (10:15-11:50) – DFS covered				
	N° of survey data	Mean (Km/h)	85° % (Km/h)	% of speeding
Autovelox data	423	60.40	71.50	51.4
Survey (12:15-13:31) – DFS uncovered 100 m before survey point				
Autovelox data	443	53.7	62.9	24.0

Data Site 2

Table 60 reports the whole of the data collected during the three survey periods by the Autovelox

Table 60 Data collected by the Autovelox in three survey periods for Site 2

Survey (9:10-10:22) – DFS covered			
	N° of survey data	Mean (Km/h)	85° % (Km/h)
Autovelox data	298	62.90	77.80
Survey (10:45-12:03) – DFS uncovered 50 m before survey point			
Autovelox data	443	53.7	62.9
Survey (12:20-13:24) – DFS uncovered in correspondence of survey point			
Autovelox data	248	58.40	74.50

10.2.4.2.1 Speed variations for Site 1

Table 61 shows the processed data relating to the variations in mean speed and the 85th percentile speed at Site 1 as regards isolated vehicles.

Table 61 Speed variations for vehicles at Site 1

	Without DFS (1)	DFS 100 m before the survey point (2)
Average speed (Km/h)	65.2	55.1
85° speed (%)	73.6	63.7

The data show a reduction in mean speed by 10 Km/h when the DFS is in use, so that the mean speed passes from a value above the speed limit to one below. The same occurs for the 85th percentile speed, which passes from a value of about 15 Km/h above the limit to a value near to, if still a little higher than, the limit itself of 60 Km/h (Figure 73).

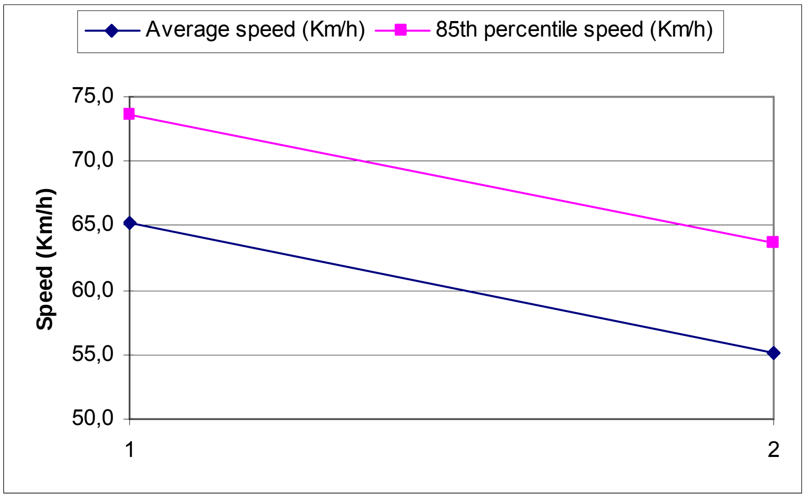


Figure 73 Speed trend for vehicles at Site 1

As regards the speed of heavy vehicles, given that the mean speed values are already below the speed limit, there is a relatively unimportant reduction in speed. The same can be said for the 85th percentile speed which, however, passes from a value above the limit to one below. Figure 74 and Table 62 show the values and trend of the mean speed and the 85th percentile speed.

Table 62 Speed variations for heavy vehicles at Site 1.

	Without DFS (1)	DFS 100 m before the survey point (2)
Average speed (Km/h)	53.3	51.4
85° speed (%)	61.5	59.1

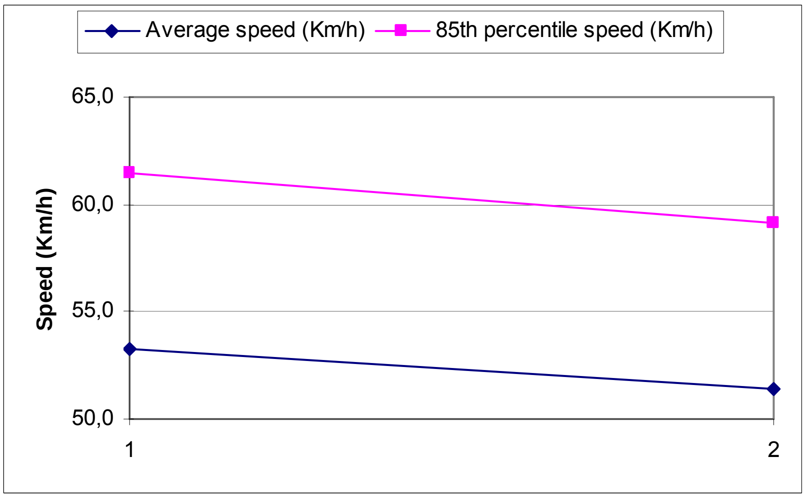


Figure 74 Speed trend for heavy vehicles at Site 1.

10.2.4.2.2 Speed variations for Site 2

Table 63 shows the speed values for Site 2 for the three survey periods.

Table 63 Speed variations for vehicles at Site 2

	Without DFS (1)	DFS 50 m before the survey point (2)	DFS in correspondence of the survey point (3)
Average speed (Km/h)	72.7	58.3	63.3
85° speed (%)	83.7	69.6	77.5

As can be noted there is a reduction in mean speed of about 15 Km/h when the DFS is placed 50 m before the survey point. Moving the DFS on a level with the survey point leads to an increase in speed again which, however, still remains 10 Km lower than the initial value. As regards the 85th percentile speed there is initially a reduction of 15 Km/h taking the values below the speed limit and then an increase to 8 Km/h above the limit (Figure 75).

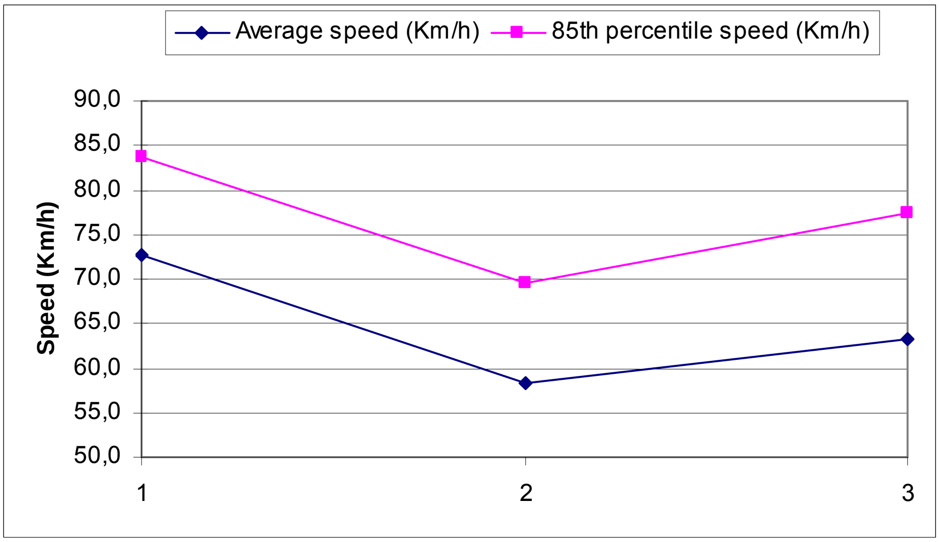


Figure 75 Speed trend for vehicles at Site 2

As regards heavy vehicles there is a reduction in mean speed of about 8 Km/h (about half the value obtained for vehicles) with the DFS in the first position. At the second survey position the speed returns to an intermediary value. The 85th percentile speed undergoes a reduction of 12 Km/h then returning to a value of about 4 Km/h below the initial value of the first survey, as shown in Figure 76 and Table 64.

Table 64 Speed variations for heavy vehicles at Site 2.

	Without DFS (1)	DFS 50 m before the survey point (2)	DFS in correspondence of the survey point (3)
Average speed (Km/h)	57.8	49.4	53.4
85° speed (%)	68.6	56.1	64.1

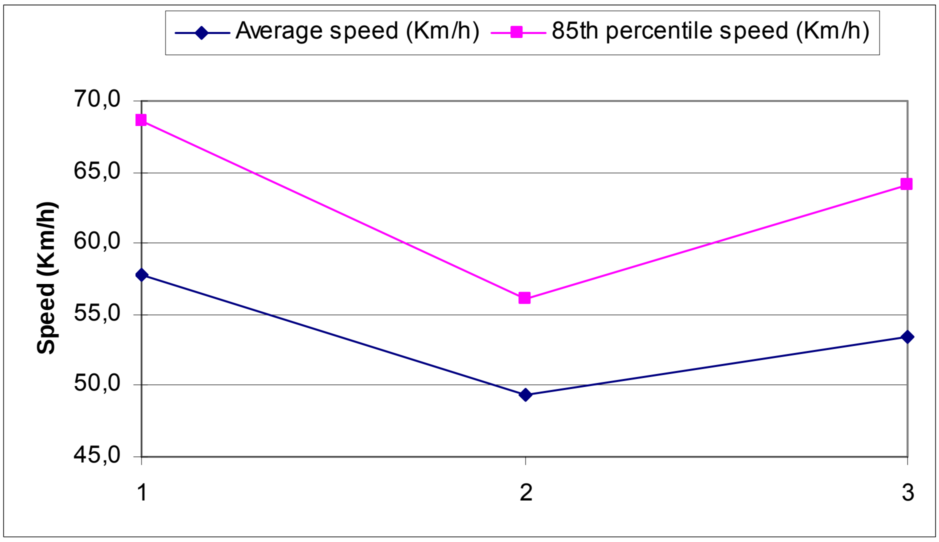


Figure 76 Speed trend for heavy vehicles at Site 2.

10.2.4.2.3 Variations in speeding violations for Site 1

The data relating to speeding violations for vehicles at Site 1 are shown in Table 65.

Table 65 Variations in speeding violations for vehicles at Site 1.

	Without DFS (1)	DFS 100 m before the survey point (2)
% of speeding	73.9	27.8
% of speeding (10 Km/h)	27.7	3.7
% of speeding (20 Km/h)	3.4	0.1
% of speeding (30 Km/h)	0.1	0
% of speeding (40 Km/h)	0	0

It should be underlined that when the DFS is used speeding violations are reduced to one-third (from 73% to 27%), while those of more than 10 Km/h go down to about one-tenth, while the others are already particularly low even in the absence of the DFS (Figure 77).

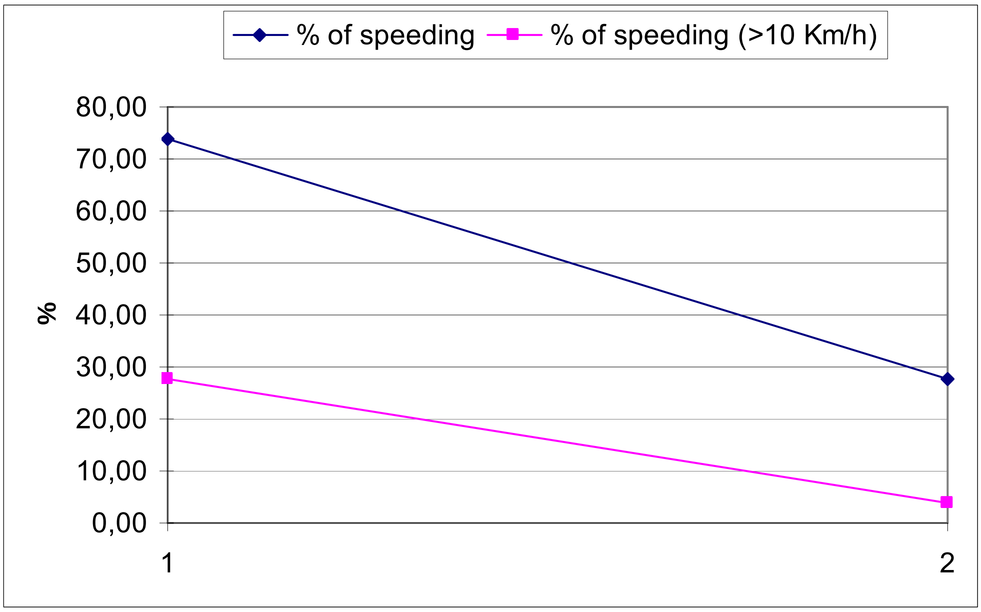


Figure 77 Speeding violations trend for vehicles at Site 1.

As regards heavy vehicles, considering only the first two categories of speeding violations given that the others are not significant, it can be seen that there is a reduction of about one-third, a significant value if we consider that the number of speeding violations is not high (Figure 78, Table 66).

Table 66 Variations in speeding violations for heavy vehicles at Site 1.

	Without DFS (1)	DFS 100 m before the survey point (2)
% of speeding	19.7	12.5
% of speeding (10 Km/h)	1.7	0.6

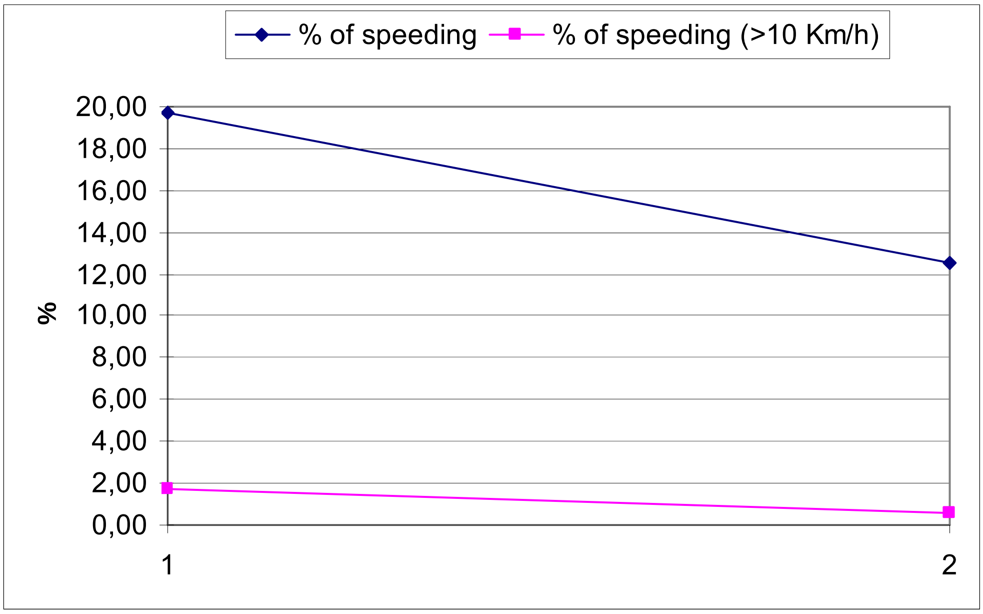


Figure 78 Speeding violations trend for heavy vehicles at Site 1.

10.2.4.2.4 Variations in speeding violations for Site 2.

The speeding violations of vehicles for the three survey periods at Site 2 are shown in Table 67.

Table 67 Variations in speeding violations for vehicles at Site 2.

	Without DFS (1)	DFS 50 m before the survey point (2)	DFS in correspondence of the survey point (3)
% of speeding	60.2	14.1	31.3
% of speeding (10 Km/h)	24.6	2.3	11.2
% of speeding (20 Km/h)	5.1	0.2	2.6
% of speeding (30 Km/h)	0.5	0	0.4
% of speeding (40 Km/h)	0	0	0

With the DFS positioned 50 m before the survey point there is a distinct reduction in violations which go down to about one-quarter (from 60.2% to 14.1%), the number of vehicles exceeding the limit by more than 10 Km/h goes down to about one-tenth (from 24.6% to 2.3%), while the rest of the values are annulled. Instead, when the DFS is moved on a level with the survey point all the values go up again to half of the initial values in all speeding categories, as is reported in Figure 79.

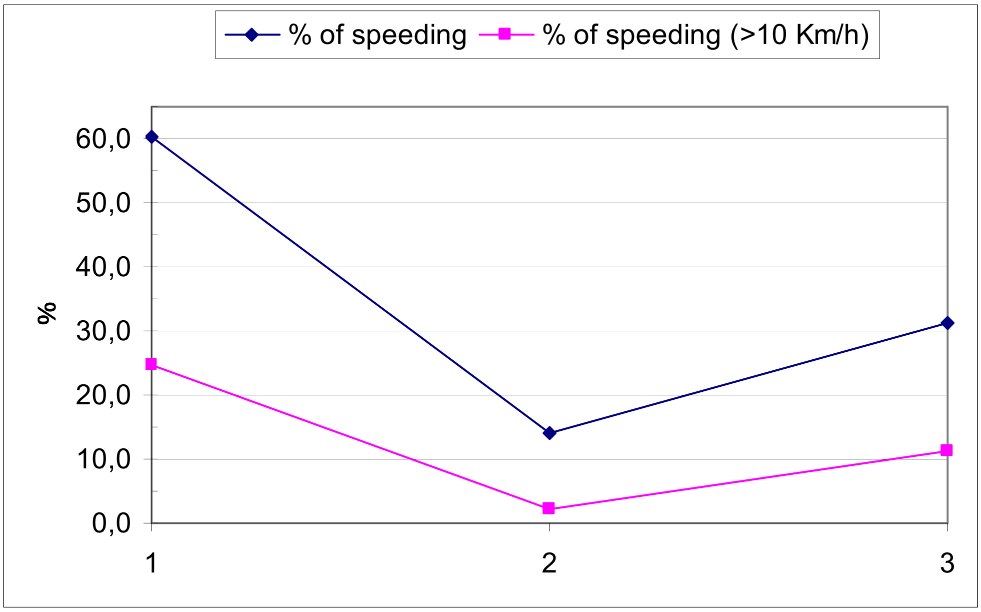


Figure 79 Speeding violations trend for vehicles at Site 2.

As regards heavy vehicles, only the speeding violations of up to 10 Km/h are taken into consideration, the others being irrelevant.
As can be seen the violations, already having particularly low values, disappear completely with the use of the DFS in its first position, returning to an intermediary value when the equipment is moved on a level with the survey point (Figure 80, Table 68).

Table 68 Variations in speeding violations for heavy vehicles at Site 2.

	Without DFS (1)	DFS 50 m before the survey point (2)	DFS in correspondence of the survey point (3)
% of speeding	12.1	0.1	5.4
% of speeding (10 Km/h)	1.7	0	0.5

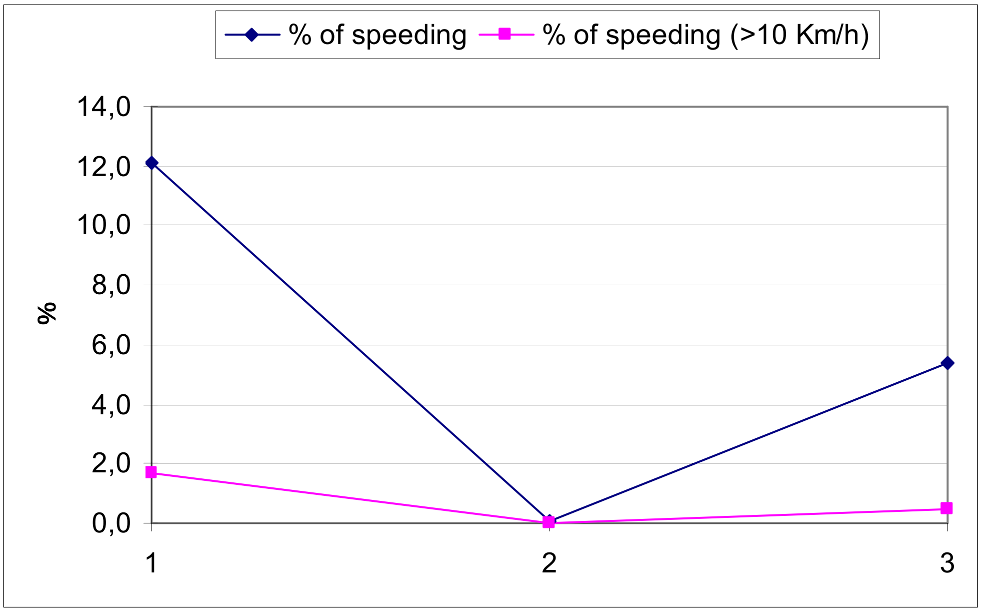


Figure 80 Speeding violations trend for heavy vehicles at Site 2.

10.2.5 Remarks on interventions monitoring

Analysing the results of the experiment it is possible to make some important considerations regarding the enforcement action carried out.

With regard to the speed limit, it can be noted that a simple road sign indicating the limit is not enough to regulate and control imprudent behaviour. As emerged in the case of tangent B, when the speed limit was lowered to 70 Km/h there was a reduction in speed of only 5 Km/h and, as a consequence, an increased number of drivers who exceeded the limit. This indicates that, to the percentage of road-users habitually breaking the limit, there should be added a high percentage of drivers who consider the new limit to be too restrictive and therefore tend to maintain the speed that they wish. Therefore, it is possible to deduce that in zones like the one examined, in which the geometric characteristics of the elements forming the stretch make it possible to reach high speeds, it is both insufficient and inadequate only to erect a speed limit sign because drivers will not respect it.

As regards the presence of electronic speed checks with a police patrol visible to road-users, it is possible to underline that for the greater distances (1,420 m and 1,600 m) there is a reduction in speed of about 5-6 Km/h considering the total number of vehicles, while for the shorter distances (670 m and 890) there is a greater reduction in speed of about 10-12 Km/h. As regards speeding violations a distinct reduction of about 15÷30% can be noted, according to whether the speed limit is acceptable or not (with the lower limit there is a smaller reduction in violations) and the position of the police patrol. This leads us to deduce that the visible presence of the police and Autovelox equipment has a very important effect on reducing speeds, an effect which continues, albeit slowly diminishing, with the passing of time. This highlights, therefore, that speed limit enforcement must be visible or, in any case, well publicised to have more than momentary/short-term, psychological effects on road-users. It should be underlined that the effects are greater on vehicles than on heavy vehicles but this is due fundamentally to the fact that heavy vehicles already travel at more modest speeds. Another important factor is that in areas which are constantly subject to enforcement, such as that in which the experiment was carried out, the residual effects on the following days were not very relevant, there already being probably a continual distributed effect.

With reference to the results obtained using the DFS, it is important to note that this kind of intervention is of a typically momentary/short-term kind. This is why it was decided to evaluate its effects at points very close to its positioning and why the residual effects in the following days were not evaluated. With reference to Site 1, that is to a site at which speeds were already reduced given the road layout, mean speed reductions of about 10 Km/h were obtained. Instead, as regards Site 2 it is possible to highlight that with less restrictive geometric conditions better results in terms of greater speed reductions are obtained installing a DFS (about 15 Km/h). This is due both to the higher speed on the preceding tangent and the greater visibility of the DFS. It should be remembered that at Site 1 the DFS was visible 80 m before the survey point while at Site 2 there was a greater visibility because this was not impeded by the road design. When the DFS at Site 2 was moved to be on a level with the survey point, the reduction in speed went down by about 8 Km/h. As regards the number of speeding violations, it can be seen that the effects are notable given that the number goes down to less than a third and violations of more than 10 Km/h are eliminated. The data collected and other experience acquired lead to the following considerations:

- The DFS is particularly suitable for reducing speed momentarily/in the short term on dangerous parts of the road (crossroads, dangerous curves, high-accident zones).
- The DFS should be located between 50 and 100 m before the crucial point, so as to give the driver time to slow down but not enough time to accelerate again.
- It is important for the DFS to be extremely visible (if possible over a range which can be estimated as 150-180 m, greater distances being useless).
- It is, in any case, necessary to guarantee space for the driver to slow down (about 150 m) from the moment that the DFS is fully visible to the crucial point.

No comparison was made of the results obtained for the different enforcement methods analysed (speed limits, police controls, DFS) because it is not possible to substitute any one method for the others. The three methods demonstrated that each one has its own particular field of application and that they can be integrated.

10.3 Improvement interventions on a curve

The aim of the interventions was to improve the fitness for traffic and usability of the road by means of improvements to the road surface and safety devices, where possible conforming to the provisions of the current technical norms regarding road planning, and improving the safety standards of a curve having an intersection in the middle (Figure 81, Figure 82, Figure 83).

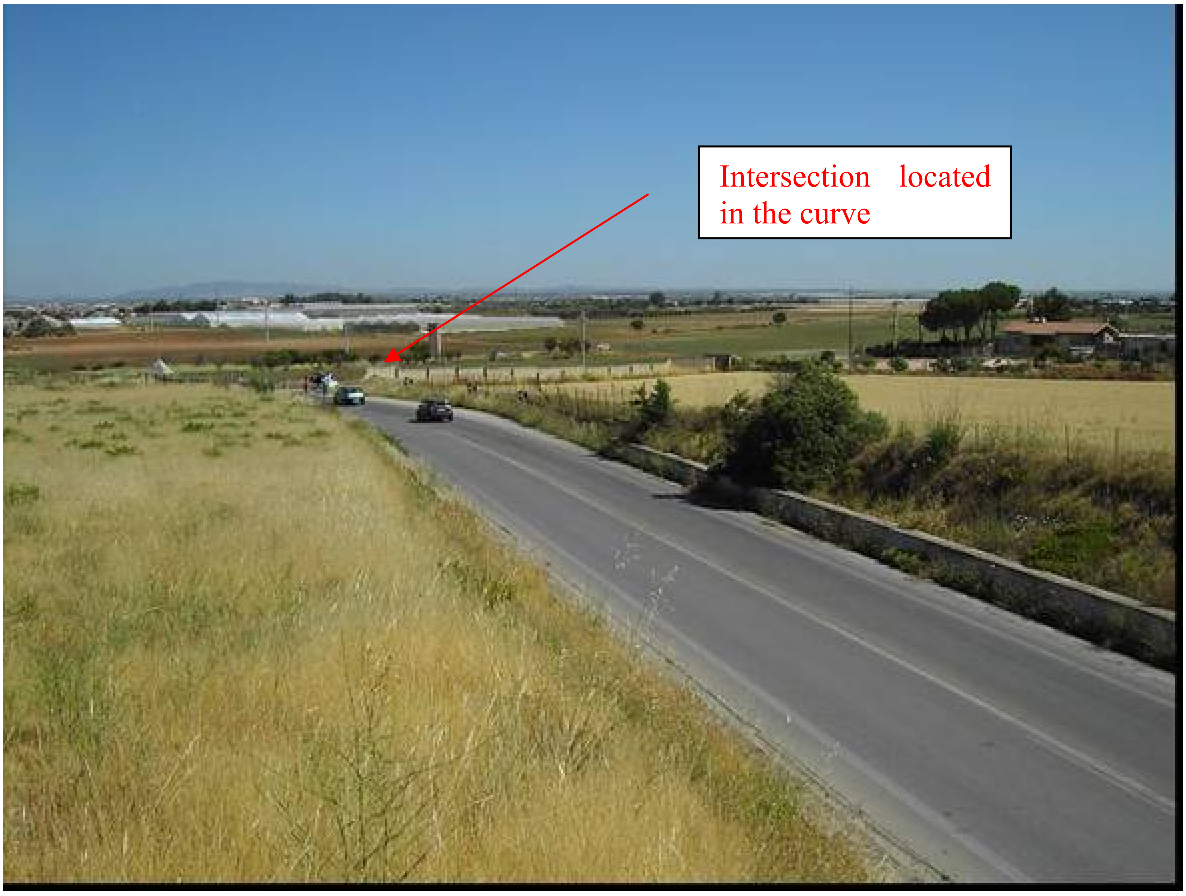


Figure 81 Location of the curve

Figure 82 The curve

Figure 83 Danger and regulation signs for the curve and the intersection

The barriers and stone walls were damaged after previous interventions (Figure 84, Figure 85).

Figure 84 Damaged barriers and terminals

Figure 85 Damaged barriers

It was not necessary for land beyond the carriageway, belonging to third parties, to be occupied during the interventions.

10.3.1 Description of the interventions

Given the quantity of traffic it was necessary to improve the barriers to modern standards. The project aimed to improve road safety also through the improvement and widening of some stretches of the road network.

The choice of the type of barrier for roadside use was evaluated bearing in mind: the geometrical characteristics of the stretch, the type of road under examination and lastly the type and quantity of vehicular traffic. To this end, given that the road under examination can be classified as an F2 (Figure 86), it was considered advisable to install H2 class lateral barriers in galvanised steel on the roadside retaining walls (Figure 87).

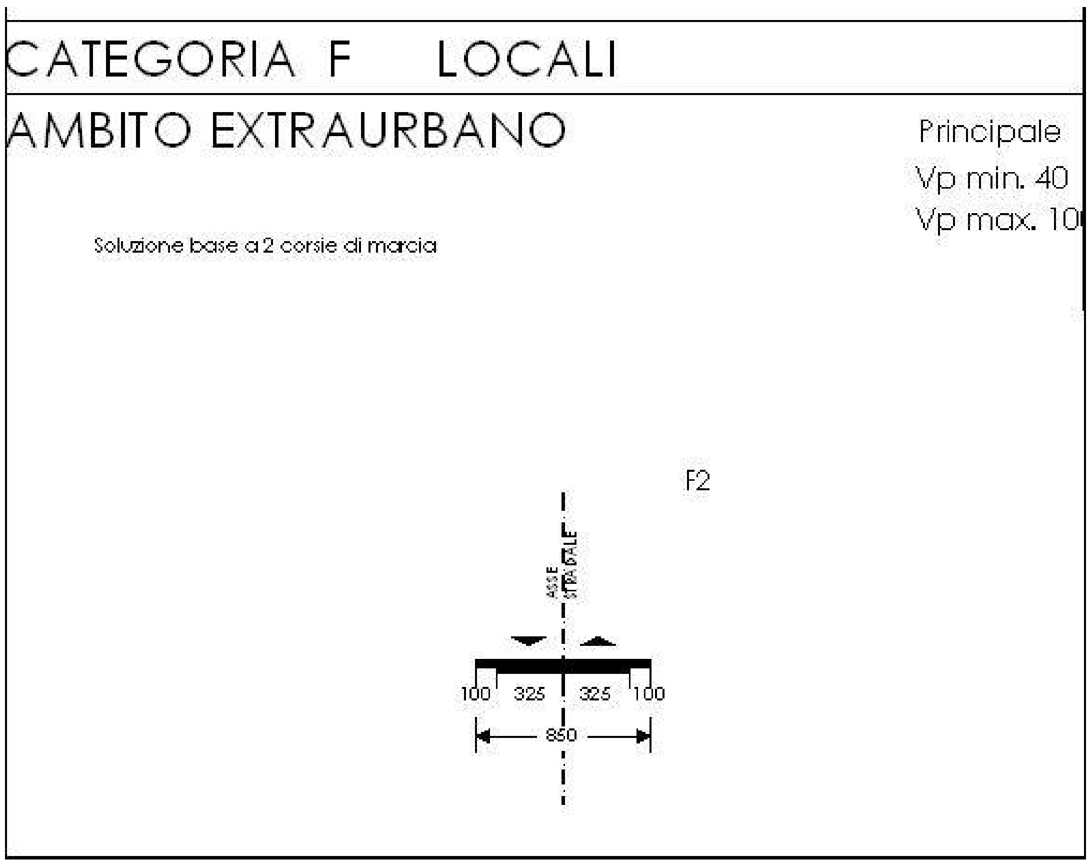


Figure 86 F2 type local, rural road

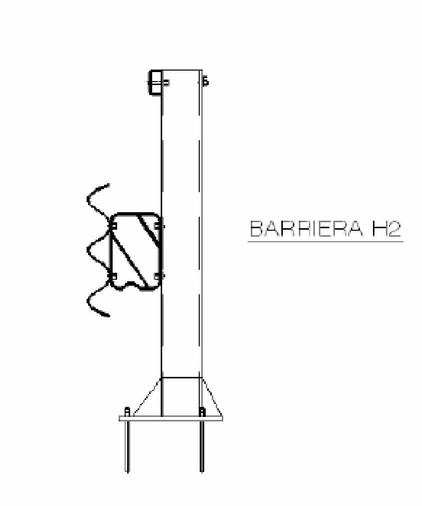


Figure 87 H2 type of protection barrier

The working project included in detail the following interventions:

- Resurfacing (Figure 88) to a width of 8.50 m and a contemporary remodelling of the transversal slopes on both the tangents and the curves (from the present 2% to 5%) (Figure 89), on the stretch from km 3+100 to km 6+100.

Figure 88 Resurfacing interventions

Figure 89 Creation of new shoulders/kerbs

- the rebuilding of some stretches of wall from km 5+300 to km 5+600 (Figure 90);

Figure 90 Rebuilding of walls

- Maintenance work on existing safety barriers in part damaged in accidents and in part to be realigned and raised, substituting old or damaged components (Figure 91).

Figure 91 Repair and substitution with H2 type approved protection barriers

- Installation of new H2 type barriers on the concrete kerb (Figure 92);

Figure 92 Installation of new barriers after building concrete kerb.

- Improvement of vertical curve creating a single gradient for the whole 71.85 m length of the curve having a slope equal to 1.6%. This gradient is preceded by a

74.65 m long stretch with a slope of 1.8% and is followed by a 45 m long stretch with a slope of 1.1 % . This guarantees the correct horizontal-vertical co-ordination and eliminates the visibility problems caused by the previous succession of short gradients (Figure 93);

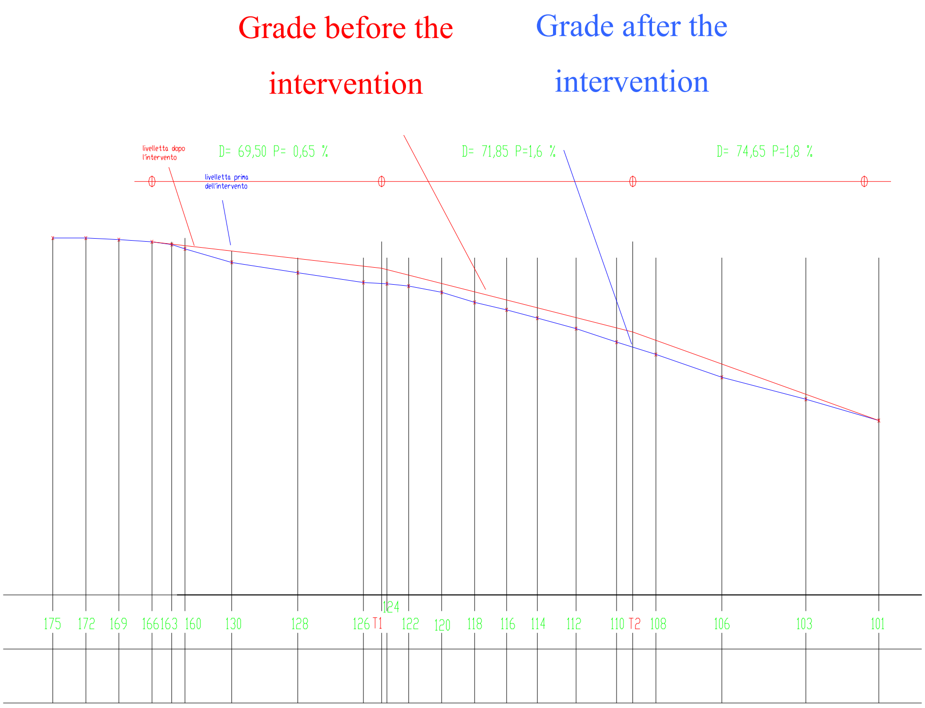


Figure 93 Vertical profile plan along the curve

- Redesigning the horizontal design of the existing curve with a single radius of 165.5 m (Figure 94);
- the intersection at the crossroads with the local road was widened providing better visibility when turning off the latter, and the gradient of the junction was also raised avoiding obstacles higher than 80 cm (Figure 95, Figure 96);
- the road markings were repainted along the whole of the stretch under examination (from km 6+000 to km 3+000), giving the lanes a uniform width of 3.25 m, external edge lines of 20 cm and internal lane markings of 15 cm and lastly the STOP sign was repainted together with the solid line at the crossroads with the local road (Figure 97).

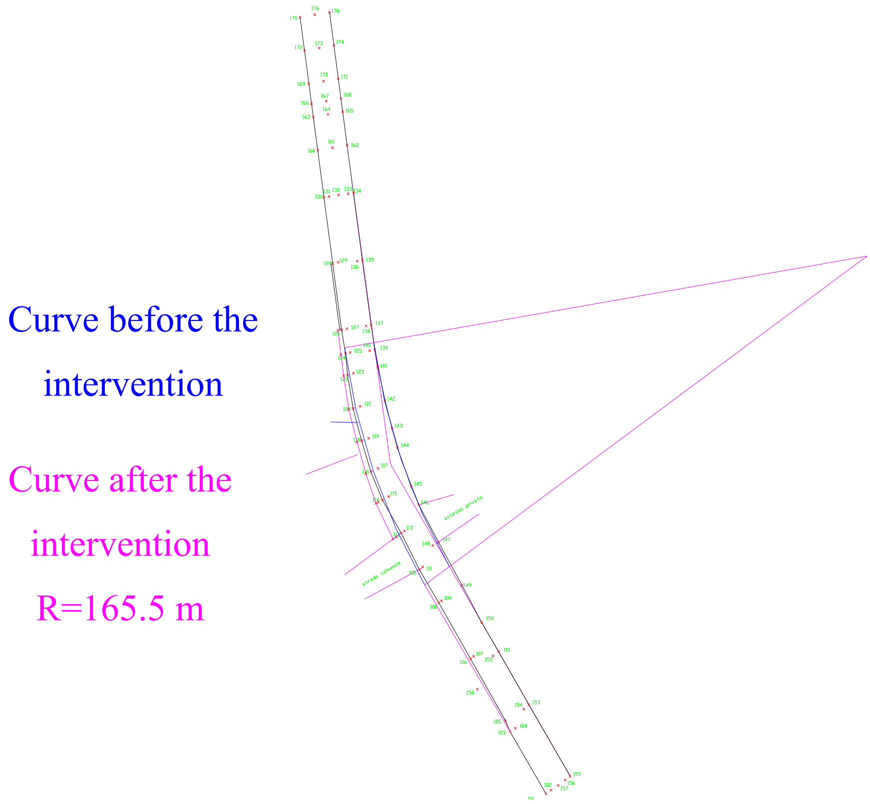


Figure 94 Horizontal design of the curve

Figure 95 Old intersection

Figure 96 New shape of the barrier at the intersection

Figure 97 Readability of the stretch near the dangerous curve after interventions

10.3.2 Before-After Analyses monitoring

<u>10.3.2.1 Method of analysis and calculation procedure</u>

There follows an illustration of the procedure used for monitoring the effectiveness of the interventions using a driving dynamics survey (speed and trajectory). In particular, videos were made using two, suitably-positioned video-cameras. The data obtained were objective variables: space, time and speed of the vehicles travelling along the stretch of road preceding and following the curve. The choice of the place to position the video-cameras was made so as to film the whole of the stretch where interventions were carried out and guarantee an adequate image resolution (Figure 98). Besides, the video-cameras were placed in a raised position with respect to the sites so as to obtain a good view of the road and not influence driver behaviour (Figure 99).

Figure 98 Position of the video-cameras

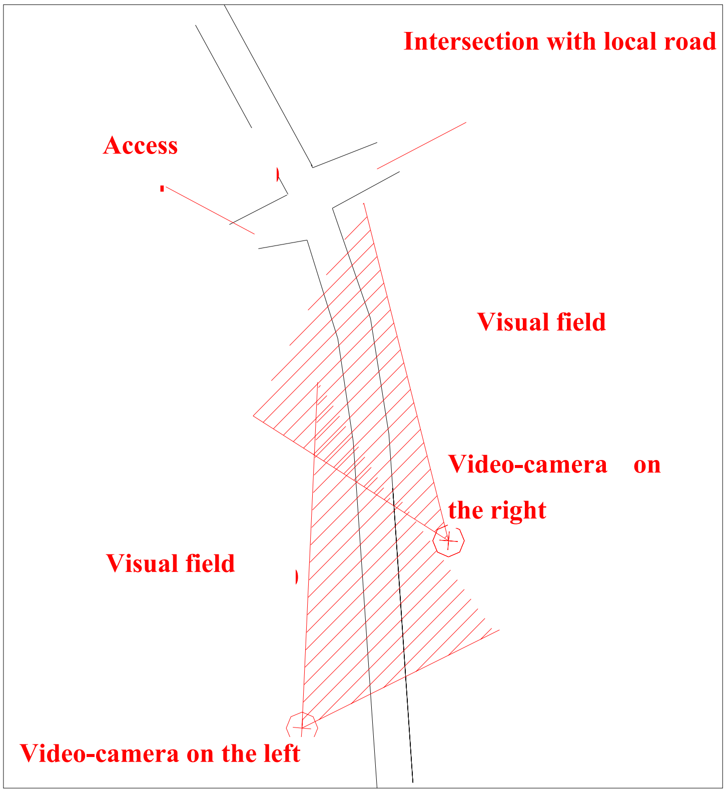


Figure 99 Plan of the examined stretch with the visual field of the video-camera

During filming skittles were positioned on the edges of the carriageway as fixed reference points for the survey grid. The skittles were place at a distance of 20 m one from the other to identify 8 sections (Figure 100) along the stretch. The distance between the external road marking and the skittles (marking the 8 sections under examination) was measured for each section.

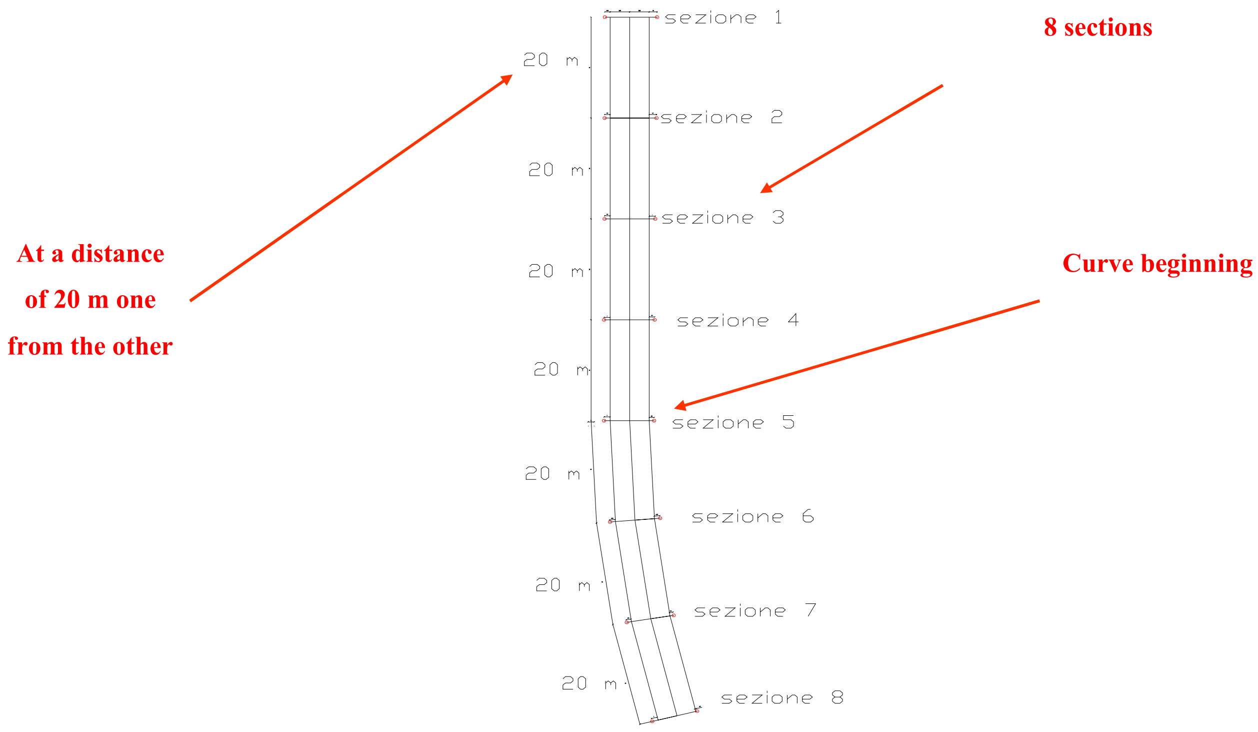


Figure 100 Plan of the stretch under examination with images of the sections

The video filming was divided into two phases: an initial survey before the improvement interventions and a second survey at the end of the interventions.

10.3.2.2 Data extraction and treatment

All the frames showing a vehicle in correspondence to the 8 survey sections were extracted from the digital films.

Overlapping the frames on the reference grid it was possible to determine the distance of the barycentre of the vehicle from the centreline of the carriageway for each of the survey sections (D1, D2, D3, D4, D5, D6, D7, D8) adopting suitable scale factors.

To calculate the mean speed of each single vehicle between two successive sections, the relationship between the longitudinal distance between the skittles (20 m) and the time difference between the successive frames was used:

$v = D / \Delta t$

where:

D = 20 m is the distance between two successive sections [m]

$\Delta t - t_j - t_i$ is the time difference between the second and first frames [s];

All the data were divided according to the type of vehicle (vehicle, heavy vehicle, motorbike) (Figure 101) and traffic conditions (isolated, in groups) (Figure 102, Figure 103).

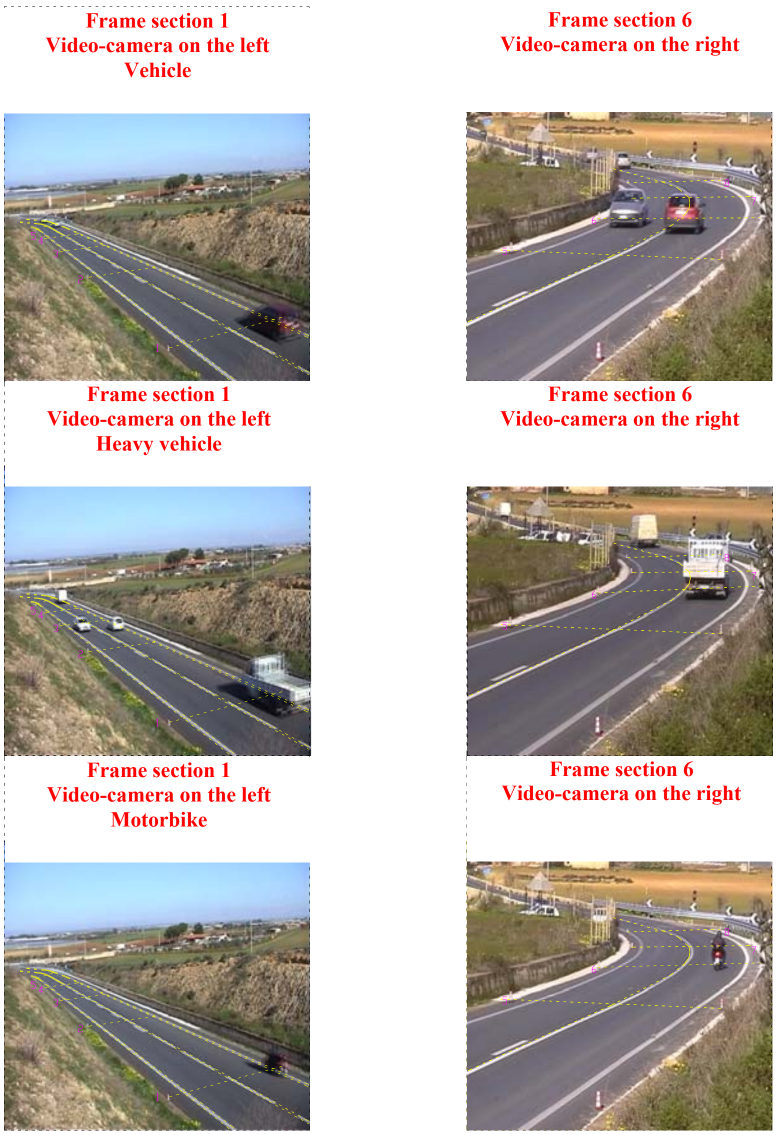


Figure 101 Frame of the first 5 sections and the last 3 sections with superimposed grid

Figure 102 Frame of an isolated vehicle

Figure 103 Frame of a vehicle queued

The mean and standard deviation of all the vehicles passing were evaluated for each section as statistical parameters relating to trajectory and speed.

This study was carried out on the stretch of road under examination in two different moments: before and after the interventions described in the previous paragraphs. This made it possible to make a comparison between the conditions in the ‘before’ and ‘after’ periods so as to evaluate the validity of the works carried out. A total of 132 vehicles were surveyed in the ‘before’ period of which 91 were isolated vehicles, 31 vehicles queued and 10 isolated heavy vehicles (Figure 104) and in the ‘after’ period a total of 130 vehicles of which 97 vehicles, 28 vehicles queued and 5 isolated heavy vehicles (Figure 105).

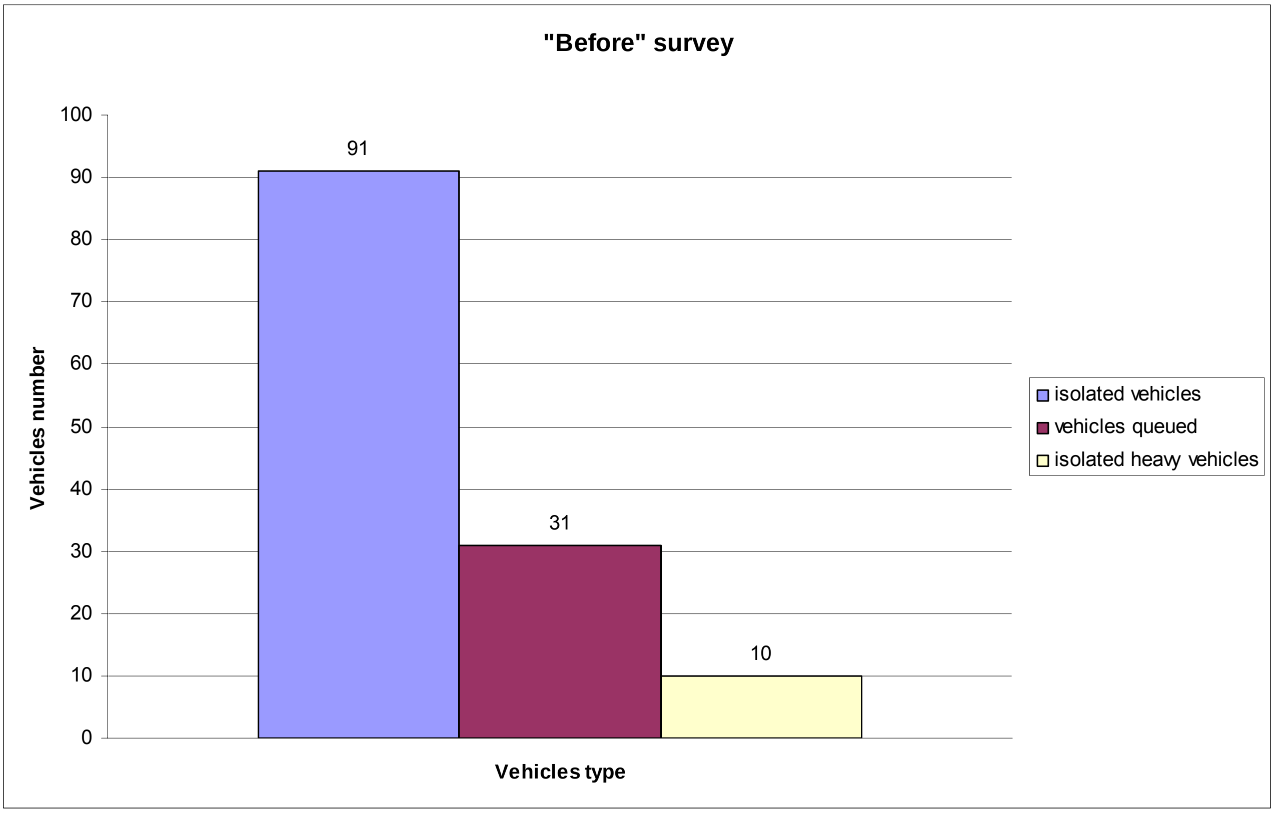


Figure 104‘Before’ survey histogram

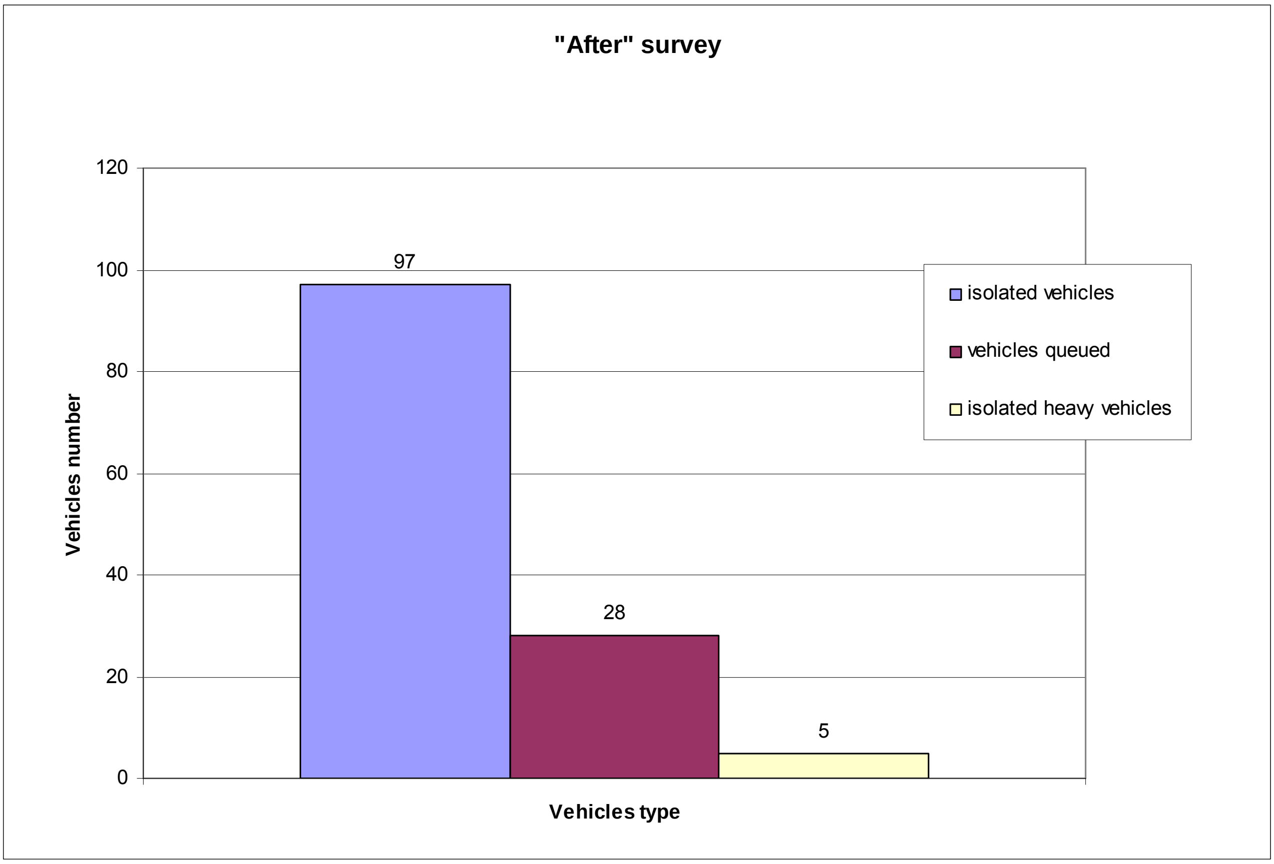


Figure 105‘After’ survey histogram

10.3.2.3 Analyses of results

10.3.2.3.1 ‘Before’ survey.

During the survey the trajectories of 91 isolated vehicles travelling along the stretch of road preceding and following the curve were studied. For each vehicle and each section the distance from the road axis was surveyed. Transferring the data to a graph the trajectory of each vehicle following the stretch of road under examination was obtained. Figure 106 shows the mean trajectory ™ of all the vehicles (divided according to type and driving conditions) the trajectory relating to the 85th percentile (T_{85}) and the trajectory relating to the 15th percentile (T_{15}) with reference to lane width. From a comparison between the abscissa relating to the mean trajectory Tm and the lane axis it was possible to obtain other data: the displacement from the axis for each vehicle and section. Positive displacement values denote those situations in which the trajectory is shifted towards the right margin as compared to the lane axis, while negative displacement values distinguish those cases in which the trajectory tends towards the road axis as compared to the lane axis. It the displacement remains constant with time, it can be deduced that the driver adapts to the design of the stretch proceeding in parallel to the road axis; instead, if the displacement varies the driver imposes a different trajectory while travelling over the analysed section.

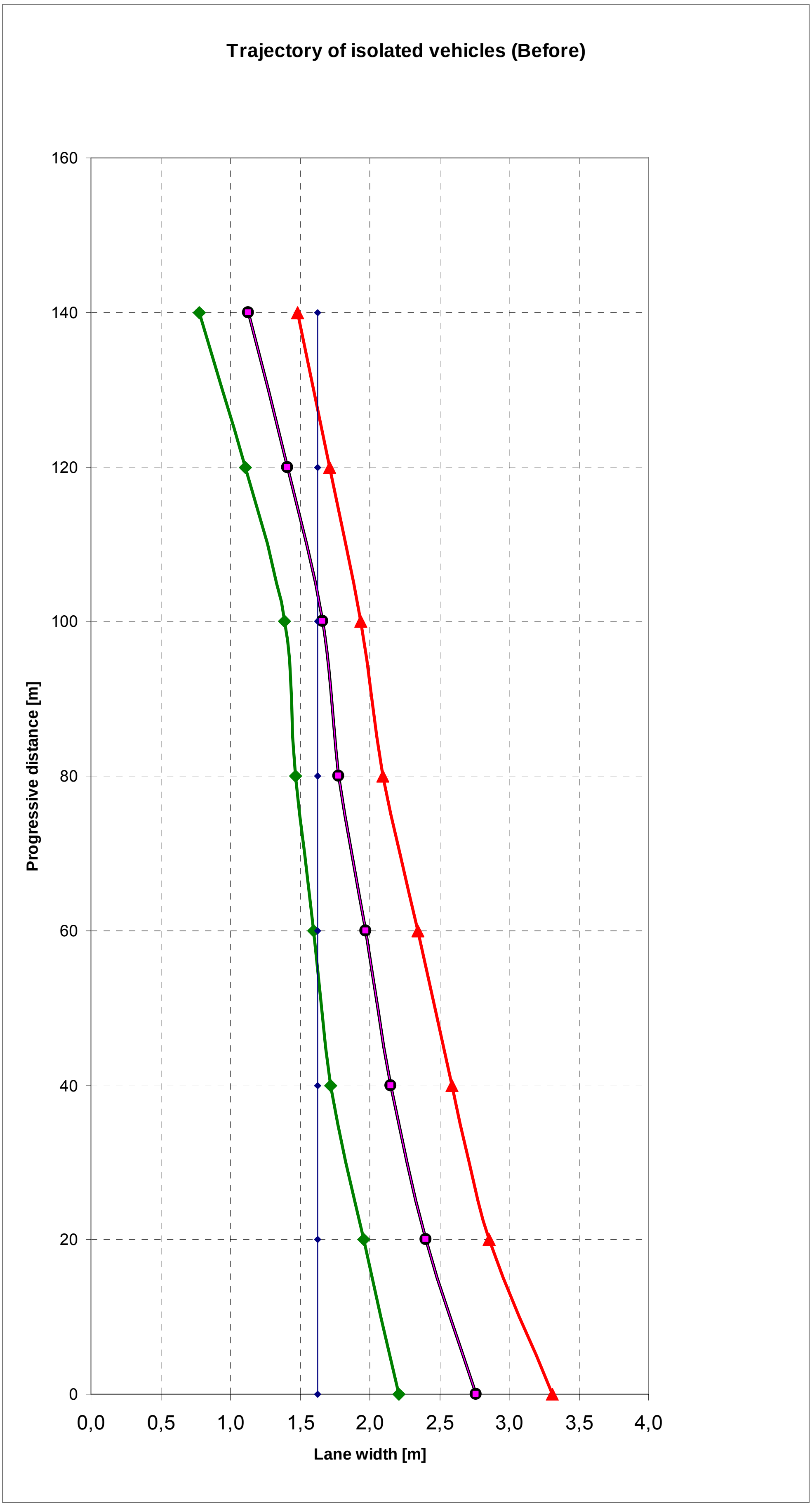


Figure 106 T_m, T_{85}, T_{15} isolated vehicles, before survey

During the survey the trajectories of 31 vehicles queued were identified (Figure 107).

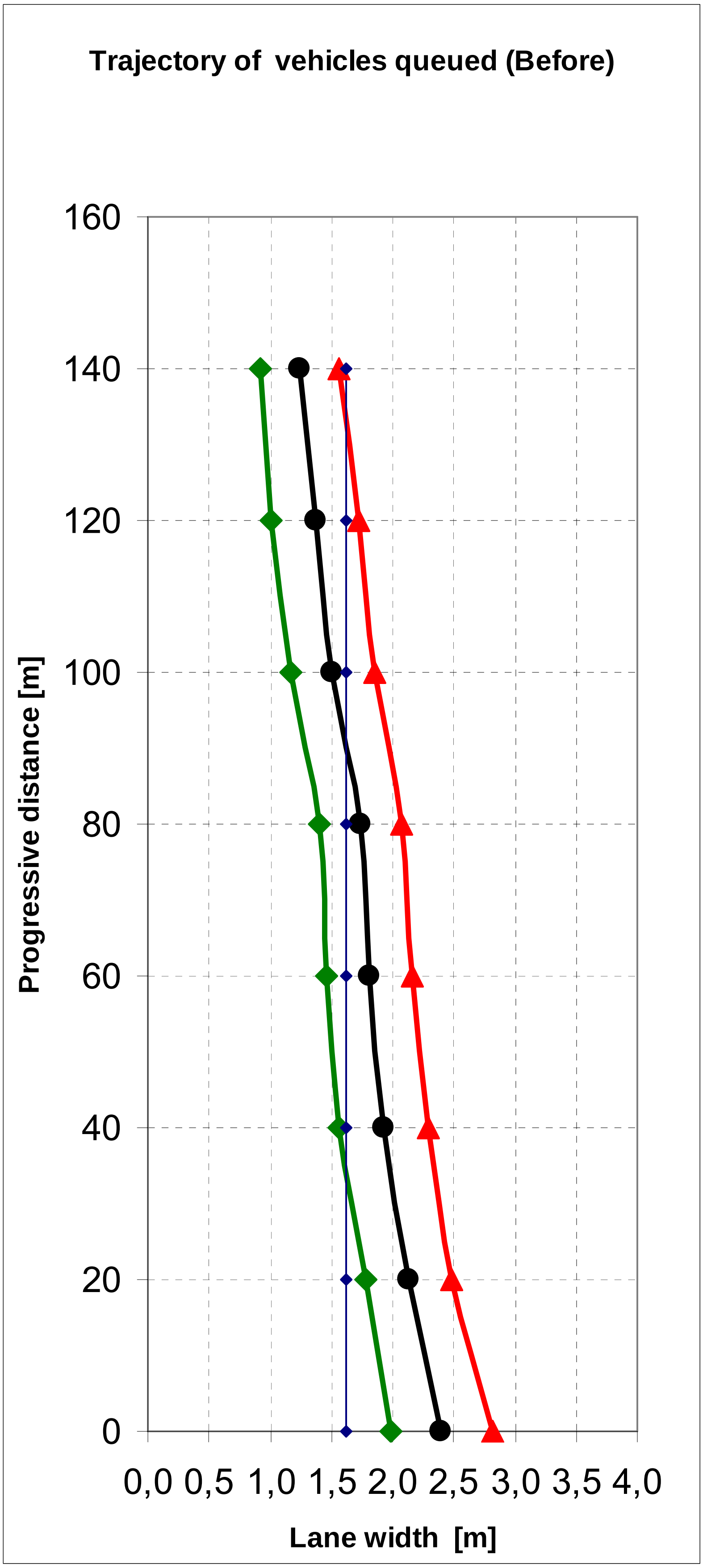


Figure 107 T_m, T_{85}, T_{15}, vehicles queued, before survey

From the survey the trajectories of 10 isolated heavy vehicles were analysed (Figure 108).

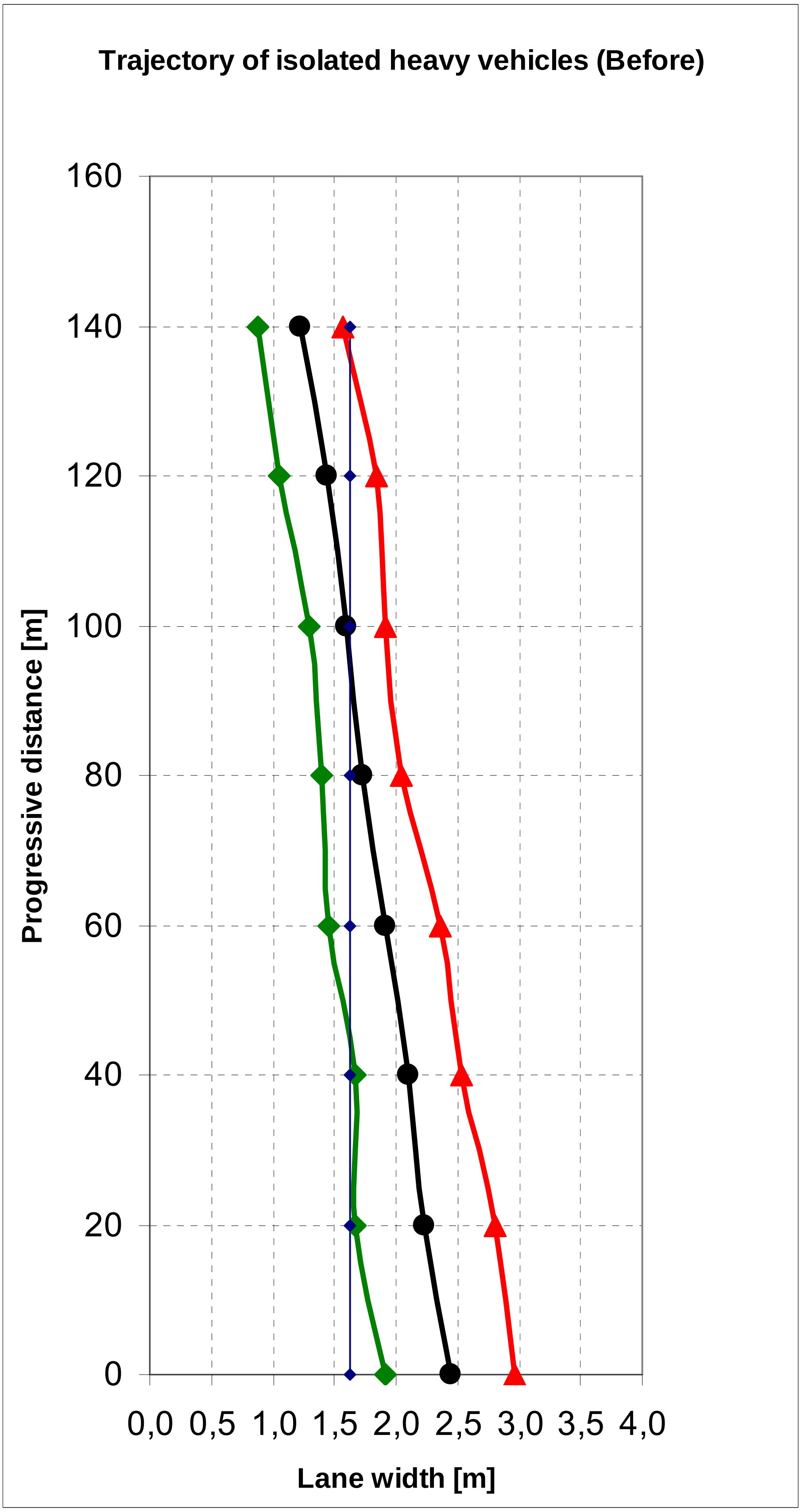


Figure 108 T_m, T_{85}, T_{15}, isolated heavy vehicles, before survey

Besides the trajectories, the study also analysed the speeds of the 91 isolated vehicles. From the graph shown in Figure 109 it is possible to note that most of the isolated vehicles have a mean speed value of between 64.5 Km/h and 71 Km/h.

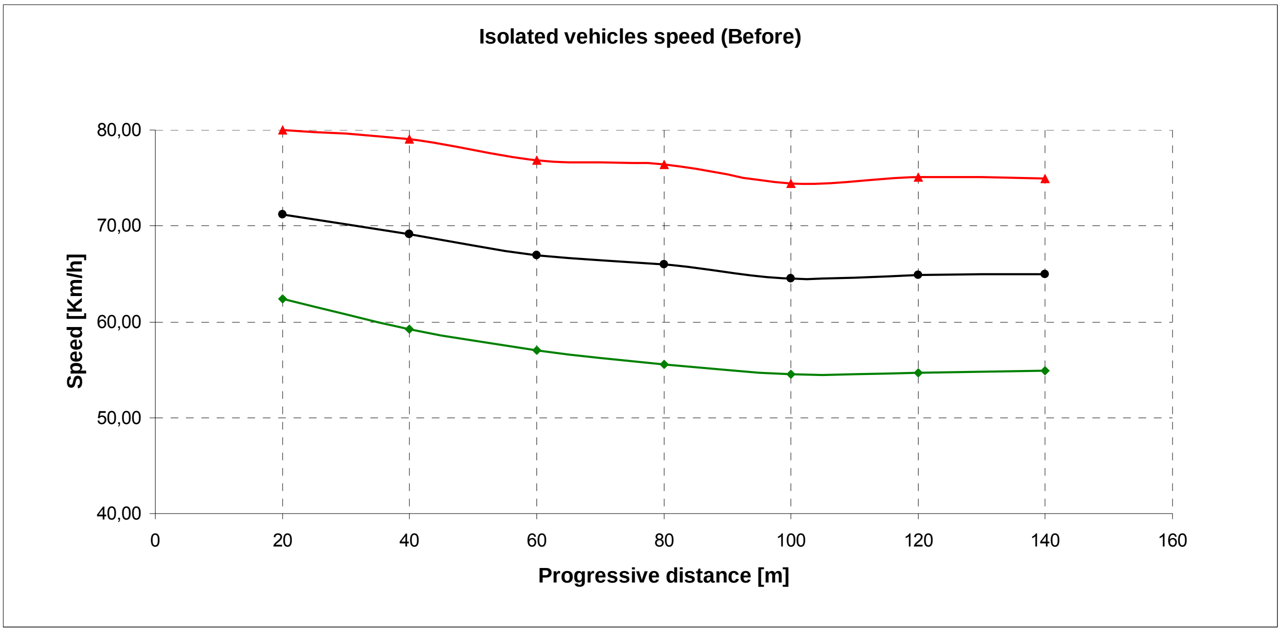


Figure 109 V_m, V_{85}, V_{15}, isolated vehicles, before survey

Speed was also measured for the 31 vehicles queued travelling along the stretch of road before and through the curve. The graph in Figure 110 shows horizontally the progressive distances and vertically the mean speeds (V_m), the 85th percentile speed and the 15th percentile speed. The graph highlights that the mean speed of vehicles queued is of between 59.4 Km/h and 65.3 Km/h.

Lastly, speed was measured for the 10 isolated heavy vehicles travelling along the stretch of road before and through the curve. The graph in Figure 111 shows horizontally the progressive distances and vertically the speeds. The graph relating to the speeds of isolated heavy vehicles shows mean values of between 66.8 Km/h and 74.3 Km/h.

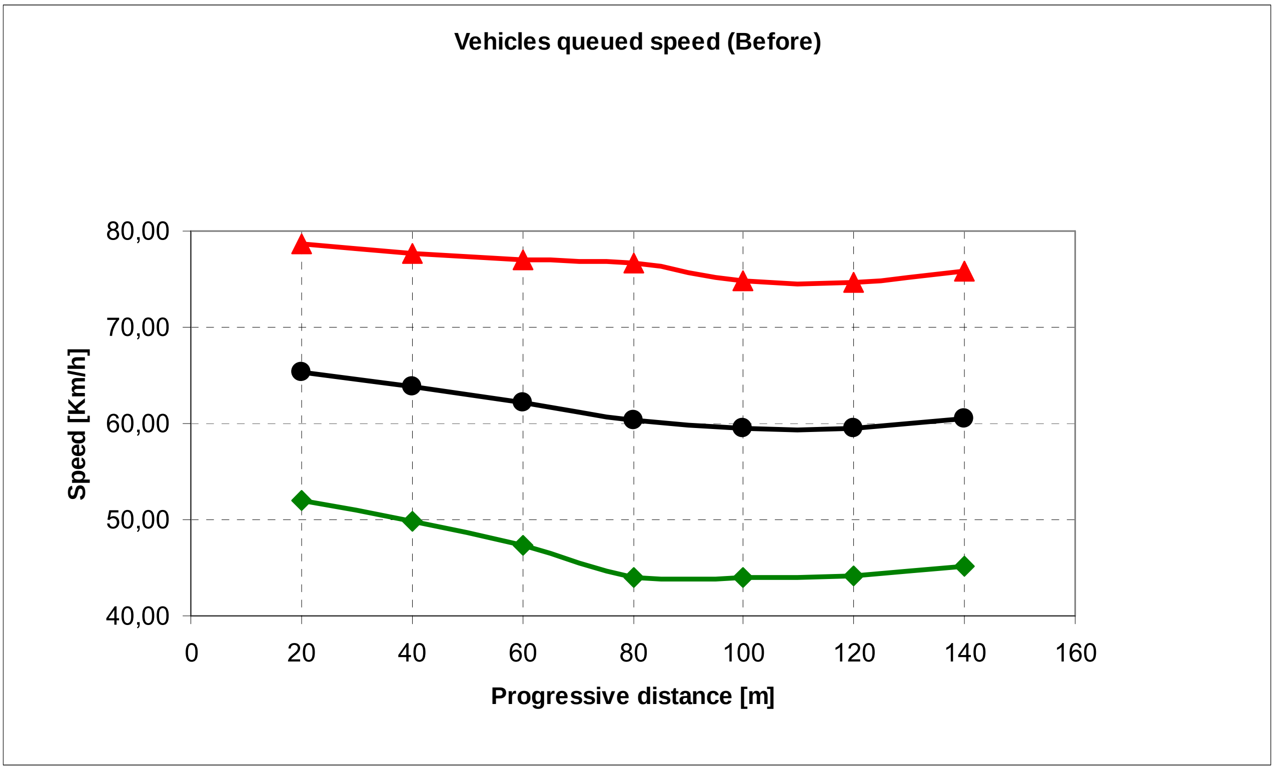


Figure 110 V_m, V_{85}, V_{15}, vehicles queued, before survey

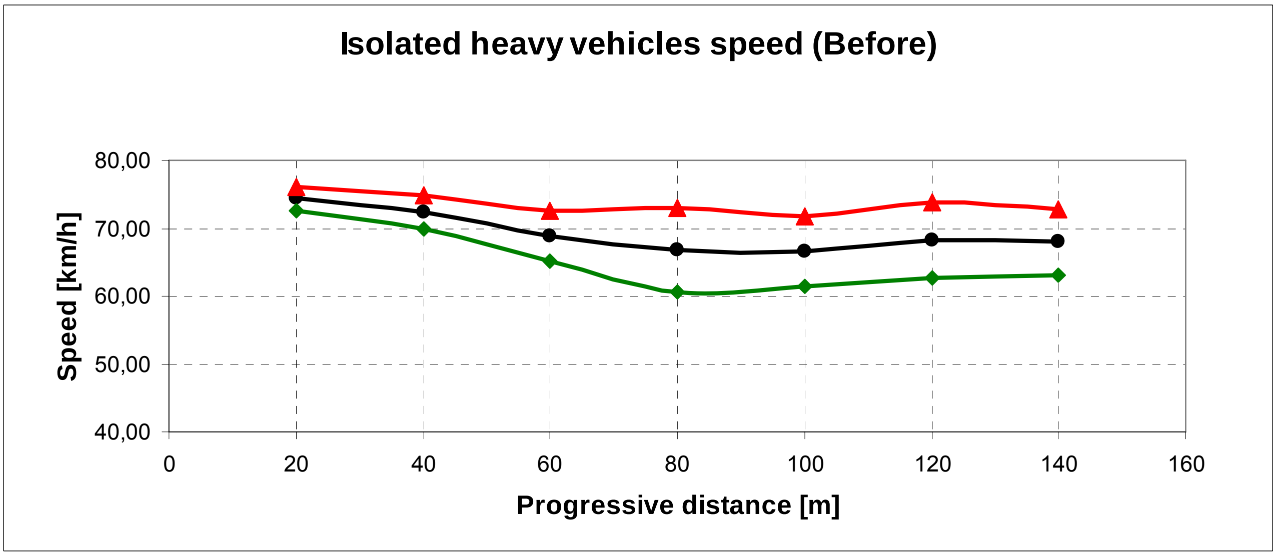


Figure 111 V_m, V_{85}, V_{15}, isolated heavy vehicles, before survey

10.3.2.3.2 'After' Survey

From the survey carried out in the period following on from improvement interventions (the 'after' period) it was possible to calculate the trajectories and speeds of 137 vehicles travelling along the stretch of road under examination. The graph in Figure 112 relating to the trajectories of the 97 vehicles using the stretch of road highlights how in the first section the trajectories are comprised between 1.50 m and 3.25 m, while for the last sections, they approach the road axis falling into an interval between 0.25 m and 2.00 m.

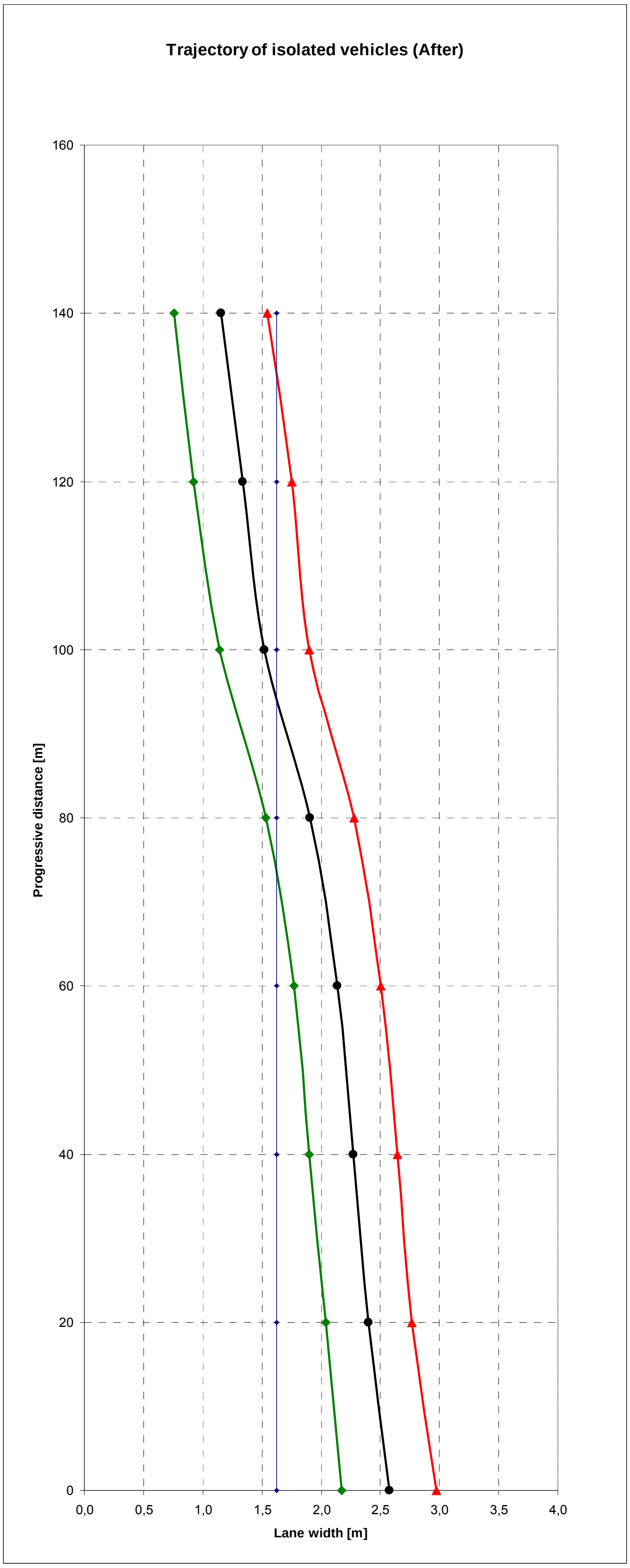


Figure 112 T_m, T_{85}, T_{15}, isolated vehicles, after survey

The graph in Figure 113 represents the trajectories of 28 vehicles queued using the stretch of road. Similarly to the vehicles surveyed before the improvement interventions the trajectory values are between 1.75 m and 3.00 m for the first section and between 0.75 m and 1.75 m for the last sections.

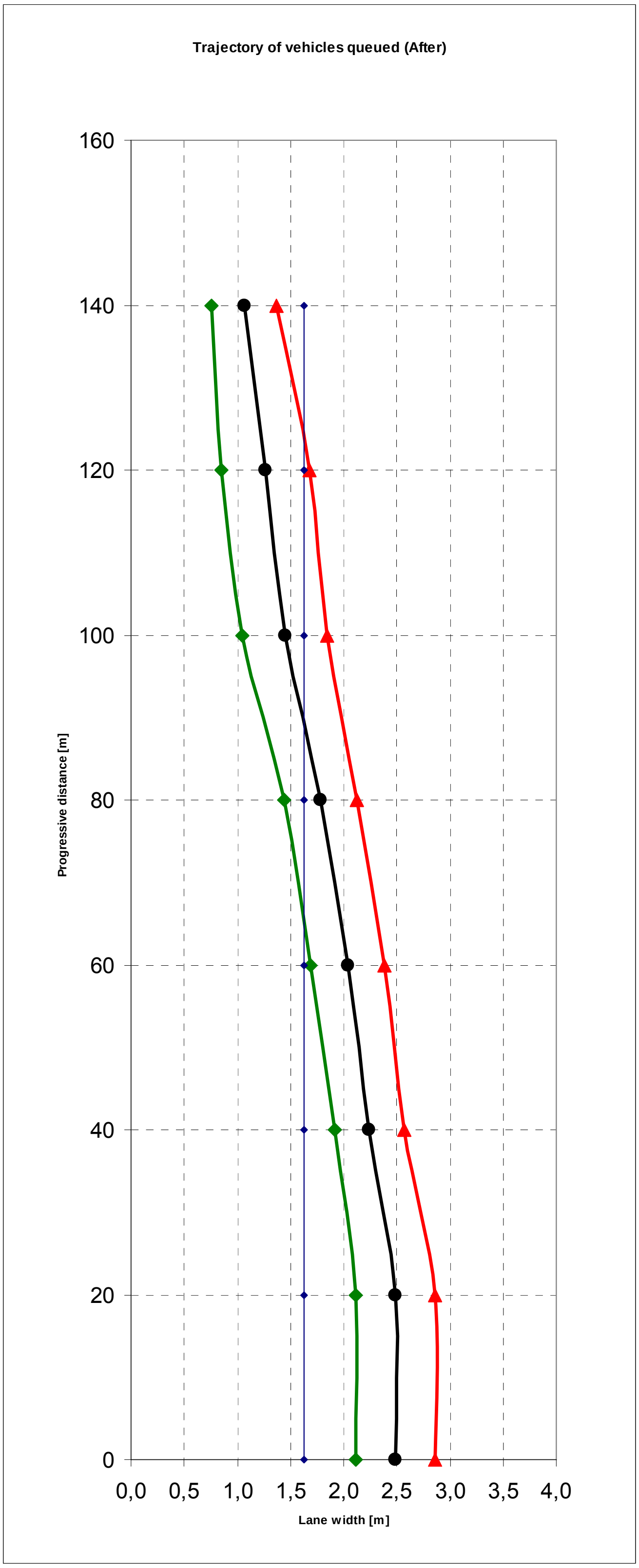


Figure 113 T_m, T_{85}, T_{15}, vehicles queued, after survey.

The second survey made it possible to evaluate the trajectories of 5 isolated heavy vehicles. The graph in Figure 114 highlights that the trajectories fall between 2.5 m and 3.0 m for the first section and between 0.75 and 1.5 for the last sections.

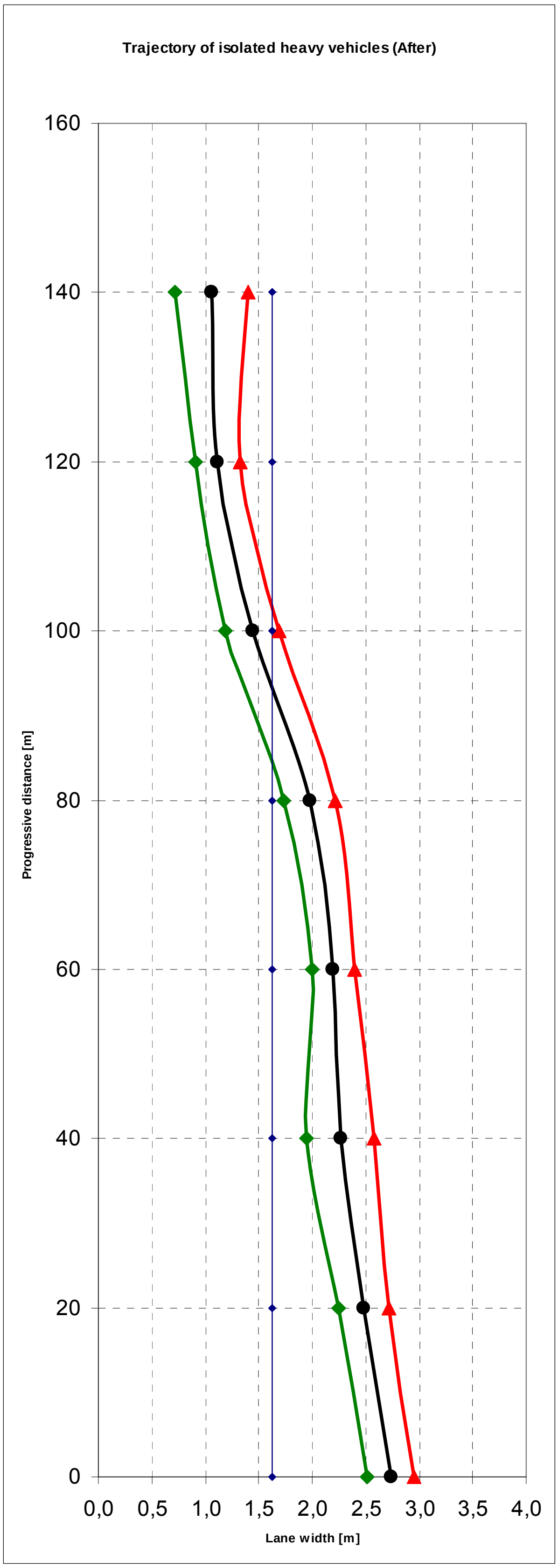


Figure 114 T_m, T_{85}, T_{15}, isolated heavy vehicles, after survey

Speed of isolated vehicles

By means of the survey carried out after the improvement interventions it was possible to analyse the speeds of 97 isolated vehicles.

The graph in Figure 115 shows that the mean speed of the isolated vehicles after improvement interventions is of between 68.9 Km/h and 73.7 Km/h.

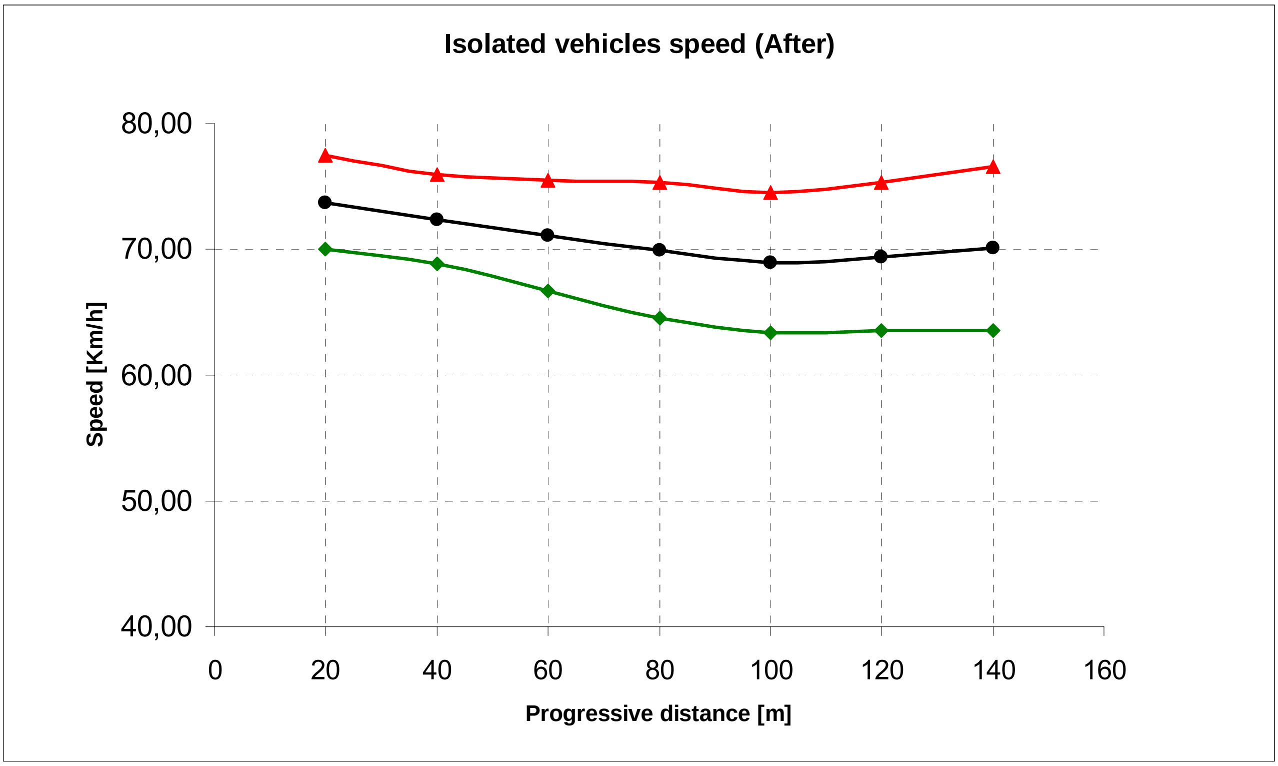


Figure 115 V_m, V_{85}, V_{15}, isolated vehicles, after survey

Speed was also surveyed for 28 vehicles queued. The graph in Figure 116 shows horizontally the progressive distances and vertically the speeds. The graph shows mean values of between 67.7 Km/h and 73.2 Km/h.

Speed was also surveyed for 5 isolated heavy vehicles. The graph in Figure 117 reports horizontally the progressive distances and vertically the speeds. The previous graph highlights that the mean speed of isolated heavy vehicles falls between 63.84 Km/h and 75.15 Km/h.

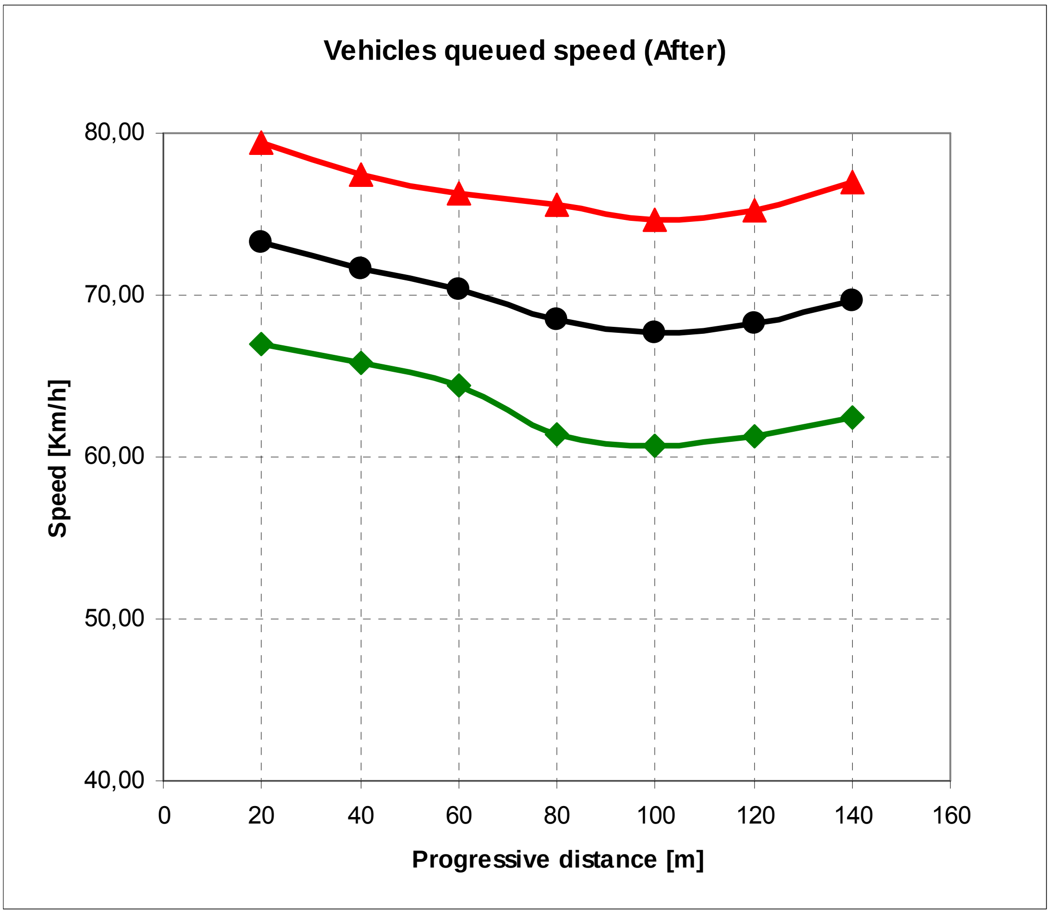


Figure 116 V_m, V_{85}, V_{15}, vehicles queued, after survey

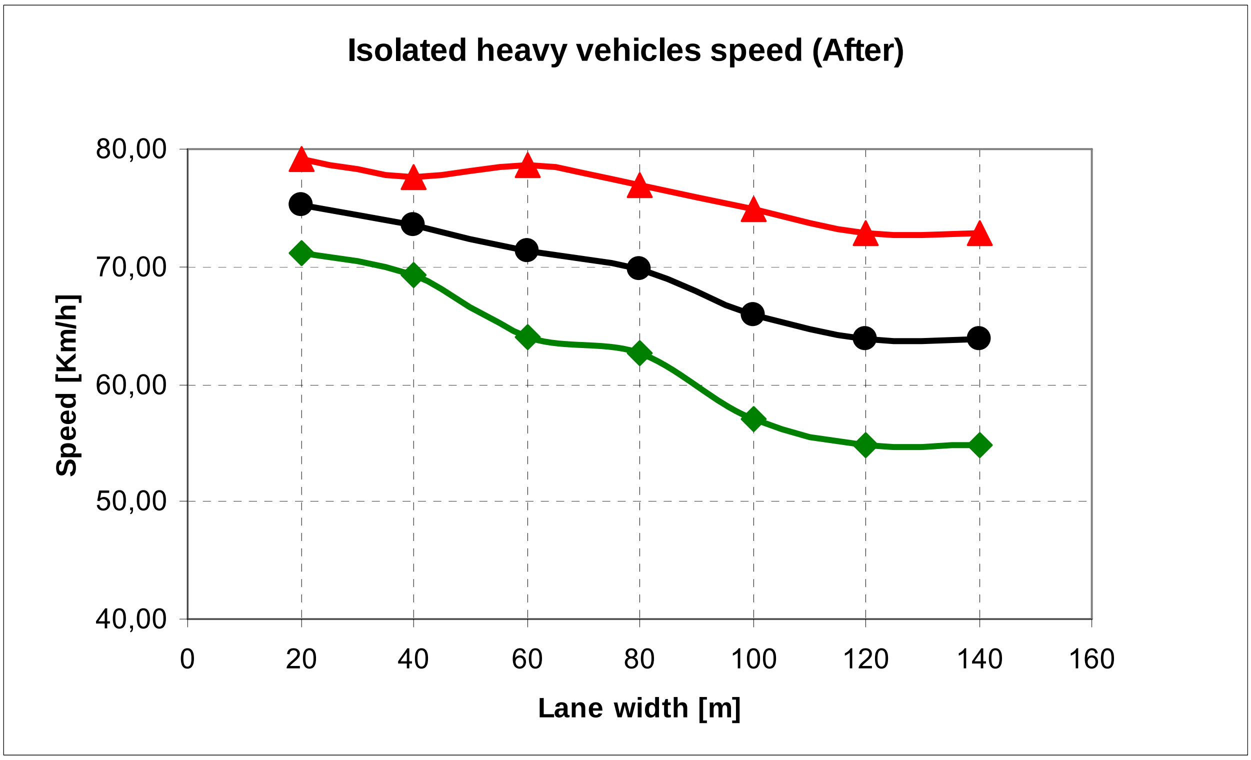


Figure 117 V_m, V_{85}, V_{15}, isolated heavy vehicles, after survey.

10.3.2.3.3 Comparison of trajectories in the 'before' and 'after' periods.

The graphs in Figure 118, Figure 119, Figure 120 show the mean trajectories (T_m, T_{85}, T_{15}) of the vehicles (isolated, queued and isolated heavy) surveyed before (unbroken line) and the mean trajectories (T'_m, T'_{85}, T'_{15}) of the vehicles surveyed after (dashed line).

A reduction in trajectory scattering was observed (size of the $T_{15} – T_{85}$ interval) in the first section which demonstrates more homogenous driver behaviour. On the curve there were no appreciable improvements while at the crossroads an increase in trajectory scattering was seen. The latter seems to be in contrast with the aims of the project and other research in the field, which after similar interventions found a reduction in trajectory scattering. It is possible that this is caused by:

- the new guard rail which has larger dimensions;
- greater visibility at the intersection.

Neither is there any noticeable improvement in the displacement of the trajectory from the lane axis. The displacement that was present in the 'before' period remains practically unchanged in the 'after' period. The main cause of this is probably the absence of a transition curve in the passage between the tangent and the curve which, although absent, was not included in the improvement interventions. The advantage gained from an improved delineation of the axis design on the curve must be set against the increase in mean speed which leads drivers to use a more comfortable trajectory (wide at the entrance and tight at the centre of the curve).

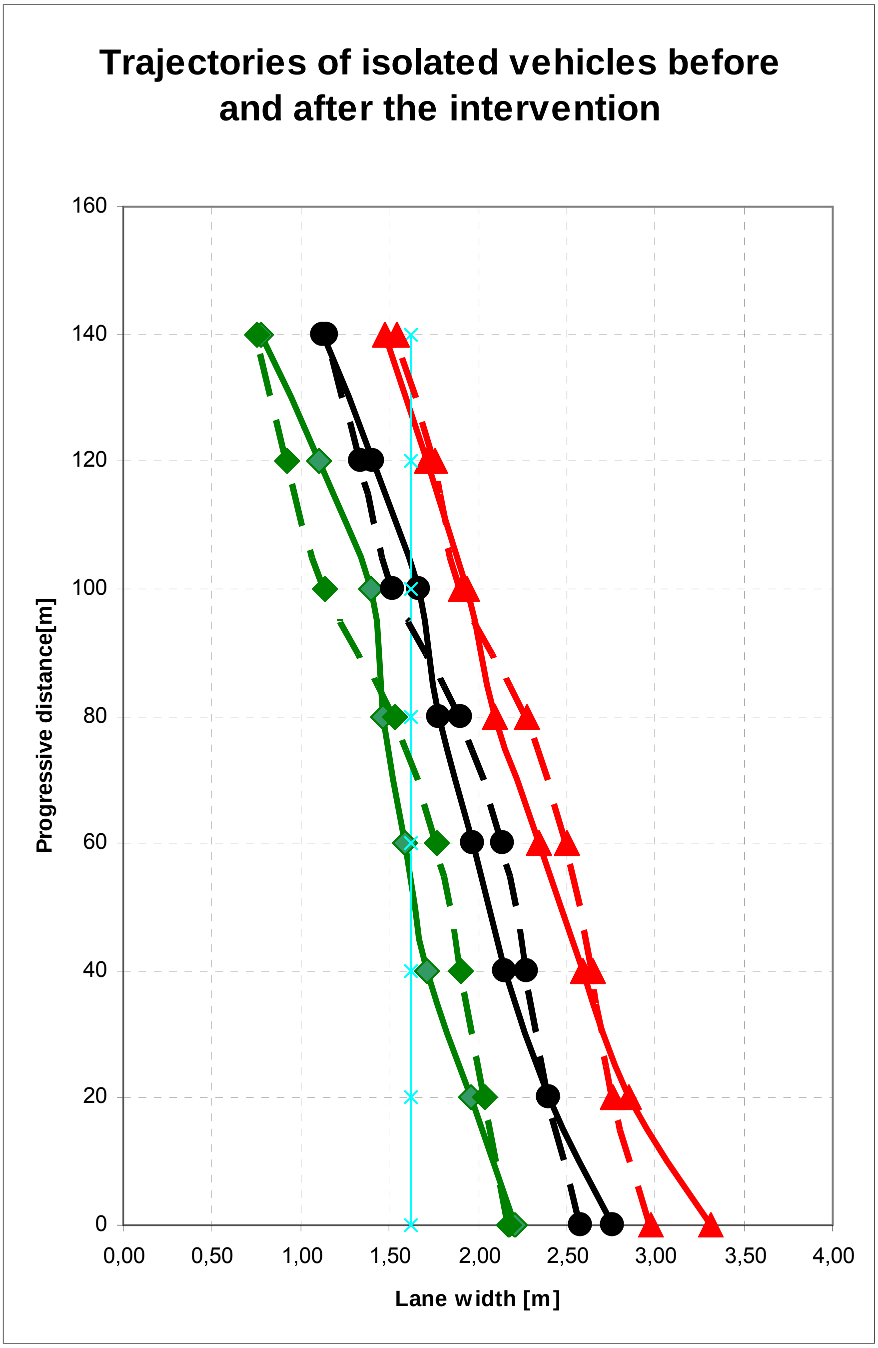


Figure 118 T_m, T_{85}, T_{15} comparison for isolated vehicles before and after improvement interventions

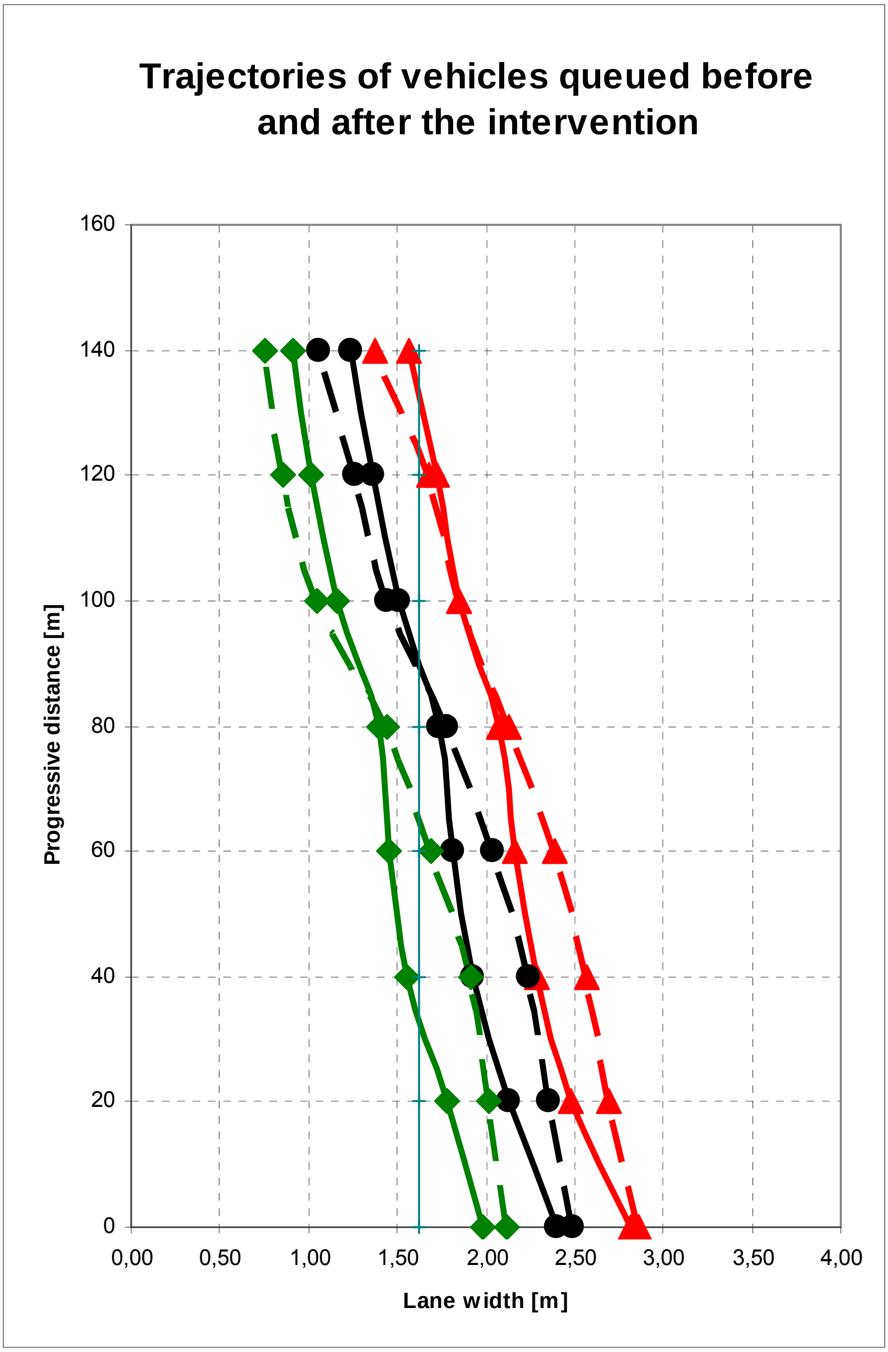


Figure 119 T_m, T_{85}, T_{15} comparison for vehicles queued before and after improvement interventions

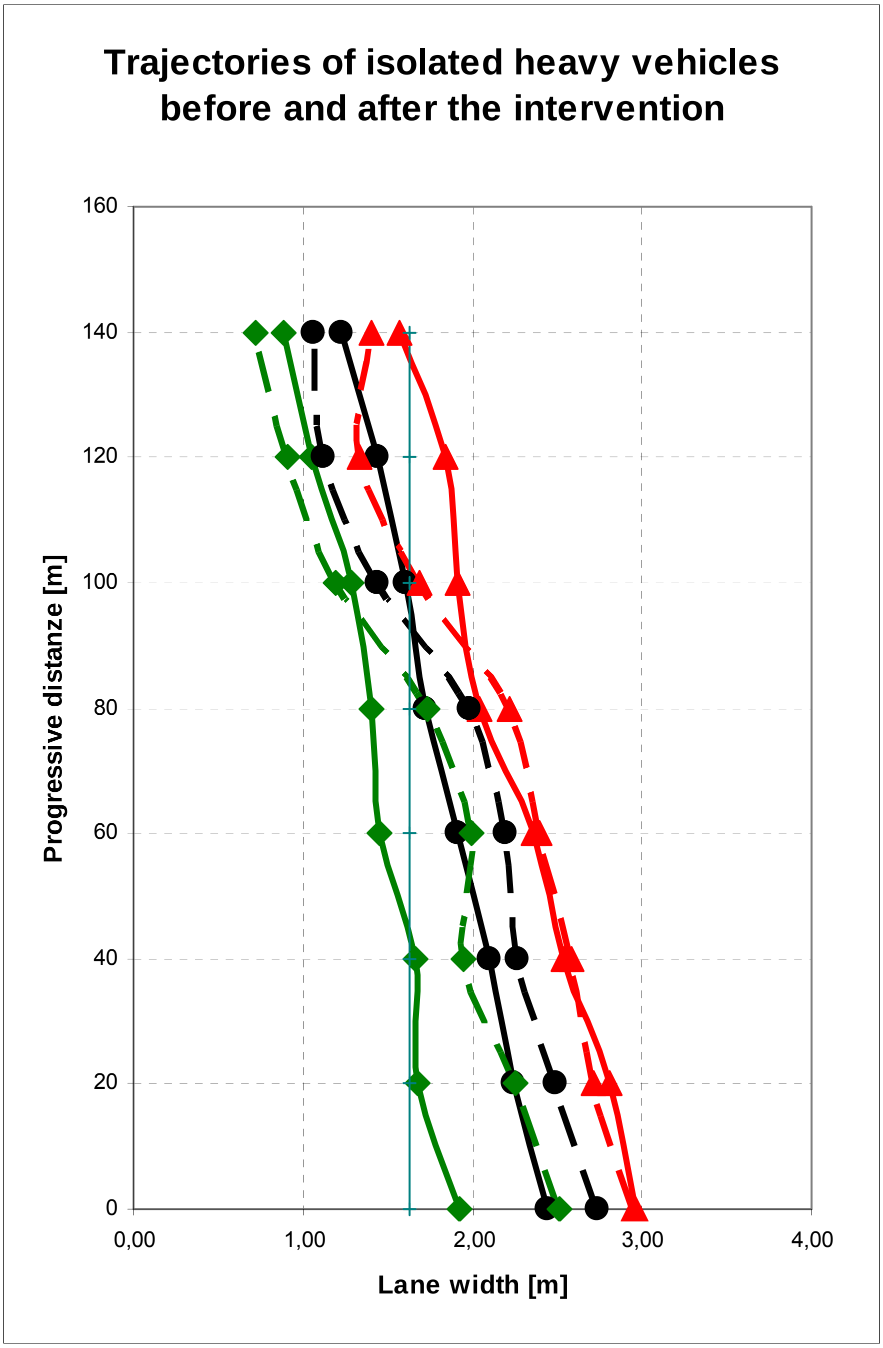


Figure 120 T_m, T_{85}, T_{15} comparison for isolated heavy vehicles before and after improvement interventions

10.3.2.3.4 Comparison of speeds in the 'before' and 'after' periods

A comparison between the data collected before (Figure 121, Figure 122, Figure 123, dashed line) and after (unbroken line) improvement interventions, made it possible to ascertain an increase in vehicle speeds. At the same time a reduction in speed scattering was found. The increase in speed is a result of increased driver security due to the improved road layout and road markings, while the reduction in speed scattering shows more uniform behaviour and greater readability of the stretch.

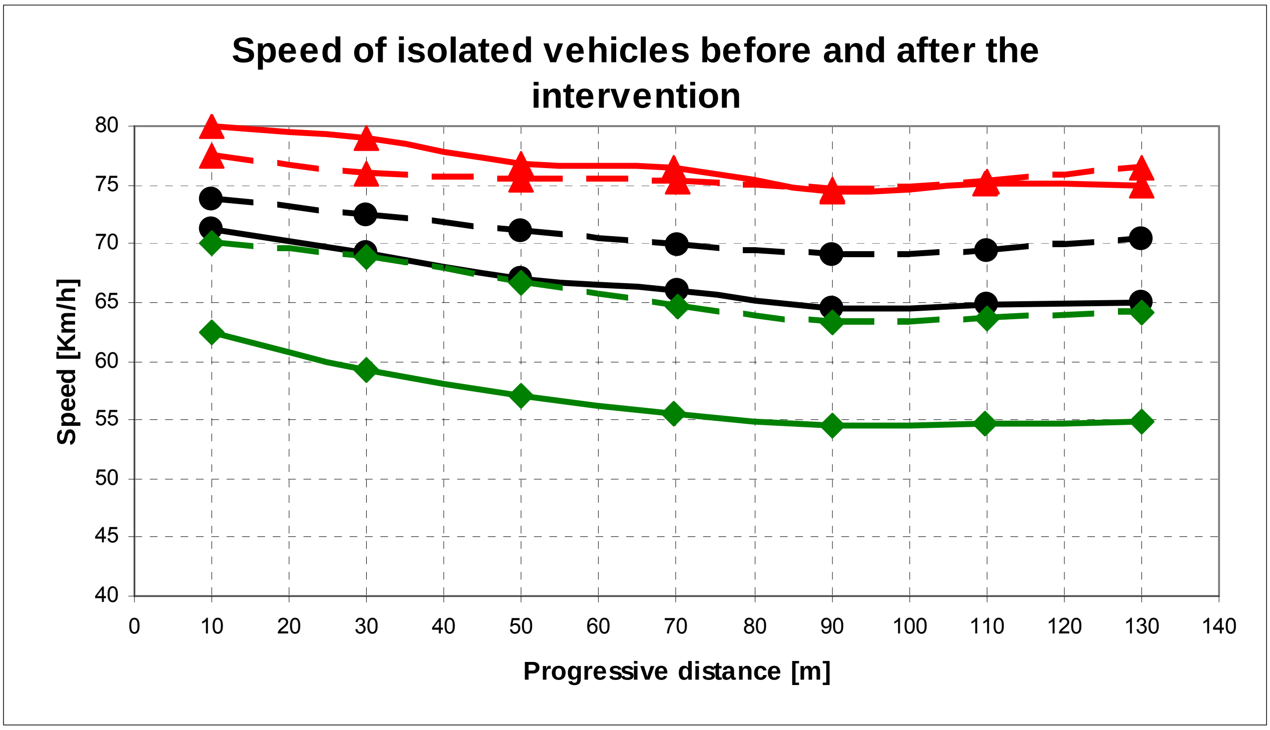


Figure 121 V_m, V_{85}, V_{15} comparison for isolated vehicles before and after improvement interventions

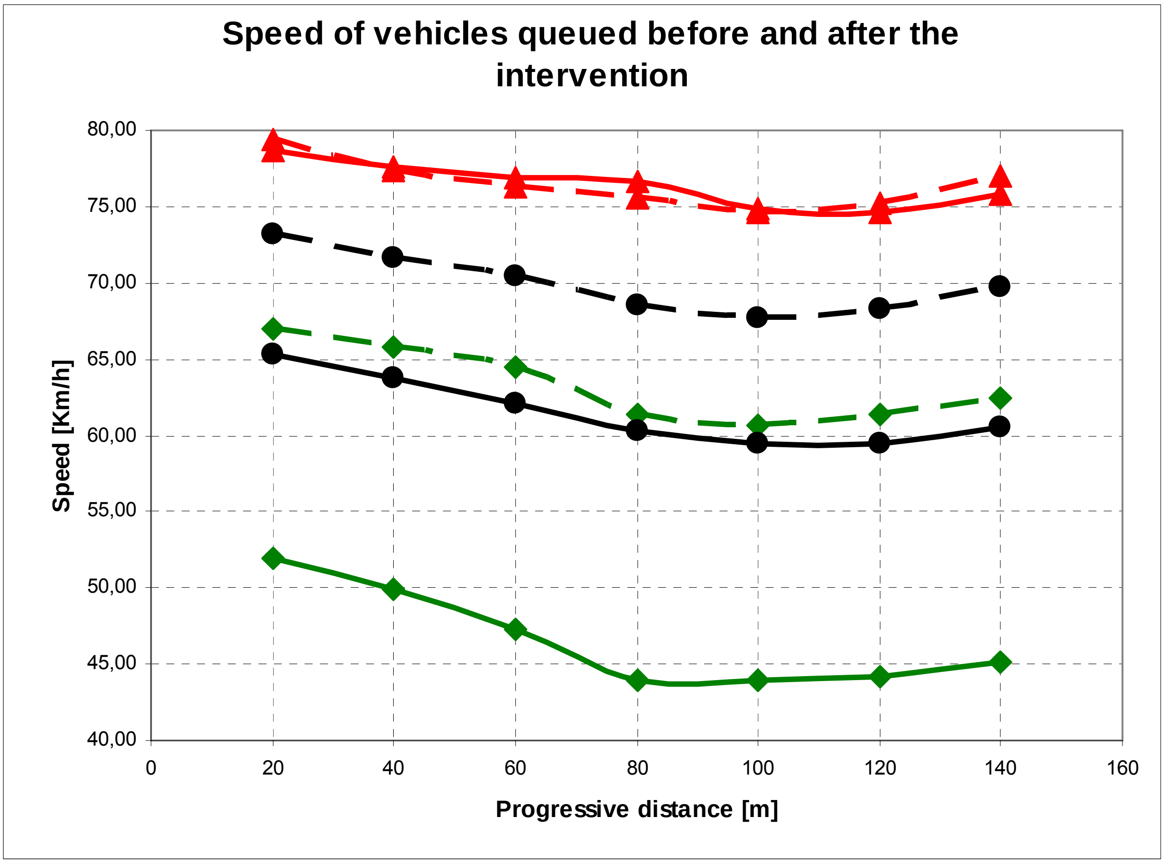


Figure 122 V_m, V_{85}, V_{15} comparison for vehicles queued before and after improvement interventions

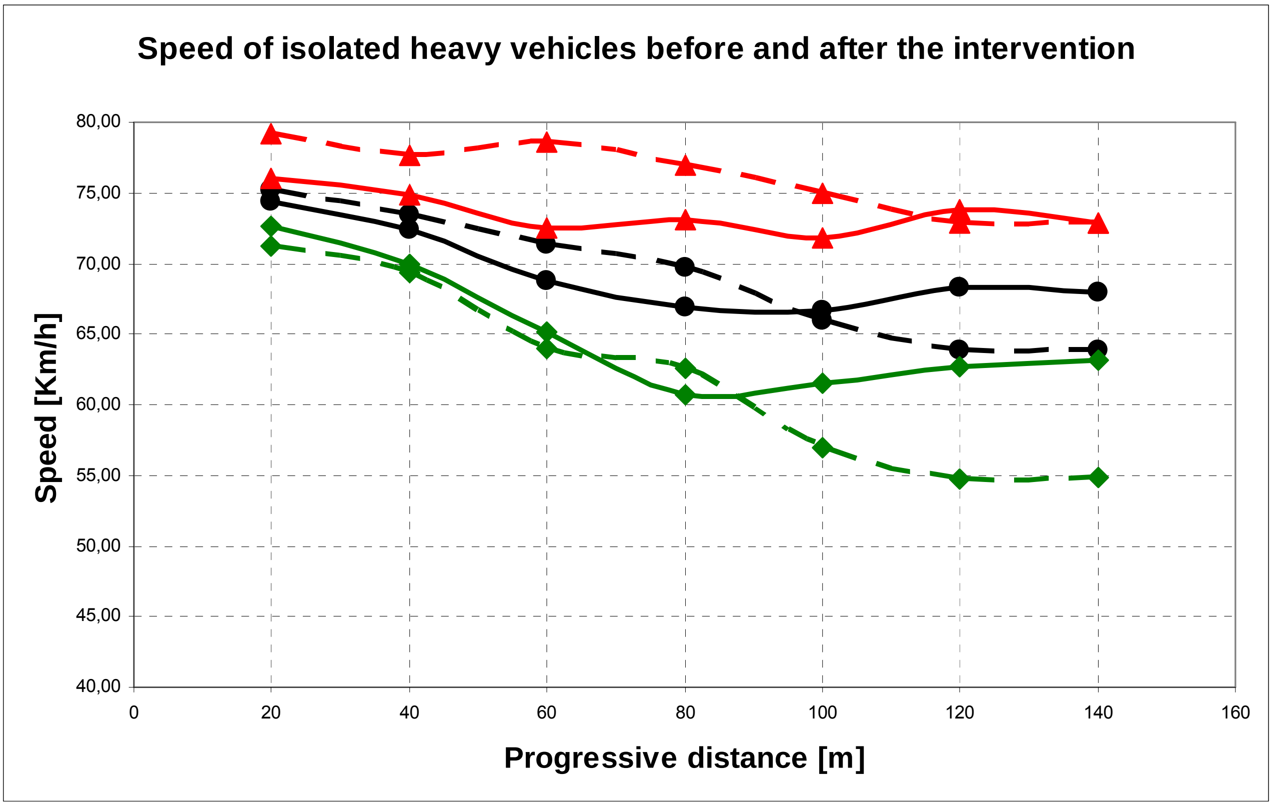


Figure 123 V_m, V_{85}, V_{15} comparison for isolated heavy vehicles before and after improvement interventions

10.3.2.3.5 The Student's t-test

In order to evaluate whether the differences between the mean speed values and trajectories obtained from the before and after surveys were statistically significant the Student's t-test was used to verify the null hypothesis of equivalent means.

In the following tables (from Table 69 to Table 74) the series of data which were significant for the t-test, having a confidence level of 5% (unequal means) have been identified.

The Student's t-test 'before' and 'after' summary tables follow, relating to the mean trajectories and mean speeds collected, subdivided according to type and driving conditions.

Table 69 Student's t-test summary table for isolated vehicle trajectories

T.student for isolated vehicles				
Section	Tm before	Tm after	Δ	T. student
1	2.76	2.57	0.187	***0.006***
2	2.41	2.40	0.002	0.971
3	2.15	2.27	-0.118	***0.038***
4	1.97	2.14	-0.167	***0.002***
5	1.78	1.91	-0.133	***0.006***
6	1.66	1.52	0.141	***0.003***
7	1.41	1.34	0.074	0.153
8	1.13	1.15	-0.020	0.697

Table 70 Student's t-test summary table for the trajectories of vehicles queued

T.student for vehicles queued				
Section	Tm before	Tm after	Δ	T. student
1	2.40	2.49	-0.090	0.369
2	2.13	2.36	-0.228	0.011
3	1.92	2.24	-0.319	***0.001***
4	1.81	2.04	-0.228	***0.013***
5	1.73	1.78	-0.049	0.566
6	1.51	1.45	0.059	0.532
7	1.37	1.26	0.104	0.287
8	1.24	1.06	0.176	***0.031***

Table 71 Student's t-test summary table for isolated heavy vehicle trajectories

T.student for isolated heavy vehicles				
Section	Tm before	Tm after	Δ	T. student
1	2.44	2.73	-0.293	0.238
2	2.24	2.49	-0.248	0.354
3	2.10	2.27	-0.167	0.445
4	1.91	2.19	-0.287	0.188
5	1.72	1.98	-0.253	0.134
6	1.60	1.44	0.161	0.316
7	1.44	1.12	0.323	0.104
8	1.23	1.06	0.167	0.375

Table 72 Student's t-test summary table for isolated vehicle speeds

T.student for isolated vehicles				
Section	Vm before	Vm after	Δ	T. student
1				
2	71.20	73.72	2.522	***0.0081***
3	69.15	72.35	3.201	***0.0023***

4	66.96	71.06	4.109	***0.0002***
5	65.98	69.96	3.980	***0.0007***
6	64.48	68.95	4.469	***0.0001***
7	64.86	69.44	4.572	***0.0001***
8	64.94	70.30	5.365	***0.0000***

Table 73 Student's t-test summary table for the speeds of vehicles queued

T.student for queued vehicles				
Section	Vm before	Vm after	Δ	T. student
1				
2	64.51	73.24	8.728	***0.002539***
3	62.47	71.60	9.128	***0.003758***
4	60.90	70.39	9.494	***0.003596***
5	59.15	68.49	9.344	***0.00813***
6	58.37	67.68	9.312	***0.005413***
7	58.60	68.26	9.664	***0.003004***
8	59.27	69.68	10.412	***0.00248***

Table 74 Student's t-test summary table for isolated heavy vehicle speeds

T.student for isolated heavy vehicles				
Section	Vm before	Vm after	Δ	T. student
1				
2	74.34	75.15	0.818	0.567
3	72.36	73.50	1.142	0.495
4	68.80	71.30	2.502	0.370
5	66.85	69.76	2.917	0.412
6	66.66	65.95	-0.710	0.841
7	68.26	63.84	-4.412	0.244
8	67.96	63.89	-4.075	0.252

The variations between the 'before' and 'after' periods are particularly significant in the tables relating to speeds.

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