Life-cycle analysis for a pavement sustainable project in Brazil

Luciana de Paula Souza[1], Rosângela dos Santos Motta[2]
（[1] Universidade de São Paulo，São Paulo, Brasil, lu.souza@usp.br）
([2] Universidade de São Paulo/São Paulo，Brasil, rosangela.motta@usp.br)

ABSTRACT

Sustainability is being increasingly adopted in pavement design and construction. Within this context, Life Cycle Analysis (LCA) of asphalt pavements provides means to evaluate sustainable aspects of different pavement applications, concerning construction and maintenance, for instance. Considering also that the transportation sector is one of the main contributors to pollution and energy consumption, LCA can be used to assist in decision-making situations of pavement project designs, aiming not only the cost-benefit aspect, but also environmental sustainability. This paper presents a LCA considering greenhouse gases (GHG) emissions and energy consumption related to the construction and maintenance of a pavement project in Brazil. Three typical pavement structures were evaluated and compared: (i) Flexible – FL (15 cm of asphalt concrete, 20 cm of graded crushed stone and 30 cm of soil-crushed stone 50/50 as reinforcement). (ii) Semi-rigid – SR (12 cm of asphalt concrete, 12 cm of graded crushed stone and 17 cm of graded crushed with 4% cement) and (iii) Rigid – RG (24 cm of Portland cement concrete, 12 cm of roller-compacted concrete and 10 cm of graded crushed stone. A model was developed addressing the production of raw materials, transportation and construction. The results showed that RG may lead to greenhouse gas emissions in much larger proportion than FL, especially due to the use of cement as raw material. On the other hand, FL could lead to higher energy consumption considering more frequent maintenance operations than RG.

Keywords: pavement; asphalt; concrete; life cycle analysis; emissions; energy consumption; sustainability.

1. INTRODUCTION

Quantification and mitigation of environmental issues related to pavement construction and maintenance are important as they may result in substantial environmental burdens. Several methodologies have been developed to assess specific environmental costs and impacts, including life-cycle analysis (LCA), environmental impact assessment and eco-labeling, among which LCA is relevant in pavement engineering [1].

LCA is an in-depth methodology that includes materials production, transportation, construction, conservation, rehabilitation, use and end of life [2,3]. LCA is regulated by the international standards ISO 14040 and ISO 14044, giving the following structure to it:

- Definition of objective and scope;
- Life cycle inventory analysis;
- Life cycle impact assessment;
- Interpretation or analysis of results.

The LCA model uses materials and energy as input data for each stage analyzed, while waste and pollution are considered as output data, which may be associated with environmental and social impacts.

The main environmental impact evaluated in the LCA methodology is the emission of greenhouse gases (GHG), which is inventoried in the present study and include carbon dioxide (CO_2), methane gas (CH_4) and nitrous acid (N_2O). The metric tons of GHG are obtained by multiplying the mass of each greenhouse gas by its global warming potential [4], where:

- Carbon dioxide (CO_2) = 1;
- Methane (CH_4) = 25;
- Nitrous oxide (N_2O) = 298.

On the other hand, energy consumption is another important aspect to be considered on the LCA of a pavement project, as a parameter of sustainability. So this paper aims to propose the use of environmental sustainable parameters throughout LCA of a highway pavement project in Brazil. The evaluation considered the emission of pollutants related to the production of raw materials, transportation and construction of the highway, as well as to the periodic services of conservation and rehabilitation along the period of analysis (30 years).

3. MATERIALS AND METHODS

This work evaluated three types of pavement structures proposed for a Brazilian project, two with an asphalt concrete (FL, SR) and the other with Portland cement concrete (RG), respectively flexible, semi-rigid and rigid pavements. LCA was used to analyze and compare them. Conservation and rehabilitation periods were defined aiming quality and serviceability until the end of the cycle of 30 years. The pavement structures were composed of typical materials commonly used in pavement projects in Brazil, addressing the requirements of the National Department of Transport Infrastructure – DNIT [6].

The amount of energy consumed for each alternative was determined, as well as the emissions of GHG in terms of CO_2, related to production, transport and application of the materials in the construction, conservation and rehabilitation during working life, as observed on [5]. Data associated to energy consumption and GHG emissions were calculated using Ecoinvent® database and SimaPro® software.

4. CASE STUDY

The pavement structures were proposed to a state highway with 10 km of extension. The project considered a subgrade of compacted soil (100% Normal Proctor) with CBR minimum value of 8%.

The traffic volume was determined using methodologies of USACE (United States Army Corps of Engineers) and AASHTO (American Association of State Highway and Transportation Officials). The N number values were obtained from traffic studies based on the value of VDM from traffic counting (passenger and commercial vehicles). As a result, $N_{USACE\ 10\ years}$ and $N_{AASHTO\ 10\ years}$ for FL and SR pavement were respectively 3.11×10^7 and 1.07×10^7, and $N_{AASHTO\ 20\ years}$ for RG pavement was 4.14×10^7.

The proposed pavement structures are compatible with each other, taking into account not only the initial design for the construction, but also the period of future interventions. Figure 1 summarizes the pavement structures design.

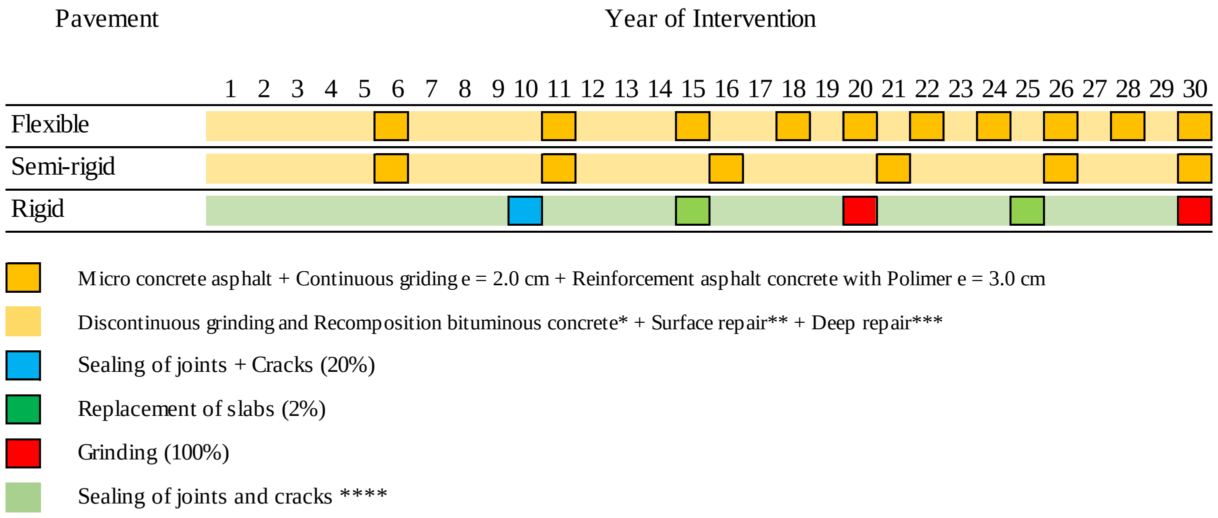
	Pavement		
Layer	FL	SR	RG
Wearing course	Asphalt Concrete (5 cm)	Asphalt Concrete (6 cm)	Portland Cement Concrete (24 cm)
	Asphalt Binder (5 cm)	Asphalt Binder (6 cm)	
	Asphalt Binder (5 cm)		
Base	Graded Crushed Stone (20 cm)	Graded Crushed Stone (12 cm)	
Subbase	-	Graded Crushed Stone with 4% cement (17 cm)	Roller-Compacted Concrete (12 cm)
Reinforcement	Soil-Crushed Stone 50/50 (30 cm)	-	Graded Crushed Stone (15 cm)
Subgrade	CBR ≥ 8%	CBR ≥ 8%	CBR ≥ 8% k = 146 MPa/m
$N_{USACE\ 10\ anos}$	3.11×10^7	3.11×10^7	-
$N_{AASHTO\ 10\ anos}$	1.07×10^7	1.07×10^7	-
$N_{AASHTO\ 20\ anos}$	-	-	4.14×10^7

k = modulus of subgrade reaction

Figure 1 - Pavement structures design

The performance models developed by Queiroz [7] were used to predict FL and SR pavement restoration solutions based on data collected by *Companhia Brasileira de Planejamento de Transporte* (Brazilian Transport Planning Company) [8]. Routine conservation activities were estimated as the percentage of total floor area analyzed after the second year of the road operation. This procedure was used by the road administration agencies and was also adopted for this research.

The most important types of defects that were considered using the performance models used were cracking and longitudinal irregularity. For RG pavement, some of the solutions recommended in the DNIT manual for the restoration of concrete pavements [9] were considered. Figure 2 shows the periodic conservation and restoration solutions proposed over the 30 years of analysis.



* 0.5% in the 2nd year, 1.0% in the 3nd year, 1.5% in the 4th year, 2.0% in the 5th year and 2.5% from the 6th

** 0.1% in the 2nd year, 0.2% in the 3nd year, 0.3% in the 4th year, 0.4% in the 5th year and 0.5% from the 6th

*** 0.02% in the 2nd year, 0.04% in the 3nd year, 0.06% in the 4th year, 0.08% in the 5th year and 0.1% from the 6th

**** 0.5% in the 2nd year, 1.0% in the 3nd year, 1.5% in the 4th year, 2.0% in the 5th year and 2.5% from the 6th

Figure 2 - Periodic conservation and restoration solutions proposed over the 30 years of analysis

5 CALCULATIONS

Initially, a quantitative survey of the materials and services required to implement the highway was carried out and all the necessary raw materials and equipment for the implementation, conservation and restoration of the highway were obtained based on DNIT - SICRO 2 - Database - March / 2016. Therefore, the amount of materials for each pavement structure analyzed was obtained. Also with the use of the composition of costs of the DNIT, it was possible to evaluate the quantity of productive hours of use of the equipment considering diesel oil as fuel for all equipment used. Then, the primary energy consumption (in GJ) for all those phases of the project was calculated, from the extraction and production of raw materials to the end of the 30 years of analysis.

For the calculation of GHG emissions related to the production of raw materials, Ecoinvent®'s database was used with the application of the SimaPro® software. In terms of equipment, the simplified methodology of the Intergovernmental Panel on Climate Change (IPCC) was used, so GHG emission values of diesel equipment were 79 g/MJ for CO_2, 0.0016 g/MJ for N_2O and 0.00005 g/MJ for CH_4.

In terms of transport distances considered in the analysis, the production plants were installed next to the construction site (geometric center of the work), while the soil deposit and suppliers of crushed materials, asphalt binder and cement were located approximately 7.8 km, 82 km, 98 km and 89 km away, respectively. Considering those distances, the productive hours of trucks needed for transportation of all materials to execute the work were calculated.

The results of primary energy consumptions along 10 km of FL, SR and RG pavements can be seen in Figure 3.

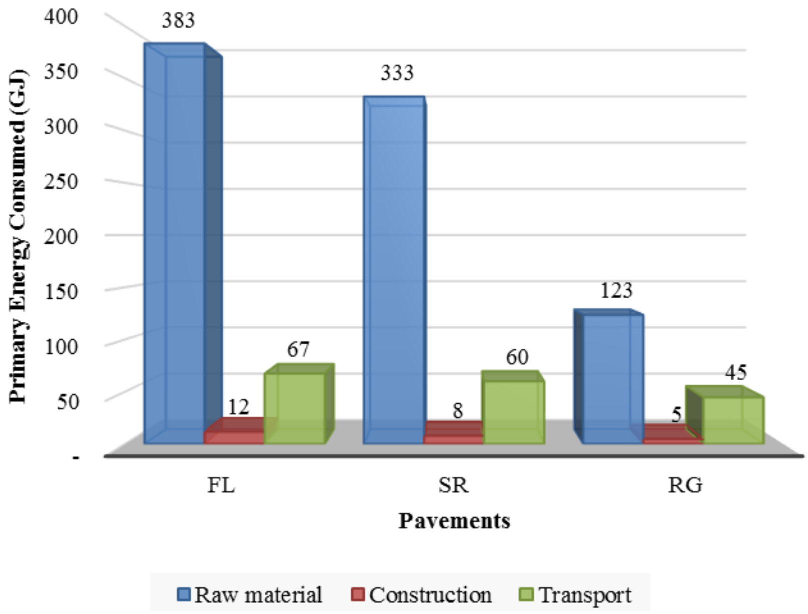


Figure 3 – Primary energy consumption from the extraction and production of raw materials to the end of the 30 years of analysis – FL, SR and RG pavement

Among the three aspects analyzed, the production of raw materials is the largest consumer of primary energy. Besides, it was observed that FL pavement presented higher primary energy consumption (3.1 times higher than the RG pavement). This result is due to more maintenance interventions necessary in the case of the FL pavement in the period of analysis (30 years).

On the other hand, emissions of GHG were also determined as they significantly contribute to the impact of global warming. The results are presented on Figure 4, where CO_2 represent 99% in the total amount of GHG in the pavement life cycle. In addition, it was also verified that FL pavement, despite being the largest primary energy consumer in comparison with RG pavement in this research, would not be considered as the main responsible for the effects of global warming, since it produced 53% less GHG emissions. As the RG pavement has cement on its composition, it is associated to significant amount of GHG emissions from the production stage of the raw materials used in the pavement construction, affecting the environment. In this phase, GHG emission was 86% lower in the case of FL pavement and 73% in the case of SR pavement.

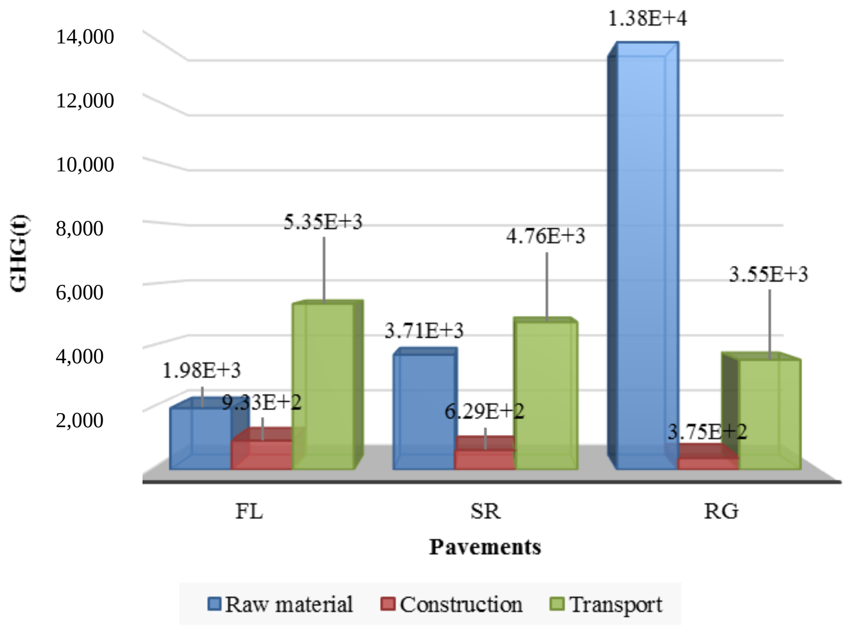


Figure 4 - Amount of greenhouse gases

In the highway construction phase, RG pavement was associated to less GHG emissions in the atmosphere. This is due to the shorter period of restorations on the highway during the 30 years of analysis (40% less than the FL pavement and 60% less than the SR). As for the materials transportation phase, the difference between the types of pavements occurs due to the number of interventions along 30 years of analysis. However, it was noted that if it was possible to reduce transport distance and materials storage by half, GHG emissions would be minimized from 36% to 41% at this stage.

6 CONCLUSIONS

LCA of the three pavement structures showed the quantity and type of impact that each material or service affects the environment, so it was possible to verify the sustainability of each alternative.

Extraction and production of raw materials are shown to be the main responsible for the release of GHG during the construction of a highway. In addition, it can be verified that the production of cement is lead to high levels of CO_2 emissions to the atmosphere. These results bring the discussion related to how to mitigate the impacts of cement production. In fact, its use does not tend to reduce, on the contrary it is estimated that it will double over the next 40 years.

In general, it can be verified that the use of the LCA tool in paving services was useful to quantify and compare different solutions, in an analytical way, in terms of sustainability indicators, from the initial construction of the pavement to the conservation and rehabilitation of it.

7 REFERENCES

[1] Yu, B., Gu, X., Ni, F., Guo, R. Multi-objective optimization for asphalt pavement maintenance plans at project level: Integrating performance, cost and environment. Transp. Res. Part A: Policy Pract. 41, pp. 64–74. 2015

[2] Santero, N. J.; Horvath, A. Global warming potential of pavements. Environmental. Research Letters, pp. 1-7. 2009.

[3] Yu, B., Lu, Q. Life cycle assessment of pavement: methodology and case study. Transp. Res. Part D: Transp. Environ. 17 (5), pp. 380–388. 2012

[4] Gohar, L.K., Shine, K.P. Equivalent CO_2 and its use in understanding the climate effects of increased greenhouse gas concentrations, Weather, pp 307-311. 2007.

[5] Zhang, H.; Lepech, M. D.; Keoleian, G. A.; Qiann, S. Dynamic life cycle modeling of pavement overlay systems: capturing the impacts of users, construction, and roadway deterioration. Journal of Infrastructure Systems ASCE, pp. 299 -309. 2007.

[6] DNIT - Departamento Nacional de Infraestrutura de Transportes. Manual de Restauração de Pavimentos Asfálticos. Publicação IPR-720. Brasília, 2006. *(In Portuguese)*

[7] Queiroz, C. A. V. Performance prediction models for pavement management in Brazil. 317p. Dissertation for the Degree of Doctor of Philosophy, University of Texas, Austin-Texas, USA. 1981.

[8] GEIPOT - Empresa Brasileira de Planejamento de Transportes. Anuário Estatístico dos Transportes 1982. 714p. Publisher Ministério dos Transportes – Brasília. 1982. *(In Portughese)*

[9] DNIT - Departamento Nacional de Infraestrutura de Transportes. Manual de Pavimentos Rígidos. Publicação IPR-714. Brasília, 2006. *(In Portuguese)*