SUBJECTIVE SAFETY
BASED ON SIMULATED ROAD VIEW PERCEPTION

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ABSTRACT

The main objective of this study was to investigate driver's behaviour and the perception of road safety related to geometric design parameters. In particular, two groups of objectives are recognised. The first group deals with objective measures derived from driving simulator and connected to driving behaviour and the second group is related to subjective measures used in the questionnaire survey. Both groups of measures were compared during statistical analysis in order to find relations between road design parameters and driving behaviour connected to speed choice and risk perception.

The main focus of this study was to search for relationships between subjective and objective road safety measures. Most of subjective measures show week relation to objective measures related to driving speed. The results lead to the conclusion, that wider studies are needed in future to disclose relationships between subjective and objective measures, so important in designing safer roads.

Some additional interesting results deal with the personal driver's characteristics relation to driving behaviour. Driving experience seems to influence subjective evaluation of some road view characteristics especially in difficult driving conditions, which appear at lover category rural roads with many curves and limited visibility.

The absence of significant relations between speed at highest category roads and driver's age and experience suggests that the demand put on drivers decrease with increasing road category, and even younger and less experienced drivers may deal better at higher categories of roads. On the lover category roads only older and more experienced drivers compensate the higher demand of driving in more difficult environment.

Keywords: subjective safety; driving speed; perception; driving simulator; questionnaire survey.

INTRODUCTION

Driving simulation based approach seems to be very promising to consider once in a time all the different variables that play different roles in the road safety processes (Allen et al., 1998; Bella, 2005), which is well documented in CRISS studies results (Benedetto, A. et al., 2009). Simulation approach takes into account human factors. In this context it is recommended to generate an environment virtually and to test driver's behavior in simulators studies.

While the behavioral measures are based on drivers perception, the visual properties of the road driven are frequently tested based on questionnaire, in direct way, as subjective opinion of users. This method was employed to test the subjective opinion on the road safety, fluency, legibility, visibility and aesthetics. Those subjective measures of the observed road view were used in the former author’s studies based on the recorded video road views. Subjective safety is closely related to drivers behavior, which is well documented in the earlier studies of the author (Zakowska 2001). Another measure employed in this questionnaire was the evaluation of how natural looks the presented virtual road view.

RESEARCH OBJECTIVES

The main objective of the research presented in this paper was to investigate driver’s behaviour and the perception of road safety related to geometric design parameters and driver’s characteristics. In particular, two groups of objectives are recognised. The first group deals with objective measures derived from driving simulator and connected to driving behaviour and the second group is related to subjective measures used in the questionnaire survey. Both groups of measures were compared during statistical analysis in order to find relations between road design parameters and driving behaviour connected to speed choice and risk perception. The detailed objectives, related to driving behaviour on curves and speed choice were presented in the former work of the author (Żakowska 2009), while here the author intends:

1. to evaluate the relation between objective and subjective road safety measures,
2. to test the effect of driving experience on road safety perception,
3. to test the effects of gender on road safety related characteristics evaluation.

THE EXPERIMENT IN CRISS DRIVING SIMULATOR

A dual-approach experiment was conducted in driving simulator, to test the effectiveness of objective and subjective measures in safety evaluation of geometric road design.

CRISS Simulator environment

Driving simulations have been performed at the driving simulator system at laboratory of the Italian Interuniversity Research Centre of Road Safety, CRISS (Figure 1). The complete model has been described and validated extensively (Benedetto, C., 2002).

Fig. 1. Two views of the CRISS driving simulator

Method

Thirty one drivers were tested in laboratory conditions of the CRISS driving simulator. Each subject was driving three sections of virtual roads representing three roads categories. All scenarios were composed of twenty horizontal curves divided by straight sections, organized in random sequence. The outcomes of driving in virtual reality environment were stored in the driving simulator system (as objective measures), then validated and analyzed.

After each road segment driven subjects were filling the questionnaire, giving rates (as subjective measures) to road visible characteristics in respect to the scenario observed while driving. Those responses were analyzed statistically and also compared with the objective measures from simulator.

Dependent variables in simulation study

Driving speed was the main variable evaluated, in forms of average speed on curve, approaching speed at the section where curve with constant curvature begins and speed in the middle of curve. The other variables were dispersion of trajectory (DT) and pathologic discomfort indicator (PD), as presented in former reports (Bendetto at al., 2009; Zakowska, 2009).

Independent variables in simulation study

Curve geometric parameters, cross-section parameters of different road categories and road environment characteristics were manipulated in the experiment. The following levels of independent variables were introduced:

- Three levels of road category reflecting the design standards in Poland, namely: classes Z, G and S. These three categories are associated with the design speed, the function of the road and the cross-section geometry, as follows:
    A. **Z class** (Vd=50km/h), 2 x 2.75m, gravel shoulders, central line painted, no edge lines painted;
    B. **G class**: (Vd=70km/h) 2 x 3.25m + 2 x 1.50 paved shoulders, central and edge lines painted;
    C. **S class**: (Vd=100km/h) 2 x (2 x 3.50m + 2m paved shoulder + 0.5m inside emergency) divided with the central greenery lane of 2-3m.
- Three levels of curve radius (300m, 500m and 1000m),
- Two levels of transition curve (with and without clothoids),
- Two levels of curve visibility restriction in an effect of steep side slopes along the road at curves (good unrestricted visibility and poor, restricted visibility of inner edge of curve).

Independent variables in questionnaire study

Subjective character of road visible parameters used in a questionnaire study required adequate measures and scales of evaluation. During pilot studies and former authors research (Zakowska, 1999, 2001) the optimal measures and rating scales were elaborated for subjective safety and road readability assessment.

Road characteristics related to the moving road view observed while driving were as follows:

- Road legibility
- Road fluency
- Road visibility
- Road safety
- Road aesthetics

- Natural view of virtual road environment

All above characteristics were given a nine point rating scale, from 1 for “very poor” to 9 for “very good”, as shown in section 6.

Subjects

Thirty one participants (twenty six men and five women; mean age of 25 years old, range 21-29 years) were recruited as volunteers from the Department of Sciences of Civil Engineering at the University Roma Tre via direct contact.

All participants had a valid Italian driving licence and had, on average, been driving for 5.9 years (range 3–10 years). The participants reported having driven, on average, 13050 km in the preceding year (range 1000–25000 km). Only four subjects experienced driving an instrumented car and four subject experienced light simulation sickness symptoms like headache during the simulations.

Scenario

Three different scenarios (A, B and C types) were designed and implemented in virtual reality environment (Figure 2), representing three categories of roads, adequately to Polish standards (A for class Z and design speed 50 km/h, B for class G and design speed 70 km/h, C for class S and design speed 100 km/h). Each scenario was composed of twenty horizontal curves (R = 300, 500, 1000 meters) and twenty one straight segments. The first straight was 1000 meters long to allow the driver to reach a significant approaching speed in the first curve. The other twenty road straights were of different length: road of higher category had longer straight sections than the lower category roads (300 meters in scenario A, 400 meters in scenario B and 500 meters in scenario C). Those straight sections between two consecutive curves have the aim of preventing driver’s behavior through curve being biased by the previous geometric elements of the road.

A: scenario representing Z B: scenario representing G C: scenario representing S

Fig. 2. Examples of scenarios (A, B and C) of the three categories of roads.

Procedure

According to the strict procedure of simulation experiments (Benedetto, A. et al., 2009), participants were required to complete a familiarization training of at least 10 min drive the simulator vehicle. The experimental drive lasted 60 min in total (3 simulations) per driver. Each subject drove three scenarios. Between each scenario participants were allowed a short break. This break was intended both to diminish as much as possible the fatigue effect of each driving period and to fill in the questionnaire. Subjects were required to drive in the centre of the right lane. Subjects could see their speed on the speedometer visualized on the screen and were free to choose the velocity they prefer, according to what the road scenario suggested them.

THE QUESTIONNAIRE SURVEY

The questionnaire format and procedure

Subjects were asked to assess (in the given nine-point scale, as shown in Fig. 3) the six characteristics of the road driven, namely: legibility; fluency; visibility; safety; aesthetics; natural view.

*Please assess (in the given nine-point scale) the enlisted below characteristics of the road driven , placing mark **V** in the corresponding box:*

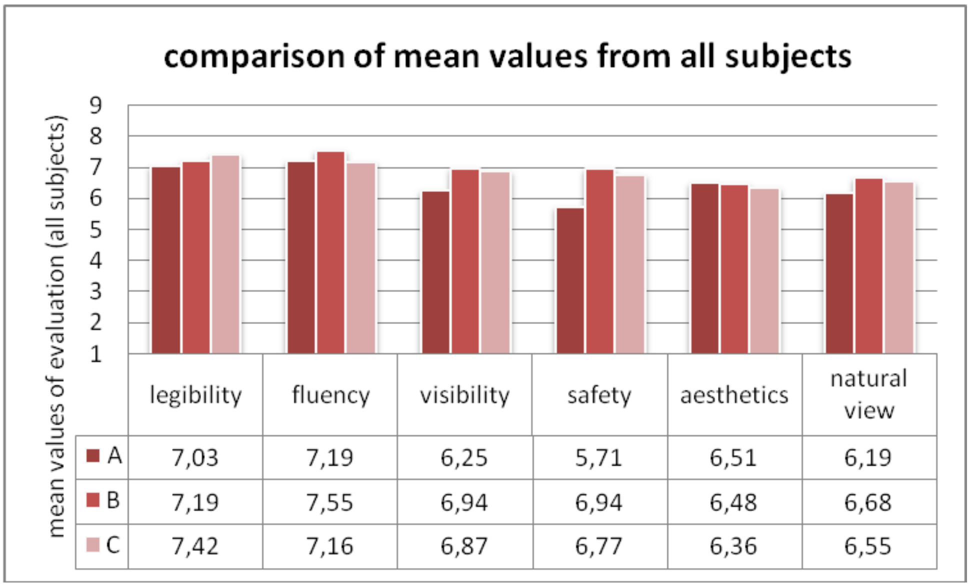
Very poor	—								+	Very good

Fig. 3. Questionnaire form used for each scenario evaluation after the simulation drive

Subjective evaluation of road characteristics

Mean values of every characteristic by all subjects evaluation were calculated for each scenario type (A, B and C), giving the general view of the rates. The comparison between all mean values are presented in Figure 4, where rate 1 represents very poor assessment and rate 9 represents the highest evaluation of subjective measures, standing for the right side rating at the questionnaire scale and meaning "very good" assessment.

Subjects tended to rank the road view characteristics relatively high, if the mean values exceed score 5. The highest ranks from all characteristics received fluency and legibility. The worst rates received subjective safety, especially at the lowest category of road (scenario type A). This suggests that road safety perception (subjective evaluation based on the road view) decreases with decrease of road lane width, and with the absence of paved shoulders and edge lines painted on rural roads.



	legibility	fluency	visibility	safety	aesthetics	natural view
A	7,03	7,19	6,25	5,71	6,51	6,19
B	7,19	7,55	6,94	6,94	6,48	6,68
C	7,42	7,16	6,87	6,77	6,36	6,55

Fig. 4. Mean values of subjective assessments for scenarios A, B and C

Subjective safety relations to other road characteristics are shown in Fig.5. All presented relations are statistically signifficant. Safety assessment is best correlated with visibility and fluency in cases of scenatios B and C. Legibility/readibility correlation with safety increases with increasing road category.

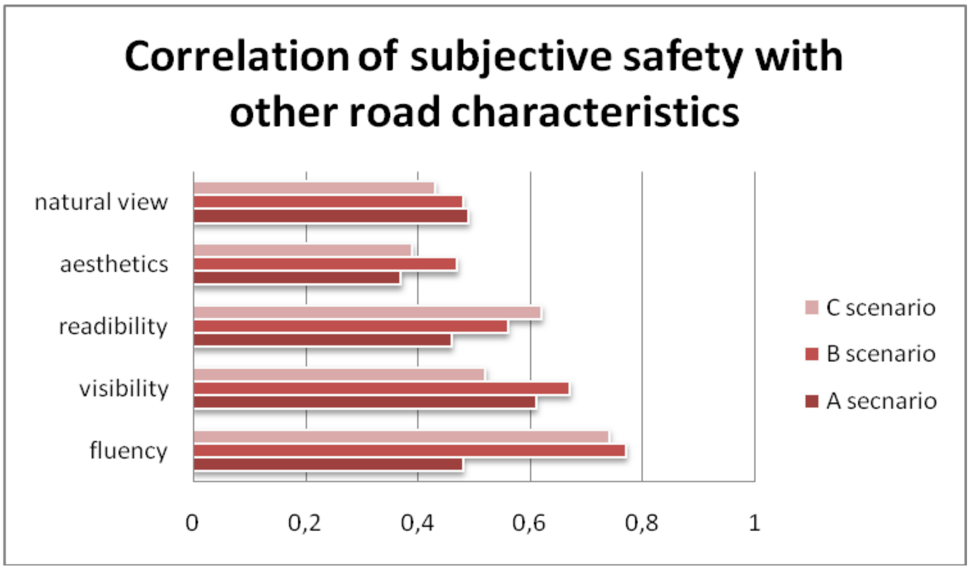


Fig. 5. Satistically significant corelations between subjective safety and other subjectively assessed road characteristics

SUBJECTIVE AND OBJECTIVE MEASURES

Driving speed relation to subjective evaluation of road view characteristics

The average driving speed was calculated for each driver at each scenario, and then compared with the subjective evaluation of road characteristics in scenarios A, B and C, respectively.

No statistically significant relations was observed in case of scenarios A and B. At scenario C, representing the higher category roads, statistically significant relation was revealed between experimental driving speed and subjective aesthetics evaluation (-0,3759 with p=0,037). With mean driving speed decrease the increase of aesthetics appreciation of the road was observed. The slower they drove, the higher aesthetical ranks they gave. The more they liked the road view, the slower they drove. This relation was significant only at scenarios C.

Subjective road view characteristics assessment in relation to other parameters of driving behaviour during experiment

Looking for relations between subjective and objective measures used in the experiment, the correlation of subjective characteristics assessments with driving related parameters from the simulation output was calculated. Among many variables, only few (7 out of 78) were statistically significant, as shown in table 1.

At scenario A (the lover category roads) two relations between drivers behavior and their subjective evaluation of road view characteristics were statistically significant, namely: lateral acceleration showed significant relation with road visibility (0,5066; p = 0,004) and dispersion from driving trajectory (keeping lane position parameter) while driving at A roads were related to evaluation of natural view of the scenario (-,3733; p=0,039). The acceleration force increased with the road visibility increase. With increasing visibility drivers were driving more dynamically. The negative relation presents evaluation of how natural is road view of scenario A with keeping lane position while driving. The more natural road view appeared, the smaller dispersion from the driving trajectory was observed. The other relations between subjectively evaluated characteristics of scenarios A and driving reactions were not statistically significant.

Table 1 Statistically significant results of correlation analysis between subjective and objective measures

	legibility	**fluency**	**visibility**	**safety**	**aesthetics**	**natural view**
Scenario A_ lateral acceleration	r= ,26	r=,35	r=,51	r=,31	r= -,02	r=,07
	p=,167	p=,056	p=,004	p=,095	p=,909	p=,726
Scenario A_ dispersion from driving trajectory	r= -,02	r= -,17	r= -,08	r=,01	r= -,31	r= -,37
	p=,897	p=,363	p=,681	p=,987	p=,087	p=,039
Scenario B_ braking pedal force	r= -,46	r= -,09	r= -,08	r= -,13	r=,07	r= -,16
	p=,009	p=,634	p=,656	p=,488	p=,704	p=,377
Scenario C_ vehicle heading angle	r=,24	r=,30	r=,38	r=,27	r=,25	r=,09
	p=,185	p=,097	p=,034	p=,144	p=,175	p=,640
Scenario C_ braking reactions	r= -,11	r= -,04	r= -,23	r= -,05	r= -,48	r= -,28
	p=,549	p=,844	p=,224	p=,799	p=,007	p=,123
Scenario C_ braking forces	r=,00	r= -,03	r=,10	r= -,24	r= -,20	r= -,44
	p=,989	p=,885	p=,584	p=,196	p=,281	p=,014

At B scenario, statistically significant relation was disclosed between braking pedal force and subjective evaluation of legibility (-0,4637; p=0,009). With the decrease of subjective legibility of the road, the force of braking pedal increased. The other relations at B scenario were not significant.

At scenario C (representing the highest road categories) subjective evaluation of visibility, aesthetics and natural view of simulated environment received statistically significant relations with driving time, speed, parameters related to lane keeping and braking reactions. Visibility evaluation was correlated with vehicle heading angle (0,3815; p=0,034). The more visible road appeared to drivers, the wider clear angle they kept from the heading vehicles.

Statistically significant relation was observed between appreciation of natural view of road simulation and the braking forces (-0,4367; p=0,014), where braking force increase with the decrease of natural view evaluation. This relation suggest that increasing the quality of simulated road view may effect in limiting rapid braking behavior of subjects driving in laboratory conditions if driving simulator. The poor quality, non-natural view of simulated road environment may cause unwilling extreme behavior related to exceeding braking force use. Good virtual view which looks like natural road view provoke driving behavior of subjects participated in simulation based experiments to be closer to driving behavior on the real road. It is desirable to put an effort to make the virtual road view of future lab experiments as realistic a possible, to receive driving behavioral parameters comparable with on-site behavior.

Statistically significant relation was observed between road aesthetics evaluation and speed related parameters, namely driving speed (-0,3773; p=0,036), braking reactions (-0,4771; p=0,007) and driving time (0,3826; p=0,034) at scenario C. With the increase of driving speed and braking reactions the evaluation of aesthetics decreased, while the increase of driving time was correlated positively with road aesthetics evaluation.

DRIVING EXPERIENCE IN RELATION TO ROAD SAFETY AND ROAD CHARACTERISTICS PERCEPTION

Looking for relations between subjects personal data and their subjective evaluation of road characteristics, correlation analysis were performed in each group of subjects. The statistically significant results (p<0,05) are presented in Table 2.

Table 2 Statistically significant results of correlation analysis between subjective measures of roads and driver's experience

	Correlation coefficient r for driving experience and road characteristics (N=31), p < 0,05			
	Annual millage driven (km)	**Driving experience (number of years)**	**Age of driver**	**Driving licence (In years)**
Visibility - scenario A	r = 0,40	r = -0,07	r = -0,10	r = -0,03
	p=,026	p=,730	p=,607	p=,876
Safety - scenario A	r = 0,49	r = -0,17	r = -0,24	r = -0,09
	p=,005	p=,353	p=,193	p=,618
Fluency - scenario B	r = 0,47	r = -0,04	r = -0,05	r = 0,00
	p=,008	p=,832	p=,802	p=,987
Visibility - scenario B	r = 0,38	r = -0,03	r = 0,00	r = -0,01
	p=,037	p=,884	p=,995	p=,958
Mean spead - scenario A	r = -0,03	r = -0,35	r = -0,45	r = -0,38
	p=,879	p=,056	p=,011	p=,035
Mean spead - scenario B	r = 0,11	r = -0,27	r = -0,40	r = -0,25
	p=,571	p=,137	p=,027	p=,182

Annual millage driven occurred to be a variable statistically significantly correlated with safety evaluation of lover categories roads, represented by scenario A. The more kilometers per year subjects driven, the higher level of safety they reported (0,4883; p=0,005). Also visibility of road in both scenarios a and B were positively correlated with the annual millage driven by subjects. Road visibility assessment increased with the increase of number of kilometers driven annually, and this correlation was stronger for scenario A (0,4000; p=0,026) than for scenario B (0,3770; p=0,037), so it decreased with increasing road category. Fluency evaluation at scenario B was significantly correlated with annual millage driven (0,4682; p=0,008), showing higher assessment of road fluency by subjects more experienced in driving. No statistically significant relation between road characteristics (road safety, visibility and all other) evaluation and annual millage driven was observed at scenario C.

Statistically significant relation was revealed between driver's age and average speed at lower categories roads (scenarios A and B). Driving speed decreased with an increase of drivers age, and this relation was stronger in case of lover road category (-0,4494 with p=0,011 for A; -0,3968 with p=0,027 for B scenario).
The number of years of driving license possession were statistically significantly correlated with average speed at scenario A, where driving speed decreased with the increase of period of driving license possession (-,3807 with p=0,035). The other relations between drivers age or experience and driving average speed were not statistically significant.

THE EFFECT OF GENDER ON ROAD CHARACTERISTICS PERCEPTION

Student T Test was performed to disclose differences between gender groups and evaluation of road characteristics. The reason of such an analysis was an uneven number of subjects in both gender groups, where in group of 31 subjects only fife were female and 26 male.
Statistically significant differences (Table 3) between men and women were observed in relation to subjective evaluation of aesthetical values of scenarios B, where women gave higher ranks to road aesthetics than men did.
Statistically significant differences between men and women were revealed in case of appreciation the A scenario virtual road view as looking natural (p=0,02), while at scenario C this difference were less significant (p=0,07) and not significant at scenario B (p=0,12). In all above cases women evaluated natural-like view higher than men did.
The other differences between gender groups assessments were not statistically significant.

Table 3 Between gender differences in subjective assessment of road characteristics and average driving speed during experiment in driving simulator

	mean Male rank	mean Female rank	t (df=29)	p	Nr of Man	Nr of Female	Std deviation Male	Std deviation Female
SCENARIO A								
legibilityA	6,96	7,40	-0,83	0,41	26	5	1,15	0,55
fluencyA	**7,04**	**8,00**	**-1,91**	**0,07**	**26**	**5**	**1,08**	**0,71**
visibilityA	6,15	6,80	-0,99	0,33	26	5	1,41	0,84
safetyA	5,65	6,00	-0,34	0,73	26	5	2,00	2,45
aestheticsA	6,31	7,60	-1,69	0,10	26	5	1,57	1,52
***natural view* A**	**5,89**	**7,80**	**-2,50**	**0,02**	**26**	**5**	**1,63**	**1,10**
SCENARIO B								
legibilityB	7,19	7,60	-0,63	0,53	26	5	1,39	0,89
fluencyB	7,46	8,00	-0,89	0,38	26	5	1,30	0,71
visibilityB	6,92	7,00	-0,11	0,91	26	5	1,55	0,71
safetyB	6,73	8,00	-1,57	0,13	26	5	1,76	0,71
aesthetics B	**6,23**	**7,80**	**-2,28**	**0,03**	**26**	**5**	**1,48**	**0,84**

	mean Male rank	mean Female rank	t (df=29)	p	Nr of Man	Nr of Female	Std deviation Male	Std deviation Female
natural view B	6,46	7,80	-1,62	0,12	26	5	1,79	0,84
SCENARIO C								
legibilityC	7,39	7,60	-0,38	0,71	26	5	1,17	1,14
fluencyC	7,08	7,60	-0,76	0,45	26	5	1,44	1,14
visibilityC	6,89	6,80	0,12	0,90	26	5	1,45	1,10
safetyC	6,77	6,80	-0,04	0,97	26	5	1,45	2,59
aestheticsC	6,19	7,20	-1,50	0,14	26	5	1,33	1,64
natural view C	**6,31**	**7,80**	**-1,88**	**0,07**	**26**	**5**	**1,67**	**1,30**

THE EFFECT OF GENDER ON DRIVING SPEED

In Table 4 the T Student test results are presented, where mean Speed AT each Road category is calculated for both gender groups, Male and female. No statistically significant results were received. Mean speeds driver by men and by women are not significantly different AT All tested scenarios A, B and C representing three different road categories. This means that gender has not occurred to influence the speed choice during this experiment.

Table 4. Between gender differences in driving speed at three road categories

	mean Male rank	mean Female rank	t (df=29)	p	Nr of Man	Nr of Female	Std deviation Male	Std deviation Female
Mean Speed scenario A	26,13	26,34	-0,10	0,92	26	5	4,34	2,60
Mean Speed scenario B	27,69	28,89	-0,63	0,53	26	5	3,82	4,41
Mean Speed scenario C	31,76	30,01	0,97	0,34	26	5	3,82	3,03

This analysis suggests that gender is not a significant factor in subject’s choice of driving speed and in subjective assessment of such a road characteristics as road safety, legibility, fluency or visibility.

CONCLUSIONS

The qualitative, subjective measures, as used in the questionnaire-based experiments, may be helpful in evaluation of those road parameters which have subjective nature. Subjective road safety is an important factor determining safe driving behavior. There are also another road view characteristics which are difficult to describe in objective, quantitative way, for which subjective measures gave better evaluation results.

Two different research approaches were used to test the effect of road design parameters on driver's perception of the road characteristics and road safety. Actual driver's behaviour while driving in driving simulator environment let the author to obtain objective, quantitative measures. The questionnaire test filled by drivers right after each scenario drive, gave subjective, qualitative measures of road visual characteristics.

The qualitative, subjective measures, as used in the questionnaire-based part of this experiment, are helpful in evaluation of those road parameters, which have subjective nature. Subjective road safety is an important factor determining safe driving behavior. Road readability, road fluency and road visibility are another road view characteristics, which are difficult to describe in objective, quantitative way, so the subjective measures gave better evaluation results. Finally, road aesthetics is of subjective nature and therefore subjective measures and qualitative methods are most appropriate for road aesthetical values evaluation.

Finally, the most challenging part of this study was to search for relationships between subjective and objective measures. Most of the subjective measures showed week relation to the objective measures related to driving speed. Driving speed and subjective aesthetics relation was significant only at the highest category roads. With mean driving speed decrease the increase of aesthetics appreciation of the road was observed. Subjective measure of road legibility and visibility showed significant, but not very strong correlations with lover classes roads driving related parameters. This results lead to the conclusion, that wider studies are needed in future to disclose relationships between subjective and objective measures, so important in designing safer roads.

Driving experience seems to influence subjective evaluation of some road view characteristics especially in difficult driving conditions, which appear at lover category rural roads with many curves and limited visibility. Interestingly, no statistically significant relation was observed between annual mileage driven by subjects and average speed performed during experimental drives.
The absence of significant relations between speed at scenario C representing the highest category roads and driver's age and experience suggests that the demand put on drivers decrease with increasing road category, and even younger and less experienced drivers may deal better at higher categories of roads. On the lover category roads only older and more experienced drivers compensate the higher demand of driving in more difficult environment.

The general conclusion of this study results is that advanced techniques of visualization and simulation of road environment can disclose some relationships between design road parameters and behavioral aspects important to creating safer transportation systems. The qualitative studies based on subjective driver's opinion should support the quantitative studies especially in the area of aesthetical values, where subjective nature is dominant.

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