Driving simulation based approach for quality control of road projects

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Abstract

A quality control of the road project is actually significant when it analyses the functional characters in relation to the different road traffic conditions. The most advanced techniques of simulation applied in Virtual Reality allows analysing for a suitable drivers' tester either the driving conditions and the behaviours driven by the different geometric features of the road, the traffic severity, the environment and the interferences. The indexes traditionally suggested by the literature are involved in the simulation in order to quantify the planimetric development of a road-line by using an only parameter. They take indeed into consideration some significant changes of the axis geometry, but they are not suitable for expressing a judgment about the quality of the service's proposal as they do not imply the driver's adaptation to the different road traffic conditions. The experimentation in virtual reality allows, instead, analysing fully the driver's behaviour.

Keywords – road safety; simulation, driving simulator, CCRs, Quality of Service, Quality control of projects

1. Introduction

A quality control of the road project is actually significant when it analyses the functional characters in relation to the different road traffic conditions. It is not, therefore, possible to express a reliable judgment based only on the correspondence between the axis geometry and determined design standards, above all when these ones are considered only in relation to the dynamic and to the kinetics of the single vehicle [7].

In this sense, a reliable appraisal of the systemic property of the infrastructure cannot be determined through the plain checking of the standards, but through the most advanced techniques of simulation applied in Virtual Reality [1], which allow to analyse for a suitable drivers' tester either the driving conditions and the behaviours driven by the different geometric features of the road bed [3], the traffic severity, the environment and the interferences.

The most recent literature provides some significant hints as to the cause/effect relationships between the design of each road element and its functional efficiency. The systemic check of the global project is indeed a sector little explored yet because of the difficulty of selecting such concise property indicators that could express a reliable judgment in regard. The problem regards especially the intervention of road conditions' suitability as, in this case, the geometric "correction" of some elements of the line cannot recover a suitable safety level for the road conditions [8]. The reclamation of the local anomalies carried out without considering the effects on the users' behaviour can involve further functional singularities which convey some dangerous situations like the ones locally reclaimed at the beginning and at the end of the line [5].

As a consequence this study is meant to demonstrate experimentally the importance of some gauges in a simulated environment in order to esteem the property of the whole line. To that end the indexes suggested by the literature such as the *CCR*, *CCRs* … [4; 6] are involved in the simulation in order to quantify the planimetric development of a road-line by using an only parameter. They take indeed into consideration some significant changes of the axis geometry, but they are not suitable for expressing a judgment about the quality of the service's offer/proposal as they do not imply the driver's adaptation to the different road traffic conditions.

The experimentation in virtual reality allows, instead, to analyse fully the driver's behaviour. In this way the judgment is expressed through an intelligible system of measurements describing the interpretative difficulties of the manoeuvres which are to be done, the possibility of correctly carrying them out as well as the consequences coming from the driver's weariness [2]. Anyway, in the light of the fact that only the equipped research centres can deal with such an experimentation, the main aim of this study will be to correlate the experimental outputs with the literature's gauges in order to allow the researcher to state a broader interpretation about the valuation of the systemic quality of the road infrastructure.

The results of this work have been yet submitted at the First STISIM Drive Users Group Meeting, at Cranfield University, UK, in September 2003.

2. Experimental survey

Different proof settings have been set and 30 drivers previously trained for adapting their driving behaviour in a simulated environment have been selected in order to form a homogeneous group. Before starting the test, the factual representativeness of the simulation has been checked (fig. 2), either by verifying for each driver the homogeneity of the trajectories described nearby the axis, and by confronting the graph of the theoretical speeds with the one experimentally surveyed.

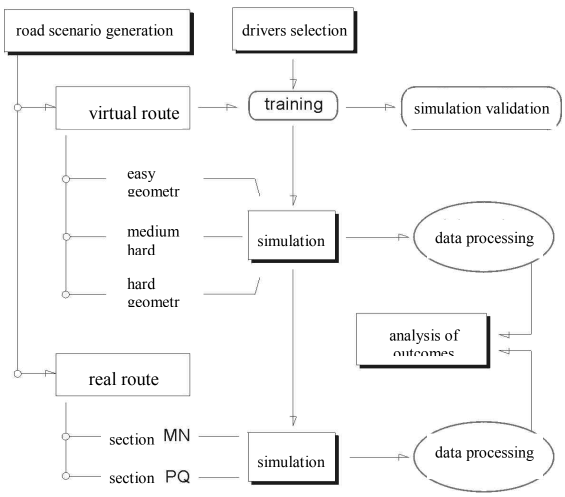


Fig. 1 – Experimental procedure

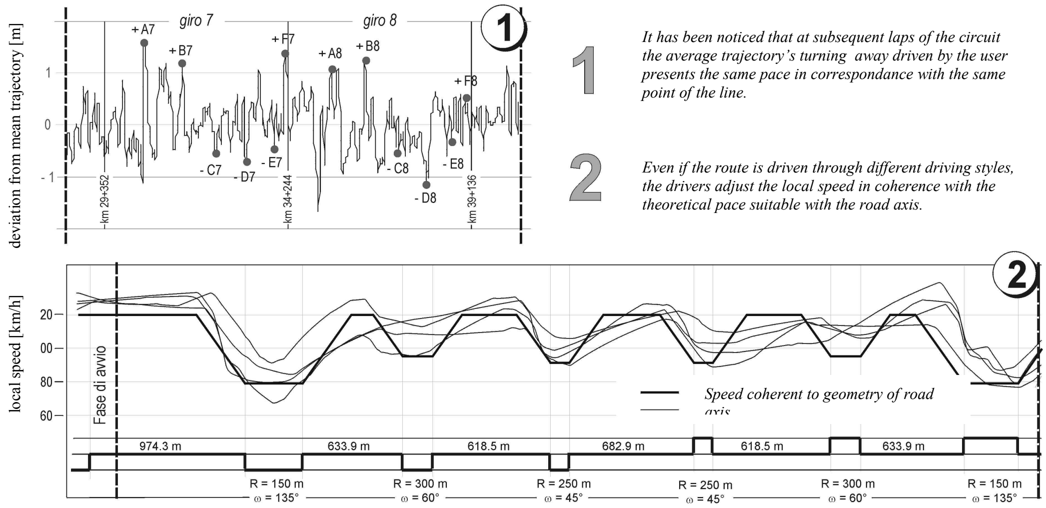
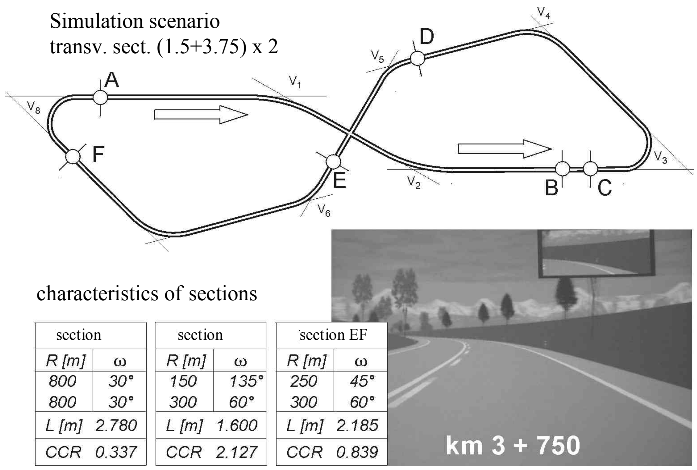


Fig. 2 – Significance check of the scenarios

2.1 Geometry of the road scenario

The geometry of the simulated scenario is described in figure 3. All the variables that are suitable to describe the cinematic of the trajectory covered at low traffic conditions by each driver (250 vehicles/h in both direction) have been surveyed for each spatial step of 5 meters (about 0.5 seconds in the time domain). In particular, the local values of the longitudinal speed, of the position of the vehicle compared to the axis line, of the trajectory's curvature and of the acceleration components have been appraised for each section. Then the numeric data have been graphically plotted to allow the researcher to make a prompt comparison among them and to be able to survey different developments that are yet characterized for the mean term by the same variables.



section		section		section EF	
R [m]	ω	R [m]	ω	R [m]	ω
800	30°	150	135°	250	45°
800	30°	300	60°	300	60°
L [m]	2.780	L [m]	1.600	L [m]	2.185
CCR	0.337	CCR	2.127	CCR	0.839

Fig. 3 – Geometry of the road scenario

Because of the very different geometries the route has been divided into three sections, from the easier to the most difficult. The data surveyed during the test have been analysed for each of them with a view of identifying the ones which, by their own or together, could better correlate to the different geometries of the lines. It is worth pointing out that these geometries greatly affected the distribution of the average speed hold by the single user. This appraisal is absolutely coherent in keeping with different authors' criterion according to which the best line is characterized by a homogeneity of the axis geometries which let the driver drive at a steady speed at low traffic conditions. So a gauge expressing the property of the service's offer (*QS*) has been thought to integrate the difference between the driver's local speeds and the average speed hold on the line either in absolute value and for unity of development. More clearly, with regard to figure 4, expressing the speed (*V*) in km/h and *L* in m it results:

$$QS = \frac{1000 \cdot L}{\sum_{n=p_1}^{p_m} |A_n|} \quad (1)$$

Anyway, before starting the calculation the researcher has to filter all the outputs in order to reduce noise and to get the main amble of the speed diagram. So, by averaging the local values with rising metric breaks, the best reached result relates to a step of 50 m. This value allows to reach, in fact, a clear graph that represents the speeds' macro steps. Moreover it is not affected by those micro variations (noise) whose frequencies are able to influence the gauge's value.

The correlation between the average of *QS*, resulting from the experiment and the *CCRs* (Curvature Change Rate), computed in rad/km, allows to realize a coherence of the steps' numerical values which confirms the *CCRs*'s fitness of expressing the complexity of the road's geometric characters (figure 5). It is useful to remember here that *CCRs* is numerically expressed as it follows [4; 6]:

$$CCRs = \frac{\left(\frac{L_{C11}}{2R} + \frac{L_{CR}}{R} + \frac{L_{C12}}{2R} \right)}{L} 63.700 \quad (2)$$

where L_{C11} and L_{C12} are the lengths of clothoids (preceding and succeeding the circular curve) [m], L_{CR} is the length of the circular curve [m], R is the radius of circular curve [m], the coefficient 63.700 = $200/\pi\ 10^3$ and L = $L_{C11}+L_{C12}+L_{CR}$ [km].

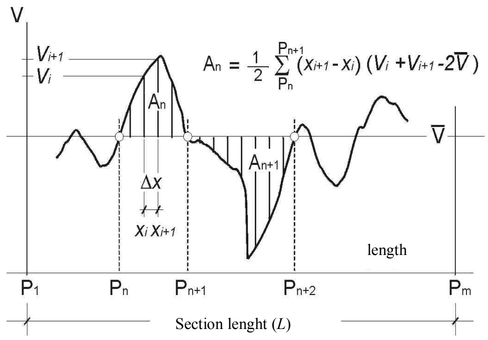


Fig. 4 – Quality of the Service *QS*

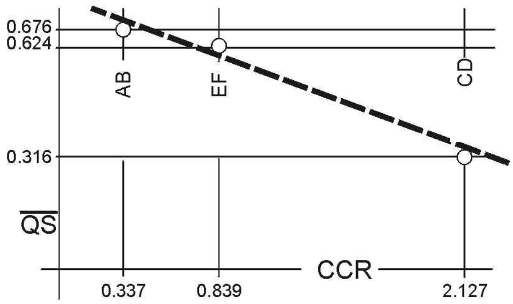


Fig. 5 – Expected value of Quality of the Service (*QS*) versus *CCR*

Anyway, because of its own nature, it is not to be considered suitable to explain the systemic property of the infrastructure as it distinguishes the lines only by their geometry without taking into consideration the effects this one determines on the driving behaviour.

With regard to this aspect the experimentation has confirmed, instead, that when the *CCRs* increases, both the vehicle's average speed and the speed of the 85th percentile decrease so that they allow the driver to compensate the difficulty of the line with a lower driving speed.

It is, therefore, impossible not to take into consideration all that when we define the systemic property of the infrastructure as the psychophysical stress as a whole to which the user undergoes when he scours a road lane at a free speed. The stress he meets depends either on the road geometry and on his skills of adaptation to the driving conditions suggested by the first aspect.

Starting from these considerations we have checked the probability of characterizing the lines by a parameter expressing the Class of Stress (*CS*) that would have taken into consideration, besides the geometry, the driving conditions the user adopts at a low traffic density. As the stress is a direct consequence of the weariness caused by the transversal accelerations this parameter has been adopted in the place of *CCRs* as the product of the transversal acceleration [m/s^2] per its application time related *t* the whole time of the distance covered in hours,

$$CS = \frac{\left|\sum_i a_{ti} t_i\right|}{T} = 3.6 \frac{\langle V \rangle}{L} \sum_i \langle V_i \rangle \omega_i \qquad (3)$$

with L = length of the line [m]; ω = angular deflections expressed in radians; V= the average speed of the whole distance covered [km/h]; V_i = the average speed of each bend [km/h].

A particularly expressive representation (figure 6) has come out by confronting the gauge of the service's property (*QS*) with the respective class of stress and after carrying out the experimentation and disaggregating the outputs, according to the lines' characteristic. It allows to notice that the experimental data are distributed into three clearly distinct areas where their dispersion is particularly expressive even if influenced by the driver's own behaviours.

Both the gauges are function of the operating speed that differently influences them according to whether it expresses the user's step along the axis geometry ($QS=f(V)$), or rather it quantifies the stress and so determines the value of the transversal accelerations ($CS=f(V^2)$). According to an 'easy' geometry (*CCRs* = 0.337) to a low class of difficulty corresponds a wide variability of the local speeds by the average speed of each user whose behaviour is greatly conditioned when the line presents an higher class of difficulty (*CCRs* = 2.127).

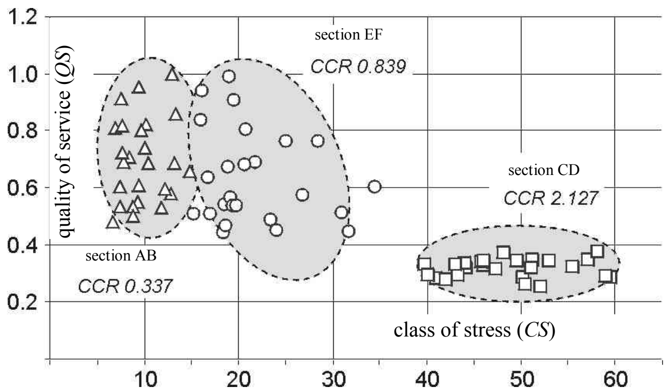


Fig. 6 –Quality of the Service (*QS*) versus Class of Stress (*CS*)

2.2 A case study

In order to validate the measures taken on the base line and, above all, to extend the experimentation to a wider casuistry, the relation between the Homogeneity Index (*CCRs*) and the Class of Stress has been checked for a road line that has been realized of late. To that end a scenario representing the geometries and the environment of a work with clear planoaltimetrical anomalies and an axis geometry greatly binding for the road exercise has been realized in virtual reality and at the same time the lines MN and PQ, that present clear functional differences, have been separately considered.

After carrying out the experimentation and processing the data previously described, in this case also two different situations, which confirm the close relation between the Class of Difficulty and the gauge of the Quality of the Service have been surveyed. All that shows that, besides attesting the importance of the correlation, the data is not linked to the specificity of a particular road line.

The base scenario has been set, in fact, with a plain course by adopting fit lines of transition (clothoids), while the real lane does not show transitional bends even if it is characterized by a complex altimetry.

So the next step has analysed the relationship between *CS* and *QS* by taking into consideration as a whole the results of the experimentation for each analysed elementary line (three of the base line and two of the real line).

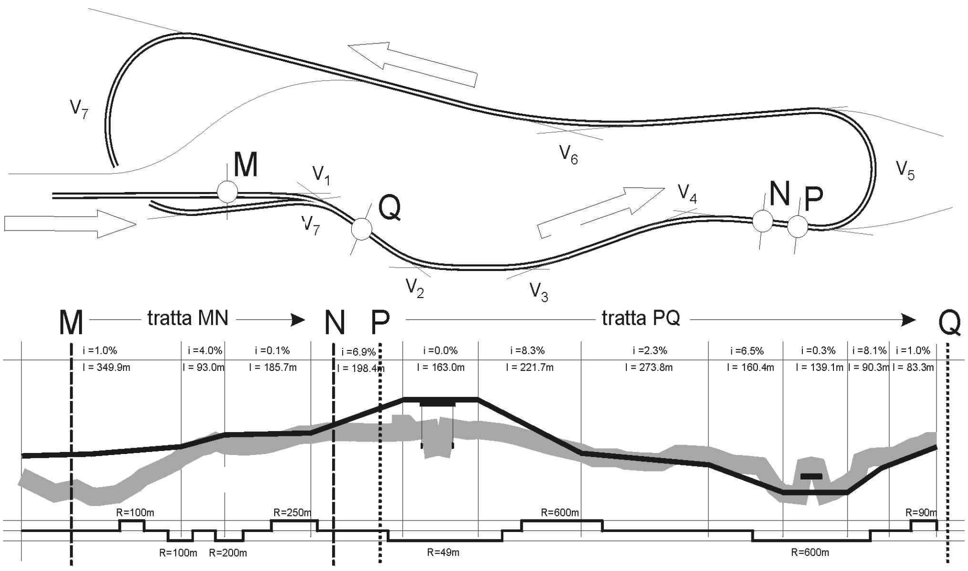
The result of the formulation is shown in figure 9 and it is worth pointing out how the trend line:

$$QS = 1.77\ CS^{-0.4} \tag{4}$$

shows with regard to very different planoaltimetrical situations a relatively high value of R^2 (=0.71) notwithstanding the variability of the single behaviour (see table 1). *CS* and *QS* must be taken as the average of the measured values in order to define the line. In the specific case if we get the third one with regard to the average values it results (see table 2):

$$QS = 2\ CS^{-0.43} \tag{4'}$$

which attests the reliability of correlation (R^2 = 0.89) and involves an acceptable average mistake.

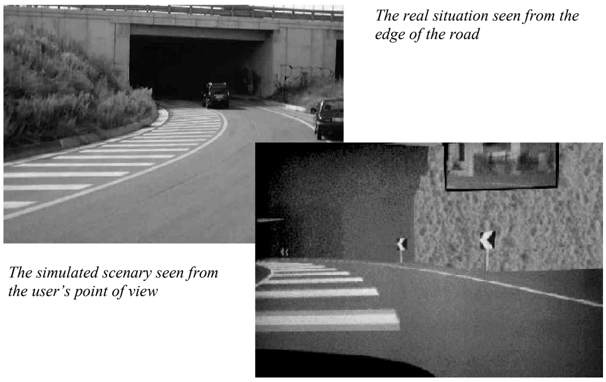


Simulation of the case study

sez. 0.50+3.50+3.50+1.50

section MN				
R [m]	*100*	*100*	*200*	*250*
ω	*33.7°*	*33.7°*	*19.0°*	*25.4°*
L = 492 m		*CCR = 3,965*		

section PQ				
R [m]	*50*	*600*	*75*	*90*
ω	*212.0°*	*18.5°*	*218.2°*	*39.3°*
L = 1.063 m		*CCR = 8,012*		



The real situation seen from the edge of the road

The simulated scenary seen from the user's point of view

Fig. 7 – The geometry of case study and the simulation scenario

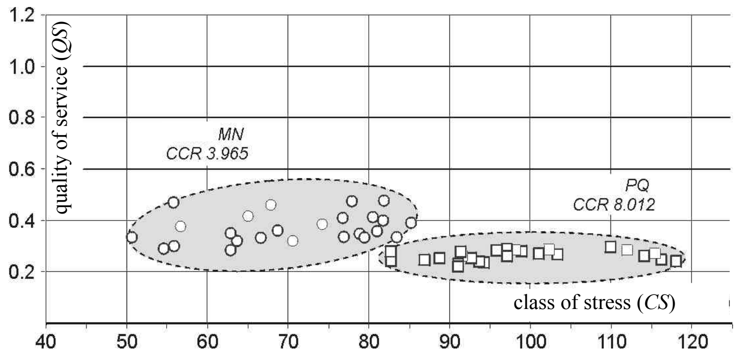


Fig. 8 – The case study: Quality of the Service (*QS*) versus Class of Stress (*CS*)

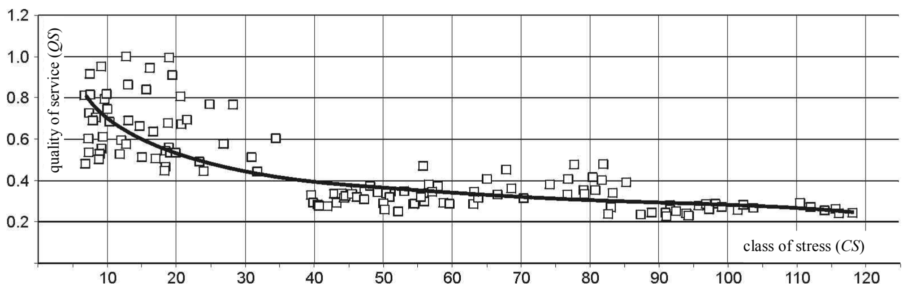


Fig. 9 – Quality of the Service *QS* versus Class of Stress *CS* (total measurements)

Tab. 1 – Comparison *QS* observed and computed (using equation 4)

CCR computed	$\langle CS \rangle$ observed	$\langle QS \rangle_m$ observed	$\langle QS \rangle_c$ computed	$\langle QS \rangle_m - \langle QS \rangle_c$	Δ %
0.337	9.785	0.695	0.750	0.055	7.9
0.839	21.597	0.636	0.534	-0.102	-16.1
2.127	48.661	0.319	0.376	0.057	18.0
3.965	70.339	0.362	0.321	-0.041	-11.3
8.012	98.982	0.269	0.277	0.008	3.1
				$\langle \Delta \rangle$%	11.3

Tab. 2 – Comparison *QS* observed and computed (using equation 4')

CCR computed	$\langle CS \rangle$ computed (5)	$\langle QS \rangle_c$ computed (4')	$\langle QS \rangle_m$ observed	$\langle QS \rangle_c - \langle QS \rangle_m$	Δ %
0.337	10.905	0.716	0.695	0.021	3.0
0.839	21.582	0.534	0.636	-0.102	-16.1
2.127	45.812	0.386	0.319	0.067	21.1
3.965	72.499	0.317	0.362	-0.045	-12.4
8.012	98.560	0.278	0.269	0.009	3.3
				$\langle \Delta \rangle$%	11.2

3. Determination of the gauge's systemic property

The result of the experimentation confirms the possibility of expressing a quality control of the road project by analysing the users' behaviours in virtual reality. This technique is extremely versatile and if a suitable gauge, describing by greater evidence the surveyed case from time to time is chosen, it can be suitable for the different specificities. The limits of the application are to be imputed only to the unavailability of suitable tools for the systemic check of the projects whose technical property, as previously shown, cannot be apart from the consideration about the users' behaviours in different traffic conditions.

The complexity of the psycho-physiological spurs, which the driver undergoes during his driving, influences the speed of the distance covered. In experimentation this conditioning is clear either as a performance of the *CCRs* and as a consequence of the Class of Stress. Then it has been supposed that, according to the Curvature Change Rate, a direct link between *CCRs* and *CS* could be possible with a view of esteeming the Class of Stress and, consequently, the quality of the service. After checking the relation resulting from the experimentation, the following expression comes out:

$$CS = - 1.373\ CCRs^{2} + 22{,}884\ CCRs + 3{,}349 \qquad (4)$$

that gives the values almost coincident with the ones which have already been measured. (the average mistake: 4,2%).

The positive result of the test allows to propose a simplified methodology which is able to define by approximation the gauge of the Service's Quality and is only based on the line's planimetric characterization. So it is apart from an expensive experimental process that can be realized only if a suitable driving simulator is available.

This practice, that is articulated according to the logic scheme of figure 10 and applied to the five lines considered here, leads to important results.

The average mistake, that has been surveyed between the *QS* resulting from the experimentation and the one calculated according to the model, is a bit higher than 10%. So the *QS* calculated according to the model effectively expresses a judgment on the project's property.

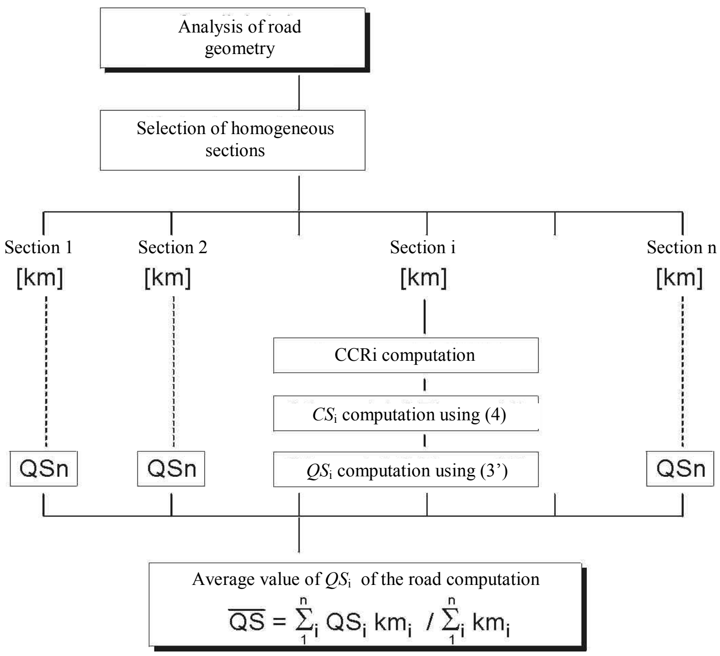


Fig. 10 – Procedure for computing the Quality of the Service *QS*

4. Conclusion

The here tested methodology for a quality control of the road project allows to consider properly the driver's behaviour. In this way a quality judgment is expressed through an intelligible system of measurements describing the interpretative difficulties of the manoeuvres which are to be done, the possibility of correctly carrying them out as well as the consequences coming from the driver's weariness. Moreover the methodology, starting from traditional indexes based only on geometry of the road (*CCRs*) and correlating them with new ones (*QS* and *CS*), allows the researcher to state a broader interpretation about the valuation of the systemic quality of the road infrastructure.

Acknowledgment

Special thanks to Dr. Chiara Gualtieri who assisted the development of software and simulations, and to Mr. Spartaco Cera who helped the laboratory activities.

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