EVALUATION OF EXISTING ROADS BASED ON DRIVERS' BEHAVIOUR

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ABSTRACT

The scientific research, from diverse years, has paid its attention to relationship among driver behaviour, vehicle, road geometry and environmental context.

The practical testing have highlighted the poor representativeness of the operative speed as the only measure of consistency, deduced moreover from the geometrical characteristics of the road.

With the aim to overcome these difficulties, the Authors have realized an instrumented vehicle capable to return some variables connected to driving behaviour and vehicle dynamic.

The evolution obtained by the present research has been reported in this paper and the most important outcome has been the specification of new indexes absolutely original. These indexes will permit to make better the comprehension of the driving phenomena not only from theoretical point of view but, especially, they could be used in the traditional road audits.

Keywords: visual behaviour, consistency, existing roads, safety criteria

1. INTRODUCTION

Generally, the design concepts and values found in road standards are based on recognized practice and research. Acceptable design values for any geometrical feature are established to assure, to the best knowledge possible, that the feature itself will not increase risk of a crash and will contribute to make better traffic operations, capacity, constructability, maintenance and so on (Lamm et al., 1999).

If an acceptable solution can be reached only with design value marginally outside normal design criteria it would be important that designers and transportation agency have a right instrument to measure where, to what extent and conditions, eventually, accept the proposed exception (FHWA, 2002; NCHRP, 2002; NCHRP, 2003).

Road standards, generally, doesn’t help designers to manage the risk of accepting a design solution outside the typical ranges. Therefore, designer have to find further and reliable information about others variables useful for assessing risk, as actual speeds, site crash history, roadside conditions and available pavement friction.

One of the main reasons for accident occurrence is lack of geometric design consistency. This characteristic is defined as the degree to which roads are composed to avoid critical drivers’ behaviour. On the contrary, an homogeneous road produce harmonized driver performance without surprising events (Wood, 1998; Gibreel et al., 1999; Fitzpatrick et al., 2005).

In general, all the works based on this argument can be classified into three main sectors:

1. speed considerations;
2. safety considerations;
3. performance considerations.

This paper will treat about performance problems and in particular, the effect of the design parameters on the driver manoeuvres, workload and anticipation. Locations of high driver workload or, in general, geometric elements that do not meet the drivers’ anticipation determine poor design.

Driver workload is the time rate at which drivers must perform a given amount of driving tasks that increases with the complexity of the road geometry (De Waard, 1996).

In this paper the Authors proposed a methodology based on driver’s visual activity that permits to evaluate driver performance by means of visual behaviour also when the road is outside of the standard ranges.

There are important reasons why the past twenty years have seen an increase in research into driver visual behaviour and, in general, into human factors. Firstly, road engineers now appreciate that the data derived from analysis of vehicle dynamics combined with a thorough understanding of the structural attributes of the road pavements are not enough to control and limit the number of accidents. At the same time, improvements in the accuracy of measuring apparatus have made it possible to reliably track the physiological magnitudes involved in driving activity, thus completing the picture of the road system in its entirety (Demiraslan et al., 1998).

From the brief overview of the more representative studies reported in this

Reference, it can be seen that the impact of visual behaviour on the driving process has been sufficiently examined over the years (Land, 1998; Land & Tatler, 2001).

Experiments performed by Wann et al. (2000) showed drivers to have greater difficulty identifying a trajectory if the object they wished to look at demanded a certain effort of attention.

In this area, Fuller (2005) proposed a tool known as the Task-Capability Interface (TCI), which describes the dynamic interaction between the demands of the driving task and an individual’s driving ability. His model allows deeper analysis of such aspects as variations in performance, the allocation of resources, the hierarchy of decision-making processes, the interdependence of task demands and ability, the relationship between the difficulty of tasks and workload.

Fuller identified the driver’s choice of speed as being the primary solution to the problem of restricting the difficulty of the driving task to subjective limits.

Finally, Easa e Ganguly (2005) proposed a method for modelling workload, which is quantified through analysis of the visual demands the driver is subject to. they propose some analytical models derived from use of the experimental visual occlusion method, which allowed the calibration of three characteristic variables, such as the visual demands relative to the whole length of road, half of it and the first 30 m of it (VDF, VDH, VD30), enabling to compare these models with others described in literature.

Nevertheless, for the purposes of the road engineer, whose ultimate objective is the safety of road users, the relationship between driving activity and the physical characteristics of the road context (geometry, traffic, speed, visibility) remains insufficiently explored, especially in the existing road.

The aim of this research is to formulate a more complete judgement of the existing road context with the aid of new indexes not considered in road standard.

2. METHODS

2.1 Choice of drivers

Before beginning road trials, the Authors selected 30 potential drivers who had completed a detailed questionnaire. This first group was made up of males between the ages of 25 and 28 who, therefore, had between 7 and 10 years’ driving experience and who were all habitual users of the sections of road under examination. The questionnaire also required volunteers to provide information regarding:

- any accidents they had had;
- presumed driving ability;
- propensity for risk-taking;
- most feared traffic scenario (dark, rain, heavy traffic, winding roads, tunnels, etc.);
- any sight impairment (and severity of);
- familiarity with the stretch of road.

The Authors analysed all the questionnaires and, in order to maximize homogeneity within the group, decided to exclude the respondents who reported major sight impairment or a high propensity for risk-taking.

During on-road trials, certain situations beyond our control involving traffic, and weather and light conditions also proved a threat to test homogeneity.

It was for the above reasons that study was restricted to the participants who shared very similar driving behaviour rather than use the more disparate 30-strong sample originally contemplated.

2.2 The trial vehicle

Equipment for tracking eye movement, the road environment and dynamic vehicle was installed on an 1600 cc Lancia Delta.

The instruments included three micro cameras, concealed within the car interior to avoid obtrusiveness. The first of these provides a reasonably faithful picture of the driver's view ahead, the second reproduces the view through the rear-view mirror and the third records head and eye movements in greater detail. Of course, these different requirements are accommodated by means of differing focal lengths and light sensitivity and the presence of infrared sensors. All three cameras are analogic and are linked to a Quad module incorporated into the dashboard which allows switching from analogue to digital signals and perfect synchronization of the images deriving from the three sources.

A special programme was written to coordinate this instrumentation since our highly specific requirements made it impossible to use any of the more standard commercial applications. This software, based on the Matlab programming language, allows:

- compression of images in real time;
- calculation of head-eye system coordinates in real time and using Image Processing techniques;
- freedom from the need to use a mouse;
- slow-motion functions in order to pinpoint the smallest details in frames;
- visualization of information on speed, acceleration, distance covered and GPS coordinates in the fourth quadrant of the monitor;
- automatic creation of a data file compatible with most computer systems;
- in a post-elaboration phase, frame by frame scrolling of videotapes.

2.3 Road Analysed

The trials took place on a country road over a distance of about 7.7 km with uniform track in terms of cross section and construction.

Morphological-architectural features are as follows:

- The cross section comprises two separate carriageways built at equal height, except for the final stretch of 300 m, where they are on different levels.
- The inland section nearest the hills carrying vehicles from north to south has three lanes each 3 m in width, while the other carriageway, running south-north, has only two 3 m lanes.
- There are two footpaths of 1.40 m each positioned alongside the edge of the carriageways; the one on the coastal side is fitted with a safety rail.
- The central reservation is planted over and varies in width from 2.5 m to 4.00

m; however, there are no crash barriers.

The trials were carried out on the carriageway nearest to the hills, using a sample group of eight drivers.

As already mentioned, these drivers all belonged to the same class as regards age, sex, driving experience, proneness to accidents, most feared driving scenarios, familiarity with the stretch of road. The trial lasted 6-7 minutes and took place under normal traffic conditions with participants unaware either of the aims of the study or of the presence of instrumentation inside the vehicle. The vehicle was also occupied by an operator responsible for making sure the computer and tracking equipment worked properly.

2.4 Variables involved

The main parameters involved in this experiment are all related to the single central factor of driver behaviour since even the parameters relative to vehicle dynamics are a consequence of driver actions. These variables can be listed as follows:

- movements of right and left eyes: X and Y coordinates of the pupil centroid in a Cartesian system in which the unit of measurement is the pixel;
- distance between pupil centroids in pixels;
- angle of line joining centroids relative to horizon line in centesimal degrees;
- vehicle speed in km/h;
- vehicle acceleration in m/s^2;
- circular curve radius in m;
- accelerator pedal percentage use %.

3. SUBSEQUENT CALCULATIONS

The recordings have permitted to recognize head-eyes movements and certain postures of the driver associated with specific manoeuvres such as: overtaking or being overtaken, passing junctions with or without traffic lights or going past access roads from private land, handling bends or slopes, going through tunnels. Also in this case, it has been necessary to setup a software ad hoc. To obtain further information about theoretical bases, all the necessary references have been included in the bibliography.

Data relative to eye movements were further manipulated to enable them to be used in the definition of recognisable and generalisable driving behaviours for at least a single class of road users.

The raw data for movements of the head-eyes system were compared with road geometry, environmental context and traffic conditions in order to pinpoint any information overload.

3.1 The Visual Load Index (VLI)

The index that quantifies this activity is called Visual Load Index (VLI) and it has been described in previous papers (Bosurgi et al., 2003; 2004; 2005) as a sudden deviation from trajectory of the driver's gaze in order to sample visual information of interest both inside and outside the standard field of visual activity.

Further aims of the research currently being undertaken are to improve the accuracy of VLI measurements in respect of eye rotation and the time devoted to information sampling. In this and in previous papers, however, VLI was used to signal deviations from standard head-eyes movements in order to demonstrate the driver's need to acquire information from context and to reference it in order to identify the areas most susceptible to information overload. In this respect, it is therefore also an index of environmental complexity in terms of road geometry, traffic flow and visibility.

3.2 The Context Information (CI)

In the subsequent phase, data relative to head-eyes movements coordinates were filtered using regression analysis. This allowed the elimination of data relating to impulsive behaviour, which VLI determination allows for anyway, and produced a function that represents only the "macro" movements of the head-eyes system (Fig. 1, 2 and 3). Although the drivers that made up the sample displayed slightly different visual behaviours in their acquisition of punctual information, they demonstrated surprising uniformity of visual behaviour in general, as can be deduced from the regression function among all the drivers.

The function chosen for the approximation of experimental data, indicated in the following figures as Context Information, was that of Fourier, i.e. a sum of sine and cosine equations up to the eighth order, of the type:

$$y = a_0 + \sum_{i=1}^{n} a_i \cdot \cos\left(n \cdot \omega \cdot x\right) + b_i \cdot \sin\left(n \cdot \omega \cdot x\right) \qquad \text{(Eq. 1)}$$

Where a_0 models any DC offset in the signal and is associated with the i = 0 cosine term, ω is the fundamental frequency of the signal, n is the number of terms (harmonics) in the series.

The general model of the Fourier equation chosen is:

$$\begin{aligned}
f(x) &= a_0 + a_1 \cdot \cos(x \cdot w) + b_1 \cdot \sin(x \cdot w) + a_2 \cdot \cos(2 \cdot x \cdot w) + b_2 \cdot \sin(2 \cdot x \cdot w) + \\
&+ a_3 \cdot \cos(3 \cdot x \cdot w) + b_3 \cdot \sin(3 \cdot x \cdot w) + a_4 \cdot \cos(4 \cdot x \cdot w) + b_4 \cdot \sin(4 \cdot x \cdot w) + \\
&+ a_5 \cdot \cos(5 \cdot x \cdot w) + b_5 \cdot \sin(5 \cdot x \cdot w) + a_6 \cdot \cos(6 \cdot x \cdot w) + b_6 \cdot \sin(6 \cdot x \cdot w) + \\
&+ a_7 \cdot \cos(7 \cdot x \cdot w) + b_7 \cdot \sin(7 \cdot x \cdot w) + a_8 \cdot \cos(8 \cdot x \cdot w) + b_8 \cdot \sin(8 \cdot x \cdot w)
\end{aligned} \qquad \text{(Eq. 2)}$$

Where the coefficients in this case (with 95% confidence bounds) are:

a_0 = -0.04581·(-0.06772, -0.0239)
a_1 = 0.08423·(0.009254, 0.1592)
b_1 = -0.1858·(-0.1986, -0.173)
a_2 = -0.01971·(-0.06645, 0.02703)
b_2 = 0.01057·(-0.05225, 0.0734)
a_3 = -0.03893·(-0.1143, 0.03647)
b_3 = 0.2601·(0.2239, 0.2963)
a_4 = -0.08281·(-0.1086, -0.05701)
b_4 = -0.02213·(-0.05311, 0.008857)
a_5 = -0.0692·(-0.07635, -0.06205)

b_5 = -0.06018·(-0.123, 0.002696)
a_6 = 0.07772·(0.05595, 0.0995)
b_6 = -0.07658·(-0.08677, -0.0664)
a_7 = 0.07786·(-0.002019, 0.1577)
b_7 = 0.08434·(0.05679, 0.1119)
a_8 = -0.004824·(-0.01484, 0.005191)
b_8 = 0.02305·(0.01397, 0.03214)
w = 0.003861·(0.003682, 0.004041)

Goodness of fit is so summarizable:

SSE: 9.022
R-square: 0.9316
Adjusted R-square: 0.9308
RMSE: 0.07921

Analysis of this function allowed to derive other important parameters. For example, knowledge of first and second order derivatives permitted identification of maximum, minimum and inflection points.

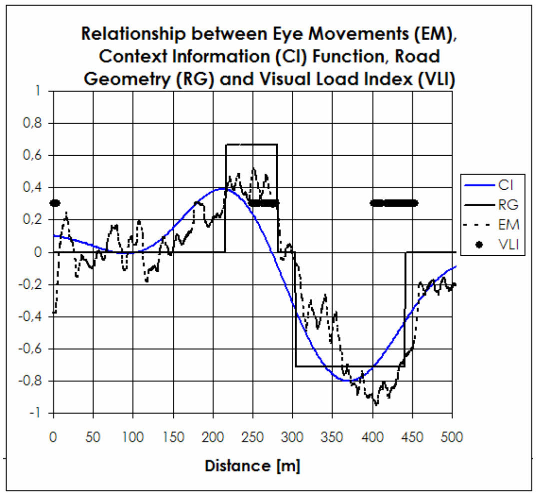


Figure 1 Visual behaviour of a driver in the section between 0 and 500 m

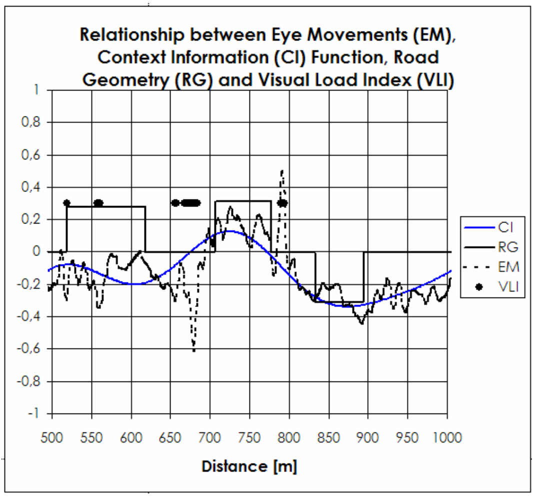


Figure 2 Visual behaviour of a driver in the section between 500 and 1000 m

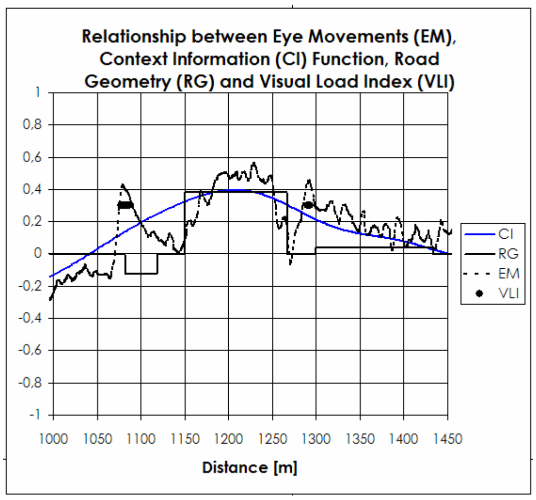


Figure 3 – Visual behaviour of a driver in the section between 1000 and 1500 m

3.3 Other Indexes

Analysis of this function allowed to derive other important parameters, better specified in the next section of the paper. For example, knowledge of first and second order derivatives permitted identification of maximum, minimum and inflection points (Fig. 4).

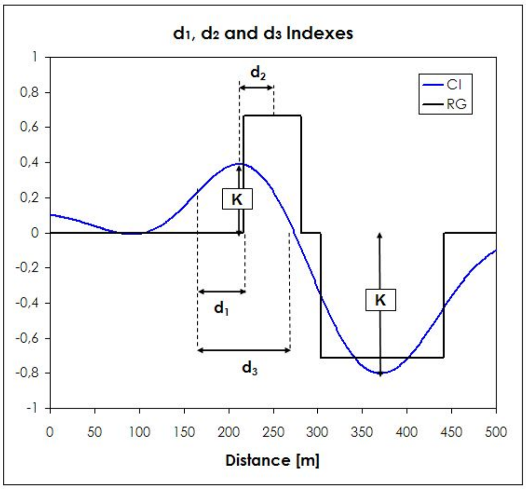


Figure 4 Relationship between Context Information function and Road Geometry

With reference to the models quoted in literature, it was found that the point in the road that coincides with the inflection point in the Fourier function is the point at which the driver begins to analyse the geometric element situated within his field of visual activity.

If the element is a curve, attention is focused on the tangent point. As the driver enters the curve, observation of the inside road edge causes the Fourier function to identify a maximum or minimum point (depending on whether the curve is to the right or to the left). Beyond the maximum (or minimum) point, the driver has no further need for additional information and proceeds with examination of the next element.

The feedforward and feedback mechanism can only be deduced from raw data in which continuous frenzied movement of the head-eyes system indicates the sampling of close-up and faraway points in order to ensure optimal driving performance.

As stated before, the maximum (or minimum) point coincides with the point inside the road bend beyond which the driver has no further need to acquire information about the geometric element negotiated and can direct his attentions to the next element. Therefore, the space and time spent (speed function) are the space and time necessary to negotiate an element in total safety; these two points, together with the width of the maximum (or minimum) point, therefore provide information on any difficulties encountered in the interpretation of the geometric element, the curve radius function, the deviation angle between the polygon sides, traffic, visibility and other factors that may make driving activity more difficult.

3.4 Visual Energy

Another interesting parameter is given by the quantification of the integral of the above function since it represents the energy expended by the driver in interpreting the road. This energy (E) can be measured for a single geometric element, such as a curve, or for a whole section of roadway in order to assign a specific or general level of difficulty (Fig. 5).

This energy expended by the driver might be considered one of the components of the mental workload with reference to performance models.

4. DETAILS OF TRIALS

Experimentation was performed in two main phases. The first was characterised by on-road trials, undertaken at the same time and under the same traffic conditions for all participants. The second phase concerned the post elaboration of telemetric data (speed, longitudinal and transversal acceleration, vehicle position and, therefore, trajectory) and, more importantly, examination of the relationship between these measurements and the driver's visual behaviour (Gonzales & Woods, 2001).

Eye movements were represented in a Cartesian diagram with units of measurement expressed in pixels. A number of flashing signals were superimposed on the graph thus obtained to highlight sudden variation in driver visual behaviour and therefore show the potential overload described as Visual Load Index. In the previous figures, VLI was shown using a segment of consistent height to represent the spatial coordinate at which the anomalous visual behaviour occurred.

Below are some conclusions deriving from the experiments performed, the results of which, (assuming identical contour conditions) indicated good correlation between individual driving styles.

The deviation among the drivers were mainly caused by local traffic conditions (junctions, passing, etc.) that had produced a different behaviour in term of speed, acceleration and eye movements.

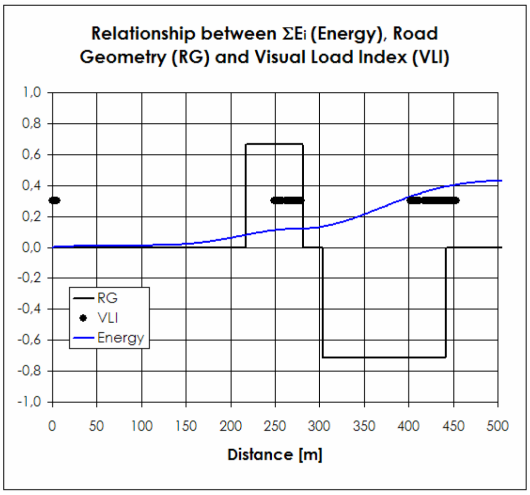
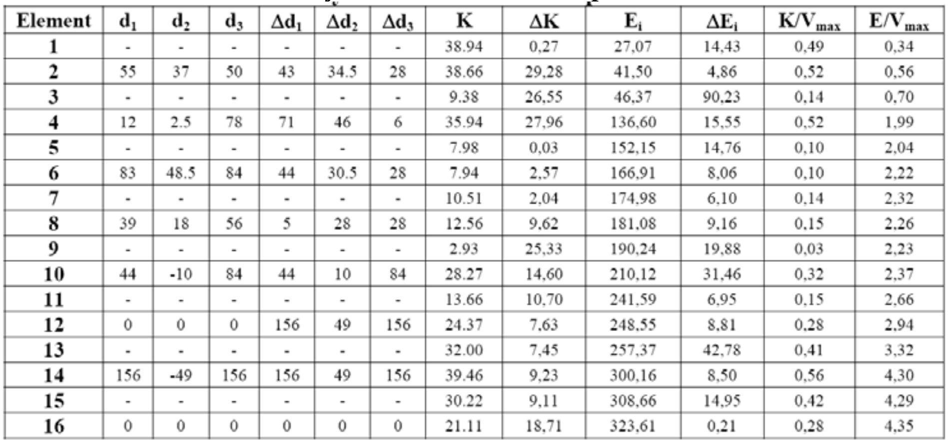


Figure 5 Visual load Index and Energy function of a driver in the section between 0 and 500 m

A table (Tab. 1), summarising the performances for each driver, have been filled in. These show the parameters listed, some of which are totally original:

- The distance d_1 between the inflection point of the function representative of head-eye movement and the start of the circular curve [m].
- The time t_1 required by the driver to reach the start of the curve following identification of the tangent [sec].
- The distance d_2 between the curve bisector and the maximum (or minimum) point of the function illustrating head-eye movement [m].
- The distance d_3 between two consecutive inflection points, indicative of the distance required to interpret the whole curve [m].
- The ordinate of the maximum or minimum point, indicated by K here; the greater the 1/R curvature, the greater this ordinate should be.
- The energy E_i expended by the driver in negotiating the whole curve, equal to the integral determined between the abscissas of the inflection points [pixel^2].
- The energy ΣE_i progressively expended by the driver over the whole stretch of road negotiated up to the element under consideration [pixel^2].
- The Context Information is a regression function representative of the statistical specimen of drivers' eyes movements;
- ΔK is the variation of the CI_{max} between two elements in succession;
- ΔE is the change of the Energy variable between two elements in succession;
- Δd_1, Δd_2 and Δd_3 are difference among the d_1, d_2 and d_3 for different bends;
- K/V_{max} is greater if the driver try to understand the road context and, consequently, reduce the speed;
- E/V_{max} has the same meaning of the K/V_{max} variable, but the value in this case depend also on the previous road alignment.

Tab. 1 – Synthesis of the driver's performance



Element	d_1	d_2	d_3	Δd_1	Δd_2	Δd_3	K	ΔK	E_i	ΔE_i	K/V_{max}	E/V_{max}
1	-	-	-	-	-	-	38.94	0,27	27,07	14,43	0,49	0,34
2	55	37	50	43	34.5	28	38.66	29,28	41,50	4,86	0,52	0,56
3	-	-	-	-	-	-	9.38	26,55	46,37	90,23	0,14	0,70
4	12	2.5	78	71	46	6	35.94	27,96	136,60	15,55	0,52	1,99
5	-	-	-	-	-	-	7.98	0,03	152,15	14,76	0,10	2,04
6	83	48.5	84	44	30.5	28	7.94	2,57	166,91	8,06	0,10	2,22
7	-	-	-	-	-	-	10.51	2,04	174,98	6,10	0,14	2,32
8	39	18	56	5	28	28	12.56	9,62	181,08	9,16	0,15	2,26
9	-	-	-	-	-	-	2.93	25,33	190,24	19,88	0,03	2,23
10	44	-10	84	44	10	84	28.27	14,60	210,12	31,46	0,32	2,37
11	-	-	-	-	-	-	13.66	10,70	241,59	6,95	0,15	2,66
12	0	0	0	156	49	156	24.37	7,63	248,55	8,81	0,28	2,94
13	-	-	-	-	-	-	32.00	7,45	257,37	42,78	0,41	3,32
14	156	-49	156	156	49	156	39.46	9,23	300,16	8,50	0,56	4,30
15	-	-	-	-	-	-	30.22	9,11	308,66	14,95	0,42	4,29
16	0	0	0	0	0	0	21.11	18,71	323,61	0,21	0,28	4,35

5. DISCUSSION

Examination of the results allowed the following observations:

- The distance d_1 (and the time t_1 necessary to cover it) can have no generally valid relationship with road geometry, because the driver simply can't have the space necessary for advance interpretation of the curvilinear element and is, therefore, forced to perform this activity over a shorter distance and space of time. In this case, the very limited length of the straight stretch of road preceding the curve under examination made a decisive difference.
- It could be said that the magnitudes d_1 e t_1 are highly dependent on the geometry of the elements that precede them and that it is, therefore, important for curve radii not to be too dissimilar from each other because if the driver does not have sufficient time to interpret a new curve, he will deal with it in much the same way as he dealt with the previous one. This observation casts further doubt on the wisdom of the current trend for designing roadways with continuous curves, i.e. with no straight lines between one curve and the next.
- Distances d_2 e d_3 are also affected by the above constraints; the variable d_2 can assume negative values; this situation occurs when the driver continues to sample useful information despite having travelled beyond the bisector point in the curve.
- The same observations can be made for energy values (E), both in respect of an isolated geometric element and of the overall extension of roadway. Parameter E_i is, in some respects, more interesting than the previously calculated distances d_1, d_2 e d_3 in that it takes the value of the function into account. As stated in the paragraph on methodology, ΣE_i could be used in conjunction with existing methods to quantify the workload the driver is subject to.
- In this regard, it would be interesting to hypothesise a threshold value for driver ability, even though this is a very subjective parameter. Working with a higher number of drivers than used in this study, it would be possible to define a value which would constitute the insuperable limit. It would be useful to establish two threshold values: the higher one representing driving ability, and the lower one being necessary to avoid a too much boredom at the steering wheel.
- The differences of these indexes between two near geometrical elements underlines incidental consistency in a more accurate way than the simple traditional criteria based only on speed comparison. This property is due to the strong relationship of these indexes and functions with driver behaviour, road alignment and environmental context.

6. CONCLUSIONS

In this paper the Authors have proposed a methodology to improve the knowledge of the relationship between existing road and real driver behaviour.

The trials, carried out in an open road, by means of an instrumented vehicle and a following phase of post processing of the date recorded, have permitted to extract some interesting indexes and functions that could help designers to evaluate in a better way the intervention on the existing roads.

In the next time it would be important to correlate these new indexes with the geometric elements. In this way an instrument could be modelled useful not only to verify the consistency of an existing road but also to evaluate a new road design.

The usefulness of this research could concern both the practitioners and researchers.

In fact, the indexes here proposed could be used by ordinary road engineers to verify design of new or existing roads, without the charge to perform new experimentations with the instrumented vehicle.

With regard to the theory side, this work could contribute to explain with great realism respect to driving simulator the relationship among driver and road context.

Although an important phase of the research has been finished, some question are still opened and, in particular:

- the validation of these conclusions with a larger statistical sample;
- the generalization of the results with different class of roads;
- the integration of this model inside the existing theory about road consistency.

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