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# A Decision-making Tool for Incorporating Cradle-to-Gate Sustainability Measures into Pavement Design

## INTRODUCTION

Pavements consume large amounts of energy, materials, and a significant portion of maintenance funds, causing a substantial strain on the environment and the economy. Hence, a sound framework for designing and constructing a sustainable pavement is needed. To measure sustainability in a pavement, various tools were developed and adopted. Among these approaches, the life cycle assessment (LCA) is a widely used quantitative method for measuring the environmental impacts of pavement alternatives. However, application of LCA in pavement is challenging, as it requires substantial time and resources to collect the required data for the analysis. Therefore, a more efficient tool is needed for sustainability performance assessment. This project provides DOT agencies with a user-friendly decision-making tool for quantifying the sustainability of pavement designs based on a cradle to gate analysis (where gate is defined as the gate of the construction job site). To ensure accuracy and consistent inventory data, the tool incorporated life-cycle environmental impact data available in Environmental Product Declarations (EPDs) to cover raw materials acquisition and manufacturing phases. The tool also provides an inventory data for transportation to construction site allowing the DOT agency to assess the "design phase" sustainability. The tool can be integrated with the AASHTO 93 as well as the MEDPG pavement design software for easy integration into the current pavement design methods.

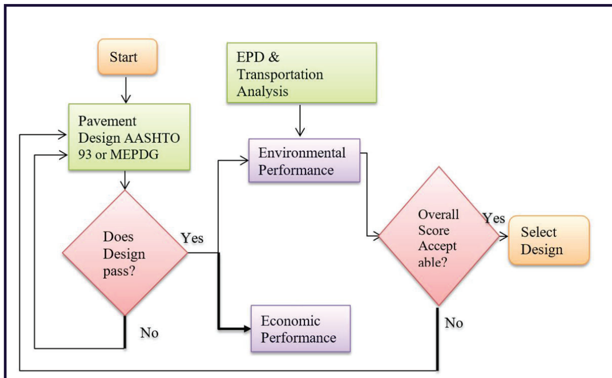


*Figure 1*
*Analysis framework*

## OBJECTIVE

The objective of this study was to conceive and develop a decision-making tool for evaluating sustainability of pavement designs and products, based on a cradle-to-gate analysis. This tool is based on EPD in order to enhance the reliability of the analysis. It was developed to be integrated with a state-of-the-art pavement design method such as the Mechanistic-Empirical Pavement Design Guide (MEPDG), as well as the AASHTO 1993 pavement design method. The tool was developed for pavement designers and decision makers in the evaluation of alternative designs and products by optimizing pavement mixes.

## SCOPE

This study presents a cradle-to-gate framework for selection of a pavement design, based on optimization of the pavement mix design/products for structural, environmental, and economic performances. The developed framework (Fig. 1) allows one to compare different design/product alternatives that balance engineering goals against environmental and economic performances and combines the two into an overall performance score, which identifies a cost-effective and environmentally preferred pavement. This approach is inclusive of (a) an EPD analysis, which quantifies the environmental impacts from raw materials extraction to manufacturing; (b) a transportation analysis, which quantifies the impact of transporting mixes from a plant location to the construction site; and (c) an economic analysis, which evaluates the economic value of an alternative. Developed modules and databases were incorporated into a simple decision-making tool, a windows-based software, which was developed for the selection of a design/product with a balance that extends across engineering, environmental, and economic performance criteria.

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**PRINCIPAL INVESTIGATOR:**

Marwa Hassan
Professor, LSU

**LTRC CONTACT:**

Kevin Gaspard, P.E.
225.767.9104

**FUNDING:**

SPR: TT-Fed/TT-Reg

**Louisiana Transportation Research Center**
4101 Gourrier Ave
Baton Rouge, LA 70808
*www.ltrc.lsu.edu*

## METHODOLOGY

The framework developed in this research included an environmental analysis carried out in conjunction with an economic analysis to quantify the sustainability of pavement products and design alternatives. Even though sustainability is balancing environmental, economic, and social needs, this study addressed only the first two components due to the limitations associated with quantifying the social component. The system boundaries for the environmental impact assessment included the activities associated with the following four phases: acquisition of pavement raw materials; transportation of raw materials; manufacturing of pavement mixes; and transportation of mixes to the site location. Although other construction activities contribute significantly to the environmental and economic analysis, this study focused on the optimization of pavement mix design/product for structural, environmental and economic performances. The system boundary (Fig. 2) represents an EPD for transportation from the plant to the construction site. For environmental analysis, a precise and accurate EPD and transportation module were developed by using a compiled EPD database and transportation inventory data collected from various data sources. Similarly, a compiled database was developed and used to evaluate the economic performance of pavement alternatives. The two performance factors were combined into a single score to represent the overall performance and to quantify the relative differences in performances among the alternatives considered.

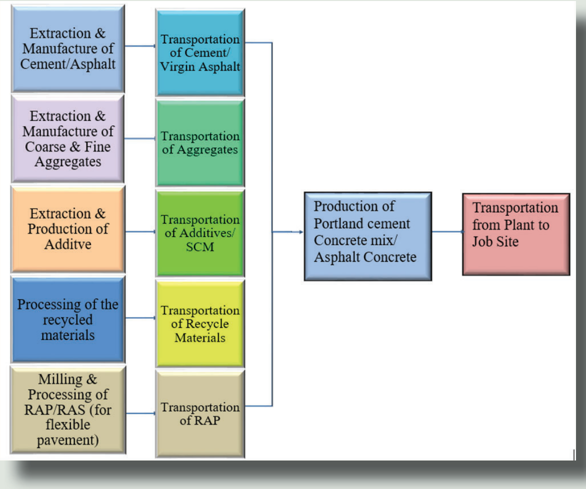


*Figure 2*
*System boundary*

Researchers designed the methodology to create a decision-making tool, which was incorporated into a software. As shown in Fig. 2, the tool analyzes designs that satisfy engineering criteria based on environmental and economic performances. The results from each criterion were then combined to assess the overall performance of a product/design. Finally, the products/design with the least overall performance score is considered the most sustainable pavement. As this study only considers pavement mix design to quantify sustainability, availability of precise and coherent data for EPD and cost plays a significant role in the accuracy of the results. Therefore, EPDs were collected from different sources and were classified into different regions: nation-wide, south-central region, and statewide region (Louisiana). For economic performance, the system boundary is similar to the environmental analysis. LA historical initial construction cost data were used to evaluate the economic performance of the pavement products.

The decision-making software allows for the evaluation of multiple pavement designs and alternative products using two modes of analysis: benchmarking and product comparison. Benchmarking provides the baseline results by averaging the impact of multiple selected mixes to quantify the total environmental impacts of a design alternative. Product comparison compares multiple products for selecting the most sustainable product. The software also allows the user to define different parameters, such as pavement design, mixes, vehicular characteristics, economic impact weights, and environmental impact category weights.

## CONCLUSIONS

This study developed a sustainability measurement tool that may be integrated into routine pavement design. The main purpose of such a tool is to aid in decision-making by providing a comparison of different pavement designs/products with respect to the environment and economic functionalities. The methodology may also be used to provide baseline results of the environmental impacts. EPD, as a consistent and comparable sustainability measurement tool, has been adopted in this study for the environmental analysis. EPD quantifies the environmental impacts from raw material extraction to the transportation of the pavement mixes to the job site, a cradle-to-gate framework.

A Windows-based software was developed (Fig. 3), based on the developed framework. The software database is editable and expandable, so that the user can add more EPD products as they become available. The intended audience for the developed software would be manufacturers, designers, and consumers. These individuals would use the software to benchmark their products and to select cost-effective and environmental-friendly solutions. Selecting a product that has an optimum balance between economic and environmental components presents a compelling, innovative way to achieve sustainability in pavement applications.

## RECOMMENDATIONS

The developed framework is suitable to compare design and product alternatives based on a cradle-to-gate framework. However, the developed tool should not be used for the comparison of flexible and rigid pavements, even after asphalt EPDs are issued as the Product Category Rules (PCRs) that each industry used to issue their EPD are different. In addition, other pavement phases carry significant impacts on all three components of sustainability, therefore for future consideration, the study may be expanded to quantify the sustainability of the product by considering the other phases of the pavement life cycle as well. A sustainability developed by considering all phases of pavement life cycle along with quantification of social components would allow for a more accurate assessment of pavement sustainability.

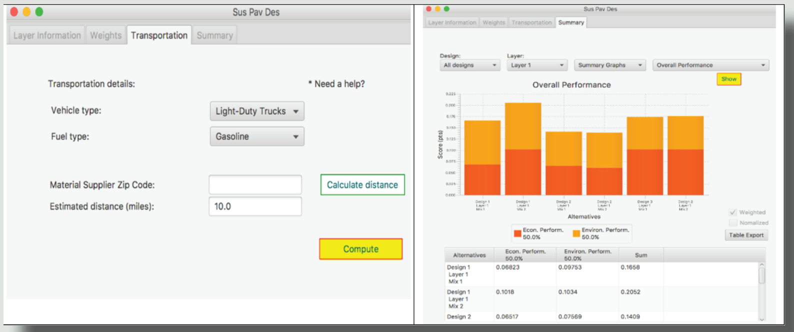


*Figure 3*
*User interface of the developed software*