Evaluation and Measurement of a quality index for existing roads

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Synopsis

The measurement of the road serviceability, respect to use and management needs, is strictly connected with the definition of road performance indices. In this way the state of knowledge evidences several performance indices related to many measurement parameters of road characteristics and operations.
In this paper, starting from current experiences in the state of art, five reference criteria of the road performance index were identified: Safety, Comfort, Services, Environment and Usefulness. It was then defined a procedure based on the MultiCriteria Analysis (MCA) in order to combine these five criteria to obtain an unique value named Quality Index (QI), able to evaluate the overall serviceability level of the road.
By structuring a problem within the MCA framework, alternatives may be ranked according to pre-established preferences in order to achieve pre-established goals. Specifically, the AHP method (Analytic Hierarchy Process) is based on the definition of a two- (or more) dimensional matrix, where one dimension expresses the various alternatives and the other dimensions refer to the criteria by which the alternatives should be evaluated.
The procedure was implemented taking into consideration two lane rural roads infrastructural typology which represent the largest part of the network and carry a considerable share of traffic mobility. However, this type of roads has often been neglected in terms of the quality required, because of both the greater inertia of local agencies and the current lack of complete and updated road data. In this way the parameters of the above mentioned five criteria and their evaluation models suitable for the specific application were identified.
The definition of the QI is, also, linked to the typology of road characteristics data survey which must coming from an high speed system. In this field it was fundamental the use of the Mobile Laboratory of the Department of Civil and Environmental Engineering, which allows to accurately collect the main part of the required information related to the infrastructural features locating them along the road.
During data post-processing, the location along the road of the surveyed information allows to deduct the performance index and permits a direct evaluation of the serviceability quality offered by the road.
The experimental application on a two lane rural road allowed to check the feasibility and the capacity of the proposed methodology based on the model and on the information acquired during the survey. In such a way the procedure defines a system of direct use and application for road local agencies

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Due to the great number of control parameters and the high cost of maintenance, the management of a road network requires an effective system based on codified procedures which can help the decision maker to select type and priority of interventions by means of a systematic and objective approach.
In this sense, the measurement of the road serviceability, respect to use and management needs, represents an important step of a road management process taking into account the definition of road quality index.
The state of knowledge evidences several Performance Indicators (PIs) defined with respect to many measurement parameters of road characteristics and operations. Modern use of performance measurements system rose out in 1950s in Japan, but prior to the late 1980s Total Quality Management and performance measures were used primarily in industrial applications and in the private sector. The use of performance measures for monitoring and operational management of highway were promoted and evolved during the last 10 years, both for new and existing roads.
The importance of these measures varies respect to several points of view: the user, the owner and the operator. For the first subject the comparison between quality of service felt and demanded results in a judgement of satisfaction based on safety, accessibility at equal cost and comfort; for the other two subjects the evaluation refers to adequate flexibility in conflicting quality objectives (safety, environmental, economic constraints). Starting from these considerations and in order to overcome the limits of classical measurement tools of traffic quality, new approaches were experimented (PIARC, 1999, Colonna et al. 2003). Furthermore, current researches focus on road users perception of service quality (Choocharukul et al., 2004) distinguishing among road types and driver categories (Hostovsky et al., 2004)
The West European Road Directors (CERD, 2004) evidences the need to develop a coherent set of performance indicators for road networks and in particular to describe the performance of Trans –European Road Network (TERN).
In Italy first performance indicators were identified at the beginning of the 80s in the field of Pavement Maintenance associating the use of some technical parameters characterizing the infrastructure or the way to manage it, with their level and distribution along the road.
Even if the state of the practice includes wide and varied approaches to performance measures, with more than 70 PIs defined in literature (NCHRP, 2003), generally the steps for determining a Quality Index (QI) foresees:

1. the identification of criteria for defining the phenomena to investigate;
2. the individuation of PIs appropriate to evaluate and to measure road characteristics and use respect to the criterion C;
3. the measure of PIs values along the road.

Moreover, the most used PIs can gather into some general categories related to: Management of “Road infrastructure”, “Road Use” and “Road Environment”, which can be further explained by subcategories described by indicators (AIPCR CT6 2002).
Starting from this current state of knowledge, in this paper the quality index of road was defined using Safety, Comfort, Services, Environment and Usefulness as reference categories. Considering differences in the evaluation of these five categories, a multicriteria approach, the Analytical Hierarchy Process (AHP), was applied in order to combine them to obtain an unique value named Quality Index (QI). The QI is able to evaluate the overall serviceability level of the road.
Road data result as indispensable basis for the definition of QI. Then, considering lack of data due to the road Agencies delay in Road Cadastre implementation, the QI computation was linked to the road data coming from an high speed survey.

1. MULTI CRITERIA ANALYSIS OVERVIEW

In its broadest sense, Multi Criteria Analysis (MCA) seeks to investigate a number of alternatives or elements, in the light of conflicting priorities (Voogd, 1983). When a problem is structured in this way, the alternatives (elements) may be ranked according to pre-established preferences in order to achieve pre-established objectives. At the heart of the analysis there is a two- (or more) dimensional matrix, where one dimension expresses the various alternatives and the other one the criteria by which the alternatives should be evaluated.
Hence, MCA requires the clear definition of possible alternatives, together with the identification of the criteria under which the relative performance of the alternatives in achieving pre-established objectives is to be measured. In general, each criterion may be linked to a surrogate measure of performance, or attribute,

arising from implementation of any particular alternative. Thereafter, MCA requires the assignment of preferences (i.e. a measure of relative importance, or weighting) to each of the criteria.
A number of MCA methodologies have been developed over time to help decision-makers to discover the most desirable solution to a multi-objective problem. The various methodologies differ in the way the preferences on the various criteria are specified and the way by which the alternatives are ranked. Previous researches (Cafiso et al, 2002a, Di Graziano et al. 2003) have highlighted the flexibility of the Analytical Hierarchy Process (AHP) method (Saaty, 1990) as MCA approach for road infrastructure management. In particular, this approach does not require an explicit definition of trade-offs between the possible values of each attribute and it is easier for users to understand how outcomes are reached and how the weightings influence the outcomes.
Hence, the approach is useful when the decision maker needs to decide whether one option is better than another on the basis of all the criteria and to easily determine the relative importance of these criteria. In the context of this work the AHP has been used to compare different criteria and parameters in order to define a relative preference quite possible clear and objective.
To achieve this target, a criteria hierarchy matrix (figure 1) has to be filled by carrying out a number of pair-wise comparisons, in which each criterion is compared to all the other criteria, according to its performance in achieving the pre-established objective respect to the others. This involves assignment of weights or numerical judgments ranging between 1 and 9 to represent the importance of each criterion relative to another one. Assigning a value of 1 if both criteria are equally important, and a value of 9 if the criterion being compared is clearly more important than the other. Intermediate values are assigned according to their relative importance (Saaty, 1990). Using the weights assigned in the criteria hierarchy matrix, a vector of priorities can be computed as a function of the relative importance of the criteria: in mathematical terms, the principal eigenvector is computed, and when normalized, becomes the vector of priorities (figure 1). Moreover a consistency (λ) in preferences can be carried out to check the redundant number of comparisons, in order to alert the Decision Maker to any inconsistencies in the comparisons. A λ value of zero indicates perfect consistency, while the inconsistency is as much high as much big is the value of the λ.

	Criteria					
Criteria	**1**	**2**	**3**	**4**	**5**	**N**
1	1.00	reciprocal	reciprocal	reciprocal	reciprocal	reciprocal
2	RW_{21}	1.00	reciprocal	reciprocal	reciprocal	reciprocal
3	RW_{31}	RW_{31}/RW_{21}	1.00	reciprocal	reciprocal	reciprocal
4	RW_{41}	RW_{41}/RW_{21}	RW_{41}/RW_{31}	1.00	reciprocal	reciprocal
5	RW_{51}	RW_{51}/RW_{21}	RW_{51}/RW_{31}	RW_{51}/RW_{41}	1.00	reciprocal
N	RW_{N1}	RW_{N1}/RW_{21}	RW_{N1}/RW_{31}	RW_{N1}/RW_{41}	RW_{N1}/RW_{51}	1.00

→

Vector of Priorities

PV
W_1
W_2
W_3
W_4
W_5
W_N

Notes: *RWij is the relative weight of criterion i with respect to criterion j*

Figure 1 - Hierarchy Matrix and Vector of Priorities

2. QUALITY INDEX COMPUTATION

AHP methodology has been applied to compute the Road Quality Index based on the combination of different criteria C (C = 1, …,s), each of which is represented by one or more attributes K (K = 1, …,p). Particularly, the Hierarchy Matrix from AHP has been used both to associate a weight to the identified reference criteria (W_C) and to define the relative importance of the attributes K combining each criterion (w_K). Furthermore, starting from the road data, the performance measurement Zc_k of each attribute K is obtained by the way of a post-elaboration (see paragraph 4).
In the figure 2 the overall scheme to compute the Quality Index (QI) is reported. In the scheme two parts are easily identifiable: one (Decision Maker Area, DMA) connected with the definition of the weights of criteria (W_C) and of attributes (w_K), the other one (Road Data Area, RDA) connected with the data related to the road.
Outputs from these two area are the inputs for the Quality Index computation. Specifically, for each criterion C, in function of the performance measurements Zc_K of the attributes K and their relative weights w_k, the Performance Criterion Indicator (PI_{Ci}) of each road segment "i" is computed as follows:

$$PI_{Ci} = \sum_{k=1}^{p} Zc_{ki} \cdot w_k \quad (1)$$

where:
w_k= Weight associated with the k-th attribute representing the criterion C (Σ w_K = 1)
Zc_{ki}= Normalized measurement of the k-th attribute for each road segment i ($0 \leq Zc_{Ki} \leq 1$)
PI_{Ci} = Performance Criterion Indicator of road segment "i". ($0 \leq PI_{Ci} \leq 1$)

Therefore, by the way of the Performance Criterion Indicator (PI_{Ci}) and the weight (W_C) associated to each criterion, the Quality Index of the i-th road segment SQI_i is obtained:

$$SQI_i = \sum_{C=1}^{s} PI_{Ci} \cdot W_C \quad (2a)$$

If a network analysis have to be carried out involving different roads, it could be appropriate to introduce another criterion related to the usefulness of the road within the network system.
The usefulness criterion (U) is valued by the computation of its attributes Zu_k and relative weights w_k as shown in figure 2. Hence, the Segment Quality Index SQI_i is valued by the following equation:

$$SQI_i = U \cdot \sum_{C=1}^{s} PI_{Ci} \cdot W_C \quad (2b)$$

Finally, in order to obtain a quality index of a road consisting of n segments, the Road Quality Index (RQI) is computed as:

$$RQI = \frac{\sum_{i=1}^{n} SQI_i \cdot L_i}{\sum_{i=1}^{n} L_i} \quad (3)$$

where
L_i : length of the i-th road segment.

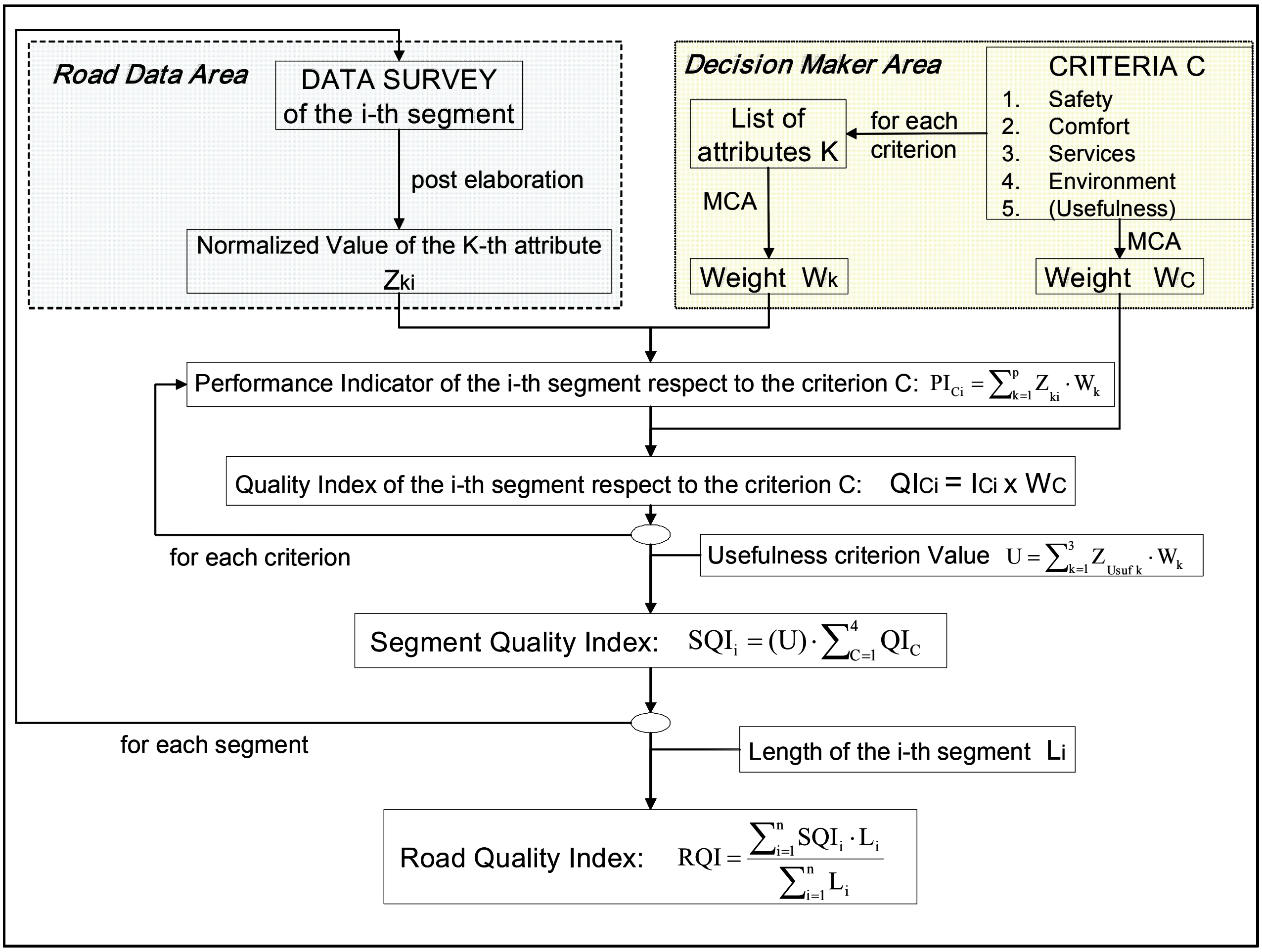

Figure 2 - Quality Index Computation Flow Chart

3. CRITERIA AND ATTRIBUTES

As introduced in the paragraph 2, the choice of the criteria and their attributes is the first step of the evaluation process.
Specifically, starting from current state of knowledge five reference criteria of the road quality index have been identified: Safety, Comfort, Services, Environment and Usefulness.
Referring to the definition of the attributes, the procedure has been related to two lane rural roads which represent the largest part of the network and carry a considerable share of traffic mobility.
For each criterion a list of attributes has been defined (table 1), with the aim to select significant parameters, also linked to road data coming from an high speed survey system.
In this field it was fundamental the use of the Mobile Laboratory of the Department of Civil and Environmental Engineering (Cafiso et al. 2003a), which allows to collect the main part of the required information related to the infrastructural features.

Table 1 – List of criteria and related attributes

CRITERION	ATTRIBUTE		
Safety	1	IHSDM Expected Accident Rate	
	2	Design Consistency	
		2a	Lamm's Criteria
		2b	Sight Distance
		2c	Percent time-spent-following
	3	Pavement: Skid Resistance	
	4	Signs	
		4a	Signs
		4b	Markings
Comfort	1	Level of Service	
	2	Evenness	
	3	Aesthetic	
Services	1	Number of service areas	
	2	Number of parking turnouts	
Environment	1	Air pollution	
	2	Noise and vibration	
	3	Water pollution	
Usefulness	1	Accessibility	
	2	Network Integration	
	3	Travel time	

3.1 Measurement of the attributes

For each criterion, the performance measurement Zc_k of the selected attributes K is the phase characterizing the Road Data Area (figure 2). For each criterion, the set of attributes K has to be representative of the road serviceability, use and management needs. In order to carry out a pilot implementation for a better explanation of potentialities of the proposed model, attributes related to the five selected criteria were defined. Different levels of detail could be observed in attributes definition, since the in-depth analysis of all attributes is not the goal of the paper which will focus above all on the methodological approach.
In the following just a synthesis of suggested measurement modalities is reported. Readers interested in a deeper explanation can consult the reported references.

Safety Criterion

The road safety performance is measured referring both to the observed accident situation and to different road features related to safety. In this way it is possible to overcome the random nature of the accident phenomenon and to highlight the road characteristics relevant for the safety improvements of the road.

Expected Accident Rate Z_{saf_1}

The prediction of the expected road safety performance was carried out by means of Crash Prediction (CP) Module of the Interactive Highway Safety Design Model (IHSDM). IHSDM is a set of highway safety analysis software tools developed by the Federal Highway Administration (Harwood et al., 2000). In the CP module the accident frequency estimate calculated with a base model is adjusted with the accident modification factors (AMFs), that represent the safety effects of individual geometric design and traffic elements. It takes into account exposure, lane width, shoulder width and type, driveway density, roadside hazard rating, horizontal curve length and radius, presence of spiral transition, additional lanes, superelevation and grade.

All the geometrical characteristics were obtained by the way of GPS survey and analytical alignment reconstruction (Cafiso et al. 2002b).
When a crash history of the site is available, the Empirical Bayesian (EB) procedure provides a methodology to combine the accident frequency predicted by the accident prediction model with the accident frequency from the site specific accident history data.
Based on the number of accidents carried out from the IHSDM, the segment can be subdivided in sections (single geometric elements) with different levels (A, …, E) of Expected Accident Rate (AR).
The performance measurement of the segment i-th respect the AR attribute acc/10^6 veic x km] is then computed by the following equation (Camomilla, 1997):

$$z_{saf\,1} = 1 - (12\%E + 8\%D + 4\%C)$$

where %C, %D, %E indicate the lengths percentages of the segment with the highest level of AR.
Table 2 shows the threshold levels adopted in the pilot implementation (paragraph 5).

Table 2 – Definition of the level of measurements

Level	Accident Rate
A	AR $\leq$ 0,20
B	0,20 < AR $\leq$ 0,30
C	0,30 < AR $\leq$ 0,45
D	0,45 < AR $\leq$ 0,55
E	AR > 0,55

Lamm's criteria Z_{saf_2a}

Lamm Safety Module (Lamm et al.,1999 - 2005) gives a classification of the horizontal alignment with three different levels (Good, Fair, Poor), coming from single quantitative safety criterion related to design consistency (Safety Criterion I), operating speed consistency (Safety Criterion II) and driving dynamic consistency (Safety Criterion III). The performance measurement of the segment i-th is computed by the following equation:

$$z_{saf\_2a} = 1 - \frac{\text{Km of poor curves}}{\text{Total km of curves}}$$

Sight Distance Z_{saf_2b}

On the base of the video-images acquisition a software has been implemented (Cafiso et al. 2003a) in order to compute the sight distance (SD). The performance measurement Z_{saf_2b} of the segment i-th is defined equal to the percentage of segment length with SD greater than or equal to Stopping Sight Distance.

Percent time-spent-following Z_{saf_2c}

This attribute could be computed following the procedure suggested by the HCM 2000 (TRB 2000) for the computation of the LoS for rural roads.

Skid Resistance Z_{saf_3}

On the base of a skid survey the homogeneous sections of the segment are computed (Cafiso et al. 2003b). The performance measurement Z_{saf_3} of the segment i-th is valued by the following equation (Camomilla, 1997):

$$z_{saf\_3b} = \%A + \frac{3}{4}\%B + \frac{2}{4}\%C + \frac{1}{4}\%D$$

where %A, %B, %C, %D indicate the lengths percentages of the segment with the highest level of skid resistance. Table 3 shows the threshold levels adopted in the pilot implementation.

Table 3 - Definition of the level of measurements

Level	Skid Resistance
A	CAT $\geq$ 60
B	50 $\leq$ CAT < 60
C	40 $\leq$ CAT < 50
D	30 $\leq$ CAT < 40
E	25 $\leq$ CAT < 30
F	CAT < 25

Signs Z_{saf_4a} - Markings Z_{saf_4b}

Based of the video analysis of the images a judgement of the signs and markings condition is carried out by the way of the values showed in table 4.

Table 4 - Definition of the judge of measurements

Judge	Value
Good	5
Fair	3
Poor	1

The measurement of the segment i-th respect the signs attribute is computed by the following equation:

$$z_{saf\_4} = \frac{L_{good} \cdot 5 + L_{fair} \cdot 3 + L_{poor}}{5 \cdot \text{Length of segment}}$$

where L_{good}, L_{fair}, L_{poor} indicate the segment lengths characterised from signs Z_{saf_4a} or markings Z_{saf_4b} respectively at good, fair or poor level.

Comfort Criterion

The road comfort performance is measured referring to traffic flow conditions, pavement-vehicle interaction and driving pleasure as perceived by the road user.

Level of Service Z_{comf_1}

The LoS has been computed using the HCM 2000 (TRB 2000) procedure. The input data have been carried out by the way of road agency traffic database and Mobile Laboratory survey (using both images and GPS acquisition and post-elaboration).

The performance measurement Z_{comf_1} of the segment i-th is defined in function of LoS value. In figure 3 the relationship used in the pilot implementation for two lane rural roads is shown.

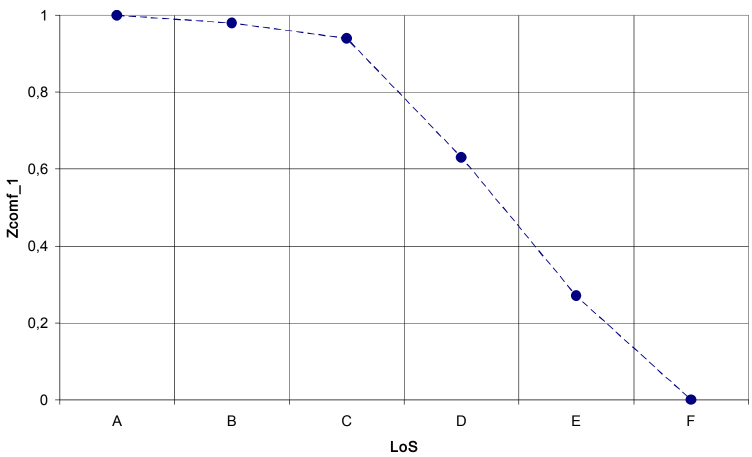

Figure 3 – Function relating LoS to the performance measurement

Evenness Z_{comf_2}

Based on the evenness survey, the IRI is computed and the homogeneous sections of the segment are carried out (Cafiso et al. 2003a). The performance measurement Z_{saf_3} of the segment i-th is valued by the following equation:

$$z_{comf\ 2} = \%A + \frac{3}{4}\%B + \frac{2}{4}\%C + \frac{1}{4}\%D$$

where %A, %B, %C, %D indicate the lengths percentages of the segment with the highest level of evenness. Table 5 shows the threshold levels adopted in the pilot implementation

Table 5 - Definition of the level of measurements

Level	IRI
A	IRI $\leq$ 2,5
B	2,5 < IRI $\leq$ 3,0
C	3,0 < IRI $\leq$ 3,5
D	3,5 < IRI $\leq$ 4,0
E	IRI > 4,0

Aesthetic Z_{comf_3}

The Aesthetic attribute represents just a component of the comfort as driving pleasure perceived by the road user and its subjective nature results in a complex measure of this parameter. Therefore, in the pilot implementation a low value of the weight w_3 (0.127) was obtained.

Based on images video analysis, a judgement of the aesthetic impact of the road environment is carried out by the way of the values shown in table 6:

Table 6 - Definition of the judge of measurements

Judge	Value
Good	5
Fair	3
Poor	1

The measurement of the segment i-th respect the Aesthetic attribute is computed by the following equation:

$$z_{comf\_3} = \frac{L_{good} \cdot 5 + L_{fair} \cdot 3 + L_{poor}}{5 \cdot \text{Length of segment}}$$

where L_{good}, L_{fair}, L_{poor} indicate the segment lengths with respectively good, fair or poor level.

Service Criterion

Referring to rural roads the number of service areas Z_{serv_1} and the number of parking turnouts Z_{serv_2} have been used to evaluate the performance of the segment respect to the services criterion. Specifically the measurement is computed by the following issues:

- for each segment the presence of a service area within a neighbourhood of 20 km is valued, assigning Z_{serv_1}=1, else Z_{serv_1}=0;
- Z_{serv_2} is equal to 1, if the number of parking turnouts in the segment is at least that one foreseen by the guidelines (1 at each 600 m), else Z_{serv_2}=0

Environment Criterion

The road environment evaluation is a complex task involving impacts due to construction, traffic and maintenance works. With the aim to define a quality index connected to the road use, the performance of the segment respect to the environment criterion has been linked to traffic impact on air pollution Z_{env_1}, noise and vibration Z_{env_2}, water pollution Z_{env_3}.

Each impact would be evaluated taking into account the amount of emission, the concentration limit and the vicinity of sensible fences.

Based on the available data, in the pilot implementation just the air pollution Z_{env_1} has been measured and considered as environment criterion performance. Specifically, the emission has been estimated by the way of the HDM-4 model (Kerali, 2000).

Usefulness Criterion

The usefulness criterion permits to take into consideration the rule of the different roads in driver travel within the network. The performance of the road respect to the usefulness criterion has been connected to its accessibility $Z_{usuf\ 1}$, its network integration $Z_{usuf\ 2}$ and to the time spent along the road respect the total travel time from origin to destination $Z_{usuf\ 3}$. All the attributes have to be computed respect to the mobility of the area and to the road network system.

In the implementation a qualitative judge to these attributes has been assigned in the range of values 1 (maximum usefulness) - 0 (minimum usefulness).

4. PILOT IMPLEMENTATION

The target of the pilot implementation was to check the applicability of the methodology to define the road quality of a two-lane rural road.
First of all, in the role of the Decision Maker the weights to represent the importance of each criterion relative to other one have been defined. Therefore, using the AHP method, the weights of the criteria have been computed (figure 4).

Hierarchy Matrix

CRITERIA	Safety	Comfort	Environment	Services
Safety	1	**2**	**5**	**5**
Comfort	0,5	1	**2,5**	**2,5**
Environment	0,2	0,4	1	**1**
Services	0,2	0,4	1	1

Vector of Priorities

Wc
0,526
0,263
0,105
0,105

$\lambda = 0$

Figure 4 – Definition of vector of priorities

Analougosily, the weights of attributes combining safety, comfort and usefulness criteria were defined with the AHP matrix. For the environment and services criteria, valued with not more than two attributes, AHP matrix was not useful (figure 5).

Safety Criterion

ATTRIBUTES	Accident rate	Design Cons.	Pavement	Sign
Accident rate	1	**2**	**2**	**5**
Design Consistency	0,5	1	**2**	**2,5**
Pavement	0,5	0,5	1	**2**
Sign	0,2	0,4	0,5	1

Vector of Priorities

Wk
0,452
0,271
0,182
0,095

$\lambda = 0{,}016$

Comfort Criterion

ATTRIBUTES	LoS	Roughness	Aesthetic
LoS	1	**2**	**5**
Roughness	0,5	1	**2**
Aesthetic	0,2	0,5	1

Vector of Priorities

Wk
0,584
0,289
0,127

$\lambda = 0{,}018$

Environment Criterion

Air pollution: $w_1 = 1$
Noise and vibration → not used in the pilot implementation
Water pollution → not used in the pilot implementation

Services Criterion

Number of service areas: $w_1 = 0{,}7$
Number of parking turnouts: $w_2 = 0{,}3$

Usefulness Criterion

ATTRIBUTES	Travel Time	Accessibility	Network integration
Travel Time	1	**1**	**1**
Accessibility	1	1	**1**
Network integration	1	1	1

Vector of Priorities

Wk
0,33
0,33
0,33

$\lambda = 0$

Figure 5 – Designation of attributes weights

A sample of about 50 km of the road named SS 417 in West Sicily were selected for the pilot implementation (Calabrò, 2004). The road has a single carriageway with two lanes, 3.75 m wide, and a shoulders, 1.50 m wide.
The road was subdivided in thirteen segments in function of the traffic level: the principal intersections were considered terminal nodes of each segment.

The performance indicator of each criterion has been computed starting from the weight w_k reported in figure 5 and the performance measurement Z_k obtained as illustrated in the previous paragraph. As a computational example, the input data for the PI related to the safety criterion are shown in figure 6.

	AR	Design Consistency			Pav.	Sign		
	IHSDM Expected Accident Rate	Lamm's Criteria	Sight Distance	Percent time spent-following	Skid Resistance	Markings	Signs	
	W_1	W_{2a}	W_{2b}	W_{2c}	W_{3b}	W_{4a}	W_{4b}	
	0,452	0,090	0,090	0,090	0,182	0,048	0,048	
Segment ID	Z_1	Z_{2a}	Z_{2b}	Z_{2c}	Z_3	Z_{4a}	Z_{4b}	PI_{saf}
SS417_1	0,76	0,80	0,40	0,53	0,71	0,66	0,64	0,66
SS417_2	0,96	0,91	0,60	0,59	0,79	0,72	0,58	0,81
SS417_3	0,12	0,43	0,70	0,90	0,68	0,68	0,50	0,41
SS417_4	0,00	0,67	0,80	0,80	0,53	0,74	0,66	0,37
SS417_5	0,26	1,00	0,80	0,25	0,50	0,63	0,65	0,45
SS417_6	0,88	1,00	0,60	0,79	0,72	0,60	0,68	0,77
SS417_7	0,75	0,90	0,70	0,50	0,72	0,60	0,64	0,69
SS417_8	1,00	0,60	0,40	0,82	0,62	0,60	0,64	0,76
SS417_9	1,00	1,00	0,20	0,82	0,72	0,60	0,67	0,79
SS417_10	1,00	0,56	0,60	0,82	0,52	0,63	0,65	0,76
SS417_11	0,52	0,50	0,40	0,87	0,58	0,71	0,60	0,56
SS417_12	1,00	0,40	0,35	0,60	0,56	0,60	0,60	0,72
SS417_13	0,98	0,45	0,35	0,32	0,75	0,66	0,80	0,72

Figure 6 – Computation of Safety Performance Indicator

A bar chart showing the values of PIs in the 13 segments of the selected road obtained for safety, comfort, environment and services criteria is reported in figure 7.

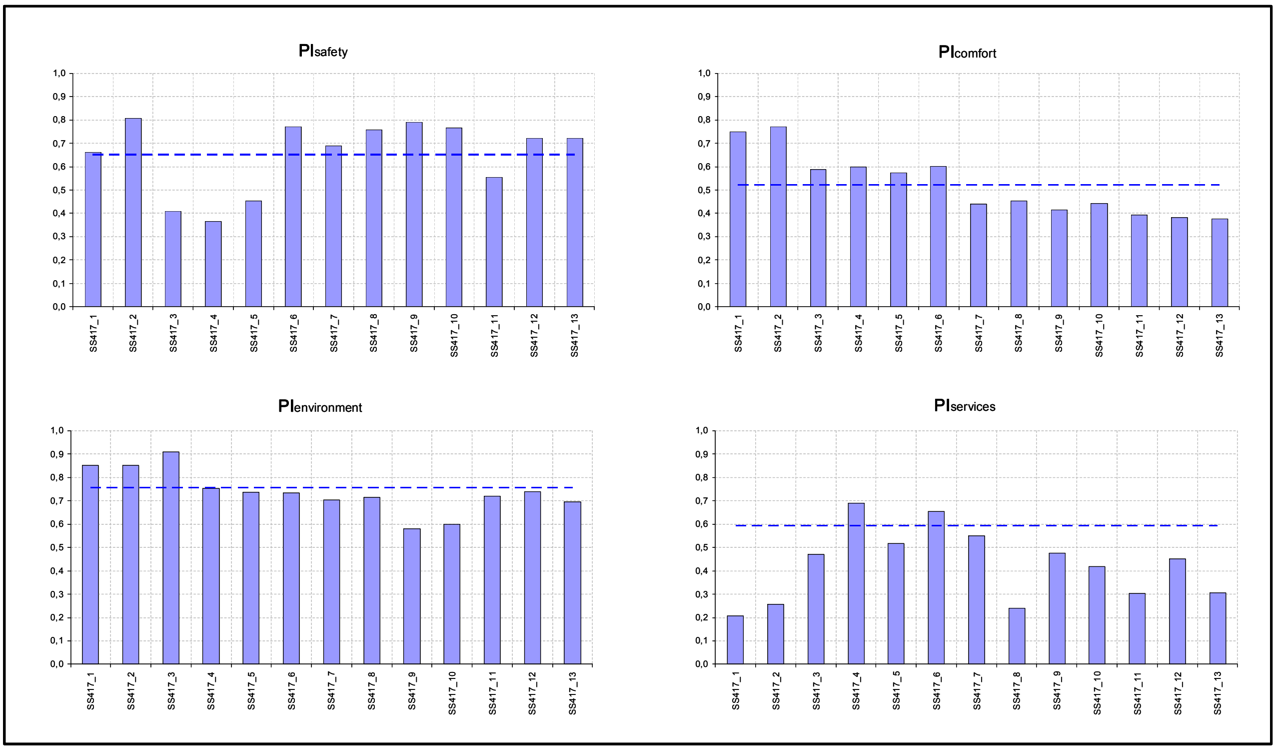

Figure 7 – Representation of overall Performance Indicators along the road

Using the weights W_C reported in figure 4, the Quality Index related to each criterion can be computed for each segment (figure 8). Then, estimating the “usefulness” of the road S.S.417 by the way of an assignment of qualitative judge to the attributes composing the Usefulness Criterion (table 7), the U has been computed.

Table 7 – Computation of the U value

Attributes	Value	Wk		
Accessibility	0,9	0,33		
Network Integration	0,7	0,33	⇨	U = 0,75
Travel time	0,6	0,33		

Therefore, the SQI of each segment with the equation (2b) and the overall Road Quality Index can be computed (table 8).

Table 8 – Segment and Road Quality Index Computation

Segment ID	PIsaf	QIsaf	PIcomf	QIcomf	PIenv	QIenv	PIserv	QIserv	U	SQI	Length [km]		RQI
SS417_1	0,66	0,35	0,75	0,20	0,85	0,09	0,44	0,05		0,511	5,075		
SS417_2	0,81	0,42	0,77	0,20	0,85	0,09	0,48	0,05		0,575	5,554		
SS417_3	0,41	0,21	0,59	0,15	0,91	0,10	0,63	0,07		0,398	5,316		
SS417_4	0,37	0,19	0,60	0,16	0,75	0,08	0,78	0,08		0,383	4,99		
SS417_5	0,45	0,24	0,57	0,15	0,74	0,08	0,66	0,07		0,402	2,108		
SS417_6	0,77	0,41	0,60	0,16	0,73	0,08	0,76	0,08		0,541	1,896		
SS417_7	0,69	0,36	0,44	0,12	0,70	0,07	0,69	0,07	0,75	0,468	8,31	⇨	0,47
SS417_8	0,76	0,40	0,45	0,12	0,72	0,08	0,47	0,05		0,482	3,828		
SS417_9	0,79	0,42	0,42	0,11	0,58	0,06	0,63	0,07		0,490	1,625		
SS417_10	0,76	0,40	0,44	0,12	0,60	0,06	0,59	0,06		0,483	2,678		
SS417_11	0,56	0,29	0,39	0,10	0,72	0,08	0,51	0,05		0,394	0,919		
SS417_12	0,72	0,38	0,38	0,10	0,74	0,08	0,61	0,06		0,467	2,472		
SS417_13	0,72	0,38	0,38	0,10	0,70	0,07	0,51	0,05		0,455	6,413		

In figures 8 and 9 two different representations of the results are shown, highlighting the quality level of each segment composing the road, ranked using different judgement levels.

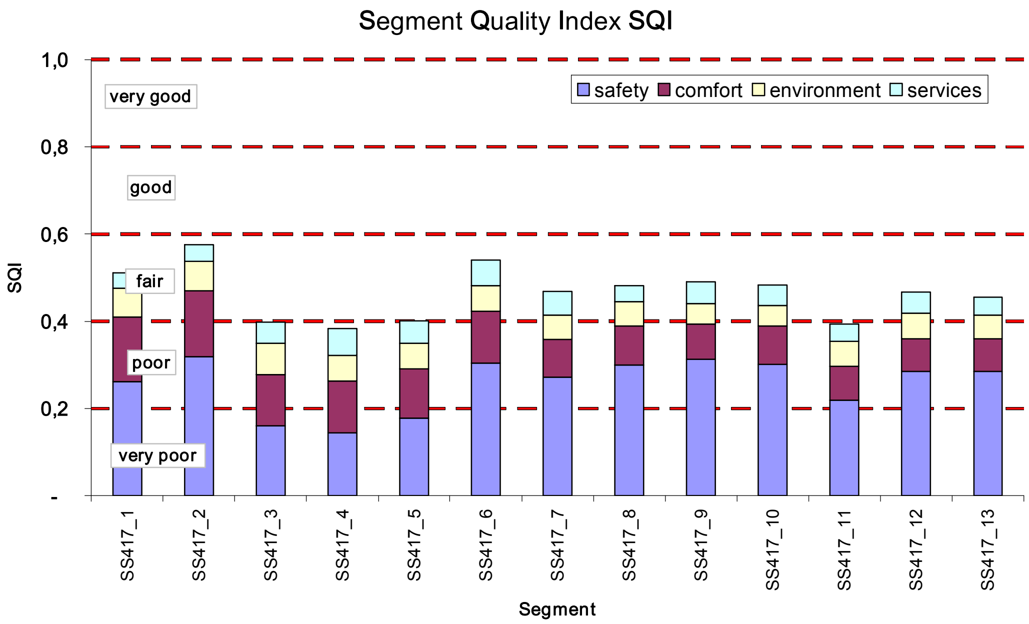

Figure 8 – Representation of SQI along the road

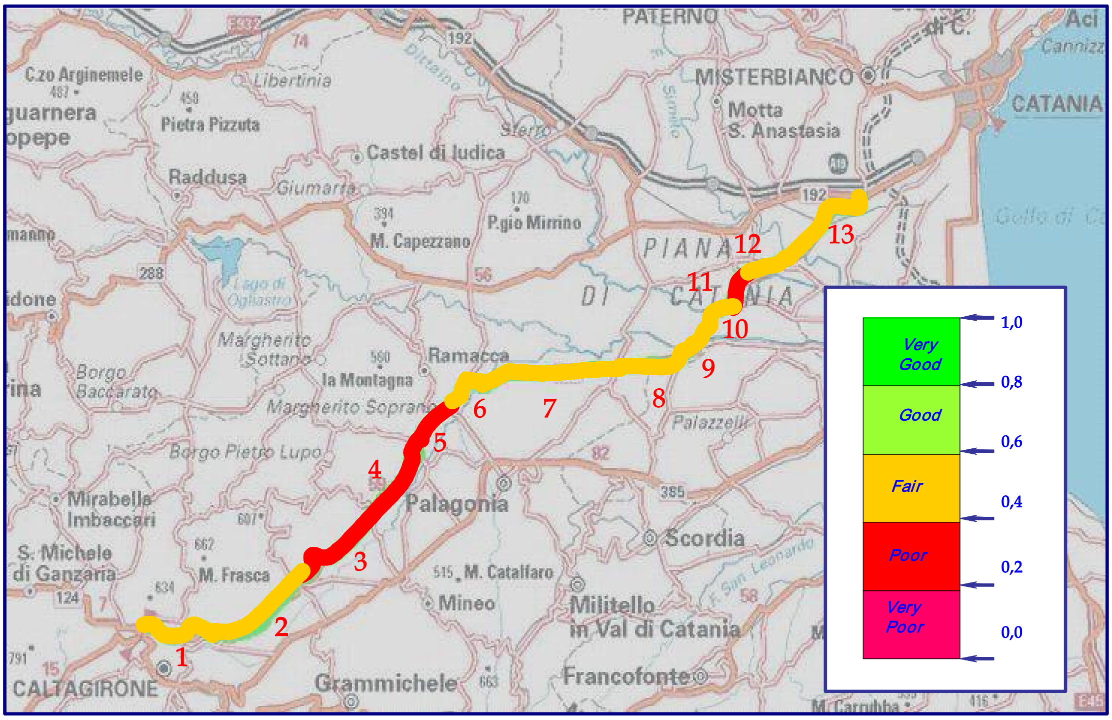

Figure 9 – Road S.S.417 valued by the way of Segment Quality Indices

CONCLUSION

The measurement of the road quality, respect to use and management needs, represents an important request into the road management process. In this field, several road performance indices related to management of road infrastructure, use and environment were defined.

Starting from the current state of knowledge, the performance of the road was valued using Safety, Comfort, Services, Environment and Usefulness as main reference categories.

Considering differences in the evaluation and importance of these categories, an approach based on the multicriteria Analytical Hierarchy Process (AHP) has been proposed, in order to obtain a Quality Index, able to evaluate the overall serviceability level of the road.

Specifically, AHP methodology does not require an explicit definition of trade-offs between the possible values of each attribute and it is easier for users to understand how outcomes are reached and how the weightings influence the outcomes.

The performance measurement of each criterion is carried out using a set of attributes representing the road serviceability, use and management needs. Referring to the definition of the attributes, the proposed procedure was related to two lane rural roads with special emphasis to attributes associated with Safety and Comfort.

Moreover, it is important to underline that type and logic of criteria and attributes could be changed without changing the working flow of the model. Also the detail of data has to be defined in function of the analysis level (strategic or programme).

The pilot implementation showed the feasibility of the proposed methodology based on the model and on the type of information acquired during an high speed survey.

The proposed approach allows to define deficiencies of each road segment which can cause low QI values. Further developments of the research can be connected to the definition of a maintenance activity prioritization procedure so as to optimize the quality offered by the road network respect to the available budget.

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