INTEGRATING HUMAN FACTOR EVALUATION IN THE DESIGN PROCESS OF ROADS – A WAY TO IMPROVE SAFETY STANDARDS FOR RURAL ROADS

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ABSTRACT

Each year between 40 and 50 thousand people are killed and more than 3 million are injured due to road traffic accidents in both the United States and the European Union. In Europe 99 percent of fatal transportation accidents are road traffic related and about 95 percent of all factors contributing to road crashes are attributed to human factors. However, research with respect to accident causes clarifies, that it is not always one single factor that causes the accident, but a considerable amount of them are originated from a combination of human errors, and the road itself.

Furthermore, it is known that, in principle, road design is a powerful instrument to influence road user behavior. Thus, this study will primarily focus on the interaction between road environment and road user behavior to develop appropriate design alternatives for improving road safety.

A brief worldwide review of geometric highway design guidelines revealed that most standards include human factor issues only implicitly.

This paper describes a methodology, developed on the basis of an International research project financed by the University of Catania and by the Italian University Ministry. The aim of the research project is to improve highway design standards for road safety with respect to human factors needs. An evaluation system to quantify driver mental workload is provided. A variety of research methods and research instruments were applied.

The field data were collected by using an instrumented car traveling under real traffic conditions on two-lane rural roads. The car was equipped with a GPS receiver, vehicle speed- and acceleration sensors, a video camera for recording the driver's view and a system to record psycho-physiological responses (i.e. Electrocardiogram ECG, Electroculogram EOG, Electrodermal Activity EDA, Electromiography EMG). A survey was conducted on roadway sections to provide a representative sample of Italian two-lane rural roads. Based on this experience a procedure was developed to distinguish between good and poor driving conditions.

KEY WORDS: SAFETY; HUMAN BEHAVIOUR; RURAL ROADS; WORKLOAD; INSTRUMENTED VEHICLE;

INTRODUCTION

For the identification of the road-environment system it is very important to analyze those impacts, that mainly influence the human- driver's behavior, in order to evaluate the effective road safety level. Therefore, important aspects related to human factors, which are potentially influenced by the system road-vehicle–environment, will be analyzed, in order to improve road safety performances with respect to highway design standards. During driving, the driver receives and processes a series of input (mainly visual), based on his own characteristics (age, sex, psycho-physical state, level of attention, threshold of subjective risk), in order to estimate the various alternatives of driving behavior (for example: operating speed, car trajectory, distance between vehicles, overtaking chances), and to decide and execute the most appropriate maneuvers and afterwards observe their effect through the reception and elaboration of new information. Thus, the driver plays the major role in determining the success or failure within the highway system. Inappropriate behavior results from deficiencies in human-vehicle interaction and/or from a misunderstanding of upcoming driving situations with respect to the roadway or environment, which can produce dangerous situations. In this connection, the most effective way to improve traffic safety is by aiding the driver in his interaction with the vehicle and by designing highways in such a way, that features, which are relevant to the driving task are perceptible, understandable, and soundly designed, based on driving behavior, driving dynamics, and psychological points of view. The achievement of suitable safety conditions could be reached by using a procedure that allows evaluating driver behavior in terms of mental workload related to road design.
It is well known, that the driving task imposes a mental workload on the driver. This workload varies greatly in task difficulty and in task frequency. The level of this workload seems to be greatly affected by driver expectations and capabilities. Roads with design inconsistencies would be expected to violate driver expectancies and impose higher workload on the driver. For this reason it will be useful to have a safety evaluation process with respect to workload, in order to predict road scenarios maximizing driver performance capability and to still leave for the driver some "residual capacity" to reply to unexpected demands. However, most of the guidelines in many countries in the world don't put into account in an appropriate way the role of human behavior so far, as described below.
The measure of psychophysiological parameters, such as cardiac-, electro dermal-, electrooculogram- and electromyographic responses, may allow to evaluate the actual driver mental workload on existing roads and under real traffic conditions.

1. GUIDELINE REVIEW

An in-depth review of International Guidelines (Canada 1999, South Africa 2003,Italy 2001, Germany 1995-96) revealed only little quantitative input with respect to Human Behavior and Traffic Safety for most of the examined design standards.
Normally, the lane width is defined related to a design vehicle including sometimes lateral moving and safety spaces. Thus, driving behavioral and safety aspects are considered more or less indirectly.
With respect to the horizontal alignment maximum tangent lengths are often defined to avoid fatigue symptoms and minimum radii of curve are given mostly, based on driving dynamic considerations. However, it is to note, that more and more relation design requirements come to the forefront, in order to guarantee consistency in the alignment.

Furthermore, besides the design speed, the actual driving behavior is regarded by an operating speed, expressed by the 85th-percentile speed of passenger cars under free flow conditions.
Regarding the vertical alignment nearly all guidelines require grades as low as possible because of safety reasons and driving behavioral aspects. Crest and sag vertical curves depend mostly on sufficient sight distance considerations.
Many guidelines discuss the three dimensional alignment qualitatively on the basis of graphical layouts to show good and poor solutions.
For sight distance considerations normally a reaction and perception time is defined, as well as the height of the driver's eye and the obstacle height.
More information, related to human factors and traffic safety is normally not given in most of the international guidelines with the exception of the New Geometric Design Guide for Canadian Roads, the Geometric Design Guidelines of South Africa and the International Highway Design and Traffic Safety Engineering Handbook (Canada 1999, South Africa 2003,Lamm 1999).
In these new design standards questions of driver performance, driver workload, driver expectancy, driver reaction, etc. are already partially discussed.
Thus, it is to hope, that the appreciation of driver performance as part of the road traffic system will become essential for effective road design and operation. Knowledge of human performance capabilities and behavioral characteristics may thus become a vital input into the future design task.

2. TEST DRIVER SELECTION

Due to the lack of a sample totally representative of all drivers it was decided to define one among driver population on the basis of numerousness (30 persons in order to meet the statistical normal distribution), homogeneity (all students aged 24-32, equally driving experienced) and validity in terms of psycho physiological parameters responds. All people that show only marginal reactions on some psycho-physiological parameters, due to illness or physical problems of their body were eliminate from the sample. For this reason and to differentiate between high and low reactive test drivers, two tests on their psychological state ("d2"-test and the letter-rotating-test) were performed in the phase of selection.
The first phase of the test drivers, called pre-selection, was executed by using a form containing information relative to age, sex, health conditions and driving experience. On the basis of the collected data it was discarded approximately the 40% of those persons which show particular characteristics regarding the standard defined. The second phase of selection was carried out on the basis of an appropriate protocol for the check-up of the psycho- physiological characteristics. In particular the protocol previewed the use of specific psychological tests and a driving PC simulation, in order to get groups of test drivers as homogenous as possible and suitable in terms of psycho- physiological parameters. In particular, it was used the Letter Rotating Test and the "d2" Test (Brickenkamp, 1998). The first one of these tests, born to verify particular aspects of the brain functioning, represents a strong "stimulus" in order to get a meaningful answer of the driver, analyzed in terms of psycho- physiological parameters, and it allows to assess the "Choice Reaction Time" that supplies a measure of the driver capability to execute choices in response to variations in the perception of physical world. The second, born to measure driving attitude and efficiency, is currently used in the field of applied psychology in order to estimate the capability to concentration and the information speed processing. During the execution of the tests subjects were opportunely monitored with an electro medical equipment purposely adapted to the specific requirements of the tests on road. The

instrument records specific psycho-physiological parameters (ECG, EMG, EOG, EDA) that are particularly representative in terms of workload during the execution of the test.

3. TEST COURSE SELECTION AND DATA ACQUISITION

The test courses for field experiments were selected from the local rural network (two-lane rural roads) in the province of Catania, Sicily. Each test course had to be at least 3 km long (max. 7 km), the AADT should not be too high, since otherwise an unhindered test ride is difficult to achieve. To eliminate habitual effects in the psycho-physiological parameters, the test driver will not know, when the test course starts and ends. At the beginning of the test side a ride of about twenty minutes is needed, that the driver becomes familiar with the test vehicle.
Before the execution of the test those main elements of the road–environment system had to be identified, which can influence human factors and driving behavior. During the test all the information able to characterize the drive behavior and workload are to be collected. Data needed have been divided into three groups: Static Data (SD), Dynamic Data (DD) and Human Data (HD).

3.1. Static Data

The Static Data represent the infrastructure features of the test courses, that don't change along the road, but which are significant with respect to the driving behavior. Features identified for the Alignment are: road signs; presence of intersections; lateral obstacles and roadside environment; and for the Cross Section: type, lane width, available sight distance. For the acquisition of the information related to the static data a survey of the horizontal and vertical alignment was done with the DGPS cinematic procedure. Measurements were carried out using two Global Position System (GPS) instruments used in dynamic differential mode. To correct the errors due to the variability of the vehicle positioning across the lane during the survey, the points were fitted using a regression 2-D cubic spline, whose parameters were used to recognize the fundamental horizontal geometric elements (curves and tangents). In the same instant of the GPS acquisition of the point coordinates a digital image of the driver vision picture was acquired for the identification and location along the road of the relevant road features and the evaluation of the sight distance.
In order to characterize the level of influence of the Static data to the driver behavior in terms of road safety, each of the previous parameters was characterized along the test course.
Alignment: The horizontal alignment inconsistency is considered as most important regarding safety. Therefore, the level of quality in alignment design was evaluated by Safety Criteria [1, 2]. Based on previous considerations three criteria have been proposed to determine the degree of safety offered by roads in relation to the characteristics of the alignment. These three safety criteria are related to:

1. The difference between the operating speed, represented by the 85th-percentile speed (V85), and the design speed (Vd) of the observed roadway section (Safety Criterion I);
2. The difference in the operating speeds between two successive geometric elements (Safety Criterion II);
3. The dynamic equilibrium in curves (Safety Criterion III), as determined by the difference between side friction assumed (f_{RA}) and demanded (f_{RD}).

As the differences between the two factors, that characterize the various safety criteria increase, there is a progressive decrease in the degree of safety and thus a probable increase in accidents. Three design classes (good, fair, poor) can be defined, which depend on the differences between the desired and the actual values of the three criteria mentioned above, as shown in Table 1.

Table 1 –Design Classes Associated with the Safety Criteria (Lamm 1999,Lamm 2002)

Safety Criterion	DESIGN CLASSES		
	GOOD	FAIR	POOR
I	$\lvert V85_i - V_d \rvert \leq 10$ km/h	10 km/h< $\lvert V85_i - V_d \rvert \leq 20$ km/h	$\lvert V85_i - V_d \rvert > 20$ km/h
II	$\lvert V85_i - V85_{i+1} \rvert \leq 10$ km/h	10 km/h< $\lvert V85_i - V85_{i+1} \rvert \leq 20$ km/h	$\lvert V85_i - V85_{i+1} \rvert > 20$ km/h
III	$0.01 \leq f_{RA} - f_{RD}$	$-0.04 \leq f_{RA} - f_{RD} < 0.01$	$f_{RA} - f_{RD} < -0.04$

The differences associated with the three criteria are based on studies of large accident data bases in the USA and Germany. Furthermore, for the evaluation of V85, various regression equations for different countries have been proposed in relation to the new design element "Curvature Change Rate (CCR_S) of the Single Curve", defined by the relationship:

$$CCR_S = \frac{\left(\frac{L_{Cl1}}{2R} + \frac{L_{Cr}}{R} + \frac{L_{Cl2}}{2R}\right)}{L} \cdot \frac{200}{\pi} \cdot 10^3 = \frac{\left(\frac{L_{Cl1}}{2R} + \frac{L_{Cr}}{R} + \frac{L_{Cl2}}{2R}\right)}{L} \cdot 63{,}700 \qquad \text{(Eq. 1)}$$

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 clothoids (preceding and succeeding the circular curve), [m].

In Figure 1 an example, selected from the test courses and evaluated by the three Safety Criteria is shown. The example reveals Fair and Poor design practices.

Sight Distance: The evaluation of the available sight distance in each point of the test course was done using a digital image elaboration software, developed to measure the sight distance from the frames acquired along the road and positioned with the GPS system (figure 1).

Road signs: The presence of specific road signs (like speed limit, dangerous curve, chevron signs) was positioned along the test courses using the information from the digital images. Stretches with speed limitations were discharged as test courses.

Section type and lane width: All the test courses were selected from the same road type (two-lane local rural roads) with lane widths of 3.00 meters and paved shoulder of 1,00 meters.

Presence of Intersections: To avoid the influence of intersections, in this phase of the research, section lengths of 150 meters before and after any intersection were not considered as part of the test courses.

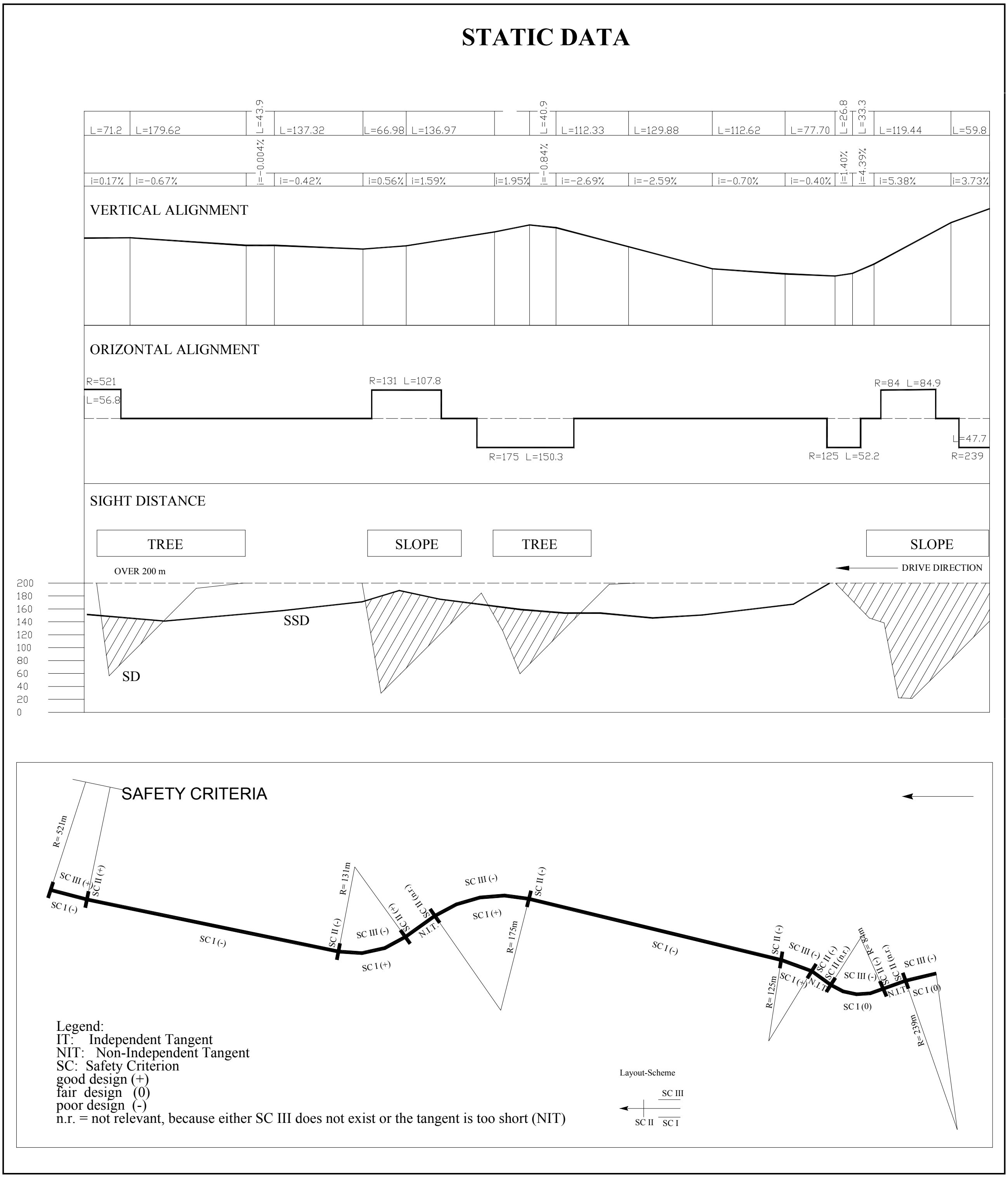

Figure 1 - Horizontal and vertical alignment, Sight Distance available (SD) compared with Stopping Sight Distance (SSD), Safety Criteria Evaluation of the example test course.

3.2. Dynamic Data

Dynamic data refer to those ones, which depend on driver behavior and road-vehicle interaction. They were identified as: Vehicle Speed, Vertical-, Lateral- and Longitudinal Acceleration, Car Trajectory, Visual Field of the driver, Spot Event Occurrence. All these data are acquired during the test with a frequency of five per second with the corresponding GPS position of the car along the test course (figure 2). In the portion of the test course without a GPS signal, the position of the vehicle can be obtained by the data coming from the odometer and gyroscope system also installed in the test vehicle.

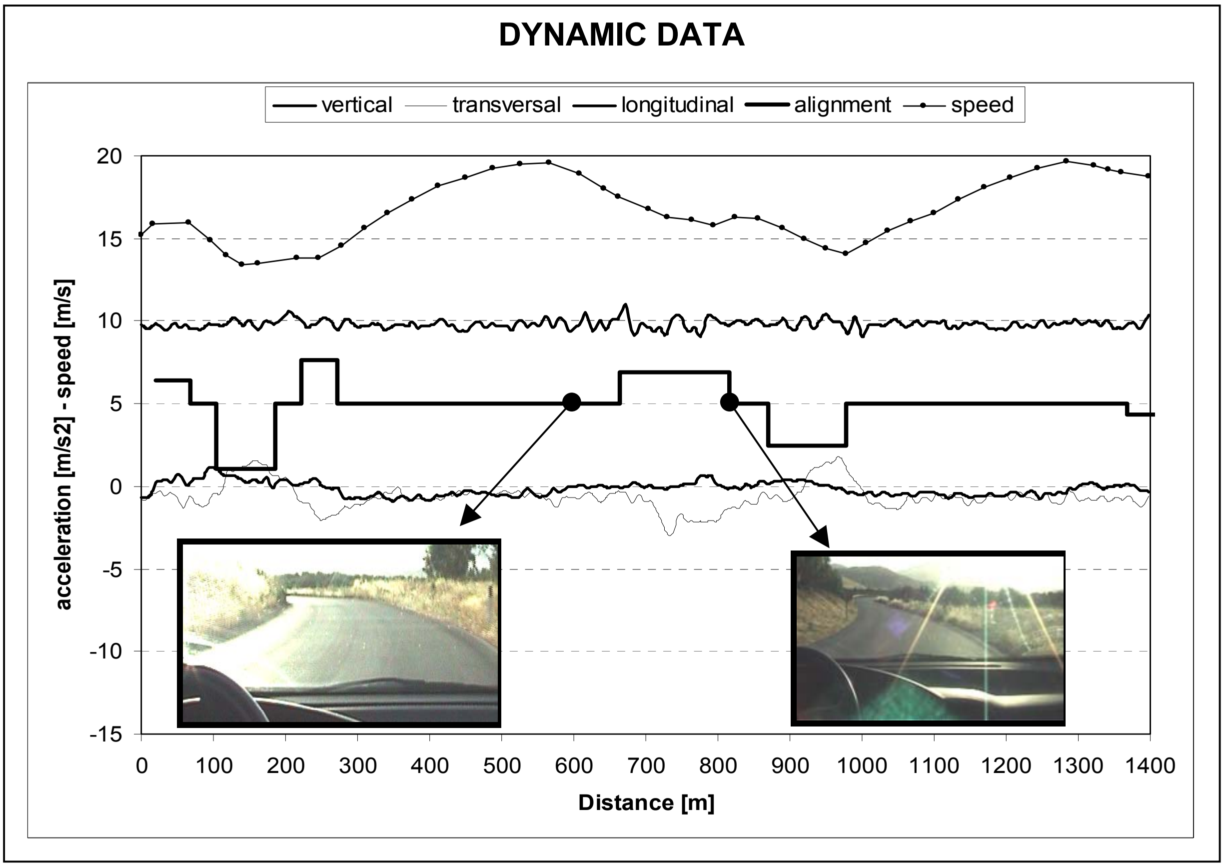

Figure 2 - Vehicle speed, accelerations and visual field of the driver during the test

3.3. Human Data:

Human Data are used to measure both the limits of human performance related to a specific task and geometric inconsistencies which show no or only marginal effects in operating speed but have considerably large effects in attention and workload demand (crest vertical curves, overtaking of other vehicles). The workload concept refers to an upper limit of human processing capabilities. The concepts of consistency and expectancy are used to avoid sudden changes in attention and workload. It is assumed that human performance is not optimal when workload exceeds or fall below median levels. These conditions lead to an higher probability of human errors, slips and mistakes which can lead to accidents in certain situations.

Psycho-physiological parameters can be related to internal processes such as emotions, attention, motivation and cognitive loads. One goal is to measure the driver's effect to cope with a task. Thereby it is generally distinguished between external workload and internal demands on different sources of capacity. Psycho-physiological parameters are indicators of internal demands and capacity requirements and they reflect internal processes which determine behavior of the driver and his performance.

The measurements on the sample of Test drivers are designed in order to acquire psycho-physiological data during driving (figure 3). An extensive literature review revealed that specific psycho-physiological signals and parameters are appropriate in the intended measurements. According to the literature(Heger 1995), the following signals were recorded from the test driver: Electrocardiogram (ECG), Electrooculogram (EOG), Electrodermal activity (EDA), and Electromyography (EMG). These are standard signals which are in common use in psycho-physiological measurement. From this signals the following parameters or indicators will be drawn: Heart Rate, Heart Rate Variability, T-Wave Amplitude, Blink Rate, Phasic EDA, Tonic EDA, and the integrated EMG of different facial and neck muscles.

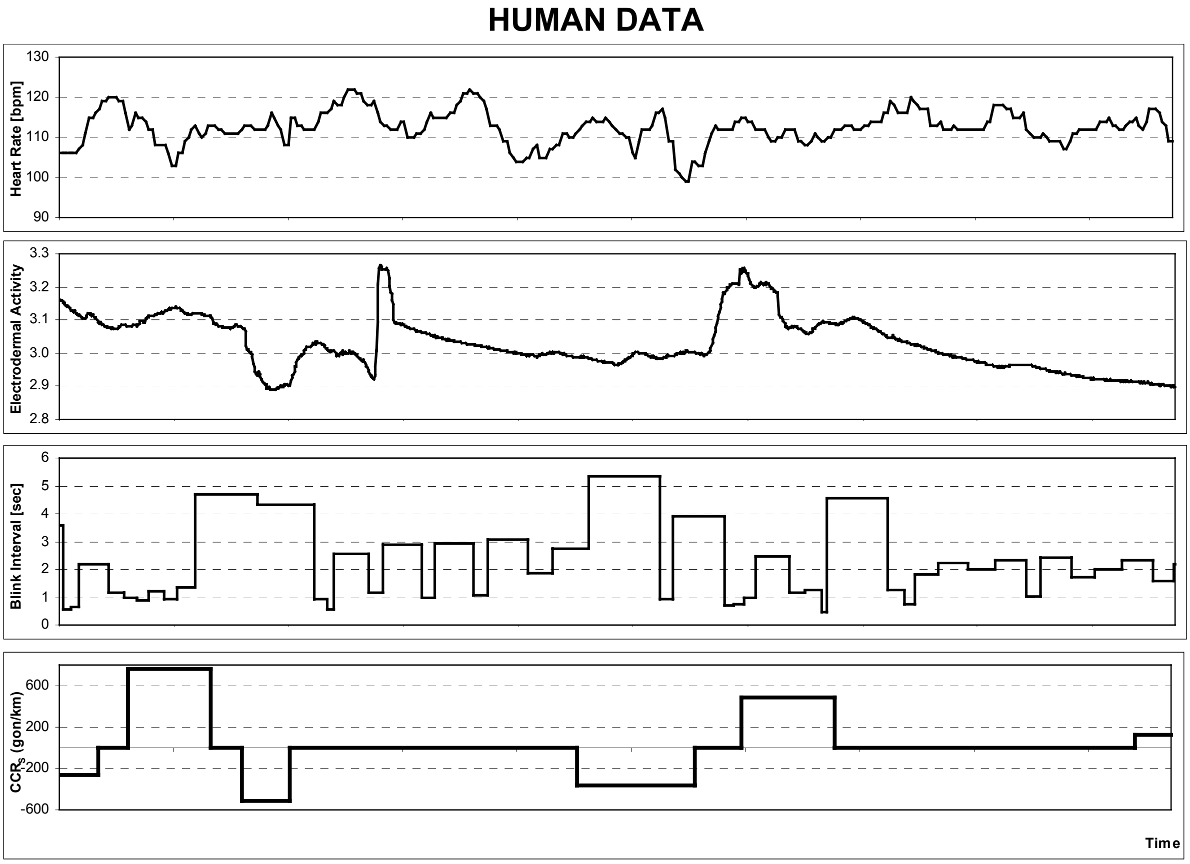

Figure 3 – Heart rate, Electrodermal activity and Blink rate related to Curvature Change Ratio during the test

The car, that will be used for the monitored drivers is a medium class car. It is equipped with the measurement system (GPS, speed-sensor, accelerometer) to monitor at each instant the dynamic data. All these data will be synchronized with the human data coming from the psycho-physiological equipment (time-event-marker-synchronization) positioned along the test course and will be also superimposed with the static data.
To reach this target, the described equipment was chosen to achieve an optimum accuracy and compatibility with the three data bases. An hardware and software system was designed and home built for the dynamic and human data acquisition, synchronization and positioning.

3. CONCLUSIONS

Although, about 95 percent of all factors contributing to road crashes are attributed to human factors, a brief worldwide review of geometric highway design guidelines revealed that most standards include human factor issues only implicitly. To improve highway design standards for road safety with respect to human factors needs, an evaluation system to quantify driver behavior and mental workload was provided.
The field data were collected using an instrumented car traveling under real traffic conditions. The car is equipped with a system designed to collect both the “dynamic data” which depend on driver behavior and road-vehicle interaction and the “Human data” representative of the psycho physiological parameters that can be related to the workload.
The test courses were characterized by the way of the “Static data”, referred to the infrastructure features significant with respect to the driving behavior and traffic safety.

The experiment conducted on a two lane rural road, showed the capacity of the system to acquire information that can characterize driver behavior and mental workload with respect to the road features.

Although, the experiment is still based on a small portion of the selected sample, the first results show a considerable influence of the horizontal alignment and sight distance on driving speed. Also, the evaluation of some parameters like Heart Rate, Heart Rate Variability, T-Wave Amplitude, Blink Rate, Phasic EDA, Tonic EDA, and the integrated EMG of different facial and neck muscles gives original information about the mental workload of the driver and its correlation with the road features.

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