APPICATION OF GLOBAL LEVEL OF SERVICE AS AN EXPRESSION OF SERVICE RELIABILITY

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ABSTRACT

The concept of transport network reliability, born and developed over more than a decade, has become an unavoidable aspect in transport design, management and planning processes.

Existing reliability studies of road networks mainly contain four aspects: connectivity reliability, travel time reliability, travel cost reliability and capacity reliability. Connectivity reliability was the first measure of performance reliability, considering. the probability that a pair of nodes in a network remains connected. In Connectivity applications, the state of a link is shown by an integer variable, which is equal to 1 if the link operates normally and 0 when it fails. This methodology well represents special events situations but it doesn’t correspond to normal ones, like daily traffic flows fluctuations. In this case it is better to use performance reliability measures representing better normal situations (travel time, travel cost and capacity reliability). Several indicators were introduced and many techniques were applied in order to calculate them. In this way some micro-level problems were solved, but at the same time the problem lost connection from a general point of view.

As it will be seen, this paper presents a new approach for computing the states of links, whereby the performance reliability of a link is defined considering a Service Index, that varies from 0 to 1 and that synthesizes the state of the more important variables connected to reliability. Using a continuous index instead of a binary one it is possible to represent both special and normal situations with the same methodology.

The Service Index used is the Global Level of Service (GLS), a continuous index able to represent the quality of traffic circulation, developed by Department of Highways and Transportation of Polytechnic University of Bari.

After introducing GLS index and the methodology able to apply it on reliability issue, in this paper a simple application is present, considering traffic collected data and several geometrical measures of the chosen road network.

Keywords: global level of service, service reliability

1. TOWARDS AN UNIQUE RELIABILITY MEASURE

In a society in which the value of time is increasing and, at the same time, becoming similar for all the social classes, the importance of guaranteeing increasing reliability of daily trips becomes a main aspect of transport policy. In order to reach this purpose transport reliability studies have become an important aspect in transport research.

A powerful analysis tool of road networks is the simplest level of reliability given from the connectivity (Bell and Cassir, 2000) (Bell and Iida, 1997). It is the probability of the presence (or the lack) of a connection between a given OD pair. Connectivity is useful in representing catastrophic events like interruptions due to earthquakes, floods or accidents that completely block a road section and therefore (at least in transition situations) all the relative link. In these cases the most important thing is to reach the destination D (for first aid or for supplying primary needs) even if travel time and travel costs are greater than the usual conditions. As the probability of such events is very low and not even calculable through historical series, the concept of network vulnerability (Berdica, 2002) and the implementation of the game theory (Bell 2000) seem to be more suitable tools to cope with this kind of situation.

The binary aspect of connectivity, expressing the existence or non-existence of a connection, is insufficient for the most frequent situations, when the connections exist but they not work well. So, to better represent reality, it would be more effective to use, instead of the 0-1 state variable of connectivity reliability, a continuous index with values between 0 and 1 (Colonna and Berloco, 2005).

Assigning to every link in the network an index that varies from 0 to 1 and that summarises the state of the more important variables connected to reliability, a methodology could be found that permits links to be examined in series, in parallel and combinations between these two typologies. The output of this methodology should be a global index that allows estimation of the level of reliability of a network and that, for extreme situations, falls back on connectivity (if a path has one link with the index equal to 0 the path is interrupted).

The service index chosen for the methodology and for the application described in next pharagraphs is the Global Level of Service (GLS), a quantitative index of the traffic levels and road service developed in recent years at the Department of Highways and Transportation, in the Polytechnic University of Bari (Italy) (Colonna, 2000), (Colonna *et al,* 2002), (Colonna *et al,* 2003)

2. THE GLS INDEX VERSUS SERVICE RELIABILITY

In the Global Level of Service theory 54 indicators are taken into account. They are parts of six macro-groups: Safety, Travel Time, Services, Environment, Traffic Conditions, Comfort. The safety group is in its turn subdivided in the following subgroups: Geometric characteristics of the alignment and section, Structural characteristics, Functional characteristics and External interferences. These indicators are expressed in 54 indexes varying from 0 to 1 and they are averaged using mean weights that leads to a total index, also variable from 0 to 1. In order to carry out comparison of weights between the indicators it is possible to apply the "Analytical Hierarchy" methodology proposed from T.L. Saaty during the early 1980s (Saaty, 2001), particularly suitable for a congruent allocation of weights to large non congruent sets . Generally speaking, the parameters influencing the service index can be divided into two categories: time independent factors (for a fixed road typology) and time dependent factors, the trends of which are surveyed.

The application of the service index to the transport network reliability implies firstly establishing a minimum threshold value of the service index for each kind of link "*i*" (ie. common or suitable LOS) and then determining the probability that this threshold is exceeded. Having the distributions of the traffic features of the examined road (speed, flow, kind of user, etc.), the mean value or a value related to a fixed percentile of x_i can be used as the expected value x_i^* . Therefore, the service reliability could be described as "the probability that the expected value of the service index (x_i^*) is exceeded".

$$R_i = \Pr(x_i > x_i^*) \qquad \text{(Eq. 1)}$$

It would be reasonable to collect data that also represent emergency or abnormal situations in order to have a complete index distribution and not only one representing ordinary conditions. The innate difficulty related to collecting this kind of data could be bypassed with micro-simulation applications placed side by side with available statistical data.

3. METHODOLOGY

In the following sections we try to characterize the criteria to estimate the service reliability index with links in series and parallel. The case of paths sharing one or more links is also considered.

3.1 Links in series

It is not possible to use connectivity formulas when indices take values between 0 and 1 because these formulas have binary input and output values . In the case of links in series, the value of the reliability of the path must be between 0 and 1. It seems reasonable to assume that this value lies between the lowest and the highest service indices of the links. For this reason a weighted mean could be used, with link weights which represent the degree of influence on the entire path. A link with an high risk of congestion (frequently low levels of service) but a short length will have a smaller relative importance than a link with the same risk of congestion but a greater length (with probability of constant congestion for all its length). Therefore, a first weight should be introduced equal to the ratio between the length of a link and the length of the path which the link belongs to (2)

$$\alpha_{ij} = \frac{W_{ik} l_i}{\sum_{ij} W_{ik} l_i} \qquad \text{(Eq. 2)}$$

where *i* is the index of the links (between 1 and *n*), *j* that of the paths (between 1 and *p*) and W_i is a constant depending on the kind of road of link *i*. In particular, considering the functional road classification and the GLS theory, every kind of road assumes a maximum value of GLS in order to compare roads functionally different with the same index. The value of W_i for the "*k*" road typology represent the mean value of the GLS_{max} afferent to the "k" and "k-1" road typology, like shown in table 1.

Table 1 Constant W_j values

Road Kind	K	GLS_{max}	W_j
Primary Road (transit and flowing function)	1	1	0,95
Principal Road (distribution function)	2	0,9	0,85
Secondary Road (penetration function)	3	0,8	0,65
Local Road (access function)	4	0,5	0,25

If all the n links of the path *j* have the same characteristics, (2) becomes:

$$\alpha_{ij} = \frac{l_i}{\sum_{ij} l_i} \qquad \text{(Eq. 2a)}$$

Therefore, the same link used in different paths will assume different weights depending on the length of the different paths. Other discriminating factors could be used in order work out the weighted mean of the service indices, such as the average speed of the single link compared to the average speed of the path. However, since this factor is already considered in calculating the service index, this would mean considering it twice in the methodology. Since the service index is representative of traffic conditions and of road geometry whereas it is independent of link length, the use of the weighted mean described previously seems simple and suitable.

Therefore, using as a weight the ratio of the single link length to the entire path length, the value of reliability of a path of our network will be equal to (3).

$$R_j = \sum_{i=1}^{n} \alpha_{ij} \Pr(x_i > x_i^*) \qquad \text{(Eq. 3)}$$

3.2 Paths in parallel

3.2.1 Independent paths

A simple average value of the values obtained for the single routes is proposed by considering "p" parallel paths connecting an OD pair and supposing that they are independent, in order to obtain the value of reliability. Considering the number of independent paths “p” and the average value $\overline{R_j}$ of R_j, a very effective representation of network reliability could be obtain: $\overline{R_j}$ is a concise description of service reliability of the available paths linking O to D, while the number *p* symbolize the connectivity effectiveness between the OD pair (the higher *p*, the higher is the probability to reach *D* from *O* in abnormal situations or special events).

$$R_{OD} = \frac{\sum_{j=1}^{p} R_j}{p} = \overline{R_j} \qquad \text{(Eq. 4)}$$

3.2.2 Interconnected paths

The ideal condition represented by the presence of independent connections between an OD pair is very rare in real networks where there are several interconnections between the paths and therefore every link is used by many different paths. Therefore, for each OD pair, there are *q* paths, but only *p* of them are independent. In this more realistic situation a different methodology must be implemented. The connections used by different paths cause more negative effects on the whole network because it is likely that they have a greater flow and therefore they have a greater possibility of failure regarding the others links. Taking this into consideration, in order to obtain the reliability of a network pertinent to a single OD pair, reductive coefficients that take account of the interferences between paths should be used. Before finding the weight pertinent to a path, we therefore define another weight to be assigned to every link given by (5), where n_o is the number of paths that share the link.

$$\beta_i = \frac{1}{n_o} \qquad \text{(Eq. 5)}$$

This weight, like that chosen for the study of the links in series, only refers to the topology of the network. A weight deduced from flows of single paths could be used, however since flows are used in calculating the service index, it already takes this parameter into account (the occurrence of an event disturbing traffic flow will be taken into account with a new assignment of network flows, or through surveys during the period in which the effects of the event are perceived).

For this reason it is preferable to use a weight that refers only to the topological conformation of the network.

Then, the weight related to the path could be equal to the (6).

$$\gamma_j = \sum_{i=1}^{n} \alpha_{ij} \cdot \beta_i \qquad \text{(Eq. 6)}$$

Therefore, considering the interactions between the paths, the reliability of the single path *q* of the OD pair will be the (7).

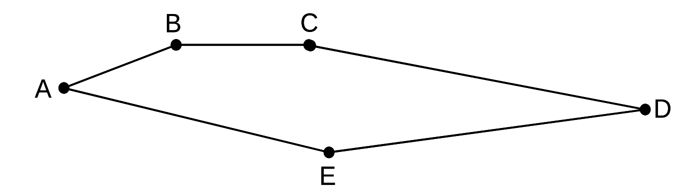
$$R_j = \gamma_j \sum_{i=1}^{n} \alpha_{ij} \Pr(x_i > x_i^*) \qquad \text{(Eq. 7)}$$

In order to obtain the reliability of the OD pair (R_{OD}), the mean of the reliability of single paths could be worked out by the (10), where R_{jp} and $R_{j(q-p)}$ have meanings similar to the ones described in the (4).

$$R_{OD} = \frac{\sum_{j=1}^{p} R_j}{p} + \frac{\sum_{j=p+1}^{q-p} R_j}{q-p} = \overline{R_{jq}} = \overline{R_{jp}} + \overline{R_{j(q-p)}} \qquad \text{(Eq. 8)}$$

4. SIMPLE NETWORK APPLICATION

In order to apply the described methodology an hypothetical simple network has been chosen, represented in the figure below with the lengths of the links:



link	length (km)
AB	2,5
BC	3,5
CD	6
AE	5,5
ED	7,5

Figure 1 network chosen with links length

The traffic data were collected on two rural roads near Bari district, in the south east of Italy. The characteristics of the network links have been assumed similar to those of the roads to which the traffic data refer.

In particular the links $\overleftrightarrow{AB}$, $\overleftrightarrow{BC}$ and $\overleftrightarrow{CD}$ could belong to the same typology and have the following characteristics:

- two-lane road
- lane width approximately 3,50 m
- paved verge width approximately 1,50 m
- good visibility
- no overtaking for approximately 35% of the route
- pavement in good condition
- absence of gutters
- medium environmental impact

- good presence of services for users
- main intersections in the nodes B and C with lighting system
- private accesses consented
- suitable emergency barriers
- good road and traffic signs.

Instead, the links $\overleftrightarrow{AE}$ and $\overleftrightarrow{ED}$ have the following characteristics:

- two-lane road
- lane width approximately 3,50 m
- absence of paved verge
- scarce visibility
- no overtaking for approximately 60% of the route
- pavement in bad condition
- absence of gutters
- low environmental impact
- absence of services for users
- main intersection in the node E without lighting system;
- private accesses consented
- absence of emergency barriers in the major part of the route
- very poor road and traffic signs.

It was assumed that the traffic data collected refer respectively to the links $\overleftrightarrow{AB}$ and $\overleftrightarrow{AE}$. Furthermore we hypothesised that the most attractive node of the network is "D"; consequently the overloaded links are exactly $\overleftrightarrow{ED}$ and $\overleftrightarrow{CD}$. In order to reach this intent some opportune flows were added in nodes B, C and E.

The traffic data was collected during three weeks in November and December 2006 along two secondary rural roads in Puglia, having similar characteristics to those described above. The surveys were carried out with a radar detector, able to gather information about the speed and class of individual vehicles as well as the traffic flow on survey sections. During the survey period no exceptional events able to influence the traffic flow (accidents, maintenance works and/or intense atmospheric events) occurred. Such data therefore seem to represent well the ordinary traffic situations in a rural zone in expansion.

The work days traffic data (from Monday to Friday) and the average daily tendency of traffic flows have been considered.

4.1 Results

In the following diagrams the traffic flows for every link of the network and the tendency of the service index (averaged on 15 days of survey from 0:00 to 24:00) are shown.

In order to calculate the service index, in addition the traffic data (flow and traffic composition) and speed distribution, the characteristics listed previously were used (for the sake of brevity not all the 54 GLS indicators under investigation are shown).

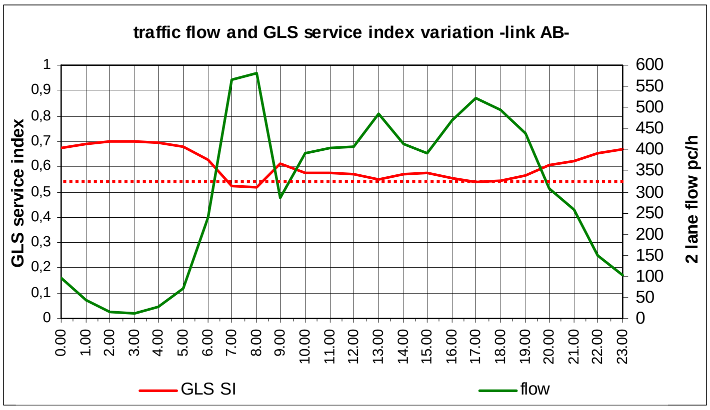


Figure 2 Flow and GLS SI trends -AB link-

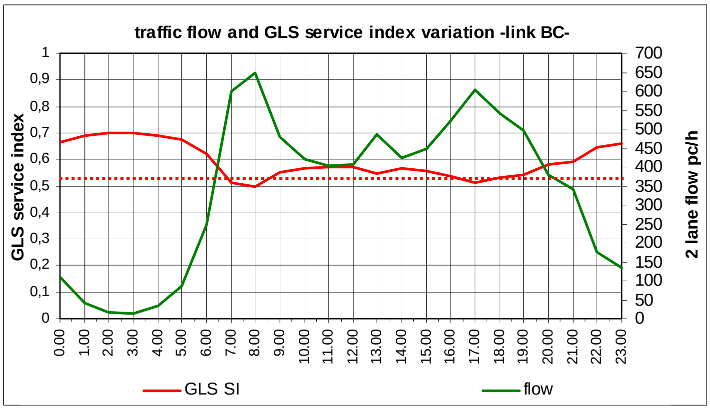


Figure 3 Flow and GLS SI trends -BC link-

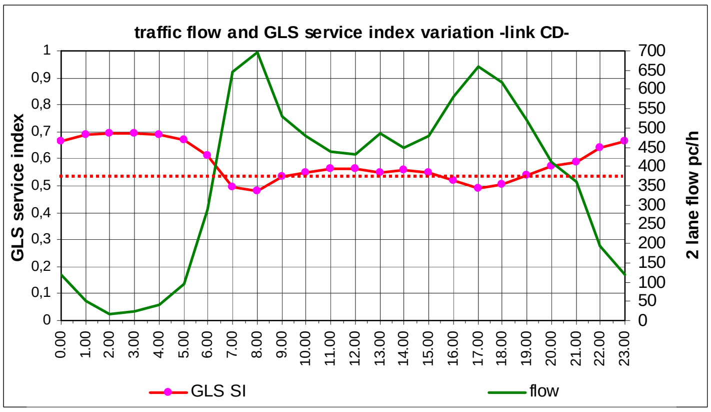


Figure 4 Flow and GLS SI trends -CD link-

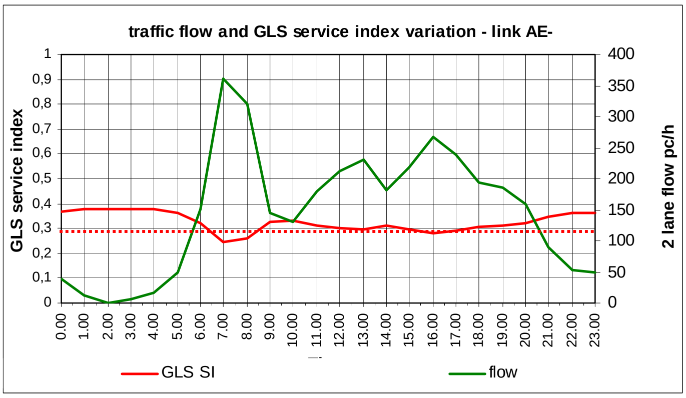


Figure 5 Flow and GLS SI trends -AE link-

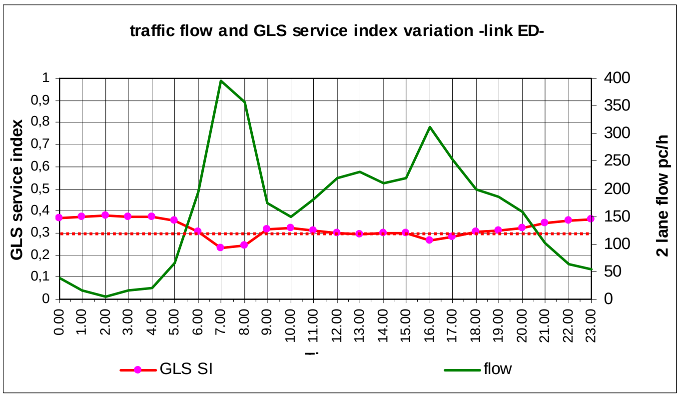


Figure 6 Flow and GLS SI trends -ED link-

Before proceeding to the calculation of the reliability of the single links, of the two paths and of the network, it was established that the fixed link index (Xi*) corresponds to the geometric characteristics assumed and to an HCM level of service "C" for all the links. As a consequence for the links $\overleftrightarrow{AB}$, $\overleftrightarrow{BC}$ and $\overleftrightarrow{CD}$ an acceptable value of the fixed index is equal to 0,55 and for the links $\overleftrightarrow{AE}$ and $\overleftrightarrow{ED}$ it is 0,29. Considering a temporal daily interval (24 hours) the following results are obtained.

Table 2 Results for actual situation -24 hours interval

	link	$\alpha_{ij} = \frac{l_i}{\sum_{ij} l_i}$	x_i^*	$\Pr(x_i > x_i^*)$	$R_j = \sum_{i=1}^{n} \alpha_{ij} \Pr(x_i > x_i^*)$
path AED - 24 hours -	AE	0,4231	0,29	0,91	**0,88**
	ED	0,5769	0,29	0,86	
path ABCD - 24 hours -	AB	0,2083	0,55	0,95	**0,85**
	BC	0,2916	0,55	0,86	
	CD	0,5000	0,55	0,80	

Therefore, since the two paths are independent, the network reliability is equal to 0,865. However, this result is only partial because considering only daytime periods during which the infrastructure is actually used, the results are supposed to be more “reliable”. In order to have a true value of reliability, the same data was analysed for a 12 hours period (from 6:30 a.m. to 6:30 p.m.), obtaining next results.

In this case the network reliability is equal to 0,445, therefore the situation represented is even more realistic and it is possible to detect that the $\overleftrightarrow{CD}$ has a greater influence. In fact it is the most overloaded link during daytime hours and at the same time the longest one of the path “ABCD”. In order to resolve this situation it would be reasonable to improve to the link in question. Since its overall situation (services, lighting system, safety etc.) is fairly good, the only possible solution would be to widen the road section but this solution would bring discontinuity to the path and would cause numerous and well-known problems.

Table 3 Results for actual situation -12 hours interval

	link	$\alpha_{ij} = \frac{l_i}{\sum_{ij} l_i}$	x_i^*	$\Pr(x_i > x_i^*)$	$R_j = \sum_{i=1}^{n} \alpha_{ij} \Pr(x_i > x_i^*)$
path AED - 12 hours -	AE	0,4231	0,29	0,67	**0,57**
	ED	0,5769	0,29	0,49	
path ABCD - 12 hours -	AB	0,2083	0,55	0,72	**0,32**
	BC	0,2916	0,55	0,32	
	CD	0,5000	0,55	0,16	

A more effective solution would be to improve the “AED” path to the same geometric and functional standard as the path “ABCD”. Analyzing this situation and leaving the traffic flows unchanged gives the results in table 4.

Table 4 Results for improved AED path -12 hours interval

path AED with improvement - 12 hours -				
link	$\alpha_{ij} = \frac{l_i}{\sum_{ij} l_i}$	x_i^*	$\Pr(x_i > x_i^*)$	$R_j = \sum_{i=1}^{n} \alpha_{ij} \Pr(x_i > x_i^*)$
AE	0,4231	0,55	1,00	1,00
ED	0,5769	0,55	1,00	

In practice, the reliability of path “AED” would be equal to 1 and the network one would be equal to 0,66. Naturally this situation could be found only during the opening period of the improved path in which only the habitual users cover it. A natural induced flow coming from the alternative “ABCD” path is expectable, since the “AED” path length (one kilometre longer than “ABCD”) could be compensated by its better level of service. A natural redistribution of the flows, besides being probable, would strengthen and bring better reliability to the entire network.

Supposing that the flows from the node “A” could be distributed equally on the two paths and that the nodes “B”, “C”, and “E” generate the same flows as at the moment, the results in table 5 are obtained.

Table 5 Results for improved situation - flows equally distributed -12 h. interval

	link	$\alpha_{ij} = \frac{l_i}{\sum_{ij} l_i}$	x_i^*	$\Pr(x_i > x_i^*)$	$R_j = \sum_{i=1}^{n} \alpha_{ij} \Pr(x_i > x_i^*)$
path AED - 12 hours -	AE	0,4231	0,29	1,00	0,99
	ED	0,5769	0,29	0,99	
path ABCD - 12 hours -	AB	0,2083	0,55	1,00	0,91
	BC	0,2916	0,55	0,96	
	CD	0,5000	0,55	0,85	

Therefore the network reliability results equal to 0.95, remarkably higher to the previously calculated one.

4.2 CONCLUSIONS

In this paper a new methodology in order to calculate service reliability has been described. The example carried out reveals that it could be very powerful to test, design and manage a road network. Specifically the simulation has been carried out using the GLS service index that comprises 54 indicators regarding safety, travel time, services, environment, traffic condition, comfort, geometrical, structural and functional characteristics. Consequently, improving one or more of these characteristics it is possible to simulate future and desirable situations in order to increase reliability of specific links and to obtain the effect on the entire network rapidly. Managing these 54 indicators is not unproblematic, therefore the future applications will be to apply this methodology to real road networks and also try to consider more complex urban networks. Furthermore, the real aim of this study is reaching a general tool in order to calculate reliability that is often represented by micro-level indicators and therefore sometimes have lost connection from a general point of view. Travel time, capacity and connectivity surely are the most effective indicators representing reliability (probably average travel time and buffer time will be the most intuitive reliability indicators for users). However, it would be better not leaving other important indicators apart as the ones considered in the LOS calculation or comfort, safety, environment, etcetera.

Future targets will be comparing the results obtained by testing the methodology on a real (and more complex) road network with other already existing techniques for calculating reliability. In addition, it will be useful to compare the results obtained by several typologies of road networks with the aim of fixing the upper and lower levels of the performance of the same ones.

REFERENCES

BELL M. G. H., IIDA Y. (1997) - *Transportation Network Analysis* - John Wiles & Sons, England;

BELL M. G. H., CASSIR C. (2000) - *Reliability of Transport Networks* - Research Studies Press, England;

BERDICA K. (2002) - *An introduction to road vulnerability: what has been done, is done and should be done* - Transport Policy, 9 (2), 117-127

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* - Proceedings of the 11th SIIV National Conference, SIIV, Verona, Italy;

COLONNA P., D'AMOJA S., MAIZZA M., RANIERI V., (2002) - *The quality of the road service as a fundamental parameter in the technical, economic and strategic choices regarding safety and the road infrastructures* – Proceedings of the In Safe Roads in the XXIst Century: 2nd Conference, Budapest, Hungary;

COLONNA P., D'AMOJA S., MAIZZA M., RANIERI V., (2003) - *The Global Level of Service (GLS) as a tool for the measure of road performance* – Proceedings of the XXIInd PIARC World Road Congress, Durban, South Africa, Italian Report, pp. 68-79;

COLONNA P., BERLOCO N. (2005) - *Proposal of a criterion for defining the levels of service in a quantitative way: the service index* - Proceedings of the 3th International SIIV Congress, 22-24 September, Bari, Italy;

COLONNA P., BERLOCO N. *(2005); "An advanced concept of connectivity: the Service reliability"*: 3th International SIIV Congress, 22-24 September, Bari, Italy.

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* - Proceedings of the 10th SIIV National Conference, Acireale, Italy;

MAIZZA M. *(2004) - Metodi di valutazione e rappresentazione dei livelli di servizio viari* - PHD thesis in *"Sistemi di Vie e Trasporti, Infrastrutture e Territorio"*, Polytechnic University of Bari (Italy), Dept. Of Highways and Transportation;

SAATY T.L.; *The Analytic Network Process* (2001): RWS Publications, 4922 Ellsworth Avenue, Pittsburgh.