THE QUALITY OF SERVICE IN TERMS OF ROAD SERVICEABILITY AS A FUNDAMENTAL PARAMETER FOR TAKING TECHNICAL, ECONOMICAL AND STRATEGIC CHOICES THAT CONCERN ROAD NETWORK INFRASTRUCTURES.

PASQUALE COLONNA, SIMONA D'AMOJA, MANUELA MAIZZA, VITTORIO RANIERI
Dept. of Highways and Transportation - Polytechnic University of Bari, Italy
v. Re David, 200 – 70125 Bari, Italy
Phone: +39.080.596.3388/389/413, Fax: +39.080.596.3329
E-mail: colonna@poliba.it, s.damoja@poliba.it, m.maizza@poliba.it, v.ranieri@poliba.it

ABSTRACT

Road serviceability represents a fundamental requirements in order to satisfy the different needs of modern society.
This research project presented in this paper has aimed at providing out-of-town roads with synthetic indexes, starting from those parameters that represent the characteristics of the road system service offered by the infrastructure. First of all, these parameters can be gathered together in sectors concerning safety, comfort, distance covering time, services, environment and traffic conditions. Their importance varies according to the point of view from which they are considered: the user's, the owner's (who could also be the manager) and infrastructures crossed countries inhabitants.
The first ones make a continual comparison between service quality felt and service quality demanded (desired). The result of this comparison is a judge of better or worse satisfaction through an equilibrium subjective process where the evaluation main parameters are safety, equal costs accessibility and comfortness.
The other subjects involved make an evaluation too, but they make a social and interactive equilibrium process whose aim is verifying disadvantage people, for the presence of road facility, absence.
The aim of this research is, therefore, that of defining an algorithm that, starting from specific findings on the road, determines the road system service offered, i.e. the *Global Level of Service* - Livello di Servizio Globale (GLS) - supplied by the road being examined.
Rational and conventional definition process of road service quality, once pointed out, has enormous application potentialities because it can be used as a basis for technique, economic and strategic choices linked to road facilities.
Since some years, the Department of Highways and Transportations of Polytechnic of Bari is studying these problems.
This paper presents the state in advance of these studies, four years later their first presentation at Kuala Lampur PIARC World Congress.

KEY WORDS

PERFORMANCE / QUALITY OF SERVICE / MAINTENANCE / MANAGEMENT / ROAD.

1. INTODUCTION

The state in advance of the research project started by prof. Colonna, Polytechnic University of Bari – Italy, is described in the following pages. Its first outcomes were published at the XXI World Road Congress – PIARC, Kuala Lumpur, 1999; the research work allowed the Authors to determine an algorithm able to estimate the quality of service offered by a road through a single one parameter called Broad Level of Service (LSA – Livello di Servizio Allargato), calculated starting from the measure in the field of some

performance indexes; (Colonna, 1998 - Colonna, 1999 - Colonna, 2000 - Colonna, 2000). After the studies presented in these pages, this procedure was renamed Global Level of Service (GLS – Livello di Servizio Globale).
The quality of road service can be defined as the capability of either a product or a service to satisfy the potential or real needs of the users, or more in general, of the beneficiaries of the product/service itself.
For a better definition of this concept some specifications are useful, (PIARC, 1995):

- user is the main beneficiary of quality of service, but he isn't the only one;
- for many reasons user can change his "quality" perception;
- this definition contrasts the old concept of high performance products. The aim is real demanded needs satisfaction: as a consequence, quality is not an abstract concept, but, if possible, it's always related to an user;
- too expensive service can't satisfy an user: so, quality of road service can't leaves out of considerations service costs.

It's important to underline that road infrastructure beneficiaries expectations can change in different countries, depending on specific cultural, social and economical context where the road is located; so, to pursue quality aims is a stakeholders responsibility.
Growing sensitization of public opinion to issues related to road safety, to comfort, and to environment, made the users perceive the road serviceability as a right, continuously comparing between perceived and demanded (desired) quality of service, expressing a major or minor satisfaction judgement through a subjective process of balance, where safety and accessibility at equal costs are mean evaluation parameters.
The other subjects involved (owners, manager and people crossed by infrastructure) make an evaluation too, this time, using a balanced process both social and interactive, whose aim is the check of disadvantaged subjects absence, because of infrastructure existence.
These considerations impose well known limits overcoming of classical measurements tools of quality of circulation, whose forerunner is Highway Capacity Manual (HCM, 1994) through new tools search able to represent performance infrastructure in a more complete manner.
Accordingly to these considerations, at Transportation Research Board 2002 Annual Meeting, session number 538, "Future direction in Highway Capacity Manual Concept of Level of Service" (AA.VV., 2002), W. Kittleson pointed out that HCM is no more an exhaustive tools able to represent all the problems related to road performances.
The study described in this page becomes part of this context. GLS is an algorithm able to associate every road section to a single numerical parameter representative of the quality of road service offered, able to consider the different needs and, as a consequence, the different parameters of judgement of the mean subjects involved (user, owner/manager, neighbouring populations), (AA.VV., 1998 - Borgia, 1996 – Camomilla, 1996 – PIARC, 1995 – PIARC, 1995 – Benedetto, 1997).

2. THE GLOBAL LEVEL OF SERVICE (GLS)

Cultural and scientific developments of last years let us to point out some important innovative elements:

1. today the user, beyond both traffic conditions and travel time, wishes a service in terms of safety, comfort and additional services; he also is more sensitive to environment;
2. road service can't ever be considered as an user exclusive privilege, but it has always to be related to road owner (or manager) efficiency, and to the consequences that user (and so road) produce in the external context.

Therefore, it’s evident that level of service based only on vehicular density is no more acceptable. It is necessary to widen the horizon taking into account all the parameters involved.
So it’s necessary to define a criterion in order to define new Global Level of Service, able to take into account all the parameters involved.
As a consequence we defined a procedure based upon a model that, considering every significant element, associate every road section with a single synthetic parameter, expression of the road service offered, called Global Level of Service – GLS.
The aim is expressing quality of service of roads through a single parameter: GLS.

3. METHOD FOR GLS ASSESSMENT

The procedure is based upon elementary concept: quality of road service is the sum of the judgements that we can attribute to a finished number of elementary qualities, (performance indicators) each of one has a different importance in the overall assessment. Elementary qualities, whose impact is at least higher than approximation by which quality itself is measured, has been called road service “indicators”.
A way of judgement has been associated with all the indicators. Through this way of judgement it is possible to attribute a numerical value to the examined road section, depending on the contribution offered to road serviceability by that quality judgment.
The introduced indicators are characterized by fast and cheap surveys, and they have to represent phenomena in an objective way.

3.1. Different points of view

As anticipated before, Global Level of Service’s aim is to take into account not only owner’s point of view (as happened till sixties), but also user and environmental points of view (as acquired).
As a consequence, an appropriate evaluation has to be done in order to assess the importance of a single parameter for the specific point of view.

4. METHOD DEVELOPMENT AND PROBLEMS FACED

Many problems has been faced during development of the method for GLS evaluation.
At first, we have to underline that it’s necessary that a road section is homogeneous as regards for road, constructive, horizontal and vertical alignments, environmental, traffic characteristics, in order to assign a numerical value to an indicator of a road section, so it’s necessary to subdivide the whole infrastructure (of which we want to assess GLS value) in n homogeneous road sections.
Moreover, a way of judgement has to be associated with each indicator, by which is possible to attribute a numerical value to the examined road section, depending on that quality’s contribution to road serviceability. Therefore, we have to identify way of judgements in a univocal manner, for each indicator, also evaluating ways of survey.
Finally, each indicator, (for each point of view) has its weight in comparison with other indicators of the same group, each point of view has its weight in comparison with other points of view of the same group, and at last, each group has its weight in comparison with other groups. Therefore a problem of weight assessment to indicators arose, not easy to solve. This assessment is really the most discretionary phase of the method. This discretion is related to the circumstance that indicators are measured by different methods

and techniques. So there is the problem of weight comparison among indicators estimated by criterion of different disciplines, whose results are not comparable.
Mean problems faced during method development were:

1. performance indicators selection and gathering in homogeneous groups;
2. algorithm development;
3. judgements assessment to indicators and survey methods;
4. homogeneous road section identification;
5. weight assessment, their calibration, and overall method calibration.

5. PERFORMANCE INDICATORS SELECTION AND GATHERING IN HOMOGENEOUS GROUPS

First of all, we identified macro-areas in regard to which we can identify right indicators. Being number of indicators too big, we needed to gather them in homogeneous areas; so, we defined 6 homogeneous groups:

1. Safety (S);
   a. Geometric characteristics (**G**)
      a_1. horizontal alignment characteristics – (**GL**);
      a_2. section geometrical characteristics – (**GS**);
   b. Structural characteristics – (**St**);
   c. Functional characteristics – (**F**);
   d. External interferences – (**E**);
2. Travel time - (**T**);
3. Services – (**R**);
4. Environment – (**A**);
5. Traffic condition (**Q**) ;
6. Comfort – (**C**).

We underline that we identified 54 indicators; moreover we specified the kind of section where each indicator can be evaluated: normal, viaduct or tunnel. Normal sections are fill sections or cut sections. Viaduct sections are all the bridges with at least one pear. Finally, all the indicators vary from 0 to 1 (see table 1). We will talk about this topic in paragraph 7.

6. ALGORITHM DEVELOPMENT

Therefore every indicator was gathered in 6 groups: S, T, R, A, Q e C.
In Figure 1, the logical scheme for GLS assessment is represented.

6.1. Group indicators for each point of view

If x_i is each i-th indicator value, for each point of view (user, owner, environment), it's possible to calculate Group Indicator value Ix_i (where x = S, T, R, A, Q, C and j = u, p, e), if Px_i (weight of each indicator compared to the other ones) is known.
For the different points of view we have:

$$I_{Xu} = \frac{\sum X_i \cdot P_{Xu_i}}{\sum P_{Xu_i}} \qquad I_{Xp} = \frac{\sum X_i \cdot P_{Xp_i}}{\sum P_{Xp_i}} \qquad I_{Xe} = \frac{\sum X_i \cdot P_{Xe_i}}{\sum P_{Xe_i}}$$

Table 1 – Indicators

Check of coordination of vertical and horizontal alignments : **GL01**$\in$[0,1];
Road where stopping sight distance is guaranteed: **GL02**$\in$[0,1];
Mean value of the ratio “actual horizontal curve radius”/”theoretical horizontal curve radius for vehicle dynamic equilibrium”: **GL03**$\in$[0,1];
Coordination between consecutive curves: **GL04**$\in$[0,1]
Comparison of straight alignments lengths L_0 and radius of interposed curves R: **GL05**$\in$[0,1];
Check of horizontal tangents length: **GL06**$\in$[0,1];
Percentage of horizontal curves with clothoids: **GL07**$\in$[0,1];
Curvature Change rates: **GL08**$\in$[0,1];
Percentage og horizontal curves with correct superelevation: **GL09**$\in$[0,1];
Sections at which passing sight distance is ensured: **GL10**$\in$[0,1].
Grades related to the road type: **GL11**$\in$[0,1];
Respect of minimum and maximum cross slope: **GS01**$\in$[0,1]
Ratio between actual shoulder width and the ideal one: **GS02**$\in$[0,1]
Ratio between actual sidewalk width and the ideal one: **GS03**$\in$[0,1]
Ratio between actual lanes width and the ideal one: **GS04**$\in$[0,1]
Ratio between actual lateral clearance and the ideal one: **GS05**$\in$[0,1]
Pavement Friction coefficient (C.A.T.); **S01** $\in$[0,1];
Roughness: **S02** $\in$[0,1];
Level of joints functional effectiveness: **S03** $\in$[0,1];
Level of bearings functional effectiveness: **S04** $\in$[0,1];
Runoff effectiveness: **S05** $\in$[0,1].
Level of suitability of tunnel facing: **S06** $\in$[0,1].
Level of suitability of road signals: **F01** $\in$[0,1];
Level of suitability of road barriers: **F02** $\in$[0,1];
Presence/effectiveness of control devices, alert systems and fire control: **F03** $\in$[0,1];
Level of effectiveness of ventilation systems: **F04** $\in$[0,1];
Presence of wind barriers: **F05** $\in$[0,1];
Condition of road nightime visibility devices: **F06** $\in$[0,1];
Presence/effectiveness of illumination systems: **F07** $\in$[0,1];
Presence and organization of deicing systems: **F08** $\in$[0,1];
Presence of anti dazzle devices: **F09** $\in$[0,1].
Frequency of private access: number/km; **E01** $\in$[0,1];
Frequency of signalized intersections: number/km; **E02** $\in$[0,1];
Frequency of intersections without traffic lights: number/km; **E03** $\in$[0,1];
Frequency of intersections with grade separation with aceleration/deceleration lanes: number/km; **E04** $\in$[0,1];
Presence of pedestrian crosswalks; **E05** $\in$[0,1]
Delays due to work areas: **T01** $\in$[0,1];
Delays due to accidents: **T02** $\in$[0,1];
Delays due to toll: **T03** $\in$[0,1];
Real travel time: **T04** $\in$[0,1].
Frequency of lays-by: **R01** $\in$[0,1];
Frequency of rest areas: **R02** $\in$[0,1].
Frequency of service stations: **R03** $\in$[0,1];
Weather, traffic and accident information: **R04** $\in$[0,1];
Presence of police and emergency services: **R05** $\in$[0,1];
Presence of GPS: **R06** $\in$[0,1];
Presence of SOS devices: **R07** $\in$[0,1]
Acoustic pollution: **A01** $\in$[0,1];
Air pollution: **A02** $\in$[0,1];
Visual impact: **A03** $\in$[0,1]
Route beauty: **A04** $\in$[0,1].
Ratio between ADT and road capacity: **Q01** $\in$[0,1];
Percentage of slow traffic: heavy vehicles, RV’s and busses: **Q02** $\in$[0,1];
Ratio between commuter and noncommuter: **Q03** $\in$[0,1].

HOMOGENEOUS ROAD SECTIONS SELECTION

⇓

ANALYSIS SECTION BY SECTION AND NUMERICAL VALUE ASSIGNATION TO INDICATORS

⇓

GROUP INDICATOR CALCULATION FOR EACH ROAD SECTION AND FOR EACH POINT OF VIEW (U, P, E):

$$I_{Xu} = \frac{\sum \left(X_i \cdot P_{Xu_i} \right)}{\sum P_{Xu_i}} \quad I_{Xp} = \frac{\sum \left(X_i \cdot P_{Xp_i} \right)}{\sum P_{Xp_i}} \quad I_{Xe} = \frac{\sum \left(X_i \cdot P_{Xe_i} \right)}{\sum P_{Xe_i}}$$

⇓

GLOBAL INDICATOR CALCULATION (GENERAL PARAMETER)

$$I_X = \frac{I_{Xu} \cdot \alpha_u + I_{Xp} \cdot \alpha_p + I_{Xe} \cdot \alpha_e}{\alpha_u + \alpha_p + \alpha_e}$$

⇓

GLOBAL LEVEL OF SERVICE FOR SINGLE ROAD SECTION CALCULATION

$$GLS_n = \frac{I_S \cdot \beta_S + I_T \cdot \beta_T + I_R \cdot \beta_R + I_Q \cdot \beta_Q + I_A \cdot \beta_A + I_C \cdot \beta_c}{\beta_S + \beta_T + \beta_R + \beta_Q + \beta_A + \beta_C}$$

⇓

GLOBAL LEVEL OF SERVICE CALCULATION:

$$GLS_{road} = \sum_n \frac{GLS_n \cdot L_n}{L_{road}}$$

Figure 1 – Logical scheme for GLS evaluation

6.2. Global Group Indicator

Each point of view has a weight α, so it can be easily determined Global Group Indicator, which take into account every point of view for the group of indicators we are considering:

$$I_X = \frac{I_{Xu} \cdot \alpha_u + I_{Xp} \cdot \alpha_p + I_{Xe} \cdot \alpha_e}{\alpha_u + \alpha_p + \alpha_e}$$

where x= S, T, R, A, Q, C.

6.3. Global Level of Service for single road section

Each group of indicators has weight ß, if compared to the others, therefore it's possible to determine Global Level of Service of n-th road section $(GLS)_n$, by the following expression:

$$(GLS)_n = \frac{\sum I_x \cdot \beta_x}{\sum \beta_x}$$

where x = S, T, R, Q, A, C.

6.4. Global Level of Service of entire road

Finally, if we know the length of n homogeneous road sections, we can calculate Global Level of Service of entire road by the following expression:

$$(GLS)_{road} = \sum_n \frac{(GLS)_n \cdot L_n}{L_{road}}$$

6.5. GLS software

In order to make method application easier, GLS algorithm has been implemented in an electronic sheet which allows users to input indicator values and an easy making operations required by the procedure.
So, for this aim, electronic sheet GLS2000.xls was created, in order to computerize the procedure able to determine GLS of each road section as a part of road network of our interest.
A typical page of the electronic sheet is represented in Figure 2.
Currently, the development of a graphic interface able to relate outputs of the electronic sheet with a GIS is in progress.

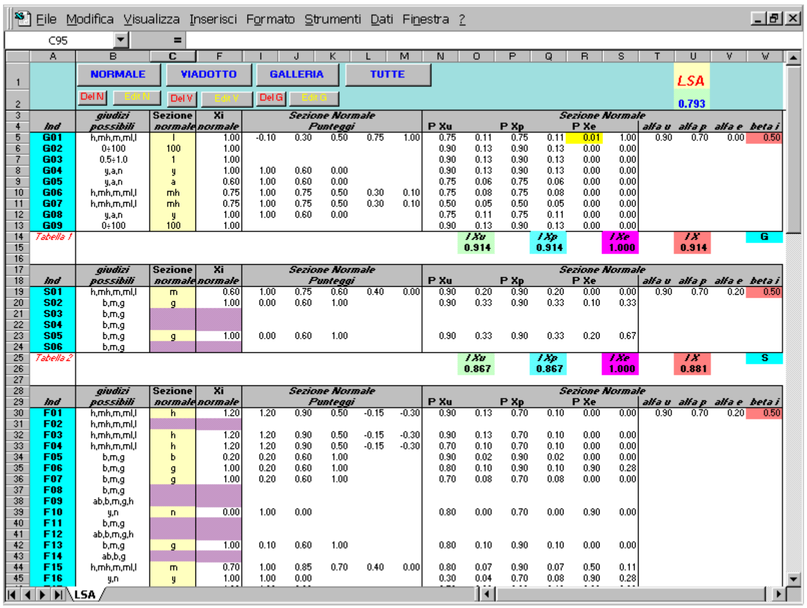

Figure 2 - video after the OUTPUT

6.6. GLS efficiency

During the studies, the assessment of a maximum GLS value related to every type of road was considered favourable. Therefore we have:

- primary road (transit and flowing functions): GLS_{max} = 1.0;
- mean road (distribution function): GLS_{max} = 0.90;
- secondary road (penetration function): GLS_{max} = 0.70;
- local road (access function): GLS_{max} = 0.40;

After the assessment of the numerical GLS value, we can determinate the so called GLS "efficiency" (h_{GLS}) of the examining road: $h_{GLS} = GLS/GLS_{max}$. It is the ratio between the estimated value of GLS and the maximum GLS value for that type of road.
Comparing efficiency values of different roads, it will be possible to assert that a road has a better quality of service than the other, apart from their function.
The introduction of this concept is useful since, the simply comparison of numerical values of GLS, could let someone believe that (e.g.) mean road characterized by GLS value equal to 0,85 has a quality of service worse than primary road characterized by GLS value equal to 0,90. On the contrary if we consider that the maximum GLS value of primary roads is 1 and maximum GLS value of mean roads is 0,90, the efficiency will be:

- GLS/GLS_{max} = 0,85/0,90 = 0,94 for mean road;
- GLS/GLS_{max} = 0,9/1,0 = 0,90 for primary road.

So the efficiency of the mean road is better.
We also defined an efficiency scale classified by letters: A, B, C, D, E , F, G.
Depending on road function, its Global Level of Service can vary from a maximum theoretical value (corresponding to the presence of all the possible services characterized by maximum efficiency, from every point of view), to a minimum value acceptable (able to guarantee at least essential functionality).
Between these extremes it's possible to look for some limit values, in order to identify appropriate intervals, by which is possible to classify in a synthetic way Quality of Service offered by road infrastructure, depending on its function. Therefore, for each kind of road efficiency scale was created and represented in the following table 2.

Table 2 – GLS efficiency scale

h_{GLS}^{k} (*) = GLS efficiency	
Level A	$0.85 < h_{GLS} < 1,00$
Level B	$0.67 < h_{GLS} < 0.85$
Level C	$0.50 < h_{GLS} < 0.67$
Level D	$0.30 < h_{GLS} < 0.50$
Level E	$0.20 < h_{GLS} < 0.30$
Level F	$0.13 < h_{GLS} < 0.20$
Level G	$h_{GLS} < 0.13$
(*) K indicates kind of road (functional classification)	

7. JUDGEMENTS ASSESSMENT TO INDICATORS AND SURVEY METHODS

Big effort of research has been done in the last four years in order to let the indicators to be easily and quickly valuable. Moreover, all the indicators have the same judgements scale variable between 0 and 1. Finally we tried to make objective as much possible the judgement scale, in order to go beyond likely mistakes deriving by surveyor subjectivity. For this aim, indicators were divided in different groups depending on the different way of evaluation:

- indicators intrinsically assessable objectively (GL02, GL03, GL04, GL05, GL06, GL07, GL08, GL09, GL10, GL11, GS01, GS02, GS03, GS04, GS05, S01, S02, E01, E02, E03, E04, E05, Q01, Q02, Q03, T01, T02, T03, T04, R01, R02, R03): numerical value of these indicators can be estimated by mathematical expressions more or less simple.
- indicators intrinsically not assessable objectively (GL01, F01, F02, F03, F04, F06, F07):

Regarding indicators objectively measurable, typical survey form is represented in figure 3. Indicator name, belonging indicator group, meaning, mathematical expression, possible corrective coefficient for divided or undivided carriageways, score interval (value), measurement methods and tools, score scale, variability, monitoring frequency and finally personnel able to measure indicator, are represented in these forms. These forms were created for each of the indicators (Colonna, d'Amoja, Ranieri, 2001 – d'Amoja, 2002).
Regarding indicators not objectively measurable, a special survey/evaluation form was created: these contain some questions by which it is possible to get an evaluation of the indicator as much possible objective.
Numerical value assessment will consist of two phases:

- during first phase the surveyor will answer the questions contained in the form;
- during the second phase answers implementation will be done in a special algorithm such as:

$$X_i = \sum_{i=1}^{n} \frac{P_i}{n}$$

where:

- n is the number of questions contained in the form;
- P_i = 1 if we have the best situation;
- P_i = 0,5 if we have intermediate situation;
- P_i = 0 if we have the worst situation

When the form provides multiple answers P_i is equal to:

$$P_i = \frac{\sum_{i}^{m} p_i}{m}$$

where:

- m is the number of different possibilities of answer;
- p_i = 1 if we have the best situation;
- p_i = 0,5 if we have intermediate situation;
- p_i = 0 if we have the worst situation

Typical example of these forms is represented in figure 4a and b.
All these forms should be filled for each homogeneous road section.
In the figures it is appreciable that for both the kinds of forms there is a cell containing multiplying coefficient in order to take into account different influence that each indicator has in the case of divided or undivided carriageway.
In the original formulation, for some indicators a double score scale was foreseen depending on divided or undivided highway.
In order to simplify the evaluation procedures, we decided to have only one score scale for each indicator. Therefore we introduced the corrective coefficient by which multiply indicators value when the road (from the point of view of that indicator) is in disadvantage situation; sometimes it happens for the divided highways and sometimes for undivided highways. The coefficient is therefore a restrictive one, always between 0 and 1.

There is a not remarkable number of indicators for which we didn't create special questionary forms.
Therefore, in order to let these indicators evaluation objective as much possible, we tried to specify possible judgements as well as we could (S03, S04, S05, F05, F08, F09, R04, R05, R06, R07, A01, A02, A03, A04).

GROUP	**SAFETY** **ROAD GEOMETRY**
INDICATOR	**GL02**
MEANING	Road where stopping sight distance is guaranteed
SECTION OF APPLICABILITY	Normal, Viaduct, Tunnel
MATHEMATICAL EXPRESSION	**GL02 =** $\frac{\sum L(D_{realsight} > D_{therosight})}{Lroad\,\sec tion}$ **,** where: - $D_{theorsight}$ = 0,78V – 0,0028V^2 + $\frac{V^2}{254 \cdot (f_e \pm i)}$ - V[km/h]; - f_e = equivalent coefficient NB1: On one carriageway, two lane roads, in the sections where no passing is possible, it's necessary to guarantee stopping sight distance equal to twice the calculated one, in order to avoid impact against a vehicle coming from opposite way, who had leaved his lane by mistake.
CORRECTIVE COEFFICIENT FOR SINGLE CARRIAGEWAY	-
INTERVAL	0-1
MEASUREMENT METHOD	Continuous along road section
MEASUREMENT TOOL	Vertical alignment and/or design project GPS/ topographic tool
INDICATOR VARIABILITY	Constant during the time
MONITORING FREQUENCE	1 survey every 5 years
QUALIFIED PERSONNEL	Technicians

Figure 3: survey form

GROUP	**SAFETY** **ROAD GEOMETRY**	
INDICATOR	**GL01**	
MEANING	Coordination between planimetric and altimetric elements verification.	
SECTION OF APPLICABILITY	Normal, Viaduct, Tunnel	
MATHEMATICAL EXPRESSION	**GL01** = $\sum_{i=1}^{n} \frac{P_i}{n}$, where: P_i = value attributed to indicator as specified in the following table; n = number of questions contained on attached form.	
CORRECTIVE COEFFICIENT FOR SINGLE CARRIAGEWAY	0,7	
INTERVAL	0-1	
MEASUREMENT METHOD	Constant along road section	
MEASUREMENT TOOL	Vertical alignment/ GPS / design project	
INDICATOR VARIABILITY MONITORING FREQUENCE	P_i	See attached form
	1	YES
	0	NO
CORRECTIVE COEFFICIENT FOR SINGLE CARRIAGEWAY	Constant during the time	
INTERVAL	1 survey each 5 years*	
MEASUREMENT METHOD	Technicians	

Figure 4a

Conditions determining coordination between horizontal and vertical alignment – GL01

1	Horizontal curve starting point doesn't coincide or isn't near to the top of crest vertical curve.	YES	NOT
2	Horizontal curve doesn't start immediately after sag vertical curve	YES	NOT
3	Rv (vertical radius) divided by horizontal curve radius is $\geq$ 6	YES	NOT
4	Small sag vertical curves aren't contained inside large horizontal curves.	YES	NOT
5	Sag vertical curve isn't positioned immediately after the end of horizontal curve.	YES	NOT
6	The top of sag vertical curve doesn't coincide or it isn't near flex point of horizontal curve.	YES	NOT
7	Horizontal curve and vertical curve tops don't coincide or aren't enough close.	YES	NOT
8	Sag vertical curve preceding or following crest vertical curve are longer than this last one.	YES	NOT
9	Sight of reappearing distance of the horizontal alignment is major than values described in the following table, depending on speed (V85).	YES	NOT

Speed [km/h]	25	40	50	60	70	80	90	100	110	120	130	140
Minimal Sight of reappearing distance [m]	150	180	220	280	350	420	500	560	640	720	800	860

Figure 4b

7.1. Restrictive coefficient for divided/undivided highways: risk analysis

In order to determine this corrective coefficient, risk analysis method was used for the following indicators: GL01, GL05, GL10, GS01, GS04, S01, S05, E04, F02, F03, F04, F05, F06, F07.
Given D the damn deriving by an accident and P the probability of happening of that accident, risk R is given by R = P x D.
If we fix a value of the risk level R*, it can be represented in P vs D plane through hyperbole exactly representing the iso-risk curve.
Therefore, given one of the mentioned indicators, D_1 and P_1 are respectively the damn and the probability of accident e.g. in the case of undivided highway. As a consequence risk will be equal to $R_1 = D_1 \times P_1$.In the same way, $R_2 = D_2 \times P_2$ is the accident risk associated with the same indicator in the case of a divided highway (the meaning of P_2 and D_2 is obvious).
In P vs D plane risk levels R_1 and R_2 are represented by two points: A and B. Restrictive coefficient could be defined by ratio between the length of segments connecting points A and B with axes origin: OA/OB = c if OA < OB and OB/OB = c if OB < OA.

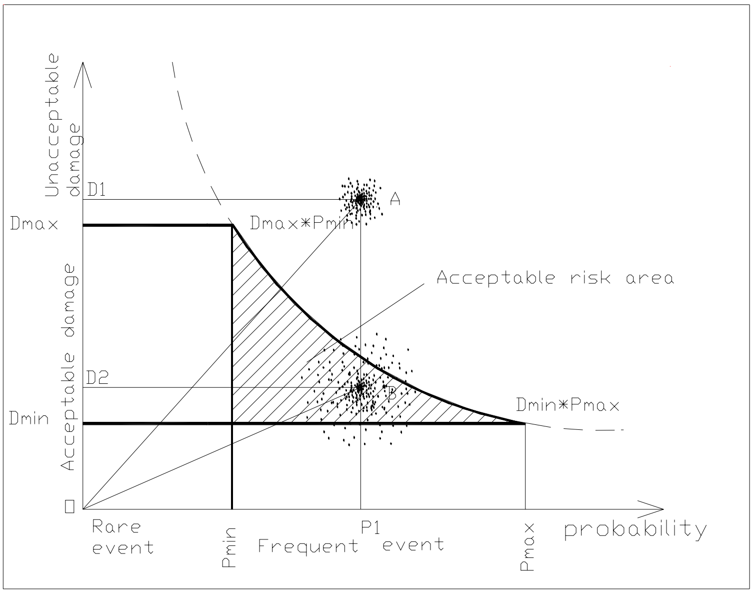

Figure 5

Example given, in figure 5, likely risk associated with GL01 indicator is represented: point A is representative of undivided highway, and point B is representative of divided highway. Risk associated to undivided highway is therefore higher than the risk associated to divided highway. In this case, the restrictive coefficient was adopted for undivided highway equal to: OB/OA = 0,7.
All the indicators for which restrictive coefficient were adopted are in table 3; it shows also if the coefficient has to be applied for divided or undivided highways.

Table 3

INDICATORS	
Undivided highways	Divided highways
GL01, GL04, GL05, GL06, GL07, GL08, GL09, GL10, GL11, GS01, GS04, S01, S05, F01, F02, F05, Q02	GS02, GS03, GS05, F03, F04, F06, F07, E01, E02, E03, E04, E05, T01, T02, T03, T04, R01, R02, R03, R07, Q03, A01, A02

8. HOMOGENEOUS ROAD SECTION IDENTIFICATION

One of the most controversial issues of researchers studying global quality of road service concerns the definition of homogeneous road sections: the correct identification of such road sections is fundamental in order to give the correct evaluation to indicators, given each section.

For this study we formulated the following definition (Colonna, d'Amoja, Maizza, Ranieri, 2002): *"an homogeneous road section is a part of road on which we haven't essential changes of horizontal and vertical alignment, section characteristic, traffic, paving and generally characteristic of any indicator of GLS algorithm"*.

Particularly, to consider a road section homogeneous the following 4 conditions should be verified at the same time:

1 General condition;
2 Cross section condition;
3 Grade condition;
4 Intersections condition.

If only one the condition above is not verified, the change of the homogeneous section is needed.

8.1. General condition

Each indicator value should not change more than 25%, along the road section.

Given X_{i-1} ed X_i the values of each indicator respectively at i-1-th and in i-th survey sections, the following condition should be always verified:

$$\Delta X = \left| \frac{X_{i-1} - X_i}{X_{i-1}} \right| \cdot 100 \leq 25$$

This condition is applied to all indicators for which the survey doesn't happen in a continuous way along the road section.

8.2. Cross section condition

The section should have constant geometrical characteristics.

The section has constant geometrical characteristics if an indicator of GS group doesn't change more than 10% for more than two consecutive survey sections.

Particularly, we define the change of x-th indicator of GS group, between two consecutive survey sections, in the following way:

$$\Delta X_{GS} = \left| \frac{X_{GS\,i-1} - X_{GS\,i}}{X_{GS\,i-1}} \right| \cdot 100$$

where: X_{GSi-1} ed X_{GSi} are the values of x-th indicator of GS group respectively at the i-1-th and at the i-th survey sections.

Table 4 gives the threshold values for the road section change.

Table 4

Condition	Road section change
$\Delta X_{GSi} \geq 25\%$	Always
$10\% \leq \Delta X_{GSi} < 25\%$	Only if it happens for more than two consecutive survey sections
$\Delta X_{GSi} < 10\%$	Never

We can talk about consecutive sections because the measurement of these indicators doesn't happen in a continuous way along the section, but for 100 meters steps.

8.3. Grade condition

This condition has been formulated referring to Lamm and HCM 2000 (Lamm, Psarianos, Mailaender, 1999 - HCM, 2000).
A road section is homogeneous if the following conditions happens:

- <u>For two lane, two way highways</u>:

any change of grade is allowed as long as the slope of each couple of consecutive grades is minor than 3%, for any length.
In all the other cases every change of slope greater or equal to 1% causes the interruption of homogeneous road section.

Table 5 – Two lane, two way highways

If only one of the couple of grades doesn't belong to the "NO" case and the change of slope is more than 1%, the homogeneous section is interrupted.	INTERRUPTION OF HOMOGENEOUS SECTION *Slopes*	
	Up to 3%	*Over 3%*
For every grade lengths	NO	Yes for $\Delta \geq 1\%$

- <u>For divided and undivided multilane highways:</u>

any change of slope is allowed as long as each of two consecutive grades is responding to one of the following conditions:

- Grade slope is less than 2% for any length;
- Grade slope is less than 3% with length < 1.2 km;
- Grade slope is less than 5% with length < 400 m;

in all the other cases every change of slope greater or equal to 1% causes the interruption of the homogeneous section.

Table 6 – Multilane highways

NB: If only one of the couple of grades doesn't belong to "NO" cases and the slope changes more than 1%, the homogeneous section is interrupted.		<u>INTERRUPTION OF HOMOGENEOUS SECTION</u> *Slopes*			
		Up to 2%	*From 2% to 3%*	*From 3% to 5%*	*Over 5%*
Grade length	*Up to 400 m*	NO	NO	NO	Yes for $\Delta \geq 1\%$
	From 400 m to 1200 m	NO	NO	Yes for $\Delta \geq 1\%$	Yes for $\Delta \geq 1\%$
	Over 1200 m	NO	Yes for $\Delta \geq 1\%$	Yes for $\Delta \geq 1\%$	Yes for $\Delta \geq 1\%$

8.4 Intersections condition

It's necessary to consider the interruption of homogeneous road section in correspondence of all controlled admission. As controlled admissions are intended all the intersections with separate grade junctions, traffic lights, stop signals, give-way signs. Moreover it's necessary to consider the interruption of the homogeneous road section

when the traffic flow generated by the intersected road is significant if compared to upstream traffic flow of the examining road.
Generally this evaluation can be considered a qualitative one; in doubt situations, we should do quantitative evaluations related to 5% threshold.

9. WEIGHT ASSESSMENT, THEIR CALIBRATION, AND OVERALL METHOD CALIBRATION

One of the most delicate phase of the procedure is represented by weight assessment to indicators.
Each indicator (for each point of view) has its weight in comparison with other indicators of the same group, each point of view has its weight in comparison with other points of view and at last, each group has its weight in comparison with other groups. Therefore it's evident the importance of weight assessment for a correct use of the method.
This assessment is really the most discretionary phase of the whole method. This discretion is related to the circumstance that indicators are measured by different methods and techniques. So there is the problem of weight comparison among indicators estimated by criterion of different disciplines, whose results are not comparable, obviously.
In order to make this comparison among indicators we chose Analytic Hierarchy Process, proposed by T. L. Saaty in the first eighties, (Saaty, 1990 – Saaty, 1990 – Saaty, 1998).

9.1 Saaty method - AHP

Saaty method, Analytic Hierarchy Process, was created for military and political disputes solution, and it's mainly used for assessment of benefits/costs ratio. It's simple and versatile method, able to represent and to solve difficult problems, and able to provide reliable and believable solutions, (Levary, Wan, 1998 - Finan, Hurley, 1999).
For this reason we decided to use this method, with the appropriate variations, in order to assess "local" weight to indicators of GLS method and for their calibration (local is a definition of Saaty method).

9.2. Weight assessment and their calibration

Here we describe the procedure for weight assessment. In particular, here we describe the case of assessment of the weight to each group of indicators in comparison with the other ones, (Colonna, d'Amoja, Maizza, Ranieri, 2002).
Estimation method, used by AHP, uses pairwise comparisons: we analyze two elements at a time, evaluating their ratio. The elements of each pair have been compared in order to assess which is the most important: the result of this comparison is the coefficient a_{ij}, dominance coefficient, representing the dominance of the first element (i) in comparison with the second one (j).
In order to assess coefficients a_{ij} values, we used scale represented in table 7 (Saaty semantic scale), where the first nine whole numbers are related to nine judgements expressing the possible results of the comparison in a qualitative manner.

Table 7: Saaty semantic scale

a_{ij}	JUDGEMENT	EXPLANATION
1	Equal importance	The two elements contribute in the same way
3	i is little more important than j	Experience lightly favours one factor
5	i is more important than j	Experience clearly favours one factor
7	i is much more importance than j	One element is much more favoured, its superiority is demonstrable
9	i is very much more important than j	Superior level of affirmation doesn't exist
2,4,6,8	Intermediate values	Compromise situations

After pairwise comparison of the n elements we have n^2 coefficients: among them only n(n-1)/2 are directly calculated, because $a_{ii}=1$ and $a_{ij} = 1/a_{ji}$, for each value of i and j.
Second condition, known as reciprocity relationship, goes out from the need to guarantee the symmetry of judgements.
Dominance coefficients calculated in this way let us determine matrix A, square, reciprocal and positive (A) named "*pairwise comparison matrix*".
Sheer estimation process starts only after matrix A is finished: elements a_{ij} are ratios (w_i/w_j) estimation; but we have to estimate weight w_i of the elements.
This matrix A will be surely reciprocal, but in the most part of the cases it will not be consistent (above all when the number of elements is high). This consistence deficiency depends above all on the difficulties that one can have to keep the coherence of judgement in every pairwise comparisons.
Unconsistence phenomenon is strictly related to human being: in spite of this every man, by his rationality, should trend to his judgements consistence and so of his actions.
In spite of for weight calculation there are many methods we adopted eigenvector method, because it let us measure, really, the relative preponderance among different options, on the contrary we only can minimize errors using other methods.
Moreover, using eigenvector method, we can use eigenvalue, as a measure of unconsistence level of judgements given; at this point, if the consistence of the results is not satisfying, we can review and in case correct expressed judgements.
Then in order to determine weight w, so that matrix A is consistent, it has been necessary to solve characteristic equation, so that eigenvalue of matrix A can be determined:

$$\det(A - \lambda I_n) = 0$$

If eigenvalue of matrix A is known, we can determine CI index (*consistency index*), that let us to measure the difference between these two value sets:

$$CI = (\lambda - n) / (n - 1)$$

In the case of perfect consistence CI should be equal to 0: when matrix is perfectly consistence mean eigenvalue is equal to n. If unconsistence growths up, CI value growths up too.
This method wants that CI index is compared with RI (random index). We can calculate this index evaluating the mean of CI index of numerous matrix reciprocal of the same order whose coefficients are generated by a computer in a random manner.
Random index RI has to be considered as the measure of maximum possible unconsistence, for a matrix of n order.

In this study RI index has been calculated on a sample of 100 matrixes, for matrixes having an order minor than n, on the contrary for orders between 11 and 15 the number of sample is 500.
The comparison between CI and RI, has been done introducing consistency ratio equal to:

$$\mathbf{CR} = CI / RI$$

Consistency ratio value equal to 10% can be considered a reliability limit of judgements.
If eigenvalue λ is known, and if we check the matrix consistence we can go on determining eigenvector A associated with eigenvalue λ.
Eigenvector associated with eigenvalue λ, is column matrix, such as:

$$(\mathbf{A} - \lambda I_n)\, w = 0$$

and so the elements of w are the solutions not banal of the system of n equations with n unknown, that we obtain by the previous expression.

Therefore in order to obtain vector of weights, objective as much possible, we have to resort to different experts judgement.
We gathered Matrixes obtained in this way, through a synthetic process in order to obtain only one matrix A reflecting judgements of every subject involved.
In this way we can assess and calibrate the weights to assess to each phase of GLS method, and then we can calibrate the whole method:

10. APPLICATION – CASE OF STUDIES

Method was applied on some road networks of Apulia region – Italy.
Figure 6 is representative of GIS analysis.
It's evident that the use of this tool can let us express quick judgement about global quality of road network. Actually, in this way, we can easily identify black holes in the network where operate.

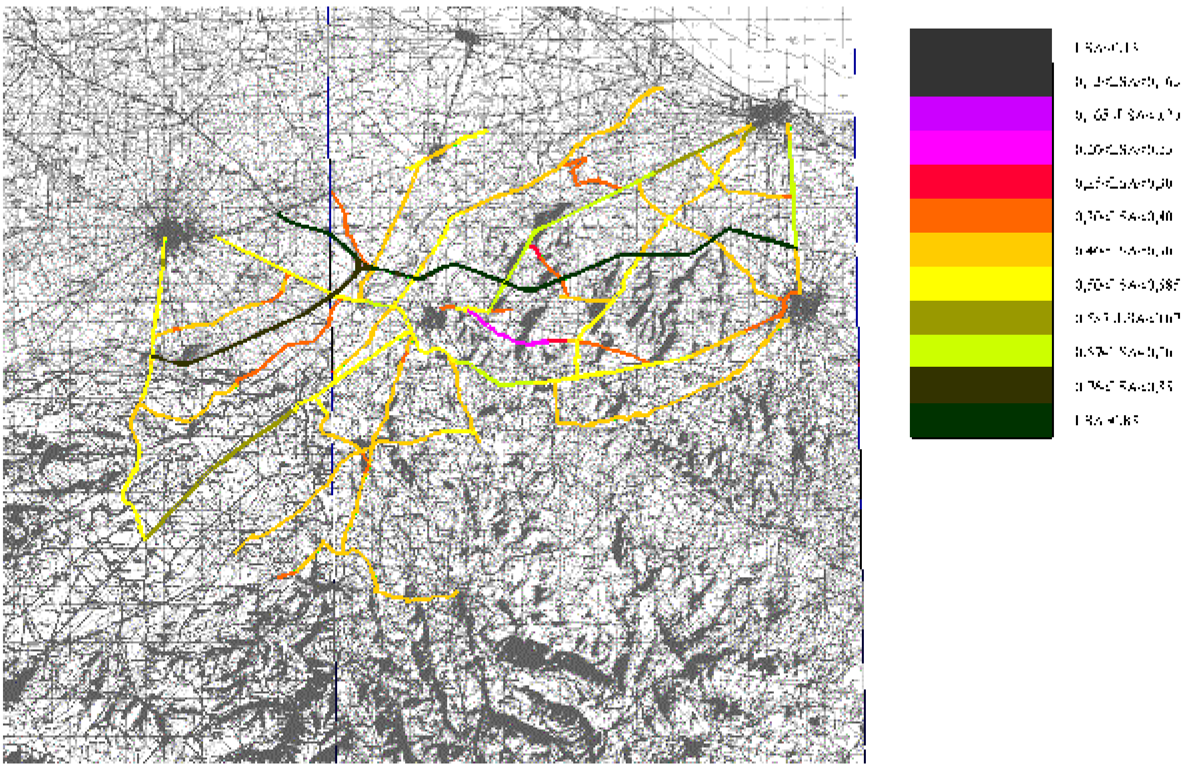

Figure 6 – Thematic map, GLS

11. CONCLUSIONS

This report represents the state in advance of the research able to define quality of road service of road infrastructure in a synthetic manner. We examined all the mean problems faced and we explained the method. This method, especially if associated with thematic maps such as GIS can be valid tool of road network analysis.
If we know road GLS values, we can actually make thematic maps where proper indicator values are pointed out. We can eventually aggregate these indicators or we can represent them separately for different point of view (user, owner and environment), therefore highlighting the best and/or the worst elements of each road, let everyone (technician and not) read clearly every factor, for each option.
This tool:

- in operation can help to identify priority of maintenance operations to do, that take into account the role held by the road in the whole network and in the context of socio-economical trends of development fixed by each Administration; actually, we don't have to neglect planning function of Administration in order to determine infrastructural system responding to economic growth and mobility perspectives of territory (Bevilacqua, 2000);
- in design phase, can help to identify the best design option: actually, in new infrastructure designs, the comparison among GLS values of different design choices can be very important in the choice;
- in driving phase, gives to the users a tool able to give information about route, after deciding an origin, a destination and the time to start the travel, according to priority scales favouring some indicators according to personal needs (travel time, comfort, landscape….)

REFERENCES

AA.VV. (1988) La qualità del servizio sulla rete Autostrade. Autostrade

AA.VV. (2002) Future direction in Highway Capacity Manual Concept of Level of Service. Annual Meeting - Transportation Research Board, Sessione n. 538, Washington

Benedetto, C. (1997) Le esigenze della sicurezza per una revisione delle norme geometriche di progettazione stradale. Atti della Giornata: La sicurezza delle infrastrutture stradali, Roma

Bevilacqua, A. (2000) L'approccio al programma manutentorio per l'esecuzione degli interventi di riqualificazione strutturale delle opere d'arte stradali

Borgia, R. (1996) Misurare la qualità percepita dall'utente come parte del livello di servizio globale. Autostrade

Camomilla, G. (1996) Il livello di servizio delle strade. Autostrade

Colonna, P. (1998) Proposta di determinazione della qualità del servizio di viabilità atteso ed offerto. Atti del XXIII Congresso Nazionale AIPCR, Verona

Colonna, P. (1999) The quality of service in terms of road serviceability as a fundamental parameter for taking technical and strategic choices that concern road network infrastructures. PIARC, XXI Congresso Mondiale della Strada, Kuala Lumpur (supplemento speciale al n° 1349 luglio-agosto 1999 di Le strade)

Colonna, P. (2000) Proposta di determinazione della qualità del servizio di viabilità atteso ed offerto. 7° Seminario AIIT, Bari

Colonna, P. (2000) La qualità del servizio di viabilità ed il livello di servizio globale GLS quali parametri fondamentali per le scelte tecniche, economiche e strategiche relative alle infrastrutture viarie. Atti del X convegno SIIV – Infrastrutture viarie del XXI Secolo: classificazione e riqualificazione del patrimonio esistente, Acireale

Colonna, P. - d’Amoja, S. – Maizza, M. – Ranieri, V. (2002) Il Livello di Servizio Globale (GLS) come strumento di misura di performance delle strade. XII Convegno Nazionale della Società Italiana Infrastrutture Viarie – Riqualificazione funzionale e sicurezza del sistema viario, Parma

Colonna, P. - d’Amoja, S. – Maizza, M. – Ranieri, V. (2002) Il GLS come strumento di misura della qualità del servizio di viabilità: verifica del parametro sicurezza. XXIV Convegno Nazionale Stradale AIPCR, St. Vincent

Colonna, P. - d’Amoja, S. - Ranieri, V. (2001) Il Livello di Servizio Globale (GLS) quale parametro per la valutazione della qualità del servizio di viabilità. Atti dell’XI Convegno SIIV, Verona

d’Amoja S., (2002), Definizione di un metodo basato sul livello della qualità del servizio di viabilità per le scelte tecniche, economiche, gestionali e strategiche relative alle infrastrutture stradali, Ph. D. Thesis in “Road infrastructure and transport systems”

Finan, J. S. – Hurley, W. J. (1999) Transitive calibration of the AHP verbal scale. European Journal of operational Research, n. 112

Highway Capacity Manual (1994) Basic freeway sections. Chapter 3

Highway Capacity Manual (2000) Transportation Research Board, National Research Council

Lamm, R. – Psarianos, B. – Mailaender, T. (1999) Highway design and traffic safety engineering handbook

Levary, R. R. – Wan, K. (1998) A simulation approach for handling uncertainty in the analytic hierarchy process. European Journal of operational Research, n. 106

Ministero delle Infrastrutture e dei Trasporti (2001)– Ispettorato Generale per la sicurezza e la circolazione stradale. Linee guida per le analisi di sicurezza delle strade. Documento approvato dalla Commissione di studio per le norme relative ai materiali stradali e progettazione, costruzione e manutenzione strade del CNR

PIARC (AIPCR) (1995) Comitato C13 (road safety) Conclusion of the XXth World Road Congress – Blackspots. XXth World Road Congress Montreal

PIARC (AIPCR) (1995) Comitato C4 (interurban roads) Conclusion of the XXth World Road Congress. XXth World Road Congress Montreal

Saaty, T. L. (1990) The Analytic Hierarchy Process – Planning, priority setting, resource allocation. Expert choice

Saaty, T. L. (1990) How to make a decision: the analytic hierarchy process. European Journal of operational research, n° 49

Saaty, T. L. – Hu, G. (1998) Ranking by Eigenvector versus other methods in the analytic hierarchy process. Appl. Math. Lett., Vol. 11, n. 4, pp.121-125