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Sustainability in Road Design: a Methodological Proposal for the Drafting of Guideline

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Abstract

This paper, starting from the U.S. experience (USGBC LEED) in the building field, through GBC ITALIA, underlines the need of a specific methodological approach in our country for a roads sustainable design. Therefore, we propose criteria for the methodological approach of a handbook of sustainability. In this guideline required and voluntary project requirements are identified; for each of these objectives, benefits, standards of reference and its methods of implementation are suggested. The above guideline, using detailed development tools (VA, LCA), could provide guidance to the road-designer in the evaluation and selection of strategies to drawing-up project performance standards of sustainability.

Keywords: Road; Sustanaibility; Manual; Global Confort.

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1. Introduction

The realization of transport infrastructure produces significant effects on the ecosystem, the economy and thus on social productivity, given the considerable consumption of not renewable resources (environmental, energy, etc.). The lack of adoption of sustainable practices integrated in the design of roads resulting in impossibility to make choices that lead to sustainable use of resources needed. Thus the idea and the need for the formulation and subsequent implementation of a system for defining and assessing sustainability techniques useful for the design, construction, operation and maintenance of road construction was born. Such a system may allow to:

- Encourage the continuous growth of skills, specifying the activities more contributing to the sustainability;
- Improve infrastructure performance by defining the objectives to be achieved;
- Measure the environmental benefits, economic and social issues related to identified design practices;
- Define and implement sustainability policies;
- Encourage the development of innovative practices and excellence;
- Diffuse the culture of sustainability among the private and public stakeholders: infrastructure designers (drafting of performance contract), consultants, local authorities (formulation of tender requirements), roads owners, managers, for maintenance and operation, contractors, research institutes.

2. The concept of sustainability

The concept of sustainability summarizes the complex issue of compatibility, globally, between economic, environmental and human values. The treatment of this theme was born from the awareness of a fundamental contradiction between the growth of the gross material and limited resources. A first realization of this situation dates back to the publication, by the Club of Rome, of the report entitled "The Limits to Growth" (Meadows, D., 1972), in which should be emphasized that the term growth does not refer to an increase purely quantitative of economic indicators rather than the qualitative dimension.

Sustainability is a global view of a form of development not only economic but also social, in which economic growth occurs within the limits of ecological ecosystems. If the man "consumes" more than the environment can provide or if he pollutes the resources, in short there will be no possibility of sustainable development, as defined in the report prepared by 'UNEP (United Nations Environment Programme) in 1987, known as the "Brundtland Report" from the name of its coordinator (published in Italy under the title "Our Common future"). It states that sustainable development is to be understood as development that "... meet the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development implies limits, not absolute, but under the present state of technology and social organization in the use of environmental resources and the capacity of the biosphere to absorb the effects of human activities ".

The term sustainable development, therefore, is the development compatible with maintaining the resources necessary to the life of humans and other organisms on the planet, the environment and the quality of human life. It follows that we need a global and preventive, rather than curative, approach and not just a good regulations in which individual measures themselves must be internally consistent and reflect a common strategic plan; we will require to policies and capacity cultural to convince the people involved in the construction of new lifestyles [1].

3. “Sustainable road” definition

Based on the above defined it is necessary to provide a definition of roads sustainability based on the concept of self-sufficiency. The road is "sustainable" if able to reach, during the phases of construction, maintenance and operation, the objectives underlying the design (regulations observance, safety, fluidity of movement, maintenance, energy efficiency, transport capacity ...) in a self-sufficient way so that the system "road" is self-sustaining, and then it can use effectively and efficiently resources, and non-renewable materials for its needs and ensures reproducibility while maintaining the. Therefore, to design "Sustainable Roads" is not enough to deal with issues of site management, recycling of materials, procurement of resources, energy efficiency, water efficiency, air pollution, etc. but we must address all the issues in a systemic way by optimizing the interrelationships [2].

4. Short overview of the international research

In the U.S., starting from what took place in the building from the USGBC (United State Green Building Council) for certification of environmental sustainability LEED (Leadership in Energy and Environmental Design), the manual for sustainable road "Greenroads", now at version 1.5, was designed and developed by the University of Washington (UW) in collaboration with CH2MHill. Greenroads is a sustainability rating system for the design and construction of roadways based on a set of "best practices" - defined as "credit" that define a score that quantifies the sustainability of the project. The foundation Greenroads, after 4 years of research tested on more than 50 various types of roads, certify, based on the score reached, the level of sustainability of the evaluated road [3], [4].

INVEST is the sustainable highways self-evaluation tool developed by the Federal Highway Administration, U.S. Department of transportation. Invest is also a collection of "best practices" - called "criteria" - which allows to integrate and measure sustainability in roadways projects. Currently being edited and improved, version 1 of the Invest tool will be release in the spring of 2012. The tool is being developed with ongoing input from state and local transportation agency officials and staff and professional organizations such as AASHTO and ASCE. INVEST also provides a score that defines the level of sustainability achieved (bronze, silver, gold and platinum) [5].

In Great Britain, The London Councils - Capital Ambition-developed the toolkit for a Sustainable "Highways Minor Works" Contract, tested by Croydon Council, which provides a series of steps to ensure the sustainability of projects in the evaluation process of public procurement. This system was designed to assist in the procurement of highway services more sustainable. In particular the following objectives are considered relevant: Increased recycled content, reduced transport DISTANCES, whole life cost important considerations, reduced energy use and CO2 Emissions, waste reduction, Reducing impact on the community ie noise and disruption [6].

5. Methodological approach for sustainable design

In analogy to what has been developed in the cited international studies, we define the following criteria for the methodological approach of a sustainability handbook. The steps to follow to introduce sustainability into the roadway design are developed in Figure 1 below. Each step, interrelated in a timely manner to the next, can define the overall design procedure in terms of sustainability by identifying the most appropriate methodological techniques to achieve the proposed strategic objectives.

STEP 1. Sustainability goals definition

We define the purpose, in terms of sustainability, which is to be achieved for each of the requirements identified in Steps 3 and 4.

STEP 2. Associated benefits definition

Useful step for the use of the methodology for the choices between different projects that can not be based solely on technical elements but also in terms of the benefits associated (environmental, social, etc…).

STEP 3. Project basic requirements definition

We define the basic requirements to be understood as the activities, procedures, analyzes, studies ... that the project must include and include the most critical aspects of sustainability (environmental aspects related to the sites crossed, relations between the road and surrounding environment, aspects of maintenance, waste management, noise pollution etc ...).

STEP 4. Project voluntary and innovative requirements definition

We define the voluntary (not mandatory) requirements that may have greater or lesser weight in terms of impact on sustainability and innovative requirements, not attributable to requirements already identified, but are "excellent" design.

STEP 5. Approach and methods definition to achieve project requirements

We suggest specific methods, traditional and universal, that allow to pursue the project requirement.

STEP 6. Key performance indicators identification

We identify the performance indicators of the performance requirement to be included in project contract.

STEP 7. Standard reference

We provide, for each requirement of the project, the regulatory and legislative reference devices that can measure the achievement of the requirements.

STEP 8. Current State of research

We provide, for each requirement of the project, information about the state of research useful for the design.

STEP 9. Case studies, examples and calculations

We provide examples of calculation and strategies for the determination of satisfaction of the requirement.

STEP 10. Criteria for awarding the score for the evaluation of the project

We provide a system, based on "environmental categories impacted", which gives the score for the effects that the achievement of observance requirement leads to the aforementioned categories.

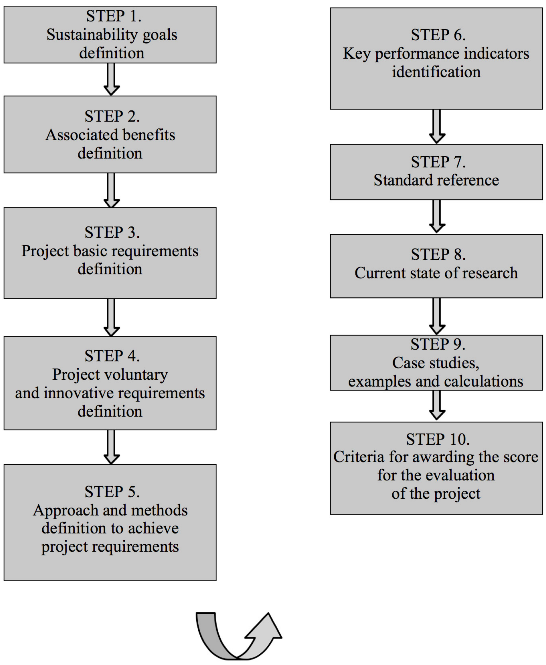

Fig. 1: Sustainability steps for road design

6. Sustainability in road action: the global comfort in road design

Global Comfort is the set of physical and mental sensations, dependent on the "Man-Road-Vehicle-Environment" set, which give the user a state of perception "optimal" using the road in all aspects of the overall performance road involving the achievement of synergistic triple objective of safety, efficiency and environmental quality. In this sense, the sustainability of plans and policies must take into account the functional balance of the required variables relating those objectives both individually and globally through the evaluation of their mutual interdependence, in the design, construction, operation and management [7].

Considered that the process of design, construction, maintenance and operation of road infrastructure is unitary, the development of algorithms, techniques and strategies for obtaining at the same time the predetermined level of safety, environmental quality and efficiency permits to ensure observance to the requirements.

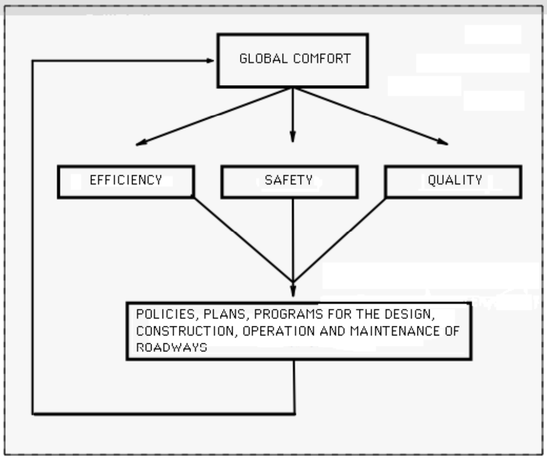

Fig. 2. The Global Comfort in the road management

By example, and as a possible initial contribution to the technical content of a sustainable roads manual, we report the results of some research, conducted in Italy, on maintenance strategies, on the reuse of waste materials, energy efficiency and road energy recovery which, having as objective the global comfort achievement, look systemically objectives of safety, efficiency and environmental quality to ensure sustainable design processing.

6.1. The optimization of maintenance

The maintenance policies and the optimal choice of intervention, in terms of resources, can produce both an increase in the level of efficiency, safety and quality. It is therefore necessary to define criteria for planning maintenance activities that achieve the best configuration for use of the financial budget for the various possible states of the pavement, taking into account the occurrence of other strategic objectives (minimization of the generalized cost of transportation, adequate level of driving comfort and safety, etc..).

In this regard, great importance is the maintenance of the intervention process optimization through analysis of relationships between different classes of variables that determine the conditions of road safety and implementation of appropriate intervention strategies that optimize the resources use ensuring the best level of functional efficiency and environmental of the road infrastructure. It must therefore provide a decision support system for the implementation of functional retraining as to secure the necessary conditions of reliability of the product road and at the same time to optimize the use of resources [8]. The awareness of the state in which the system is starting from functional and structural conditions is certainly basic premise of each maintenance strategy to determine a synthetic indicator of system state. These conditions are shown too in the Greenroads Manual v 1.5 - PR-9 (Pavement management System) at page 111 where the figure PR 9.3 represents the pavement conditions related to accumulated axle loads. Some recent studies have shown that the presence and influence of factors of uncertainty in the maintenance process makes necessary the use of stochastic models with which, starting from the knowledge of the initial state, one can calculate the state probability distribution at the end of the period (controlled stochastic process).

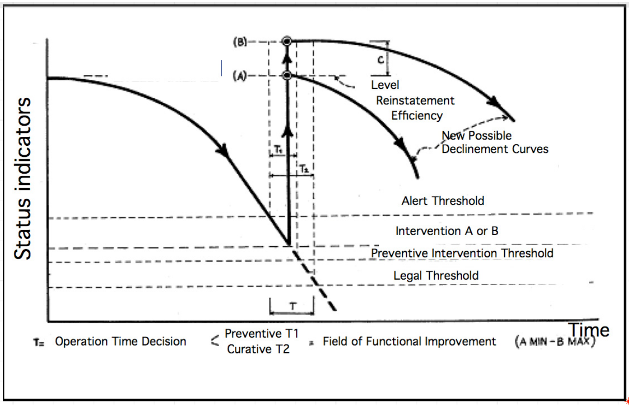

Fig. 3 Status indicators of the pavement conditions

Thus going beyond the models of preventive maintenance (certain knowledge of the state) and curative maintenance models (knowledge of the state takes action only when maintenance), you can include the use of a stochastic dynamic programming, such as processes decision and the law of a Markov deteriorating system in which each maintenance action is performed by successive steps in order to consider a finite number of possible states (rather than two: good and failed or three of the previous models) in which classify the system infrastructure through monitoring and knowing the deterioration at all times in order to decide the alternative intervention. It remains to be established then the optimality criterion (minimization of the average cost per unit of time, etc. ...) in order to determine the intervention policy. Following this approach, we assume that the set of possible actions is finite. Let $c_{ik}(t)\geq 0$ ($i=0,1,\ldots,m$; $k=1,\ldots,K$; $t=0,1,\ldots$) finite values of the average cost incurred at time t given that the system is observed in state i at time t, we envisage the decision dk. It is assumed that cik(t)=cik,, independent of t. Indicating, also, with Ct (t=0,1,…) the average cost at time t as a result of the decision strategy D, you want to get the strategy that minimizes the variable [8].

$$\Phi = \lim_{T\to\infty} \sup \frac{1}{T}\sum_{t=0}^{T} C_t \qquad (1)$$

that is, the average cost per unit of time

Using the transition probabilities p_{ij} of a Markov chain $\{X_t\}$, with a finite set of states, all belonging to the same class and ergodic, it can be shown that the function to minimize becomes:

$$\Phi = \sum_{j=0}^{m}\sum_{k=1}^{K} x_{jk} c_{ik} \qquad (2)$$

subject to the constraints of non negativity x_{jk}.

It is also shown that the solution of the algorithm exists and it is unique using the technique of Markov chains with regard to the probability of transition between the possible states of the artefact and applying to them a rule "excellent" for a decision formulated as a linear programming problem.

Ultimately, by analyzing a variety of integrated components that characterize the degradation of infrastructure, policies of intervention in terms of ride quality for the user and safe operation, for example, at lower cost average per unit of time (maximum efficiency) in optimum conditions in terms of the use of economic resources can be worked out.

6.2. The reuse of waste materials as secondary raw materials

The road construction produces large quantities of solid waste that must be managed through specific plans to minimize its disposal and reduction. The choice of materials used has implications for the construction, through the cycle of extraction, processing, transportation, use and disposal; the use of "local" material can support the local economy and reduce the transport.

Research on recycling techniques, namely the use of secondary materials to replace natural ones, has represented and still represents a major challenge to reduce the environmental costs of processing, allows the use of the residual materials resulting from manufacturing processes by increasing the quality of the final products. Several researches are being testing the reuse of unused residual materials from manufacturing processes in various industrial sectors for road pavement construction (glass, rubber, "ravaneto" ...). The use of the “ravaneto” (a residue of marble processing), has been evaluated, for example, in Corriere, F. , Et al. , D. (2007) [9]. To characterize the materials standard tests were conducted in laboratory; it was found that residues fall within the limitation range of base and foundations layers for road construction and performance contracts (Fig. 4, 5).

The evaluation of the acceptability of the materials to be used is, in fact, higher priority than to the later stages of analysis.

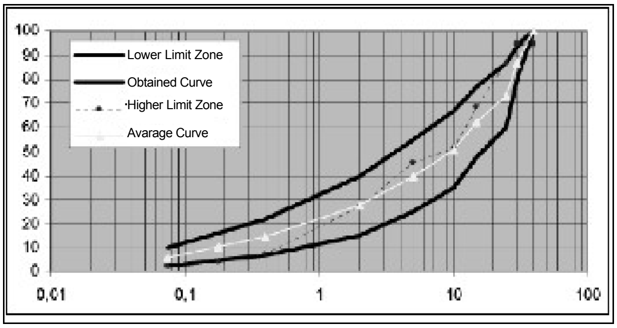

Fig. 4. (a) Zone limitation and granulometric curve of the Foundation Layer;

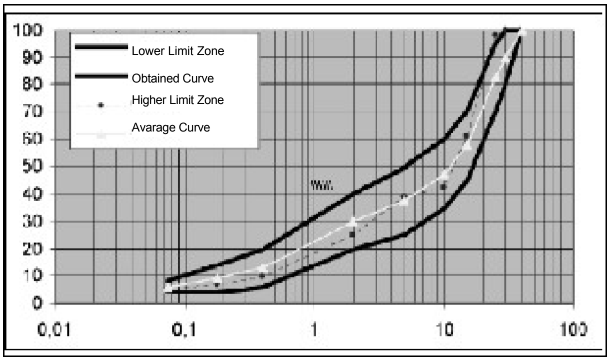

Fig. 4. (b) Zone limitation and granulometric curve of the Base Layer

Table 1 shows the results obtained for the foundation layer of Los Angeles test, CBR index and AASHTO test Mod. in comparison with the expected values in the contract. It is also reported in Table 2 the results of the Marshall test.

Table 1. Comparison of contract values and those of the test - layer of foundation Table 1. An example of a table

Layer of foundation (Dmax< 71 mm)	Contract values	Test values
Prova Los Angeles	< 30 %	24,96 %
Indice CBR	> 50	51,78
(dopo 4 gg di imbibizione in acqua)		
Prova AASHTO mod.	5	W=8 %
		Gs=2,09 g cm $^{-3}$

Table 2. Marshall test – layer of foundation Comparison of contract values and those of the test - layer of foundation

Marshall Test			
Bitumen (%)	Stability Marshall[N]	Slip [mm]	Rigidity [N mmˆ-1]
3,0	13.764	2,88	4.816
3,5	13.580	3,40	4.008
4,0	11.222	3,58	3.141
4,5	8.737	3,40	2.569

The research cited above also performed an economic analysis about the direct costs related to the process of extraction and transportation of natural aggregate in a wide area that includes much of the province of Trapani and the western part of Palermo and stressed the "indifference" between the use of natural “ravaneto” and aggregate. The use of residual materials “ravaneto” as recycling also means higher operations of the companies that extract and process the marble, where the unused portion is around 70 -80% of total extract, since it would eliminate the cost of provision and disposal as waste processing. The goal of “reduce lifecycle impacts from extraction and production of virgin materials” is considered too in the Greenroads Manual v 1.5 - MR-4 (Recycled Materials) at page 385. This is a favorable result for the reuse of “ravaneto” both from the standpoint of environmental and industrial applications as it would satisfy the dual advantage of reducing the growing demand for new quarry, for extracting, transforming a cost (allocation of the residue) in a potential revenue generated from the use of “ravaneto” for interventions, implementation and / or maintenance of roads.

6.3. Energetic - environmental efficiency and energy recovery from the road

One of the last challenges of applied research is to think the road like a space to potential energy content.

It is possible to "produce" energy from the passage of vehicles through the use of special grids, positioned below the road pavement, which exploit the pressure of the vehicles in transit and capture the kinetic movement in the braking phase. Then there is the possibility of channelling the energy generated by the road lighting systems with smart grid, always placed below the pavement. Solutions and other technologies such as mini wind turbines with vertical axis turbines, photovoltaic installation with solar cells, systems for the recovery of thermal energy from the ground, lighting systems with LEDs on the roadsides, high capacity sound absorbing panels, etc. can be installed along the road and contribute to the production and recovery of energy from the road itself, see for example Greenroads Manual v 1.5 - MR-6 (Energy efficiency). Figure 6 shows the economic, energetic and environmental diagram of the project Total Tool Zero Km road for 1 km of road [10]. Recently other researches are developed about environmental implications of traffic flow delays [11].

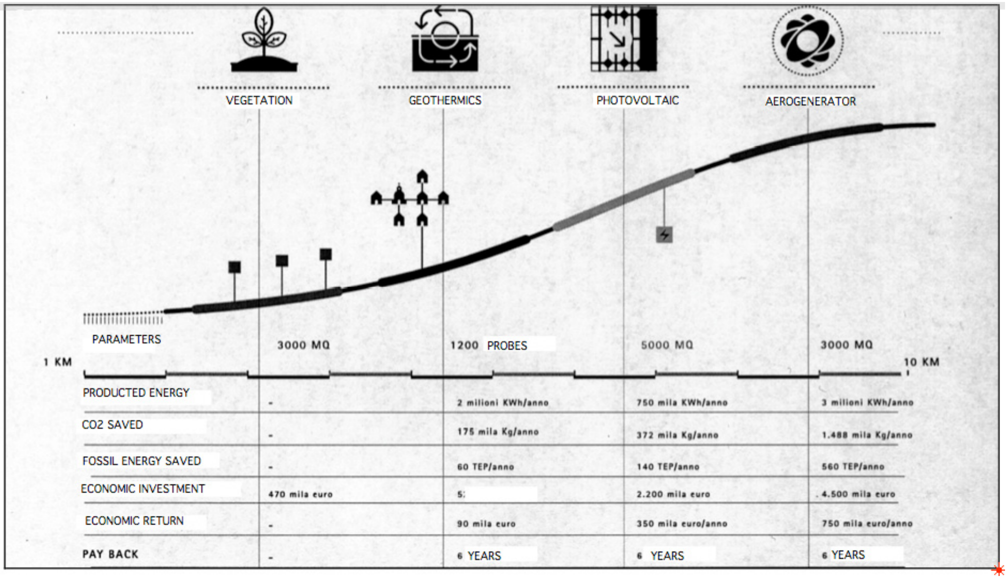

Fig. 5. Energy - environment equation - Total tool Km zero road

7. Conclusions

Today in Italy the relationship between road design and environment is essentially limited to the preparation of “environmental impact studies” that are translated into a set of mitigation measures, more or less effective, of the road on the environment; while there are no sustainable practices integrated in the design of roads and so is impossible to make choices that lead to sustainable use of resources needed.

To achieve roads sustainability is necessary to disseminate the culture transforming the way the roads are designed, constructed, maintained and managed, including through raising awareness of all those involved in process of construction of roads on the impact that they have on the quality of life of citizens. Therefore, contrary to what happens, we need to think organically to the application of sustainability in road design and then make sure that every element of design, and the project as a whole, respond to sustainability understood in technical and scientific terms and not in "emotional" way as is often done. In this paper “Sustainable Road” is intended the road able to reach, during the phases of construction, maintenance and operation, the objectives underlying the design (regulations observance, safety, fluidity of movement, maintenance, energy efficiency, transport capacity...) in a self-sufficient way so that the system "road" is self-sustaining, and then it can use effectively and efficiently resources, and non-renewable materials for its needs and ensures reproducibility while maintaining the resources.

This paper emphasizes the need, felt at the national level, to formulate and then implement a rating system for defining and assessing sustainability techniques for the design, construction, operation and maintenance of road construction; this rating system is to be understood as a guideline for the sustainability design and also as a method to quantify the merits of the project in terms of sustainability with a suitable score with which to assume a constraint on the use of public funds. To achieve this aim in this research it was elaborated a methodological proposal that identifies 10 steps to follow to introduce and evaluate the sustainability of the roads:

STEP 1. Sustainability goals definition

STEP 2. Associated benefits definition
STEP 3. Project basic requirements definition
STEP 4. Project voluntary and innovative requirements definition
STEP 5. Approach and methods definition to achieve project requirements
STEP 6. Key performance indicators identification
STEP 7. Standard reference
STEP 8. Current State of research
STEP 9. Case studies, examples and calculations
STEP 10. Criteria for awarding the score for the evaluation of the project

Further research will develop 10 steps of the procedure outlined and, above all, the criteria for awarding the score for the evaluation of the project in terms of sustainability that can be used as an indicator of sustainability for the roadway. In this way it will be possible qualify and quantify, trough different level of score obtained, roadway sustainability. Finally, by example and in a prodromic form, in this paper we provided some contributions of the research carried out in Italy can be useful to develop the above mentioned sustainability manual related to maintenance issues, reuse of materials and energy efficiency, in light of the unified vision of "global comfort" in the road infrastructure.

References

[1] Solow, R.M. (2001). Il capitale ambientale In Ed. Il sole24 ore ISBN 88-8363-277-X, Il Capitale-Le nuove strade dello sviluppo sostenibile (pp.21-41). Milano.
[2] Green Building Council Italia. (2011). Sistema di verifica GBC Home Per progettare, costruire e ristrutturare edifici residenziali.
[3] University of Washington (2011). Greenroads Manual v 1.5, http://www.greenroads.org
[4] Muench, S.T., & Anderson, J., & Bevan, T. (2010). Greenroads: A Sustainability Rating System for Roadways. International Journal Pavement Research Technology, n. 3(5), 270-279.
[5] Pilot test version INVEST (2012). Sustainable Highways Self-Evaluation Tool Federal Highway Administration. US Department of Transportation http://www.sustainablehighways.org.
[6] Highways Tendering Toolkit London Councils (2012). http://www.londoncouncils.gov.uk/capitalambition/projects/sustainableprocurement/sustainablehighways.htm
[7] Corriere, F. (2010). Gli aspetti della sostenibilità nei piani e nei programmi. Proceedings of Conference AIIT Rome, Italy.
[8] Corriere, F. , & Russo, R. (2003). I piani manutentivi per la sicurezza d'esercizio delle infrastrutture viarie: Un modello matematico per l'ottimizzazione dell'efficacia degli interventi. Proceedings of XIII Conference SIIV Padova, Italy.
[9] Corriere, F. , & Di Vincenzo D., & Giuffrè T., & Ticali , D. (2007). L'uso del "ravaneto" nelle costruzioni stradali".Le Strade,9,148-156.
[10] Total Tool KM Zero Road. (2012). http://www.Kmzeroroad.it.
[11] Corriere F., Peri G., La Rocca V., Rizzo G., (2012). "Environmental implications of traffic flow delays: a model for urban streets", 2012 Asian Pacific Conference on Energy, Environment and Sustainable Development (APEESD 2012), published by *Applied Mechanics and Materials*, ISSN: 1660-9336, (in press)