ROAD DESIGN AND HUMAN FACTOR INTERACTION: A NEW EVALUATION METHOD

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ABSTRACT

The human factor is the most important element in studying road safety: in fact, the mechanisms involved in perception and in recognition and the decisional processes of the road user directly condition the degree of risks of accidents. The natural unpredictable component of human beings make any inquiry into the behaviour of users difficult to study: clearly, the psychology and the reactions of the driver with a specific road scenario are hard to quantify; however, it is necessary to know them in order to design a road environment which is consistent with what the drivers perceive, with their capacities and their actions.
These are the reasons which inspired various studies aimed at identifying the expressive parameters of the behaviour of drivers. The level of risk perceived when driving along certain road stretches is certainly one of the most valid and flexible ones. The average risk trend perceived by the user in a road stretch is certainly an indicator of the homogeneity of the stretch itself, and directly affects the behaviour of the drivers when driving along it.
These are the foundations for a method used to analyse the behaviour of the road user; it calls for drawing up a questionnaire-interview, where a representative sample of the population of road users expresses a subjective opinion about the risk level perceived in certain situations and road scenarios, specifying the value on a scale of points. This procedure has made it possible to gather a large amount of numerical data and this data has been submitted to an in-depth statistical analysis which has provided interesting conclusions about psychology and behaviour on the one hand, while on the other hand it has also made it possible to establish a direct relationship - by applying suitable regression models – between the geometrical and environmental features of the road. The latter is an extremely important result, since it represents a first approach to road design which takes into direct account the expectations of the users who are expected to drive along the road.

KEY WORDS

ROAD SAFETY / HAZARD PERCEPTION / HUMAN FACTOR / DESIGN CONSISTENCY.

1. INTRODUCTION

In road design, the methods accounting for the interaction between infrastructures and human beings may be subdivided into three large groups:

1. Methods for the classification of the driving activities though the assessment of check parameters such as operational speed (usually represented by V_{85}), actual trajectories followed by drivers and a speed diagram (Lamm et al., 1999);
2. methods to assess the road geometric profile through the analysis of the planimetric-altimetric co-ordination and determining design consistency by means of ad-hoc geometric parameters (*Degree of Curvature – DC, Horizontal/Vertical Curvature Change Rate – CCR*) (Lamm et al., 1994);
3. methods to asses the drivers' behaviour with reference to the road by means of ad-hoc consistency checklists or parameters (Driver Workload, Driver Visual demand, Driver

Hazard Perception), determined through surveys on test-tracks, roads or by means of drive simulators (Wooldridge et al., 1994).

The method developed in the present study belongs to the latter group. The starting point was the principle that driving, as an activity, is constantly modelled on the actual hazard level perceived by the driver while driving along a road; thus Hazard Perception was taken as a parameter to assess the relationship between infrastructures and human beings.

2. EXPERIMENTAL SURVEY

To conduct the study, a secondary country road stretch approximately 10 km long was filmed. The road has a single roadway and one lane per direction, and is crossed by grade level intersections without traffic lights. It crosses small towns and lacks guard-rails. The camera was placed at the level of the eyes of a driver in a light vehicle moving at a 55 km/h average speed. Based on the shooting, a questionnaire-interview was drafted and administered to a selected group of 51 drivers, whose age ranged between 2 and 79, with different driving experiences in terms of when they had received their driving licence and the number of km driven per year. A the beginning, the questionnaire asked a subjective assessment of the hazard perception level, the foreseeable nature of the planimetric-altimetric development of the road, the road section, the safe driving speed of the same road in case of rainfall and the influence of possible retention devices on road safety. Then, the shootings of two small stretches of the same road were shown again, one of them in an urban area, the other in the countryside, both characterised by a series of four curves. The informants were asked for their hazard perception while each curve, and then all the stretch, was covered (Figure 2). All subjective assessments were expressed according to a 1 to 7 (Figure 1) cline.

D.3 WHAT HAZARD LEVEL DO YOU PERCEIVE WHILE DRIVING ALONG THE ROAD?
(1 = very low, 7 = very high)

-	1	2	3	4	5	6	7	+

Figure 1 – questionnaire structure

3. DATA ANALYSIS AND PROCESSING

3.1. Psycho-behavioural consideration on drivers

The interpretation of descriptive statistics and frequency histograms relating to the data collected, with the support of a sampling analysis, led to psycho-behavioural considerations on the driving population in Northern Italy. The road danger was classified as average, since the average hazard perception value amounted to 4,12 out of 7. However, the informants claim that they would drive at a higher speed than that shown in the film, but they would maintain the same speed (55 km/h) only in case of bad weather. Therefore drivers show the tendency to drive too fast with reference to the type of road covered, which is typical in country roads. The bi-varied stepwise correlation analysis also showed that a foreseeable road and the presence of guard-rails lead to a marked decrease in the hazard perception. Finally, the influence of the driving experience on the answers was assessed by subdividing the informants into two groups according to their ages and years with a driving licence and implementing the "ANOVA" procedures and "Contingency tables". Both revealed that the group of "expert drivers" (average age of 55, average years with a driving licence: 32) tend to maintain lower driving speeds than the "inexperienced group" (average age of 23, average years with a driving licence: 5) both in case of fair weather conditions and in case of rain, although they consider the road as less dangerous.

3.2. Hazard perception and geometric characteristics of the road

The research also led to the assessment of the influence that the geometric and environmental characteristics of the road may have on the hazard perceived by the driver. As expected, the informants consider the urban environment remarkably more dangerous than the countryside. While taking a curve, the average hazard perception increases according to the width and decreases as the curve radium increases.
Such remarks served as a starting point to develop Linear regression models to establish a numeric relationship between the independent variable expressing the hazard perception in a curve (RP) and the independent variables expressing the curve width (A) and radius (r) and the road environment (T).
The Stepwise Backward Regression procedure implemented produced three alternative models and showed that the curve width A is the most influential geometric characteristic for the average hazard perception, followed by the radius r, whereas the road environment T does not provide a relevant explicative capacity for the dependent variable. That finding, together with an analysis of the determination coefficients (R^2, corrected R^2, multiple R) for the three alternatives, led to the selection of the most explicative model which may be best adjusted to the population; it reads:

$$RP = \beta_0 + 0.035A - 0.002r$$
$$R^2 = 0.67$$

where:
RP is the average hazard perceived by the drivers during the curve,
$\beta_0 = 3.068$ is a constant value depending on the type of road and the characteristics of the reference informants,
A is the curve width, in degrees (°),
r is the curve radius, in metres (m).
The interpretation of the dispersion diagrams of the model showed that the numeric value of R^2 is partly influenced by the presence of three anomalous values: in particular, it should be mentioned that curve 2 (Figure 2), which is relatively narrow, corresponds to a relatively high hazard, owing to a bump right in the middle of the curve, whereas curve 4 has a low hazard value as compared to its width, probably because it is located between two very dangerous curves. Thus, the anomaly highlights a lack of consistency in the road which may lead to incorrect driving behaviour. Finally, curve 5 is also related to a low average perception value with reference to its width: the reason may be related to the good visibility of the curve and the presence of a gradual connection to the preceding straightway.

3.3. Design consistency evaluation criteria

The model developed shows that the subjective hazard perception in a parameter connected to the planimetric characteristics of the road and can therefore be resorted to in order to assess the geometric consistency of a road and, consequently, to evaluate its safety level. According to the available data and processing, two safety evaluation criteria were developed valid for secondary country roads which, along with the regression model, showed to be useful tools to plan a road according to the drivers' expectations.
The first criterion is generally valid and refers to the planimetric consistency of the whole road and, in the case of secondary country roads, determines that,

$$RP < 4.61$$

The hazard perception needs to be maintained within a higher limit which, in this case, corresponds to the maximum higher limit of the confidence interval of the average hazard perception while driving along the considered itineraries. The second criterion is aimed at ensuring the geometric consistency of the following planimetric elements and was achieved by assessing the confidence intervals for the average hazard perception values while driving alone individual curves; it is valid for two generic adjacent curves *i* and *i+1*:

$$|RP_i - RP_{i+1}| < 0.86$$

Table 1 – Experimental design consistency evaluation models

N	Parameter	Description	Model	Variables	R^2
1	RP	Hazard Perception	RP = 3,068 + 0,035 A - 0,002 r	A = width (°) r = radius (m)	0,67
2	WL	Driver Workload	WL = 0,193 + 0,016 CD	CD = curve degree (°/100 m)	0,90
3	VD	Driver Visual Demand	$VD = 0,297 + 25,832\ r^{-1}$	r = radius (m)	0,71
4	V_{85} (km/h)	Operational speed 85° percentile	$V_{85}=93,96 - 0,633CD+0,0026CD^2$	CD = curve degree (°/100 m)	0,86
5			$V_{85} = 104,82 - 3574,51\ r^{-1}$	r = radius (m)	0,76

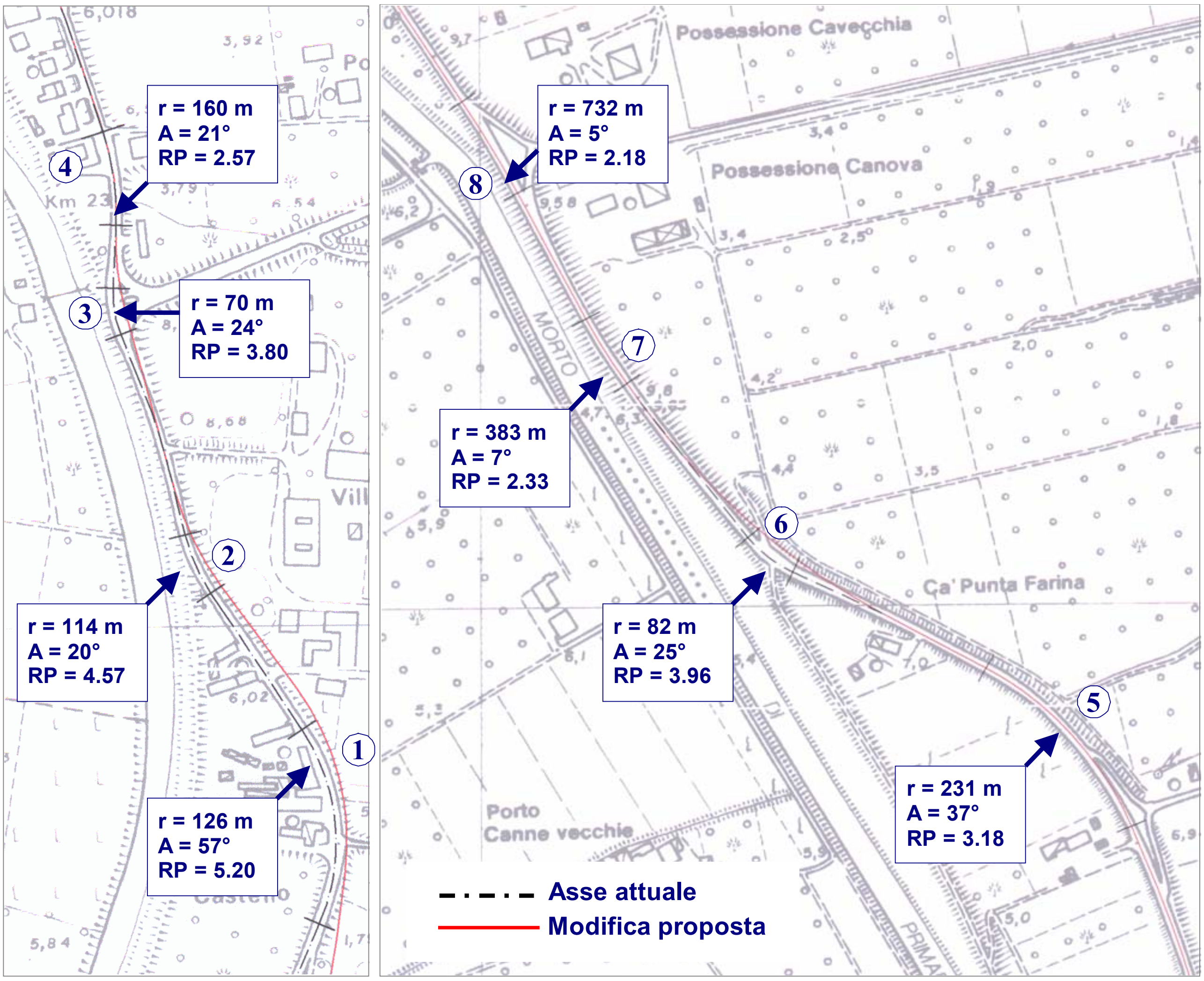

Figure 2 – Road modifications

Thanks to such two criteria and the regression model, a new design was proposed for the road under discussion so as to provide drivers with greater geometric consistency, easierto-drive roads and thus better safety conditions (Figure 2). To summarise the conclusions of the present study, in order to achieve a qualitative assessment of the validity level of the RP parameter and the ensuing model to measure design consistency, a synthetic comparison and contrast with other parameters sharing the same function made available by the literature was conducted (Table 1). It is immediately apparent that the width variable appears only in the model connected to the hazard perception, whereas in the other cases parameters only depend on radius. Therefore the model was freed from that variable by setting A=45°. The comparison and contrast showed that the model proves to be less sensitive to the radius variation as compared to others and that, consistently with the starting hypotheses, the RP parameter decreases when V_{85} increases along with the other two parameters connected to the driver's behaviour (WL and VD). Finally, mention should be made of the fact that the RP index provides results consistent with the other models in the literature, although it should not be considered as a parameter equivalent to V_{85}, since it does not assess the effects of the road influence on the driving behaviour: rather, it is aimed at quantifying the driver's hazard perception during the first stage of the decision making process regulating the driving activities.

4. CONCLUSIONS

As regards road safety in general and road planning in particular, controlling the human factor is a difficult task, but it needs to be assessed and specifically "planned" in its interaction with the road design so as to make the road "readable", consistent with the driver's expectation and its development.
All the most recent road design regulations (in Italy, Europe, United States and Canada) point to that direction and envisage one or more design consistency evaluation methods so as to minimise the driver's decisions and reduce unexpected situations.
The most frequently used methods consist in the assessment of the consistency of transversal sections, operational speed and driver's workload along the road. The RP index cannot and should not be an alternative tool to those described above; rather, it complements them for the study and assessment of the "dynamic" consistency of roads. Moreover, experimental data led to the development of two new evaluation criteria of the road geometric consistency which proved to be user-friendly and practical.
The RP index the and ensuing model to assess road consistency with reference to the driver's hazard perception certainly are a first step towards the necessary future integration of road planning, traffic psychology and safety. Finally, it should be remembered that in reality drivers "read" the road and the environment surrounding them and drive according to what they "see". Therefore a new and important field of research and development to assess the relationship between road planning and the human factor is provided by 3-D visualisation software and the new virtual reality technology.

REFERENCES

Fitzpatrick, K., Elefteriadou, L., Harwood, D. W., Collins, J. M., McFadden, J., Anderson, I. B., Krammes, R. A., Irizarry, N., Parma, K. D., Bauer, K. M. and Passetti, K. (2000) Speed Prediction for Two-Lane Rural Highways, Final Report. FHWA-RD-99-171, Federal Highway Administration, Washington, D.C.

Fitzpatrick, K., Wooldridge, M. D., Tsimhoni, O., Collins, J. M., Green, P., Bauer, K. M., Parma, K. D., Koppa, R., Harwood, D. W., Anderson, I., Krammes, R. A., and Poggioli, B. (2000) Alternative Design Consistency Rating Methods for Two-Lane Rural Highways, Final Report. FHWA-RD-99-172, Federal Highway Administration, Washington, D.C.

Krammes, R. A., Brackett, R. Q., Shafer, M. A., Ottesen, J. L., Anderson, I. B., Fink, K. L., Collins, K. M., Pendleton, O. J. and Messer, C. J. (1995) Horizontal Alignment Design Consistency for Rural Two-Lane Highways. Report No. FHWA-RD-94-034, Federal Highway Administration, Washington, D.C.

Lamm R., Psarianos B. and Mailander T. (1999) Highway Design and Traffic Safety Engineering Handbook. Professional Book Group, McGraw-Hill, New York, N.Y., USA.

Lamm R., Smith B.L. (1994) Curvilinear Alignment: An Important Issue for More Consistent and Safer Road Characteristic. Transportation Research Record No. 1445, Highway and Facility Design, Cross Section and Alignment Design Issues, Transportation Research Board, National Research Council, National Academy Press, Washington D.C., pp. 12-21.

Marchionna, A., Crisman, B., Roberti, R. and Perco, P. (2002) Il Comportamento degli Utenti attraverso la Valutazione delle Velocità Operative. Strade & Autostrade, Anno VI - n°2, Marzo/Aprile 2002, pp.145-152.

Wooldridge M.D. (1994) Design Consistency and Driver Error. Transportation Research Record No. 1445, Highway and Facility Design, Cross Section and Alinement Design Issues, Transportation Research Board, National Research Council, National Academy Press, Washington D.C., pp. 148-155.