GIORNATA di STUDIO S.I.I.V.

S.I.I.V.

UNIVERSITÀ DI CATANIA

La Sicurezza Stradale nell'Adeguamento della Viabilità Esistente

Catania - 2 Dicembre 2005

Design Consistency: verifiche geometriche, velocità operativa e comportamento di guida

Design Consistency: alignment indices, operating speed and driver behavior

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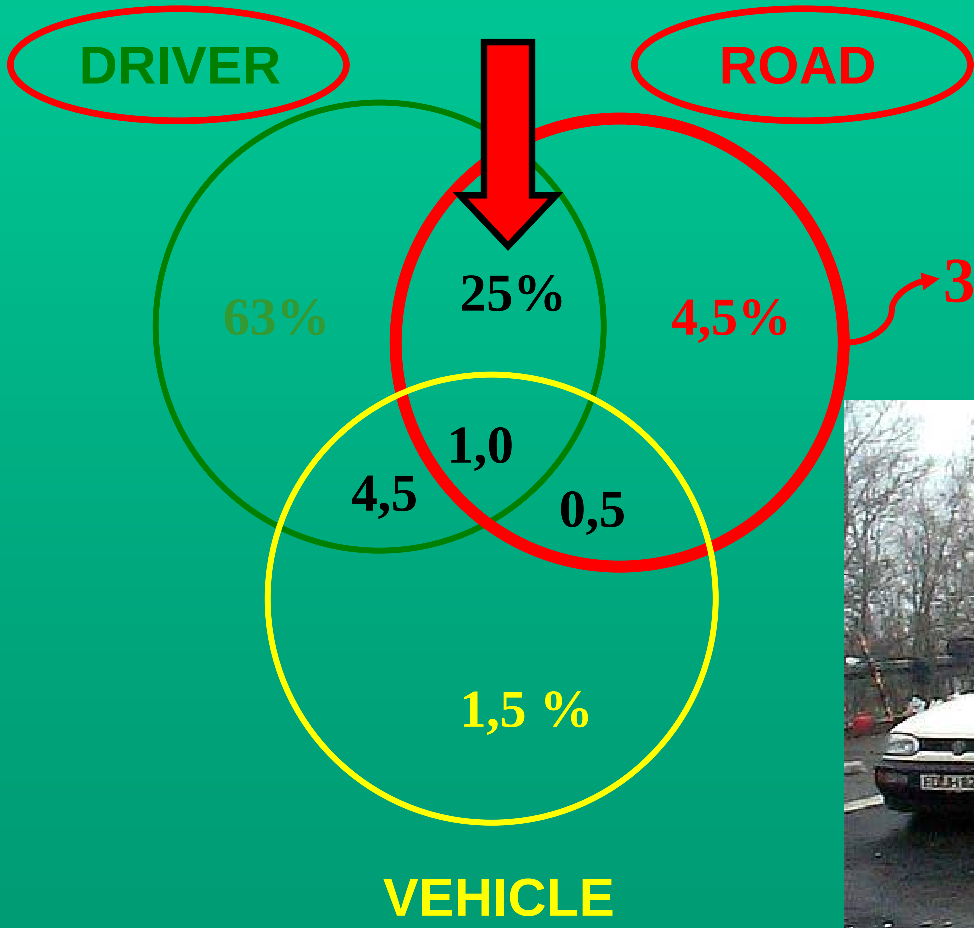
List of Contents

93% 4% 1% **ISTAT 2004**

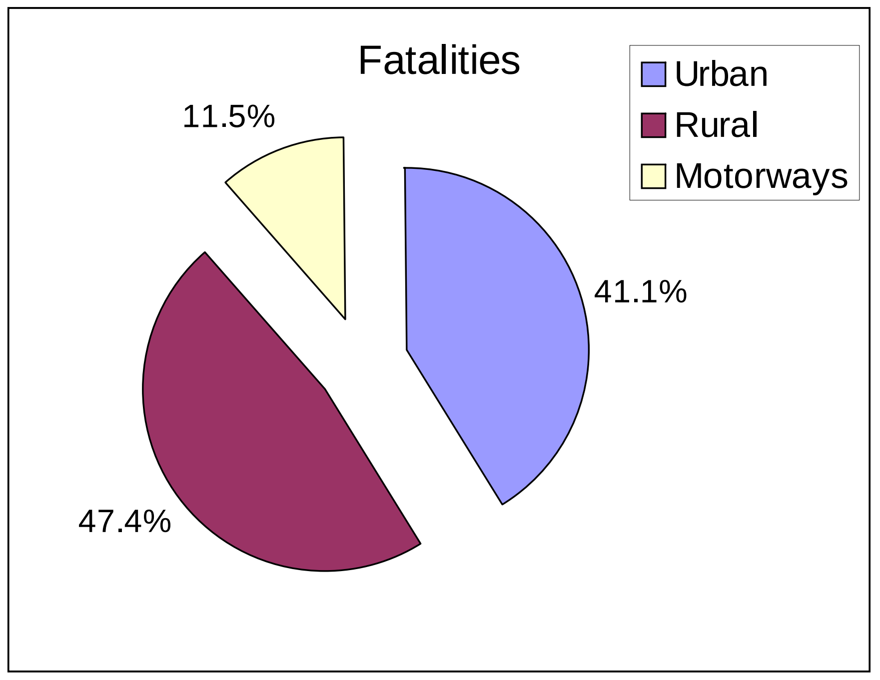
DRIVER ROAD VEHICLE

224.553 crashes (-3.1 %)
5.625 fatalities (-7.3 %)
316.630 injuries (-3.3 %)



30% **ROAD SAFETY ENGINEERING**

Rural Roads



60% OF ALL FATAL CRASHES

- Single vehicles: 35% fatal
- Head-on Crashes: 25% fatal
- Crashes at intersections: 20% fatal

DESIGN CONSISTENCY and DRIVER BEHAVIOR

Design consistency definitions:

- (J.C. Glennon and D.W. Harwood, 1978), “Design consistency implies that the design or geometry of a road does not violate either the **expectation** of the motorist or the ability of the motorist to guide and control a vehicle in a safe manner”.

- (C.J. Messer, 1980), An inconsistency in design can be defined as "a **geometric feature or combination of adjacent features** that have such unexpectedly high **driver workload** that motorists may be surprised and possibly drive in an unsafe manner.”

- (R. Lamm, E.M. Choueiri, B. Psarianos, and G. Soilemezoglou, 1995), “A consistent alignment is important because the relationship that exists between **consistency and safety**. The inconsistencies that exist on a roadway can produce a sudden change in the characteristic of the roadway, which can surprise motorists and lead to **speed errors**. A consistent alignment would ensure that "most drivers would be able to operate safely at their desired speed along the entire alignment."

DESIGN CONSISTENCY

A consistent alignment would ensure that "most drivers would be able to operate safely at their desired speed along the entire alignment (Lamm, 1995)

Questions are:

1) How we can measure Design Consistency ?

2) How we can give evaluation criteria?

GEOMETRIC DESIGN CONSISTENCY

(measure parameter)

- Alignment indices;
- Driving Behavior (Operating Speed, Vehicle Dynamics);

Designer – side

- Mental Driver Workload

User – side

ALIGNMENT INDICES

Target: *define relationship between design consistency and:*

- A large increase/decrease in the values of alignment indices for successive roadway elements or segments
- Differences between individual and average value of the alignment index

Alignment Indices Types

Horizontal Indices

Curves: Accident studies indicate horizontal curves experience a higher accident rate than tangents, with rates from 1.5 to 5 times greater than on tangent sections; higher speed gradients occur on curves of little bending radius

Tangents: Tangent length defines maximum operating speed; long tangents implies tedium and a difficult distances perception

Vertical Indices

Grades: Vertical alignment conditions vehicles speed (heavy vehicles) and sight distance for overtaking.

ALIGNMENT INDICES

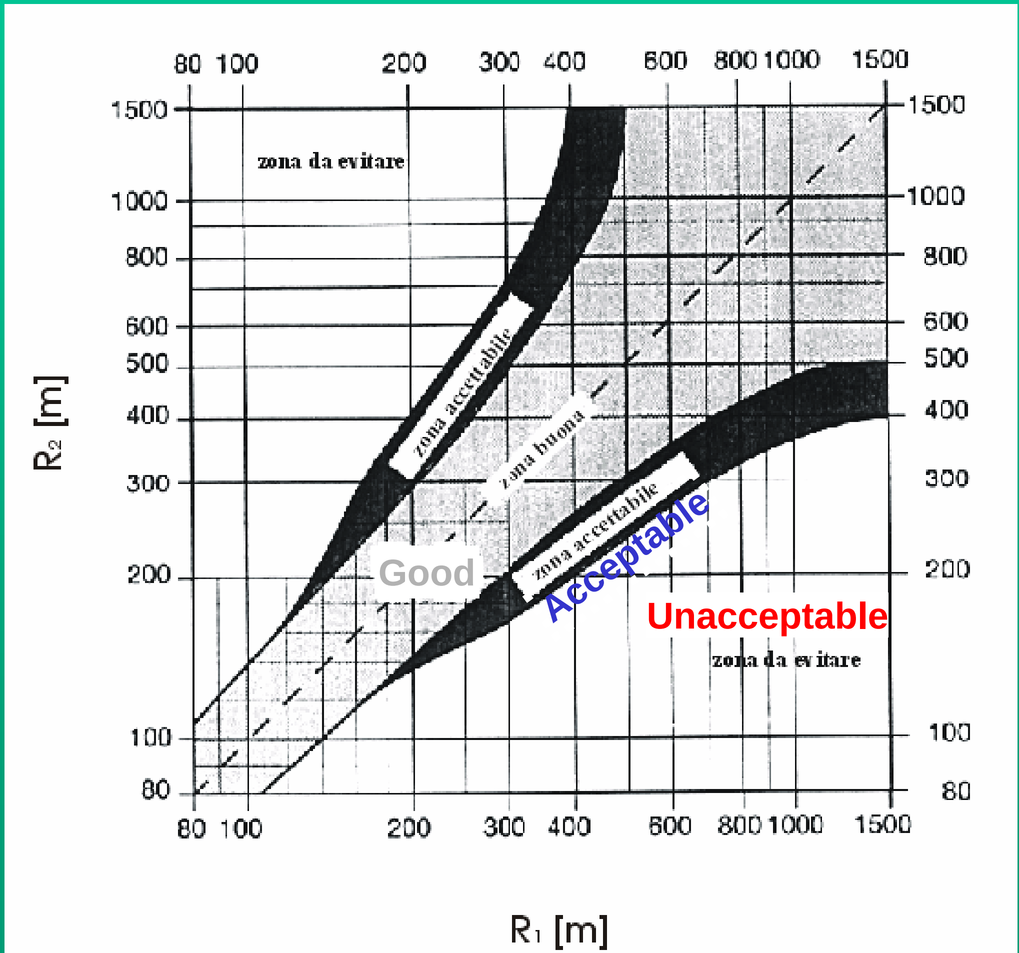
(measure parameters)

- Average radius of curvature for a roadway section
- Ratio of minimum radius to maximum radius for a roadway section
- Ratio of individual curve radius to the average radius for whole roadway section
- Average length of tangent
- Ratio of individual tangent length and average tangent length
- Average rate of vertical curvature for a roadway section

ALIGNMENT INDICES

(Relation Criteria - Italian Design Guidelines, D.M. 5/11/01)

Curve to Curve



Tangent to Curve

$L_{tangent} < 300 \text{ m} \Rightarrow R > L_t$

$L_{tangent} \geq 300 \text{ m} \Rightarrow R \geq 400 \text{ m}$

Clothoid to Curve

$R/3 \leq A \leq R$

Transition Curves

$$\frac{2}{3} \leq \frac{A_1}{A_2} \leq \frac{3}{2}$$

ALIGNMENT INDICES

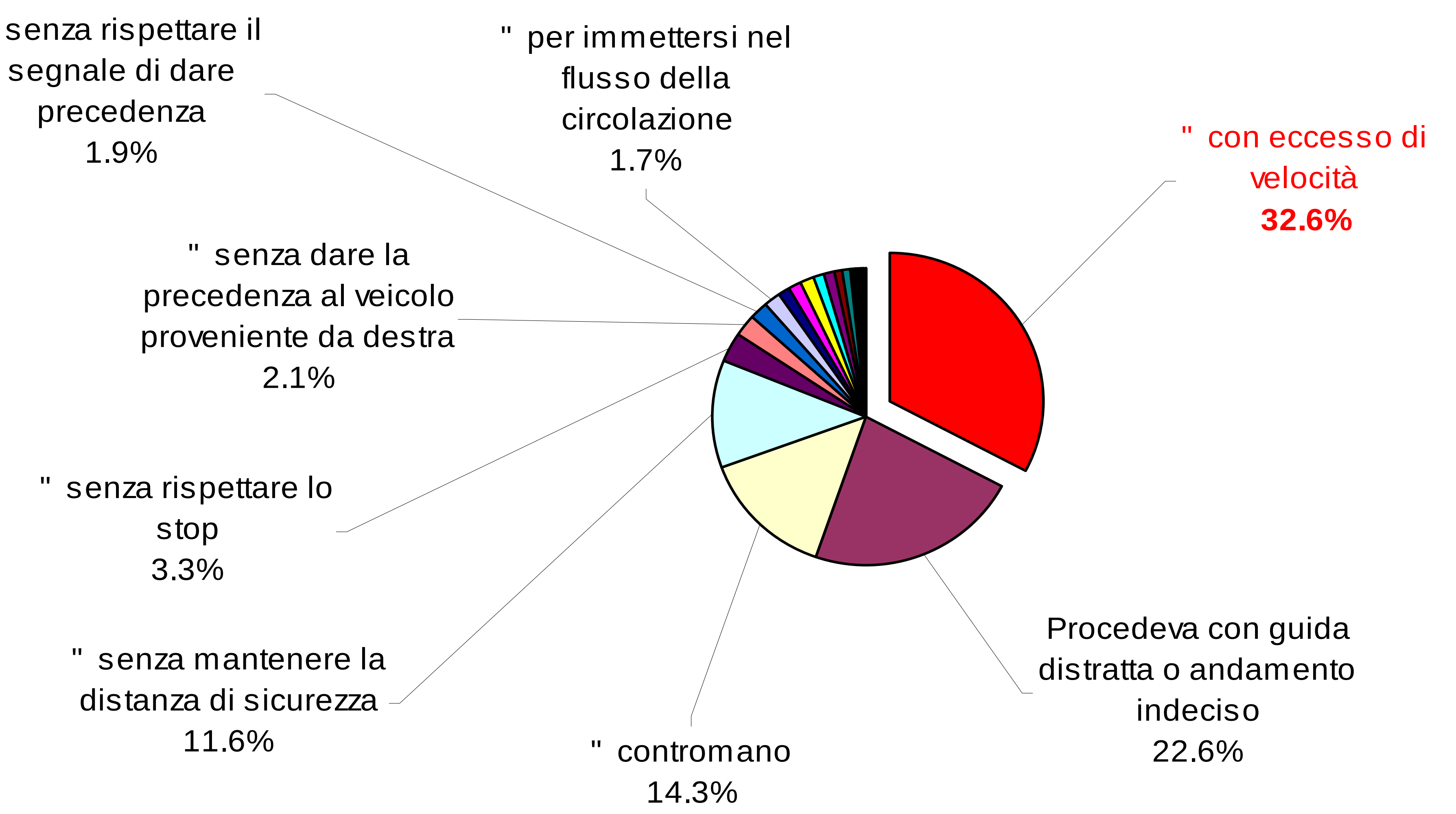
(Accident Data relationships and Conclusions)

Results: comparison between **Alignment Indices** and **Accident History** [FHWA, 2000]:

- **Most significant** indices are:
  1) Ratio of an individual curve radius to the average radius for the roadway section as a whole ;
  2) Average radius of curvature for a roadway section ;
  3) Average rate of vertical curvature for a roadway section.
- **Combined** indices are no significant.
- Statistical relations with **accident** data less significative respect to speed change parameter

Conclusions: Alignment indices can be used as additional measures respect to **speed** change evaluations.

SPEED versus ROAD ACCIDENTS
fatal accidents due to drive too fast



GEOMETRIC DESIGN CONSISTENCY

SPEED EVALUATION

Operating Speed Criteria:

Expected actual driving speed on free flow conditions

Maximum driving speeds values in function of alignment geometry under the following conditions: day time light, good visibility (~ 150 m), free flow, dry/wet pavement, no junctions, no speed limits.

The 85th percentile of speed distribution (V_{85}) can be considered as reference value of operating speeds.

DESIGN CONSISTENCY EVALUATION

3 Safety Criteria

Prof. Ruediger Lamm of the Karlsruhe University (D), defined three quantitative safety criteria for the evaluation of the endangerment of two-lane rural roads with respect to new designs, redesigns, RRR-projects, of new and existing alignments:

Safety Criterion I - Consistency in the alignment, which corresponds to a reasonable agreement between the design speed and the actual driving behaviour, expressed by the 85th-percentile speeds of passenger cars under free flow conditions.

Safety Criterion II - Consistency in the operating speed, which corresponds to a limited variation between the 85th-percentile speeds of successive design elements.

Safety Criterion III - Consistency in the driving dynamics, which represents a favourable correspondence between side friction assumed with respect to the design speed and side friction demanded with respect to the 85th-percentile speed.

The developed safety evaluation process has been accepted by the professional highway engineering community as illustrated by the fact that several **Road Agencies internationally**, including those in Canada, Greece, Hungary, Japan, South Africa, and the United States, have adopted or referenced it in their geometric design guidelines.
The application of the methodology by the United States includes partially its adoption for the **IHSDM** software, developed by the Federal Highway Administration.

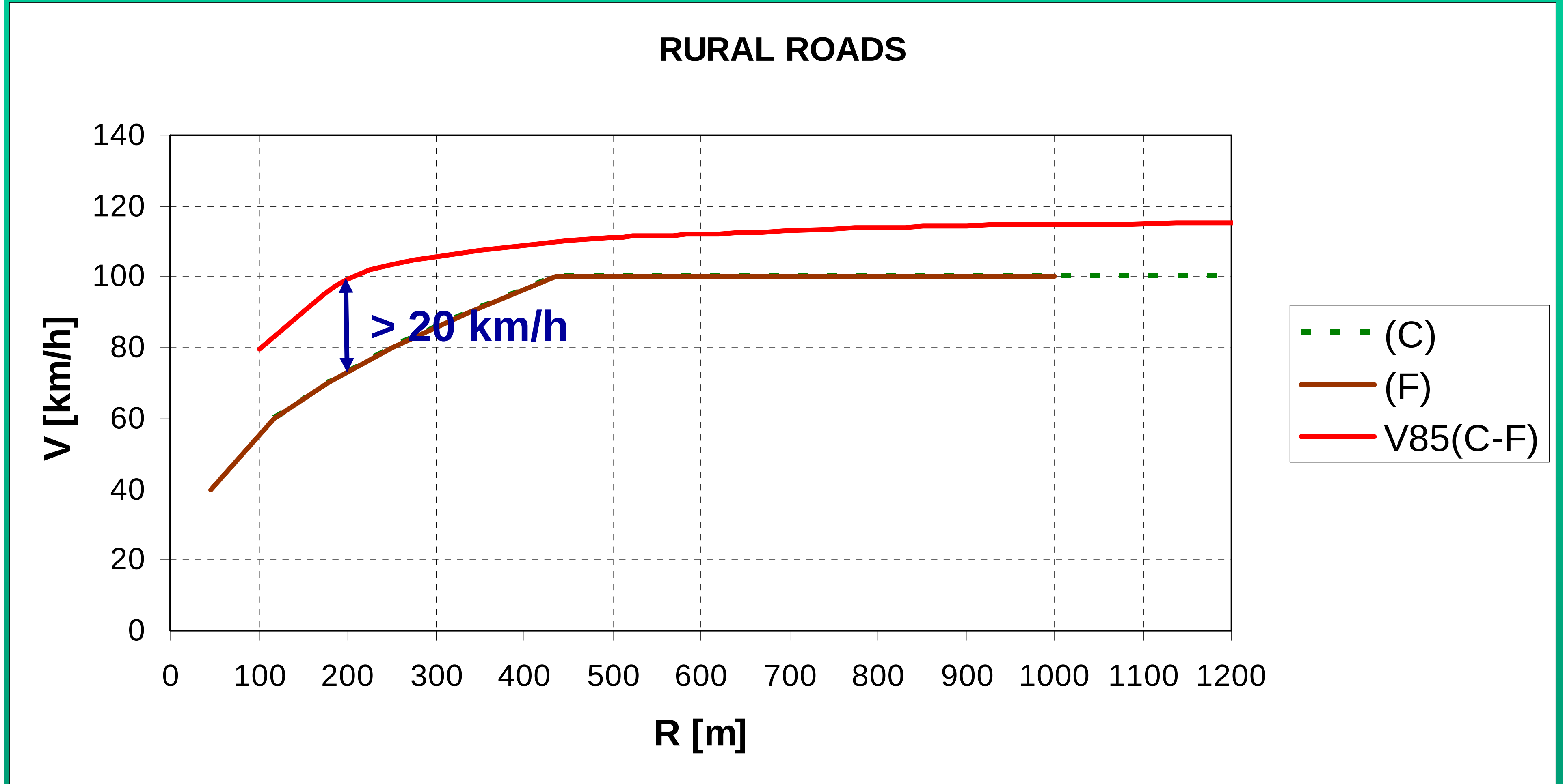
SAFETY CRITERION I

Design speed consistency

Difference between design speed and operating speed

Safety Criterion	Classi di variazione tra velocità operativa (V85) e velocità di progetto Vd		
	GOOD	**FAIR**	**POOR**
	Differenze accettabili	**Differenze tollerabili**	**Differenze non accettabili**
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

OPERATING SPEED Vs DESIGN SPEED
D.M. 05/11/2001



SAFETY CRITERION II

Operating Speed Consistency

Changes in operating speed between two successive elements

Safety Criterion	Classi di variazione tra velocità operativa (V85) di due elementi successivi		
	GOOD	**FAIR**	**POOR**
	Differenze accettabili	**Differenze tollerabili**	**Differenze non accettabili**
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

SAFETY CRITERION III

Driving Dynamics consistency

Difference between side friction assumed (f_{RA}) and side friction demanded (f_{RD})

Safety Criterion	Classi di variazione tra velocità operativa (V85) di due elementi successivi		
	GOOD	FAIR	POOR
	Differenze accettabili	Differenze tollerabili	Differenze non accettabili
III	$f_{RA} - f_{RD} \geq + 0.01$	$- 0.04 \leq f_{RA} - f_{RD} < + 0.01$	$f_{RA} - f_{RD} < - 0.04$

$$f_{RA} = 0.925 \ f_T \ n$$

$$f_{RD} = \frac{V_{85}^2}{127 \cdot R} - e$$

GEOMETRIC DESIGN CONSISTENCY

(Criteria based on speed measures – Critical Considerations)

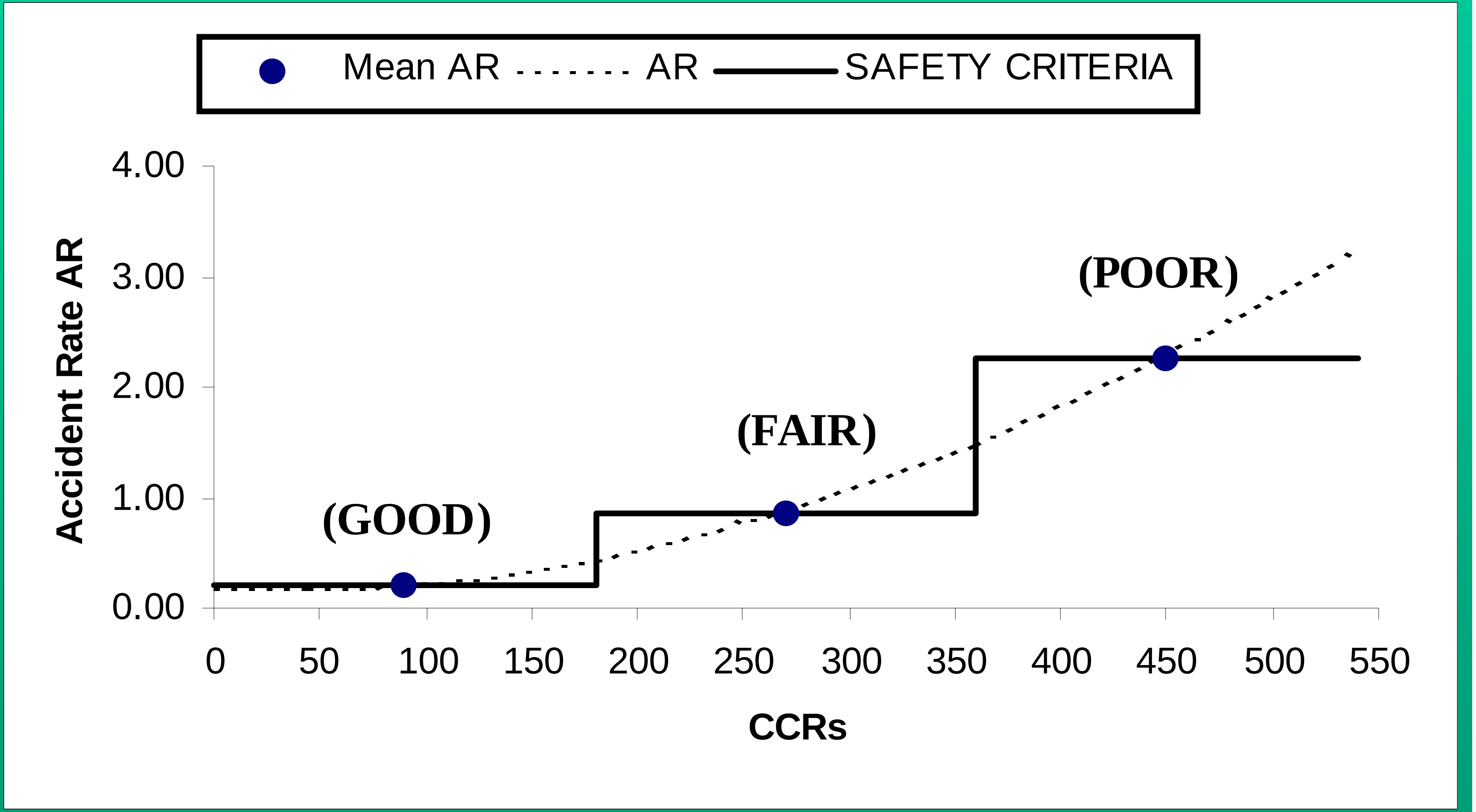
Evaluations based on operating speed gives satisfactory relationships with accident data

The theory remains promising but improvement could be made and research effort is needed

- **Cut-off points** based on accident databases from USA, Germany and Greece
- Abrupt chance in the judgment due to the **step variation** with cut-off points

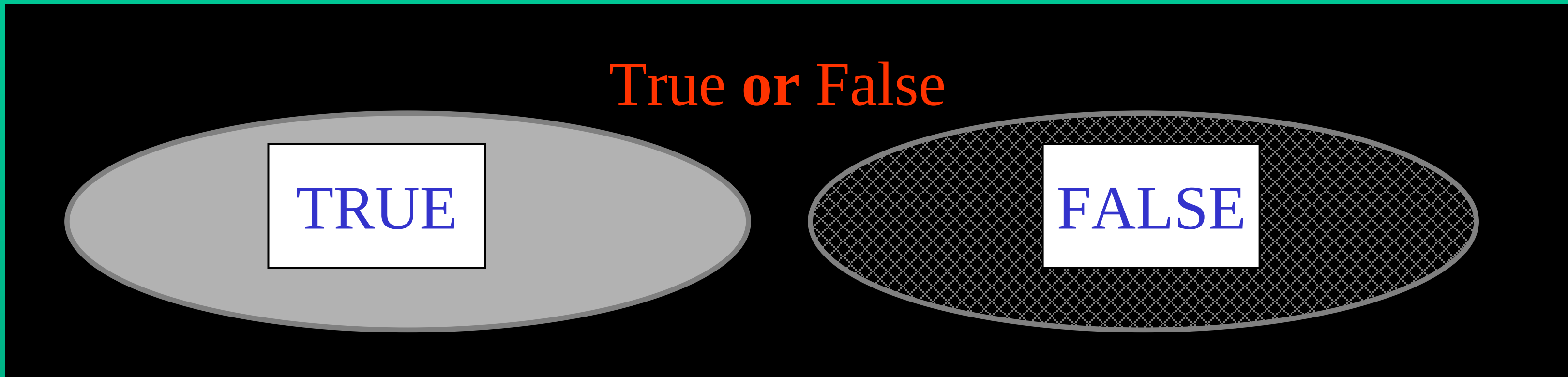
- $\mathbf{V_{85}}$ values assessment is based on **prediction models** which change both in different countries and on sampling criteria (Criterion I & II)
- **Statistically** differences between the variation of V_{85} between successive elements (ΔV_{85}) and the 85th percentile of speed differences ($\Delta 85V$) $\Rightarrow \Delta 85V \approx 2 \times \Delta V_{85} \div \Delta V_{85}+7.5$ km (Criterion II)
- The scheme of the **point mass** vehicle having circular trajectory does not take into account of the real distribution of wheel contact forces and of driving behavior, **friction values** based on research carried out in the 1940's (Criterion III)

Why modify Lamm's Safety Criteria?

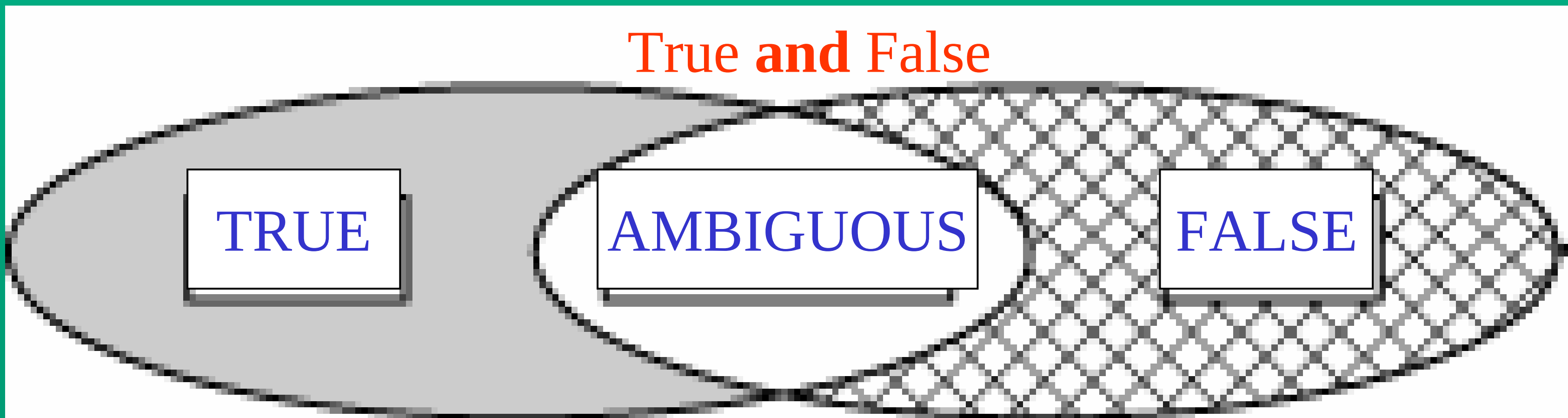


Why use Fuzzy Logic?

CONVENTIONAL MATHEMATIC LOGIC (CRISP)

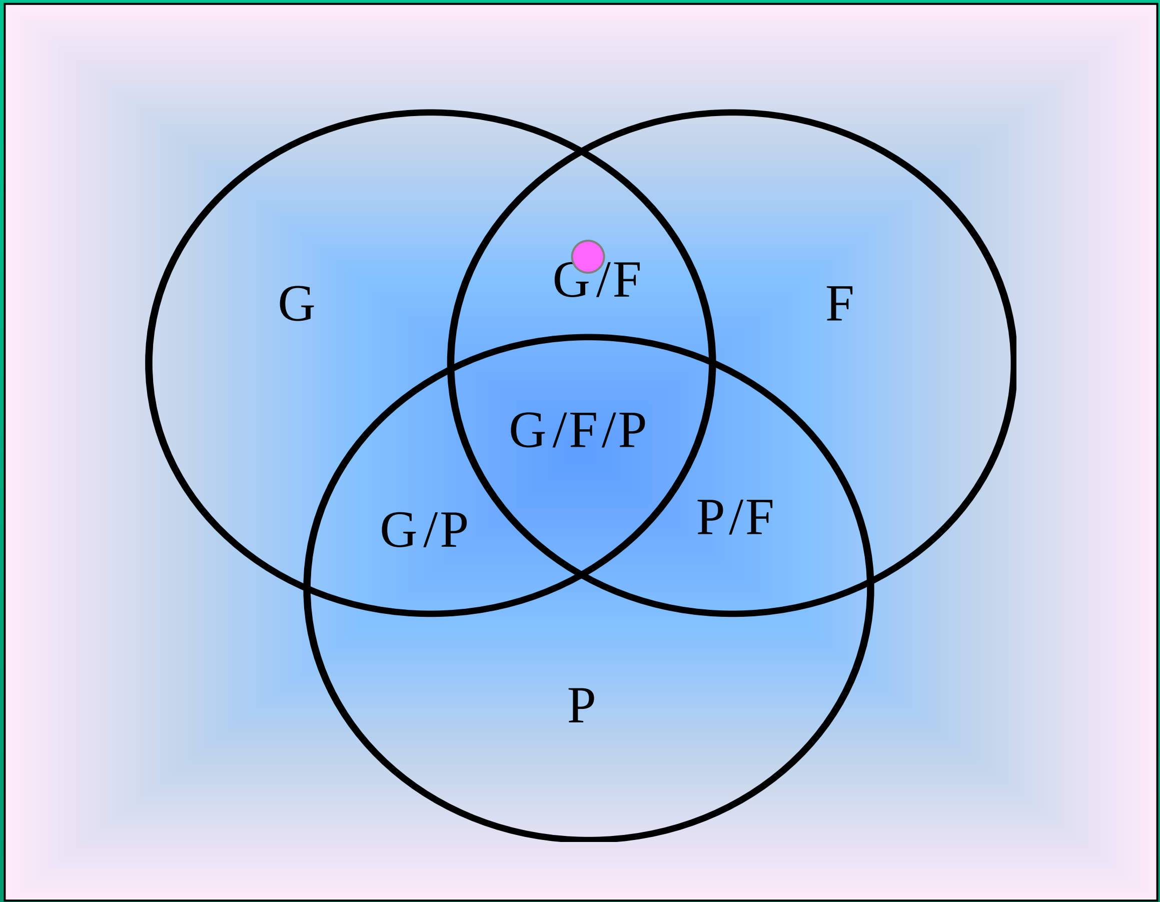


FUZZY LOGIC (Zadeh '65)



Fuzzy Logic

The application of the Fuzzy Logic with respect to the Safety Evaluation Process



Venn's Rule

$$p=2^n-1 = 2^3 - 1 = 7$$

G = Good

F = Fair

P = Poor

G/F = Good/Fair

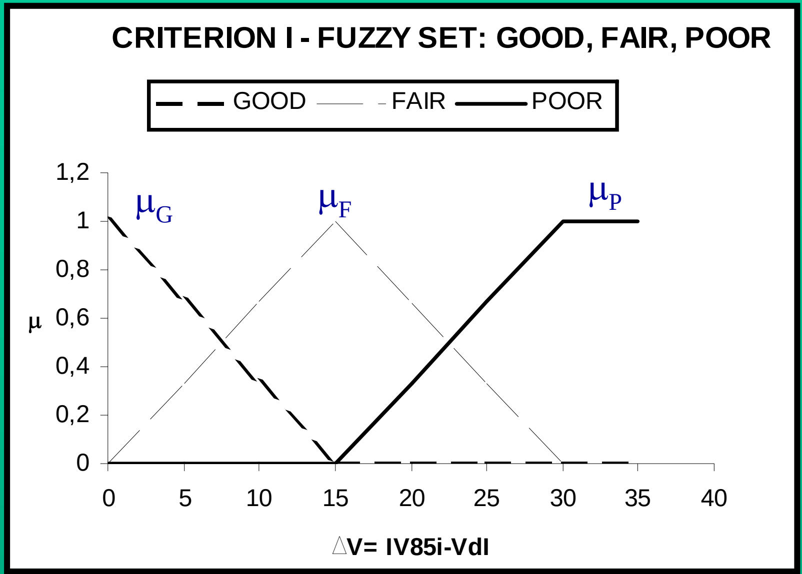
G/F/P= Good/Fair/Poor

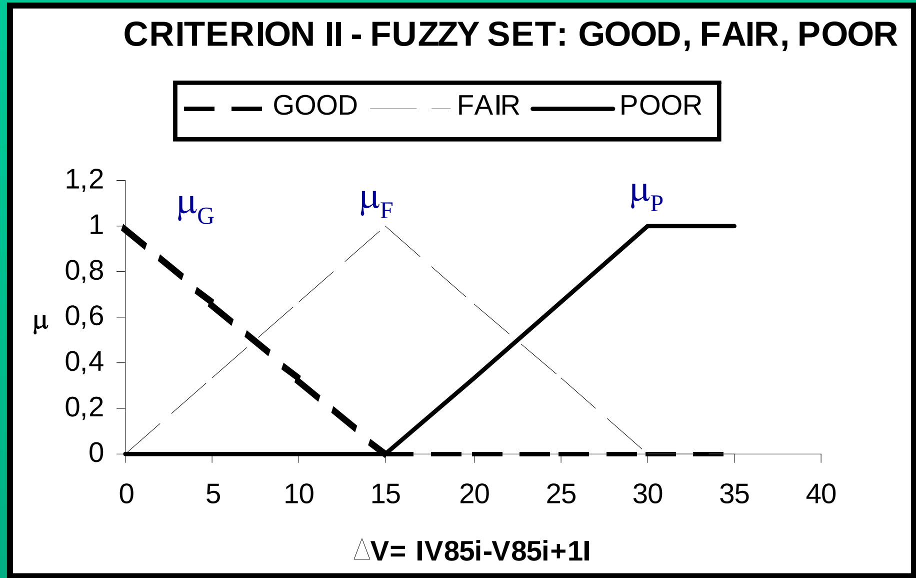
G/P= Good/Poor

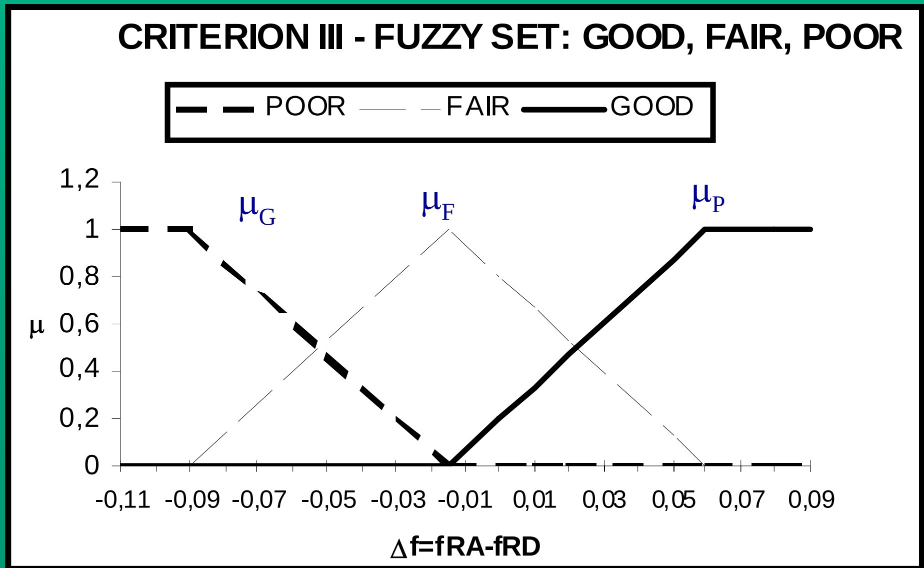
P/F= Poor/Fair

Sets partitions for each Safety Criterion according to Venn's Rule

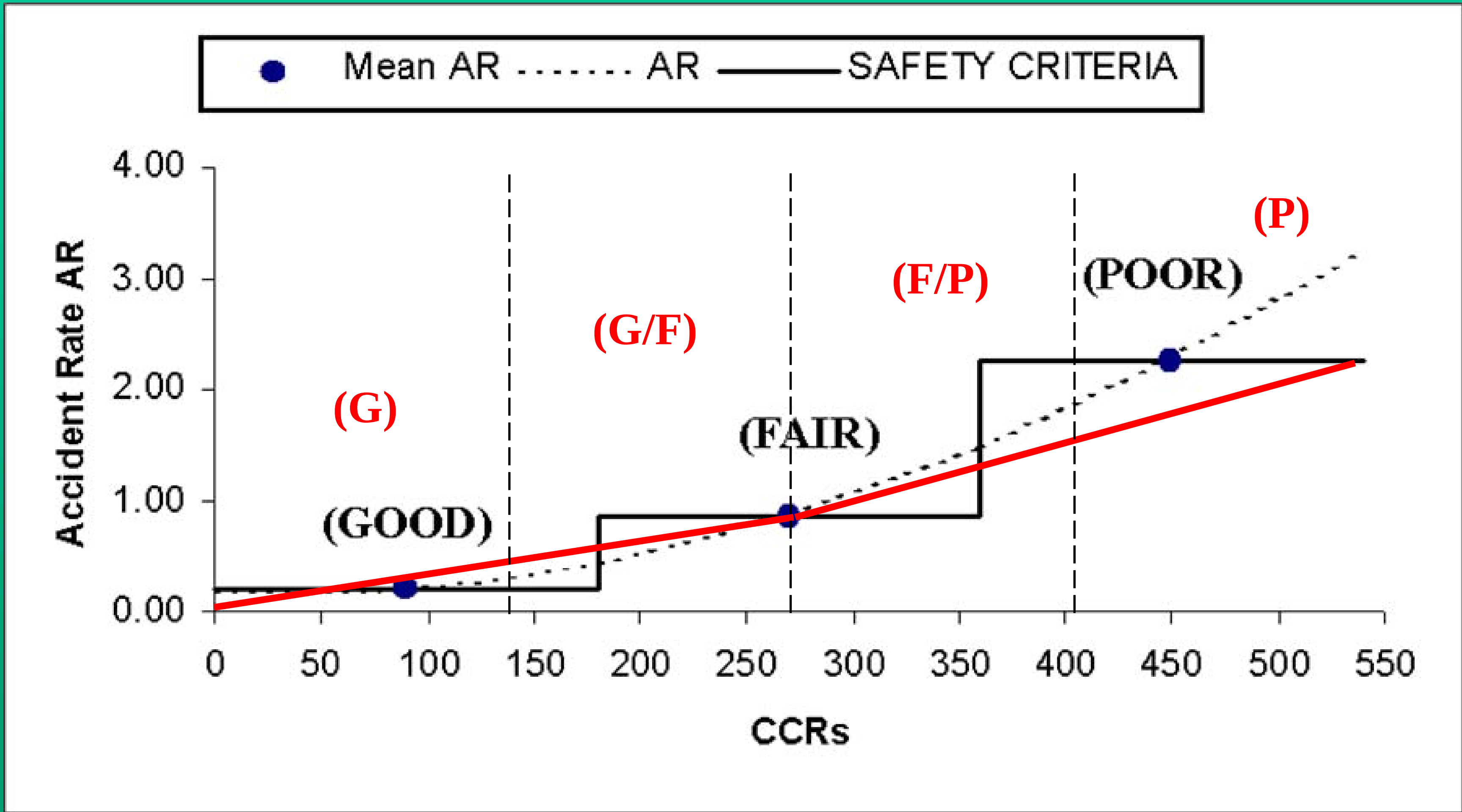
The Membership Functions







Agreement between the fuzzy model (AR_{fuzzy}) and the expected accident rate (AR)



[Lamm, Cafiso, La Cava - 2004]

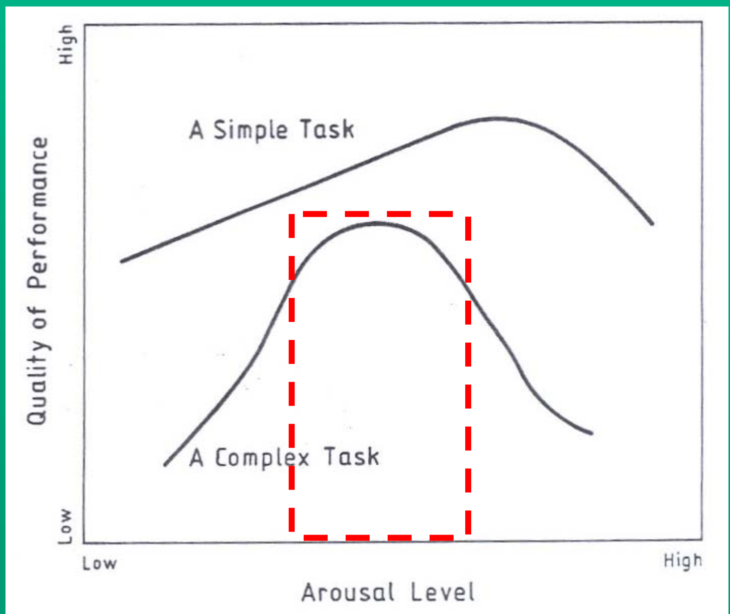
GEOMETRIC DESIGN CONSISTENCY

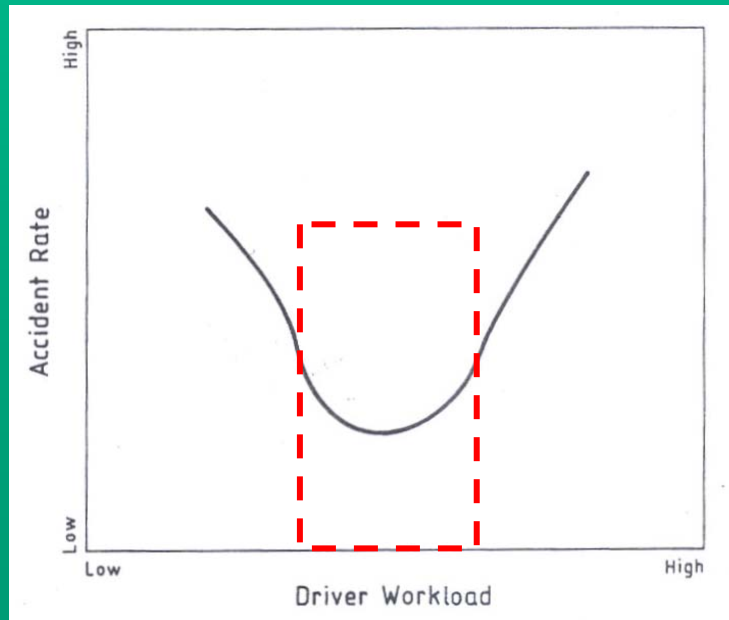
(criteria based on Workload measures)

what is Workload ?

(Senders 1970): "a *measure of the 'effort' expended by a human operator while performing a task, independently of the performance of the task itself*"

(Knowels 1963): the answer to two questions :
"*How much attention is required ?* "
"*How well will the operator be able to perform additional tasks ?* "





MENTAL WORKLOAD

How to measure workload?

As demand for attention resources increases, performance on some or all of the different activities that a driver is doing tends to degrade. At the same time, as mental workload increases, different body functions and physiological processes also change in response to the “stress” that any kind of workload, mental or physical, brings. It is necessary to individuate what of these performances change in an actual driving situation:

- **Primary task Measures**: as the task becomes more difficult, performance deteriorates (vehicle trajectory moving, speed variations). Above certain critical levels the driver maintains adequate levels of performance leaving out any secondary task;

- **Secondary Task Measures**: while performing a primary task, the driver also performs a secondary task such as doing mental arithmetic or discriminating audio or visual signals; the more difficult the primary task, the poorer the performance on the secondary task.

MENTAL WORKLOAD

Subjective Measures

As the primary task increases in difficulty, so does the driver's estimate of his/her own workload

Difficulty Level	Demand	Anchors	Rating
Very easy	No mental effort needed to drive	As easy as driving a straight, flat road	1
Easy	Little mental effort needed to drive		2
Little difficulty	Some mental effort needed to drive		3
Minor difficulty	Moderate mental effort needed to drive		4
Difficult	Considerable mental effort needed to drive	By concentrating you can steer a smooth path	5
Very difficult	High mental effort needed to drive		6
Major difficulty	Maximum mental effort needed to drive		7
Very major difficulty	Maximum mental effort needed to stay in lane		8
Almost impossible	Maximum mental effort needed to stay on road		9
Impossible	Cannot stay on the road	Curves are too sharp to stay on road	10

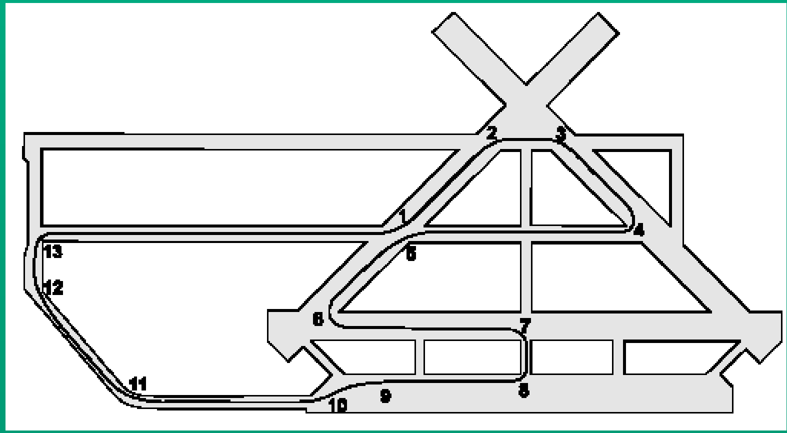
[Scale of Cooper-Harper Modified (MCH)]

MENTAL WORKLOAD

Visual Demand measure

(Johanssen, 1979) An important component of workload is the information acquisition phase (mostly visual).

Vision occlusion method



Visual demand VD

$$VD = \frac{\text{t\_glance length [sec]}}{\text{t\_request - t last\_request [sec]}}$$

MENTAL WORKLOAD

Psycho - Physiologic measure

As mental workload increases, different body functions and physiological processes also change in response to the "stress" that any kind of workload, mental or physical, brings.
It is necessary to identify what of these performances change in an actual driving situation

Psycho - Physiologic parameters

- **Heart rate**: the frequency (HR) tends to increase with physical effort, HRV decreases (HRV) as workload increases.
- **Blink rate**: Blink rate (BR) and blink rate duration (BRD) are related to workload. BR decreases as workload increases, so as BRD.
- **Pupil dilatation**: As arousal increases, the pupil tends to dilate;
- **Muscles contractions**: certain muscles contractions occur under high workload levels (frontales, orbicularis oris, neck).
- **Electrodermal activity**: Under stress increase there is an increase in skin conductance (EDA).
- **Brain activity**: brain activity linked to eye, body, and heart potentials produces small potentials (10÷20 micro volts).

Driver **I**nstrumented **V**ehicle **A**cquisition **S**ystem

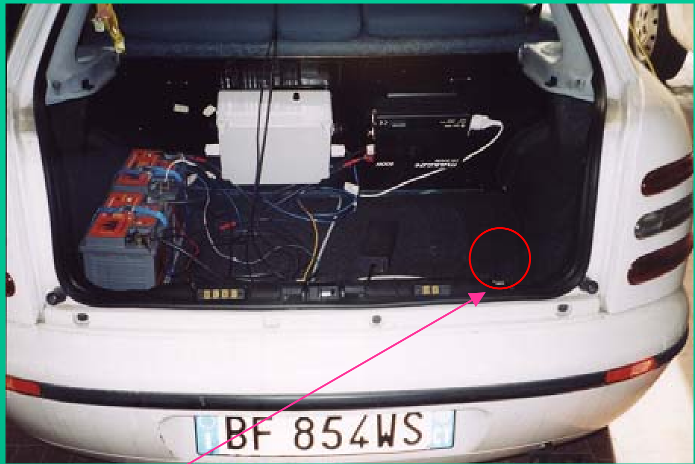
National Research Project COFIN 2001

RELEVANCE OF DRIVER – HIGHWAY SYSTEM ON HUMAN BEHAVIOUR
WITH RESPECT TO ROAD SAFETY

Co-financed by the Ministry of University and Scientific and Technological Research

DRIVER INSTRUMENTED VEHICLE ACQUISITION SYSTEM

DIVAS



Power charge

GPS

Triaxial accelerometer

Odometer Gyroscope

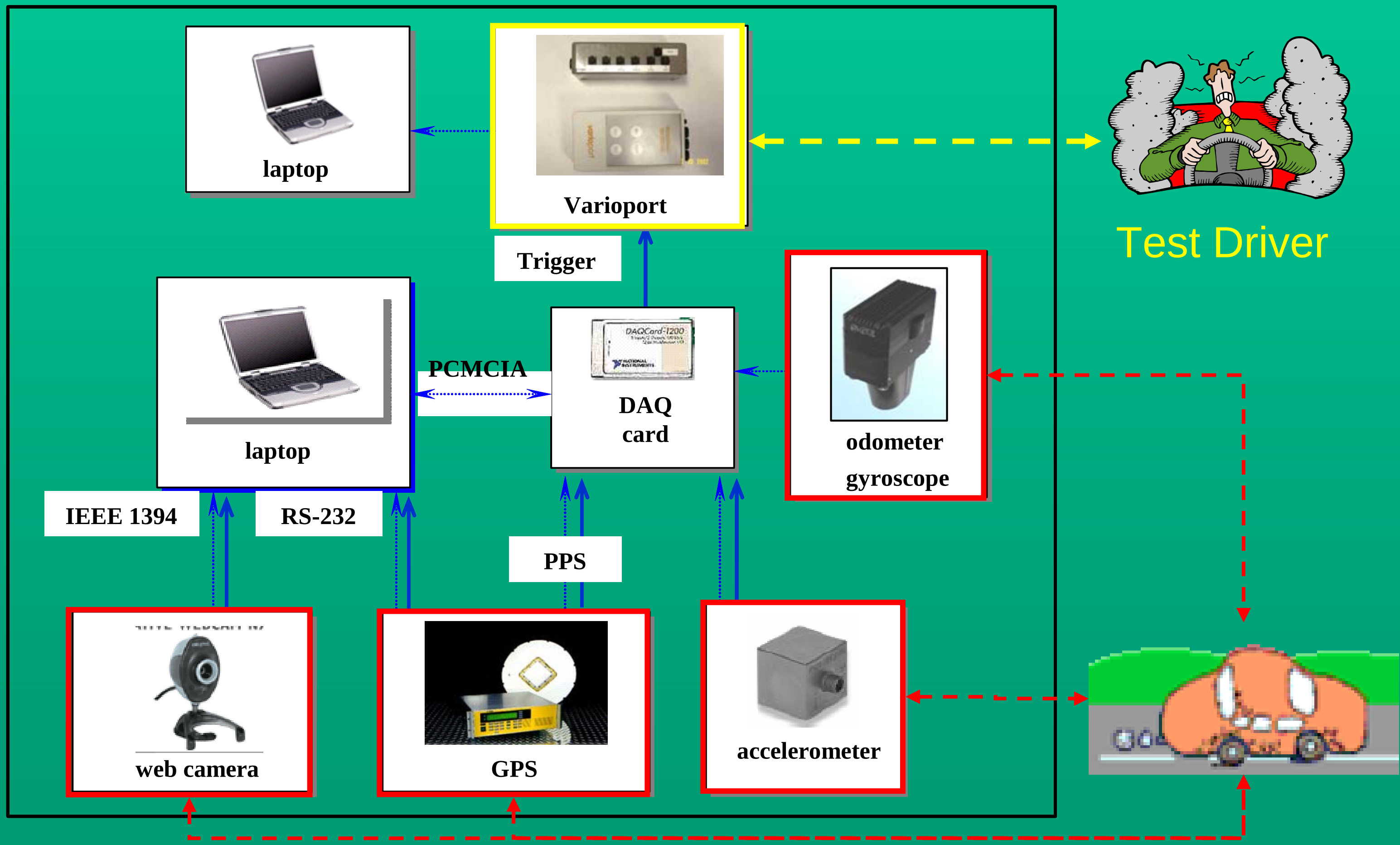
Two Laptop

Varioport

Video images

Driving Instrumented Vehicle Acquisition System

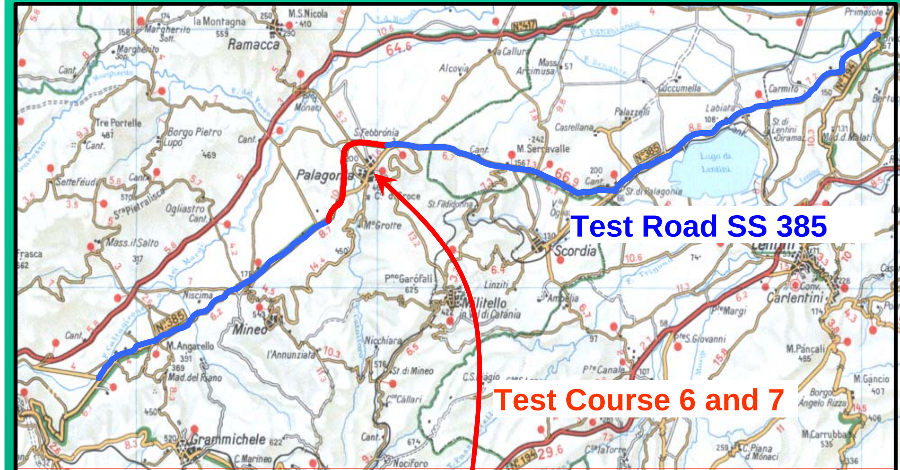
Hardware and software system designed for data acquisition of **driving data** and **psycho-physiological parameters** during road field test

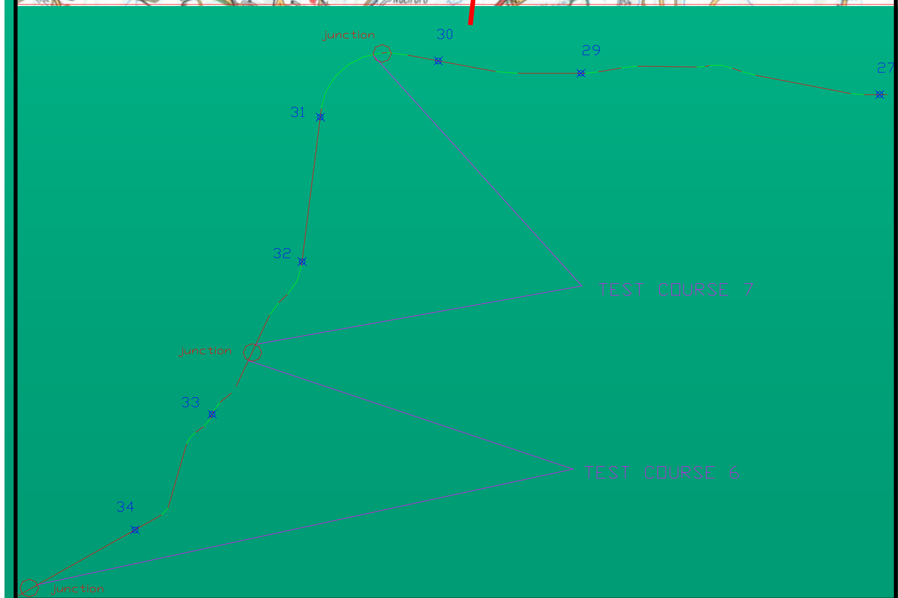


DIVAS Experiment

Static Data

Alignment; Roadside environment; Cross Section; Available sight distance; Traffic sign; Presence of junctions; Surface characteristics

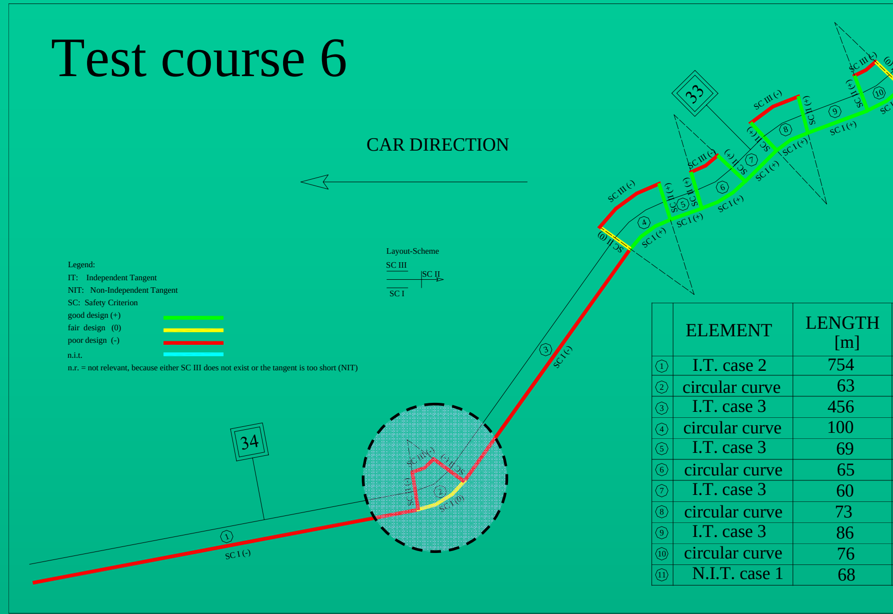




DIVAS Experiment

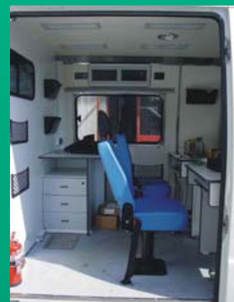
Static Data

Safety Criteria evaluation



	ELEMENT	LENGTH [m]
1	I.T. case 2	754
2	circular curve	63
3	I.T. case 3	456
4	circular curve	100
5	I.T. case 3	69
6	circular curve	65
7	I.T. case 3	60
8	circular curve	73
9	I.T. case 3	86
10	circular curve	76
11	N.I.T. case 1	68

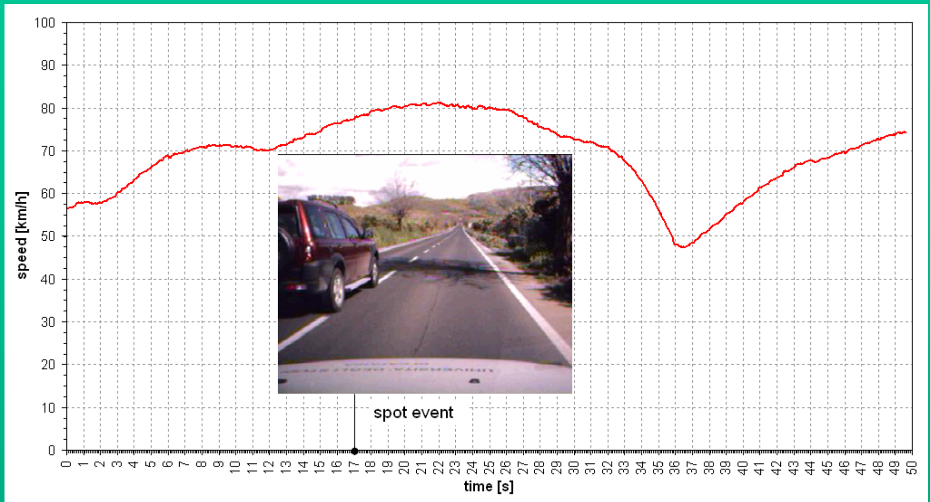
Laboratorio Mobile DICA

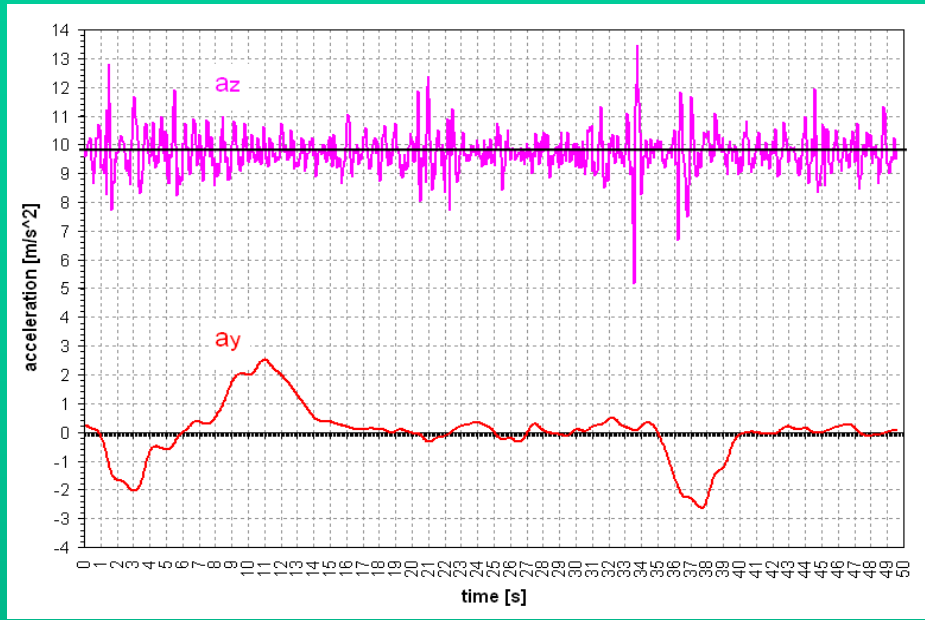


DIVAS Experiment

Dynamic Data

Vehicle Speed, Vertical and Lateral Acceleration, Car positioning, driver's Visual Field

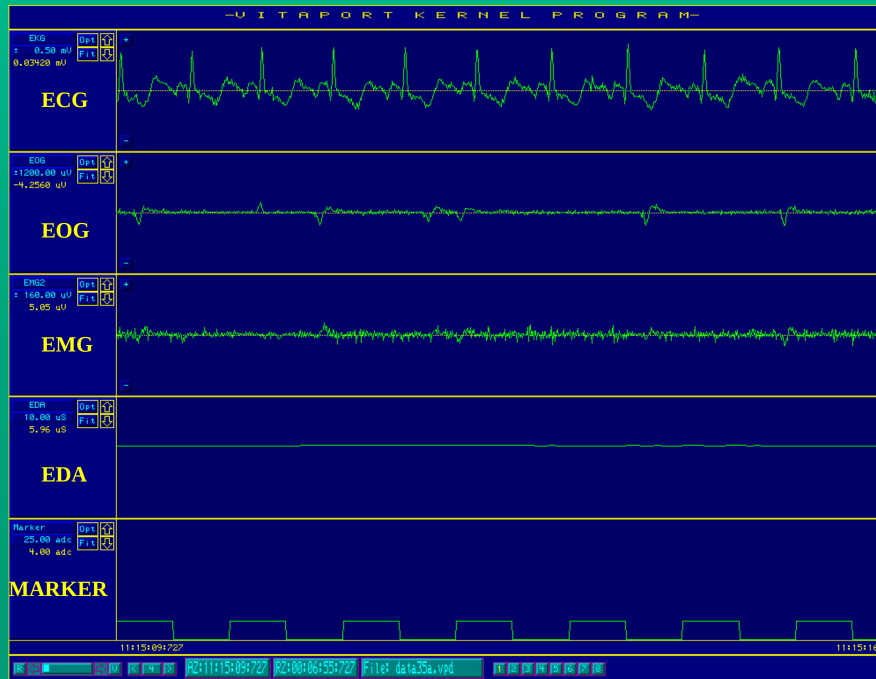




DIVAS Experiment

Human Data

Electrocardiogram (ECG), Electrooculogram (EOG), Electrodermal activity (EDA) and Electromyography (EMG)



[Lamm, Cafiso, La Cava, Heger - 2003]

TEST DRIVER

1. EMG (frontales)

2. EOG

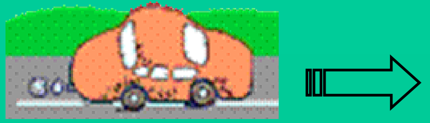
3. EMG (orbicularis oris)

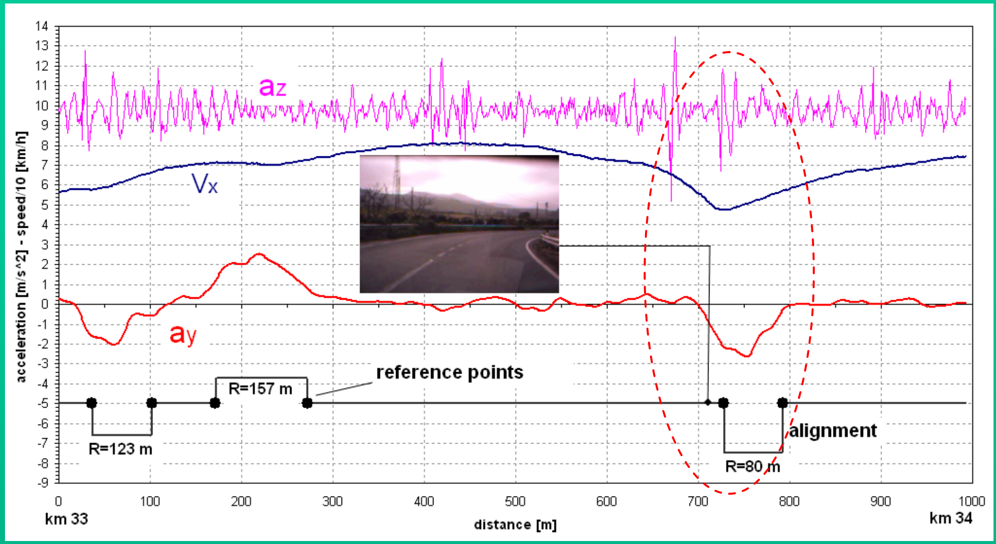
4. EMG (neck)

5. ECG

6. EDA

7. MOT



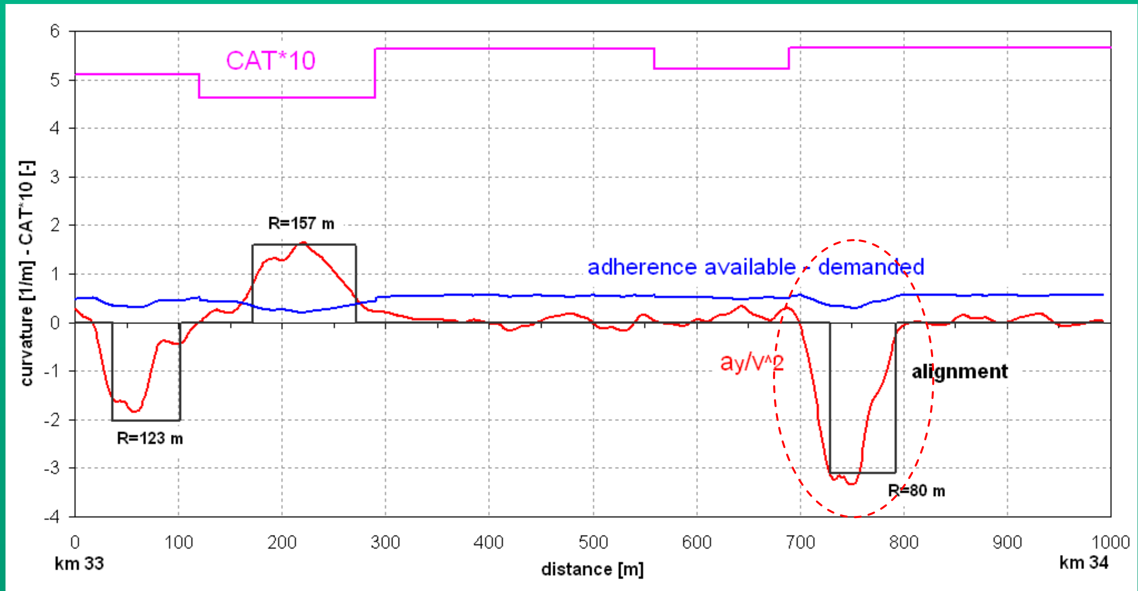


DIVAS Experiment

Workload

Primary Task

Speed profile, Acceleration intervals, Trajectory offset



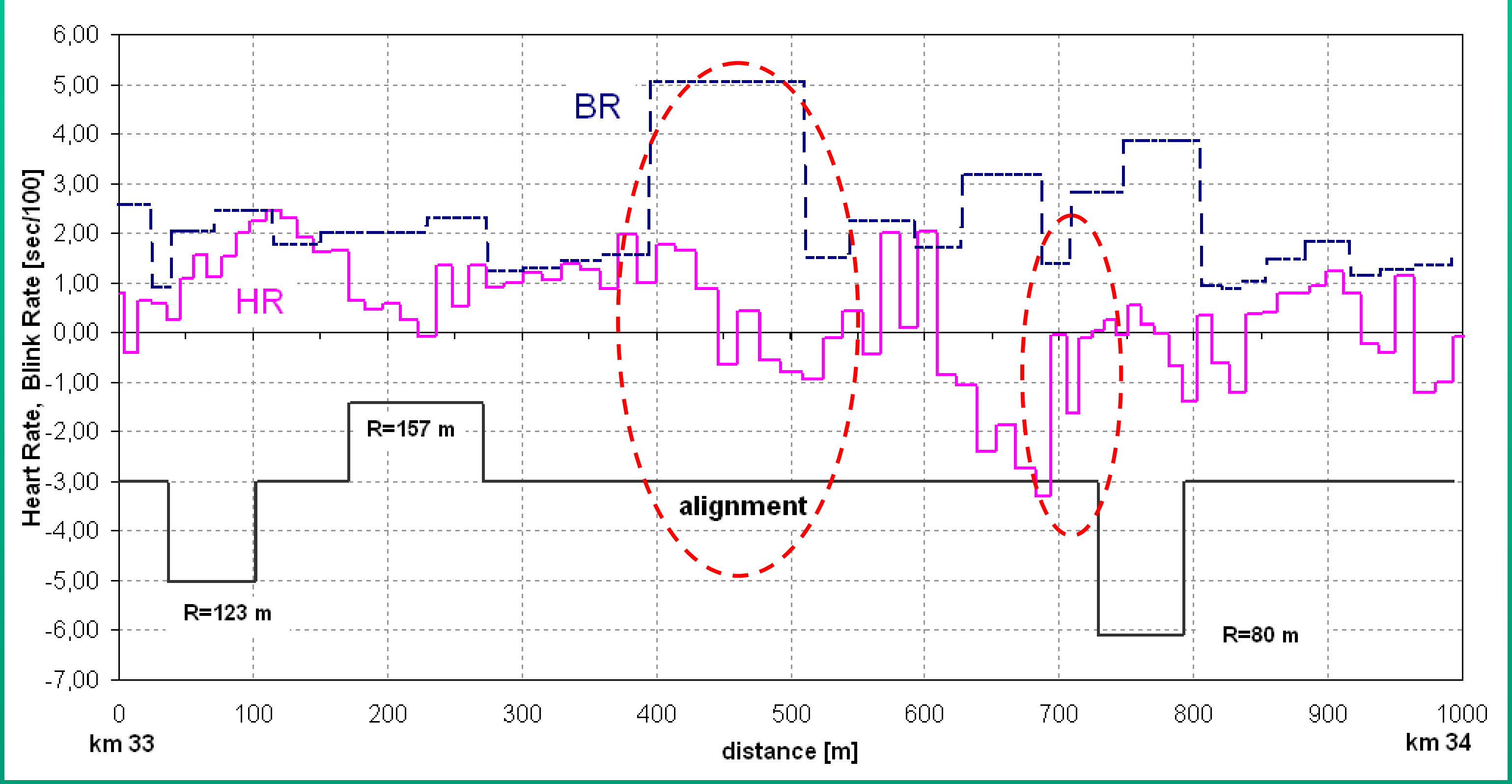
[Lamm, Cafiso, Di Graziano, La Cava - 2004]

DIVAS Experiment

Workload

Psycho - Physiologic parameters

Heart Hate, Heart Rate Variability, Blink Rate, Blink Duration, Electro Dermal Activity



CONCLUSIONS AND FUTURE WORK

Geometric inconsistency produces tense driving behaviour.

Driving behaviour and workload can be quantitatively measured by the DIVAS

Driving inconsistencies were highlighted by high speed gradients, transversal accelerations and car path curvature

The comparison of driving behavior with Safety Criteria (Lamm) highlighted that criterion II (operating speed consistency) and partially criterion I (design consistency) better describe driver expectancy with respect to horizontal alignment.

DIVAS system has permitted also the collection of psycho-physiological parameters (Human Data, HD) for the evaluation of mental workload.

(new COFIN 2004) It is foreseen that experimental results from DIVAS together with those deriving from a driver simulator will provide useful information regarding human factors and road user behavior in order to design Safer Roads.

Thank you for your Attention !