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ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS FOR PAVEMENT MANAGEMENT SYSTEMS

Mohamad Wajdi Bardeesi, PhD candidate, MS
Youssef Attallah, Associate Professor, PhD
Civil and Environmental Engineering Department**,**
Faculty of Engineering, Beirut Arab University, Lebanon

Abstract

Sustainability and specifically environmental factors are emerging as prominent issues in engineering decision-making. Environmental parameters are not considered part of current pavement management systems for many road authorities, despite having duties such as pavement construction and maintenance which can greatly affect the environmental impact of a project. This paper demonstrates the feasibility of integrating environmental performance measures into pavement management process. To illustrate these concepts, a sustainable pavement management framework is proposed. Background information is given on life-cycle assessment (LCA). The proposed framework life-cycle and LCA phases are discussed, in addition to the system's data and data sources. A list describing the data used for environmental calculations is included, Special attention is given to recycled materials and environmental measures. Concluding remarks suggest different contexts for potential applications of the proposed framework, together with network tools that can be used to meet user needs and applications as well as to address feasibility and cost.

Keywords: Pavement Management, Sustainable transport, Life Cycle Cost Analysis, Environmental Impacts

Introduction:

Pavement systems are fundamental elements of the passenger and freight transportation systems worldwide. While the transportation of people and goods has expanded significantly in recent decades, pavement systems have serious impacts on the environment and the economy. Asphalt and concrete are the most common materials used in the construction of pavement systems. The use of both asphalt and concrete poses significant environmental

1. Sustainability in Pavement Systems:

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With increasing expansion of pavement systems globally, the need for more sustainable pavement development becomes even more important. Sustainable development can be defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable pavement system development requires a comprehensive evaluation framework that takes into account environmental, economic, and social indicators simultaneously (Figure 1).

Traditionally, material scientists and engineers have focused on a limited set of performance criteria in design activities within the material development process, while industrial ecologists and economists have maintained a macro-level perspective for analyzing the life cycle impacts at the infrastructure systems level. The sustainable design framework helps ensure regular flows of information between these two processes. Alternative materials designed in the material development process are translated into life cycle inventory inputs for life cycle analysis of an infrastructure system. An aggregated set of social, environmental, and economic indicators are derived for the infrastructure system from material resource extraction to end of life management. These sustainability indicators can be used to guide changes in material design in order to optimize system performance. This design, evaluation, and re-design sequence can be repeated until sustainable solutions are reached.

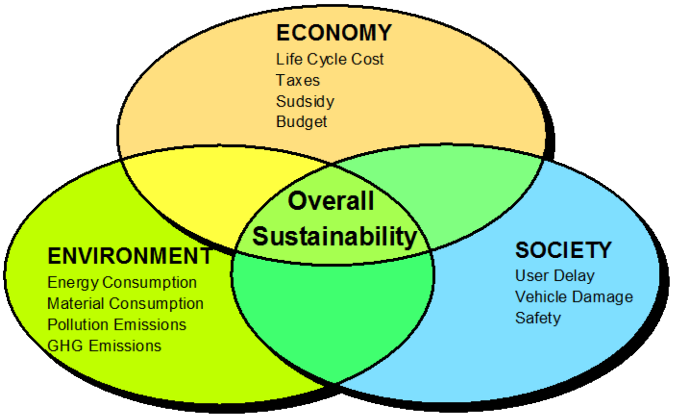

Figure 1 Sustainability in Pavement Systems

Currently, few sustainability indicators are considered in the evaluation of alternative materials in pavement systems. Traditionally, agency costs are used by highway agencies to compare different designs. Energy consumption, greenhouse gas emissions, user costs, and environmental damage costs are not often considered in the decision making process (Wilde, et. al.. 2001).

Additionally, besides the evaluation of pavement construction, many factors during pavement usage are not evaluated by highway agencies, such as traffic congestion caused by construction activities and surface roughness effects caused by pavement deterioration.

2. Life Cycle Assessment

Life Cycle Assessment (LCA) is an investigation and valuation tool of the environmental impacts of a given product or service caused or necessitated by its existence. The goal of LCA is to compare the full range of environmental damages of the products and services, in order to be able to choose the least burdensome one.

The term 'life cycle' refers to the notion that a fair, holistic assessment requires the assessment of raw material production, manufacture, distribution, use and disposal including all intervening transportation steps necessary or caused by the product's existence. The sum of all those steps - or phases - is the life cycle of the product. Common categories of assessed damages are global warming (greenhouse gases), acidification, smog, ozone layer depletion, eutrophication, eco-toxicological and human-toxicological pollutants, desertification, land use as well as depletion of minerals and fossil fuels.

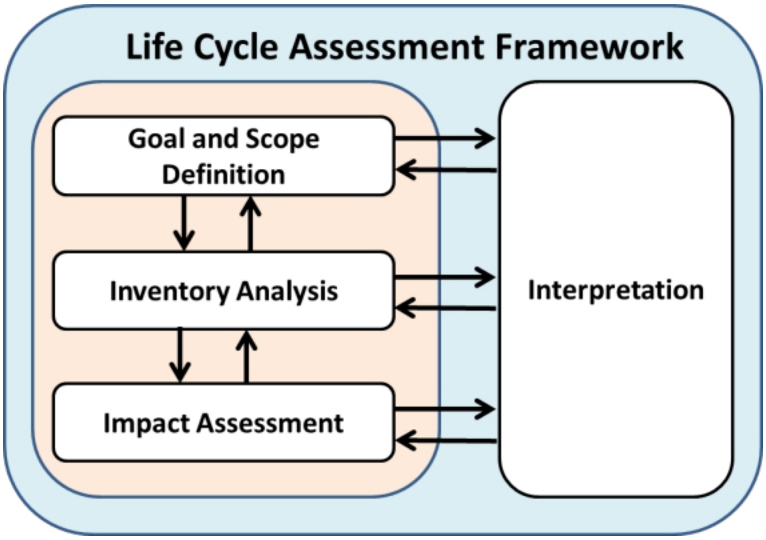

Figure 2 General LCA Framework (ISO. 2006).

A Life Cycle Assessment is carried out in four distinct phases (Figure 2). Goal and scope - In the first phase, the LCA-practitioner formulates and specifies the goal and scope of study in relation to the intended application. Life cycle inventory - The second phase involves data collection and modeling of the product system, as well as description and verification of data. The third phase 'Life Cycle Impact Assessment' is aimed at evaluating the contribution to impact categories such as global warming, acidification, etc. Interpretation - The last phase is the most important one, as it's an analysis of major contributions, sensitivity analysis and uncertainty analysis leads to the conclusion whether the ambitions from the goal and scope can be met.

2.1 Pavement LCAs

The most crucial methodological decision in a pavement LCA is the selection of system boundaries. From a life-cycle perspective, boundaries should be drawn so that all relevant processes are included in the assessment. When one or more relevant processes are arbitrarily excluded, the quality and confidence of LCA results are jeopardized, as excluded phases and components can have a large impact on the results (Santero, et. Al. 2009). Figure 3 illustrates a comprehensive map of the pavement life cycle.

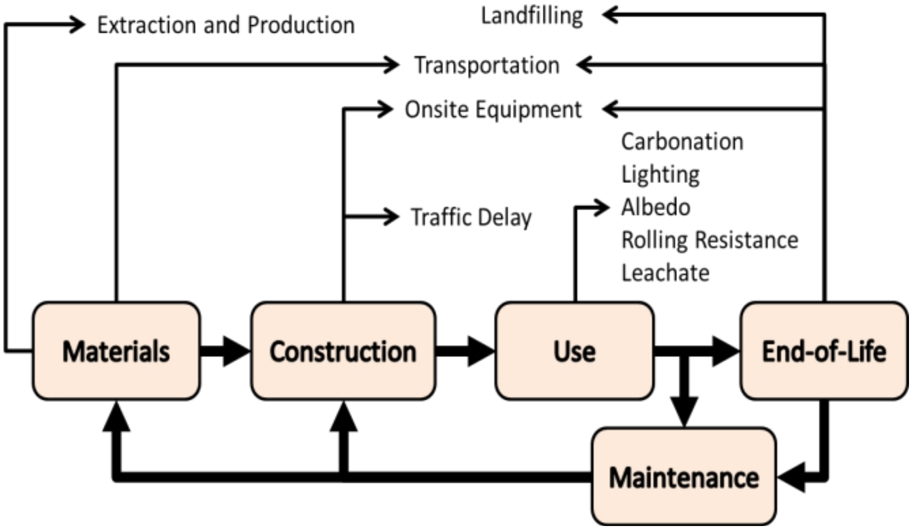

Figure 3 Suggested System Boundaries for Pavement LCA
(Santero, et. al. 2011)

The goal and scope of the pavement LCA also plays an important role in determining proper system boundaries. Needs differ between pavement LCAs and it is difficult to establish a one-size-fits-all boundary system.

Movement towards a standardized pavement LCA framework will provide designers, researchers, and stockholders the ability to accurately and consistently characterize the impacts of pavement structures. With respect to comparative LCAs, previous studies have lacked comprehensive systems boundaries, leading to inaccurate representations of both the concrete and asphalt life-cycle impacts (Santero, et. al. 2011).

2.2 Improving LCA through LCCA

Life cycle cost analysis (LCCA) can evaluate the economic impacts of pavements in various ways. For example, LCCA can be used to compare alternative designs, evaluate payback periods for proposed improvements, or calculate the cost-effectiveness of environmental improvement strategies. Regardless of the approach, accompanying the environmental impacts from LCA with the economic impacts from LCCA creates a marked advancement in the utility of the assessment as a whole. Whereas LCA quantifies the important environmental issues, LCCA provides the necessary economic context to implement those solutions into the marketplace.

2.3 RealCost Software

The FHWA developed RealCost to instruct pavement designers and decision-makers on how to perform LCCA, and to help integrate LCCA into the decision-making process through a functional tool. Users enter anticipated construction, preservation, maintenance, and repair costs and timings and the software converts this to a present value life-cycle cost. RealCost encourages the use of best practices by supporting probabilistic calculations and estimating user costs due to work zone delay. Probabilistic calculations are performed using Monte Carlo simulation if activity costs and timings are entered as probability functions rather than deterministic values. User costs are calculated through comparing traffic demand to the roadway’s capacity during normal flow and work zone conditions (RealCost 2004).

3. Quantifying Sustainability in PMS

Environmental stewardship considers the use of renewable resources at below their rates of regeneration and non-renewable resources below rates of development of substitutes. The need to provide a clean environment from both an air quality and water quality perspective could be included in an environmental monitoring plan, as well as including pollution prevention, climate protection, habitat preservation and aesthetics (Ramani, et al 2009).

Recycling, reusing, and reclaiming of existing materials is crucial to advance sustainable development (Carpenter, et. el. 2007).. Construction materials can be expensive and now some resources are in limited supply, making it important to make good use of available materials.

Alternative materials also hold the promise of being able to enhance sustainability in pavement management. Research has shown that materials such as recycled asphalt shingles, recycled rubber tire, recycled glass, and reclaimed carbon from copier toner can be successfully incorporated into new pavements (Chan, P. Et. al. 2010). The incorporation of innovative materials can also potentially enhance pavement performance and reduce the demand for virgin materials (Horvath, A. 2004),.

Minimizing or eliminating noise pollution is another element of a sustainable design and construction program, and it follows that standards imposed on construction may also be applicable to maintenance operations.

4. **Environmental Impact Tools**

The environmental tools mentioned here fall into two very distinct categories: environmental calculators and environmental rating tools. Every tool has its own set of boundary conditions and various life-cycle activities are included and omitted from each.

An environmental “calculator” is a software tool that uses material or equipment inputs to estimate the amount of pollutants produced or other environmental impacts of a project. Environmental calculators may estimate a single pollutant, or multiple types of pollutants. The tools which fall into this category, for example, are: MOVES2010, NONROAD, asPECT, Changer, and PaLATE.

An environmental “rating tool” is defined as a methodology that calls for the gathering of predominantly environmental impact information for a transportation project and uses this information to assign a rating or score to the project. Rating tools can be in the form of a checklist, a questionnaire, or a procedural description and may require varying levels of documentation and verification.

Rating tools do not perform estimates or calculations themselves but may require the outputs of environmental calculators or other measurement systems to establish the appropriate rating. The environmental rating tools, for example, are: Greenroads, GreenLITES, IN-VEST, I-LAST, and Ceequal.

5. Proposed Sustainable Pavement Framework (Figure 4)

To implement a non-trivial but also trusted framework, the following is proposed:

1) Limit calculations to emissions and resource usage (data will be more available and reliable).
2) Integrate probabilistic capabilities.
3) Supply a default database for easy use, and allow for extensive customization.
4) Provide a notification advising the users if they are left on default values.

It is important to note that a project-level environmental impact tool should be used as part of a larger environmental impact or sustainability strategy (network level). Higher level evaluation should take place, examining how potential roadway projects are expected to impact the environment and the sustainability of the transportation system and interconnected sectors as a whole. After this evaluation has taken place and a decision has been made to move forward with a project, a tool such as the one proposed can be used to compare the environmental impacts of various alternative designs and construction strategies.

5.1 Environmental Factors

The proposed framework considers four factors believed to be the most practical and useful in providing environmental impact information for use in a decision support capacity. These four factors are:

a) Emissions due to extraction and production,
b) Emissions due to construction activities,
c) Resource consumption, and
d) Emissions due to work zone travel delay.

a) Material Extraction and Production

To estimate material extraction and production effects, users select a production facility and mix design from the database. Mix designs are associated with specific production facilities and consist of a collection of materials, their percentage in the mix, and their individual hauling distances from extraction sites to the production facility. Each material has an emission factor and probabilistic distribution stored in the database which will be accessed when the mix is selected. Production plants also have an associated emission factor and probabilistic distribution. Proposed input options are shown in Figure 5.

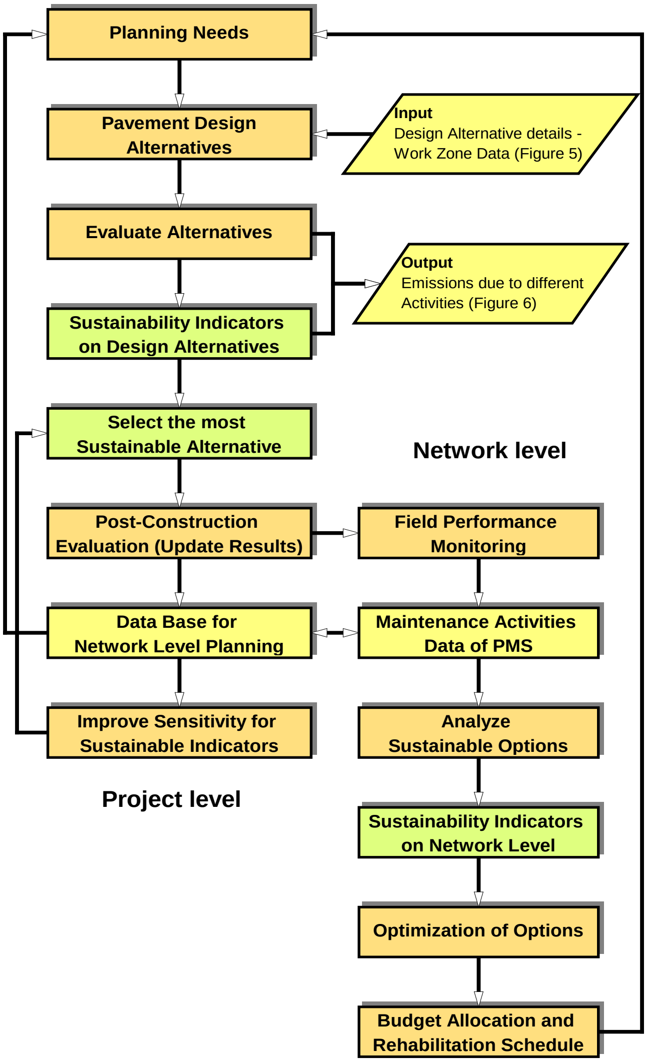

Figure 4 Proposed Sustainable Pavement Framework

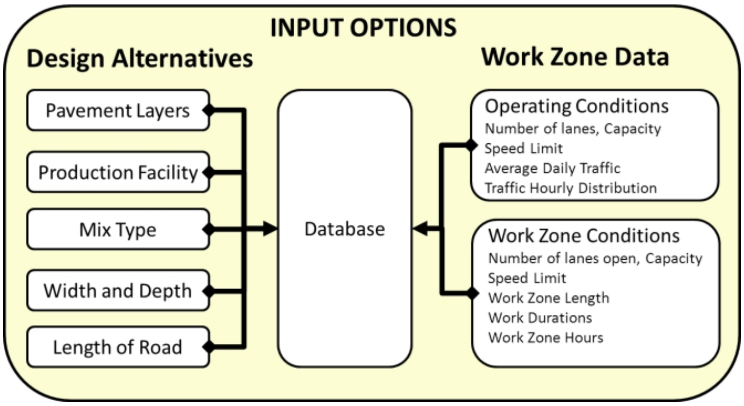

Figure 5 Input Options

The material amount is multiplied by the associated emission factors stored in the database to calculate the emissions impact of the material extraction and production.

Inputting energy consumption, energy sources, and the amount of material produced will call on the tool to use these inputs to calculate the emissions factor for the new facility. Equation (1) states that the emissions factor of a production facility is the sum of the amount of energy used from all energy sources multiplied by the emissions factor for the corresponding energy source, divided by the total amount of material produced by the facility.

$$EF_{pro} = \frac{\sum_{i=1}^{n}(E_{pro,i} \times EF_{est,i})}{A_{pro}} \qquad (1)$$

Where,

EF_{pro} = Emissions factor for a production facility (tons emissions/ton of material)

$E_{pro,i}$ = Energy Amount of type i used by the production facility over a known time span (kwh, gallons…)

$EF_{est,i}$ = Emissions factor for energy type i (tons emissions/kwh, gallons…)

A_{pro} = Amount of material produced over same time span (tons)

Equation (2) states that the emissions factor for a material's extraction is the sum of the amount of energy used from all energy sources multiplied by the emissions factor for the corresponding energy source, divided by the total amount of material extracted.

$$EF_{ext} = \frac{\sum_{i=1}^{n}(E_{ext,i} \times EF_{est,i})}{A_{ext}} \qquad (2)$$

Where,

EFext = Emissions factor for a material's extraction (tons emissions/ton of material)

Eext,i = Energy Amount of type i (electricity grid, gasoline, diesel…) used by the extraction

facility over a known time span (kwh, gallons…)

EFest,i= Emissions factor for energy type i (tons emissions/kwh, gallons…)

A_{ext} = Amount of material extracted over same time span (tons)

b) Emissions due to Construction Activities

Emissions due to construction activities are based on hauling distance from production facilities to the project site in addition to site preparation and laydown activities. Users indicate the hauling distance for each material layer and select a "construction profile," which will be the emission factor for the project. A construction profile consists of a single emission factor representing all anticipated preparation and construction activities for a project, or a set of emission factors which each represent a single preparation or construction activity.

c) Resource Consumption

Many agencies have already adopted a “resource conscious” stance on the use of pavement materials. This can have both economic and environmental benefits, and supporting the ability of agencies to make resource conscious decisions will be a valuable addition to a LCA tool. The resource consumption feature helps justify decisions on whether or not to make use of recycled (RAP, RCA,…) and reused (fly ash, blast furnace slag,…) materials. Engineers and contractors can reasonably estimate the amount of recycled and reused materials they intend to include in a design. Simple inputs of layer depths, widths, and lengths is combined with this data to allow the tool to create resource usage tables that can be used to compare materials use of different designs, processes, and material sources.

d) Emissions due to Work Zone Delays

Work zone related travel delay is a significant source of emissions in the road construction process (Huang, et. al. 2009).. Standard gasoline engines burn least efficiently during deceleration, acceleration, and idling. The slow speeds and reduced capacity of a work zone necessitate such decelerations and accelerations, as well as often creating traffic delays that extend the effects outside of the construction area. Despite the clear impact construction activities have on local traffic and therefore on the associated emissions, these emissions are not currently considered as a part of the construction process (Santero, et. al. 2009).. It was not included in any Environmental Calculator tool reviewed during this study. This feature of the framework allows agencies to make informed decisions on construction timing and traffic management strategies in order to balance conventional practice and agency cost measures with user costs and emission impacts.

RealCost currently requires the input of traffic data as well as capacity during normal operation and construction conditions in order to calculate user cost due to delay. These delay calculations, paired with an already developed emission model such as MOVES, can yield the full range of gaseous and particulate emissions or a CO2e value depending on the chosen settings. This data is necessary for calculating traffic conditions during construction for comparison with normal roadway operation. In RealCost, this comparison is used to show variations in User Cost between different alternatives and work zone strategies. The proposed framework uses the comparison to calculate emissions due to work zone related traffic congestion.

5.2 Customization

a) Define New Material, Mixture, Production Facility

While a limited database of default values should be provided with the framework, these values will inevitably fail to cover certain equipment, techniques, and materials and go out-of-date as new equipment, techniques, and materials are developed. For anything beyond general guidance on the impacts of various materials and processes, users should be encouraged to provide their own data if it is available.

b) Probabilistic Calculations

Each material, production facility, construction profile, and hauling distance should be able to be entered either as a single number (deterministically) or as an expected value with an associated distribution function (probabilistically). Users are able to choose uniform, normal, truncated normal, triangular, or truncated triangular distribution. The proposed framework performs a sensitivity analysis by varying the deterministic variables a set amount above and below their input values.

5.3 Calculations and Outputs

The proposed framework has the capability to calculate substantially large amounts of information, which may be more than needed or desired by the agencies that will make use of it.

Users are also able to select different levels of output aggregation or disaggregation, such as examining emissions as a range of gases and particulates or having the program reduce this to a CO2e value. The output tables will display the amount of total aggregate and binder used in the design, measured in tons, as well as total virgin aggregate and binder tonnage (Figure 6).

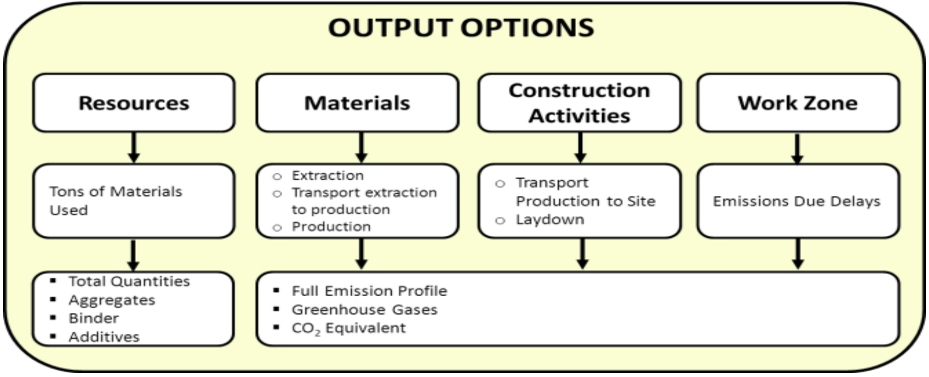

Figure 6 Output Options

Conclusion:

In order to integrate sustainability into their current practices, pavement decision-makers need a comprehensive framework which includes a set of environmental decision support tools. While a variety of environmental impact tools are currently available, they suffer from a number of drawbacks which serve as barriers to their implementation.

This paper proposed a framework which addresses many of the limitations of previous environmental impact tools. The proposed framework estimates multiple environmental impacts, including emissions due to work zone delays which are not considered by any other currently available tool. The tool also performs probabilistic calculations and has a database which can be added to and updated by users. The developed framework will help decision-makers in incorporating environmental factors into pavement management systems.

The proposed framework calculates resource usage and a wide range of emissions rather than just CO2e. It will have a database which allows for immediate employment of the framework and this database can be fully customized through additions by the user. The proposed framework also has probabilistic capabilities, allowing users to take risk and uncertainty into account in their decision-making.

After the proposed environmental impact Framework is developed, a database specific to a chosen locality should be developed. This should be achieved through working with local material sources and production facilities to determine their energy usage and material production. Variation in energy use and material production over the time period the database is being built can be used to generate probabilistic distributions specific to individual material and mix providers. The value of such geographically and temporally specific data will eclipse the general database and should be used to perform case studies demonstrating the usefulness of the Framework.

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