Environmental analysis of different construction techniques and maintenance activities for a typical local road

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A B S T R A C T

In this paper, considering the severe impact of road infrastructures on both the surrounding environment as well as on the consumption of locally available natural resources, different road construction techniques have been studied and compared, in order to be able to rank the best solution in terms of environmental sustainability. For the aims of this study, a Life Cycle Analysis has been carried out on a road infrastructure with the most representative geometrical characteristics among those widely used in Italy, in suburban areas, with the help of an appropriate software, the PaLATE. The environmental effects due to both the use of recycled materials, such as the Reclaimed Asphalt Pavement (RAP) from dismissing damaged pavement layers, and the reuse of fine soil from excavation, traditionally sent to landfill, has been studied. The latter is possible thanks to lime stabilization of clayey soils, that allows to reduce the need of transport to the dump as well as the need for non-renewable natural resources for road subgrades and embankments. The results here obtained show how the use of RAP, can lead to a significant reduction in pollutant emissions and energy consumption compared to that due to pavements constructed with virgin material only. A similar observation can be made for fine soils stabilized (in situ) with lime: it is demonstrated that this technique is able not only to significantly improve the mechanical properties of useless soils that, otherwise, would be considered as a waste to be dumped but also to provide considerable environmental benefits. Finally, in order to identify a criterion for achieving lower generalized costs in the whole life cycle of a road, the different construction options have been estimated in terms of total direct costs, assessed as the sum of construction and maintenance costs. It has been verified that the use of sustainable construction techniques (RAP and lime stabilization of clayey soils) can lead to the reduction of total cost and thus allows allocating greater financial resources to perform an “ideal” maintenance plan.

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1. Introduction

Transport infrastructures play a crucial role in assessing the development level (Herranz-Loncán, 2007; Rietveld, 1994) and welfare (Knaap and Oosterhaven, 2011) in a country. The necessity to satisfy the ever-increasing transport demand and protect the environment requires taking an approach to road design, maintenance and management which is more and more oriented towards the identification of both construction (Roth and Eklund, 2003; Kucukvar et al., 2014) and management choices (Giordi et al., 2013; Fürst and Oberhofer, 2012; Oxley et al., 2012) with a reduced environmental impact.

Numerous researches have dealt with this subject (Barros et al., 2013; Mayer et al., 2012; Fernández-Sánchez et al., 2015) by specifically addressing the life-cycle analysis (LCA) of an infrastructure. Most of them are based on more traditional approaches (Eriksson et al., 1996; Huang et al., 2009a; Milachowski et al., 2011; Santero et al., 2011a,b), while others are integrated with specific analyses of the induced effects on the climate (Stanley et al., 2011) and ecosystems (Amekudzi et al., 2009).

However, the subject is so complex that such researches have never concomitantly examined all the environmental effects due to
the materials used for the infrastructure construction, its maintenance activities and environmental impacts created by its functioning (mostly dependent on the traffic flow). In addition, maintenance phases do not generally take into account any delay in traffic flows caused by maintenance operations (Santero et al., 2011a,b), thus underestimating air pollutant emissions.

Especially road infrastructure planners and managers are not naturally keen to adopt multi-parametric approaches to road construction and maintenance suitable to meet structural, logistic, environmental and economic needs in an adequate manner. Therefore, this study aims at overcoming these limitations and suggests a method for assessing the global road infrastructure impact based on appropriate constructive solutions and particularly on pavement materials (base, subbase, upper part of the embankment, embankment body, subgrade), and the different strategies and relevant maintenance activities.

In order to study the impact of materials, each processing phase (starting from the material supply) was closely investigated and the energy quantity required for each of them was estimated.

Finally, in order to complete the analysis with all the other information that a Road Authority may consider when ranking the possible construction and maintenance solutions, the total direct costs (related to each different scenario) were assessed.

2. Methodology

The global environmental impact of a road infrastructure must be evaluated for the period of time between the extraction of raw materials necessary for its construction and its disposal or recycling at the end of its life cycle (Santero, 2010).

2.1. Life Cycle Analysis

This research assessed the environmental impacts of a typical Italian suburban road by implementing the LCA methodology, in agreement with the ISO 14040 and ISO 14044 standards (ISO, 2006a,b).

The LCA is divided into the following four phases (see Fig. 1):

1) goal and scope definition.
2) inventory analysis.
3) impact assessment.
4) result interpretation.

Different techniques for constructing the road pavement and subgrade were compared to identify their characteristic environmental externalities and consequently the eco-friendliest among them. More precisely, different scenarios were analysed based on the exclusive use of virgin materials, reuse of discarded RAP materials and in situ lime stabilization of fine-grained soils. If applied to clayey soils, the last technique highly improves the mechanical resistance and rigidity (Celauro et al., 2012a,b). It also allows to achieve considerable environmental (and often economic) benefits in the construction of new infrastructures (Celauro et al., 2015). Further benefits derive from the reduction in transport activities of virgin and dumped materials (discarded soil).

Our case study concerns a suburban road (C2 category, cfr. the Italian Guidelines for the Design of Road Infrastructures), also seeing that in Italy the secondary road network is much wider than the highway network (see Table 1).

Therefore, in order to set a parametric value, a life-cycle analysis of a kilometre of road section in embankment was carried out. It is worth pointing out that the suggested methodology is “general” and can be applied to trenched and transverse sections as well as to main and secondary works (e.g. viaducts, bridges and tunnels).

2.2. LCA software

The scenarios of interest and the relevant construction and maintenance phases of their road pavements and subgrades were analysed with the PaLATE (Pavement Life-Cycle Assessment Tool for Environmental and Economic Effects) software following the techniques suggested by the Greenroads Manual (Muench et al., 2011; Corriere and Rizzo, 2012). This tool is able to examine the life cycle of road pavements, constructed with virgin or recycled materials, in the different life cycle phases, i.e. raw material extraction, production, construction, maintenance and end-of-life.

The PaLATE software expresses environmental results in terms of energy and water consumption, global warming potential (GWP), human toxicity potential (HTP) and produced air pollutants and hazardous waste (Horvath and Hendrickson, 1998). It also allows to make an economic evaluation of the transport infrastructure by calculating all the costs borne in the initial construction phase as well as during the maintenance activities over the analysed time period.

The main qualities of the software derive from its analytical structure which makes it possible to analyse every phase independently of one another, its adaptability to territorial contexts and visualisation of the algorithms implemented in the software (Huang et al., 2009b).

3. Case study

The LCA was carried out with the help of the PaLATE software on a typical sub-urban road consisting of a single carriageway with one lane for each direction (two-lane single carriageway) (AASHTO, 2011).

The road section is made up of 3.50 m lanes and 1.25 m

| Sub-urban (km) | 172.356.00 |
| Motorway (km) | 6668.00 |
| Km Sub-urban for 10,000 inhabitants | 28.30 |
| Km motorway for 10,000 inhabitants | 1.09 |
| Km Sub-urban for 100 km² | 59.64 |
| Km Motorway for 100 km² | 2.21 |
| Km Sub-urban for 10,000 vehicles | 46.24 |
| Km motorway for 10,000 vehicles | 1.80 |
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