Comparative Pavement LCAs With Uncertainty

Problem

There is a growing interest in green design of pavements in order to improve environmental emissions in the US. Improving the sustainability of pavements requires a thorough evaluation of the variation of environmental impacts across a variety of scenarios. There are different sources of uncertainty associated with the lifecycle. A probabilistic approach incorporates different sources of uncertainties in environmental life cycle analysis to capture the range of possible outcomes in the footprints of alternative designs.

Approach

We have developed a methodology for the comparison of environmental life cycle impacts of pavements in the presence of uncertainty. Two designs are shown here to demonstrate the methodology for a low volume road in southern California. The scope of the LCA consists of the initial construction and material impacts, fuel loss due to pavement-vehicle interaction (PVI), carbonation, lighting, maintenance requirements, and the end-of-life. The statistical fluctuations in parameters defining the material quantities as well as their associated environmental impacts are characterized by probability distributions. This uncertainty is quantified based on inherent measurement variation and data quality assessments. The uncertainty associated with the appropriateness of each flow is quantified using the data-quality indicators established by the ecoinvent life cycle inventory database. These probability distributions are incorporated in the LCA and translated into the variation in the environmental impact using a Monte-Carlo simulation. Finally, the resulting probabilistic descriptions of overall footprints are compared to investigate whether the difference in the overall environmental footprints in two cases is statistically significant. This comparison is performed using a comparison indicator (CI) variable that divides the impact of one design alternative by the impact of the other alternative for each run of the Monte Carlo simulation, allowing for the accounting of correlation between the two designs. Examples of this correlation would be the environmental impacts of materials and processes found in both designs and the rate of fuel loss due to changes in roughness, among others.

Findings

Figure 1 shows the results of a probabilistic LCA of the two pavement designs taking into account the aforementioned sources of uncertainty. Figure 2 depicts the probability distribution of the indicator variable; values less than 1 show that design B has a lower impact than design A.

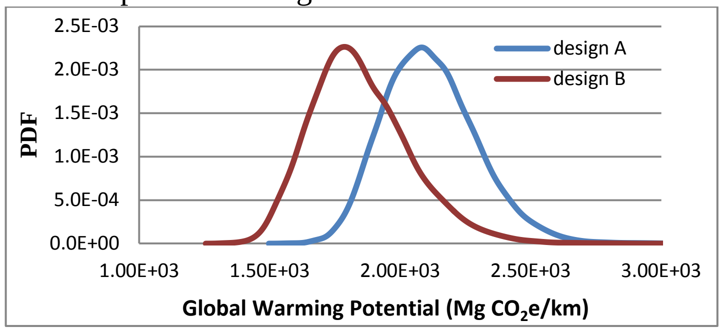

Figure 1: Comparison of probability distribution of GWP
*__Design A__: 4.8" HMA/5.4" CTB; **Maintenance**: 3" AC (Yr 20) / Mill 3"AC (Yr 30) / Mill 2.5" AC (Yr 40) / Mill 3" AC (Yr 50)
*__Design B__: 8.4" JPCP/4.2" LCB; **Maintenance**: 2% Patch, DG (Yr 25) / 4% Patch, DG (Yr 30) / 6% Patch, DG (Yr 40) / 3" AC (Yr 45)

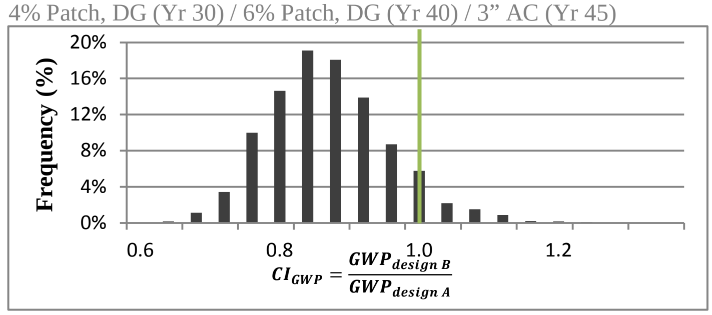

Figure 2: Histogram of comparison indicator variable (CI).

While there is overlap between the two distributions in Figure 1, Figure 2 shows that the impact of design B is actually less than design A 90% of the time.

Impact

This research provides a probabilistic model for comparative life cycle environmental assessment of pavements in the presence of uncertainty and variation. Making use of this model (while accounting for correlation between designs) under a variety of scenarios enables decision-makers to choose a pavement with an associated degree of confidence.

More

Research presented by Margaret Wildnauer, research assistant, and Arash Noshadravan, postdoctoral associate, supervised by Randolph Kirchain and Jeremy Gregory.

This research was carried out by the CSHub@MIT with sponsorship provided by the Portland Cement Association (PCA) and the Ready Mixed Concrete (RMC) Research & Education Foundation. The CSHub@MIT is solely responsible for content. For more information, write to CSHub@mit.edu.

*Figures 1 and 2 revised 11/2012 with updated data