May 2010
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Pavement Life Cycle Assessment Workshop

University of California Pavement Research Center, Davis and Berkeley

California Department of Transportation

Institute of Transportation Studies, UC Berkeley and UC Davis

With collaboration of: International Society for Asphalt Pavements, Asphalt and the Environment Technical Committee, International Society for Concrete Pavements

University of California, Davis
Davis, California
May 5–7, 2010

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BACKGROUND

The University of California Pavement Research Center (UCPRC, Davis and Berkeley) and the University of California Institute of Transportation Studies (Berkeley and Davis) are working together on establishing common practices for conducting environmental life cycle assessment (LCA) for pavements. Funding for this work is provided by the California Department of Transportation in partnership with the MIRIAM pooled fund project which is led by the Danish Road Institute (Ministry of Transportation, Road Directorate). This work is being done in collaboration with the International Society for Asphalt Pavements (Asphalt Pavement and the Environment Technical Committee, ISAP APE) and the International Society for Concrete Pavement (ISCP).

Research products under development as part of this work include:

a. An LCA framework for pavements.
b. A summary of system boundaries and assumptions for the framework, as well as an examination of the pros and cons of alternatives.
c. Assessment of models/data for each phase of the life cycle with regard to project type.
d. Documentation requirements for pavement LCA studies sufficient to permit comparison between studies in terms of completeness, assumptions, system boundaries and data/models.

Desired Outcomes of the Workshop:

1. Review and discussion of documents prepared by the research team for each of the four items (a through d) listed above.
2. Brief presentations and discussion of critical issues for pavement LCA where conflicting practices or gaps in knowledge have been identified.
3. Summary of areas of consensus and disagreement with regard to items a, b, c, and d above and documentation of alternative views.

The UCPRC/ITS research team will use the results of the workshop to improve the LCA framework and recommended documentation requirements. The focus of the framework and documentation will be for studies to be performed for California, and later for the MIRIAM project; however, they may serve as guidance documents for pavement LCAs performed in any region. A follow up will likely be required to capture similar information for European studies to be performed as part of the MIRIAM project. The final documents prepared by the research team, after incorporation of the workshop results, will be posted for comment and critique by the pavement and LCA communities. The intention of the research team and workshop sponsors is that the results will provide the following benefits:

- Use of appropriate assumptions, system boundaries, models, and data by the research team for the California and MIRIAM studies.
- Better understanding of LCA among pavement LCA practitioners, sponsors, and consumers of pavement LCA information.
- Recommendations for improvement in practice of LCA studies.
- More transparency in the documentation of how pavement LCA studies are performed.

DISCLAIMER

The contents of this workshop document reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California, the Federal Highway Administration, the University of California, the MIRIAM project or its sponsors, the International Society for Concrete Pavements, or the International Society for Asphalt Pavements. This workshop document does not constitute a standard, specification, or regulation.

WORKSHOP AGENDA AND SCHEDULE

Day 1—Wednesday, May 5

8:30–9:30 a.m.	Sign in and introductions
9:30–10:15 a.m.	**Introduction to Life Cycle Assessment (45 min.)** Alissa Kendall, Nick Santero An introduction to LCA, including ISO 14040, and a simple, general LCA example A review the objectives of this workshop
10:15–10:45 a.m.	*Break*
10:45–11:30 a.m.	**The Pavement LCA Framework Proposed by the UC Team (45 min.)** Alissa Kendall, John Harvey A presentation of the proposed framework for pavement LCA A description of the standard assumptions and system boundary proposed by the UC team A description of the UC team's proposed pavement LCA documentation checklist A review of the important questions to be discussed
11:30 a.m.– 11:50 a.m.	**Introduction and Initial Discussion*:** **Materials, How to Consider Bitumen Feedstock Energy (20 min.)** Nick Santero *Note: The intent of the prepared discussions is to provide a brief overview of the issue(s), and to pose the questions to be discussed further by smaller groups in the breakout sessions.
11:50 a.m. - 12:15 p.m.	**Introduction and Initial Discussion:** **Materials, Allocation of Impact from co-Production** **(25 min.)** Alissa Kendall, Nick Santero
12:15–1:30 p.m.	***Lunch***
1:30–2:00 p.m.	**Introduction and Initial Discussion: Materials,** **Average Data vs. Local Data (30 min.)** Alissa Kendall, Tom Van Dam
2:00–2:45 p.m.	**Introduction and Initial Discussion: Use Phase, Pavement Surface and Structural Characteristics and Vehicle Rolling Resistance (45 min.)** Karim Chatti, John Harvey (with input from Ulf Sandberg and Stefan Deix)
2:45–3:15 p.m.	*Break*
3:15–3:45 p.m.	**Introduction and Initial Discussion: Use Phase, Impacts of Pavement Surface Characteristics on Goods and Vehicle Damage (30 min.)** Wynand Steyn
3:45–4:45 p.m.	**Discussion (All): Create list of topics for discussion in breakouts. (60 min.)**
4:45–5:00 p.m.	**Individuals fill out forms for personal preferences for discussion groups.** **(Final selection of topics and discussion group rosters to be made by organizing team prior to start of Day 2.)**

Day 2—Thursday, May 6

8:30–9:00 a.m.	**Organization of Groups and Discussions (30 min.)** The assignment to groups, a discussion of the break out discussion process, and expected deliverables from each group
9:00–10:30 a.m	**Break-Out Discussions Part 1 (90 min.)**
10:30–10:45 a.m.	*Break*
10:45–11:15	**Introduction and Initial Discussion: Multi-Criteria Analysis (LCA and LCCA) and Implementation (PMS and other) (30 min.)** Nakul Sathaye
11:15–12:00	**Break-Out Discussions Part 2 (45 min.)**
12:00–1:15 p.m.	***Lunch***
1:15–2:00	**Break-Out Discussions Part 2 *cont'd* (45 min.)**
2:00–2:15 pm	*Break*
2:15–3:45 p.m.	**Break-Out Discussions Part 3 (90 min.)**
3:45–5:00 p.m.	**Groups prepare brief summaries from Break-Out Discussions (75 min.)**

Day 3—Friday, May 7

8:30–10:30 a.m.	**Presentation of Break-Out Session Summaries (120 min.)** • Review summarized results from each breakout session and questions and answers clarifying group summarized results. • Discuss areas of consensus/disagreement.
10:30–10:45 a.m.	*Break*
10:45–11:45 a.m.	**Presentation of Break-Out Session Summaries *cont'd* (60 min.)**
11:45–12:15 p.m.	**Next steps to be taken by research team** **Adjourn**

SYSTEM DEFINITION AND STANDARD ASSUMPTIONS

Prepared by the Pavement LCA Group at UC Davis (Kendall, Lee, Wang, Harvey, Santero)

This document is intended to provide preliminary system definitions for basic elements of pavement life cycle assessment (LCA). Elements labeled “factors to be included” and those without any explicit indicators are considered significant, and likely to be included within an LCA’s system boundary or in a sensitivity analysis. Elements considered potentially trivial or in need of further discussion before they are included in the analyses are labeled “factors requiring discussion before deciding on inclusion.”

It is important to establish the difference between a pavement and a roadway LCA. The decision to build a roadway is a complex product of mobility and accessibility demands, and balances a host of social, economic, and environmental issues within the decision-making framework *[1]*. From purely an environmental impact perspective, the construction of a new roadway (or expansion of an existing one) will open up new areas of potential impact, such as those spawned by changes to the local and regional economies associated with the transformed corridor. When performing a roadway LCA, it is critical that these indirect (yet highly influential) issues be accounted for in the results.

Performing a pavement LCA is more straightforward than performing a roadway LCA, as the former is a subset of the latter. Assuming a reasonable pavement serviceability threshold, accessibility and mobility are indifferent to the type of pavement used on the roadway and can thus be omitted from the scope. Therefore, the scope of a pavement LCA is confined to the issues that are related to the design, materials, construction, and other characteristics of the pavements itself. This delineation is crucial in order to correctly identify what should and should not be included within a pavement LCA. Isolating pavements from roadways allows for a more focused analysis and encourages recommendations to be made that are specific to pavements and their characteristics.

Goal Definition

Defining the goal of a pavement LCA includes identifying its purpose and audience. For pavement LCA, the purpose might be to characterize a category of projects with subsequent policy or decision-making implications, or it might be project specific, where information for decision making is sought for a specific project. If the goal of the LCA is a framework that can be used across multiple projects, information reflecting average temporal and spatial variability may need to be used. Conversely, in project-specific

LCAs, site-specific and project-specific information should be used (when available) to develop local results. This type of resolution will be particularly important at the impact assessment stage.

Functional Unit

The International Organization for Standardization *[2]* defines *functional unit* as "quantified performance of a product system for use as a reference unit" (p. 4). For pavement LCA, the *functional unit* needs to address both the system's physical dimension and pavement performance.

1) Physical dimensions
    a) b) Physical dimensions of pavements refer to length, width, and number of lanes for a highway system. However for some applications such as parking lots or intersections, total area or other dimensions may be more appropriate. Physical dimensions need to reflect the scale of a real-world project because certain activities can only be modeled at the scale of a practical project (e.g., mobilization of equipment or traffic analysis). For highway systems, a typical project length could be 0.5~100km.
    b) Inclusion of shoulder
2) Performance requirement
    a) Functional design life
    b) Truck traffic
    c) Climate
    d) Subgrade
    e) Criteria for functional performance

Analysis Period

The *analysis period* refers to the time horizon during which the inputs and outputs associated with the functional unit for a system or systems are inventoried. The initial construction of each system will have a different functional design life, and may be followed by a series of different maintenance and rehabilitation (M&R) activities to preserve its function. Properly assessing the pavement system over a time horizon presents a major challenge. Some proposed approaches to determine the analysis period include:

1) Using 1.5 times the longest functional design life among all alternatives
2) Using minimum next major rehabilitation activity
3) Annualizing/amortizing construction events

Life Cycle Inventory

1) Energy consumption

   - Feedstock energy must clearly be distinguished from combusted energy.

2) Greenhouse gas emissions

   - This requires the life cycle inventory of major greenhouse gas emissions, including CO_2, CH_4, and N_2O. In addition, NO_X, particulates (including black carbon), and other pollutants that are emerging as critical climate change factors should also be included as the scientific consensus develops on their effects/global warming potentials.

3) Material flows, including fossil/non-renewable resource flows, and water flow.

4) Air pollutants, including NO_X, VOC (Volatile Organic Compounds), PM_{10}, $PM_{2.5}$, SO_2, CO, and lead.

5) Water pollutants and solid waste flows, including toxics or hazardous waste.

Life Cycle Phases and Their System Boundaries

The life cycle phases of the pavement include pavement design, material production, construction, use, M&R, and end-of-life. A framework including each phase is shown on page 11.

1) Pavement Design

a) Structural design of each alternative in the analysis, including surface, base, subgrade, shoulder, and drainage.

   If the LCA is applied to a rehabilitation activity where the base/subgrade/drainage remains unchanged, these aspects of the structural design can be reasonably left outside the system boundary.

2) Material Production

➢ *Factors to be included:*

   a) Material acquisition/production

   b) Mixing process of HMA or PCC in plants

   c) Feedstock energy

   d) Transport of materials from/to site, and from/to mixing plant

➢ *Factors requiring discussion before deciding on inclusion:*

   a) Cut-off rule for oil excavation and refining

   b) Allocation of impacts during oil refining (asphalt production)

c) Technology improvement over time

d) Equipment manufacturing and capital investments in production facilities

➢ *Factors outside the system boundary:*

a) Land use/occupation

3) Construction, Maintenance & Rehabilitation

➢ *Factors to be included:*

a) Transport of materials and equipment to site

b) Equipment use at the site

c) Water transport

d) Water use

e) Energy used for lighting, if the construction happens at night

f) Storm water system (drainage): generally included. For a specific project, if alternative design changes the drainage, then it should be included; otherwise it can be neglected.

g) Emission/fuel consumption due to traffic congestion during construction

- Changes to traffic flow during construction events should be included in the analysis.
- Critical changes to traffic over time should be included in a sensitivity analysis or a similar assessment.
  - Dynamic traffic growth
  - Dynamic vehicle technology/emission

h) Building of roadway lighting system

➢ *Factors requiring discussion before deciding on inclusion:*

a) Equipment manufacturing and capital investments in construction-related production facilities

4) Use

➢ *Factors to be included:*

a) Additional vehicle operation due to pavement deterioration, including fuel economy effect, damage to vehicles, damage to freight, and tire wear. Traffic growth and vehicle technology improvement should be included in a sensitivity analysis.

b) Heat island effect

The mechanisms that affect heat island effect include albedo and evaporative cooling (for pervious pavement). The heat island effect causes changes in energy consumption associated with the heating/cooling of buildings or vehicles.

c) Non-GHG climate change effect

At present, only the radiative forcing from albedo is considered. Radiative forcing can be interpreted as the rate of energy change per unit area of the globe as measured at the top of the troposphere due to external factors. High albedo contributes to global cooling by reflecting a portion of the incoming radiation back to space, thus producing a negative radiative forcing. This can be quantified by CO_2-e offset.

d) Roadway lighting

This generally includes the electricity use.

e) Carbonation

Carbonation occurs when components in cement, such as $Ca(OH)_2$, react with CO_2, sequestering it in the pavement.

f) Water pollution from leachate and and runoff

- *Factors requiring discussion before deciding on inclusion:*

a) Long-term asphalt emissions of GHGs and other emissions (asphalt binder aging chemistry).

b) Differences in rolling resistance related to pavement type.

5) End of Life (Material Recycling and Landfilling)

- *Factors to be included:*

a. Recycling imposes a critical problem regarding the allocation of net input/output between the system that generates the "waste" and the system that recycles the "waste." The method of input/output allocation and crediting the virgin material saving regarding using recycled materials need to be reasoned and documented in an LCA practice.

b. Emissions and fuel use from the hauling of demolition

- *Factors requiring discussion before deciding on inclusion:*

a. Leachate from landfilling

b. Leachate from once bound materials now being used as unbound base

Impact Assessment

Impact assessment translates the inventory into meaningful indicators of a product or system's impact on the environment and human health. This is generally achieved by classifying inventory flows into impact categories and characterizing the inventory results through appropriate impact indicators. Some common impact categories include:

1) Climate change

   The inventory of greenhouse gases should be tracked and reported in CO_2-equivalents or a similarly well-understood climate change indicator—preferably one that accounts for the timing of emissions. The source of method used to calculate CO_2-equivalents must be reported in the analysis.

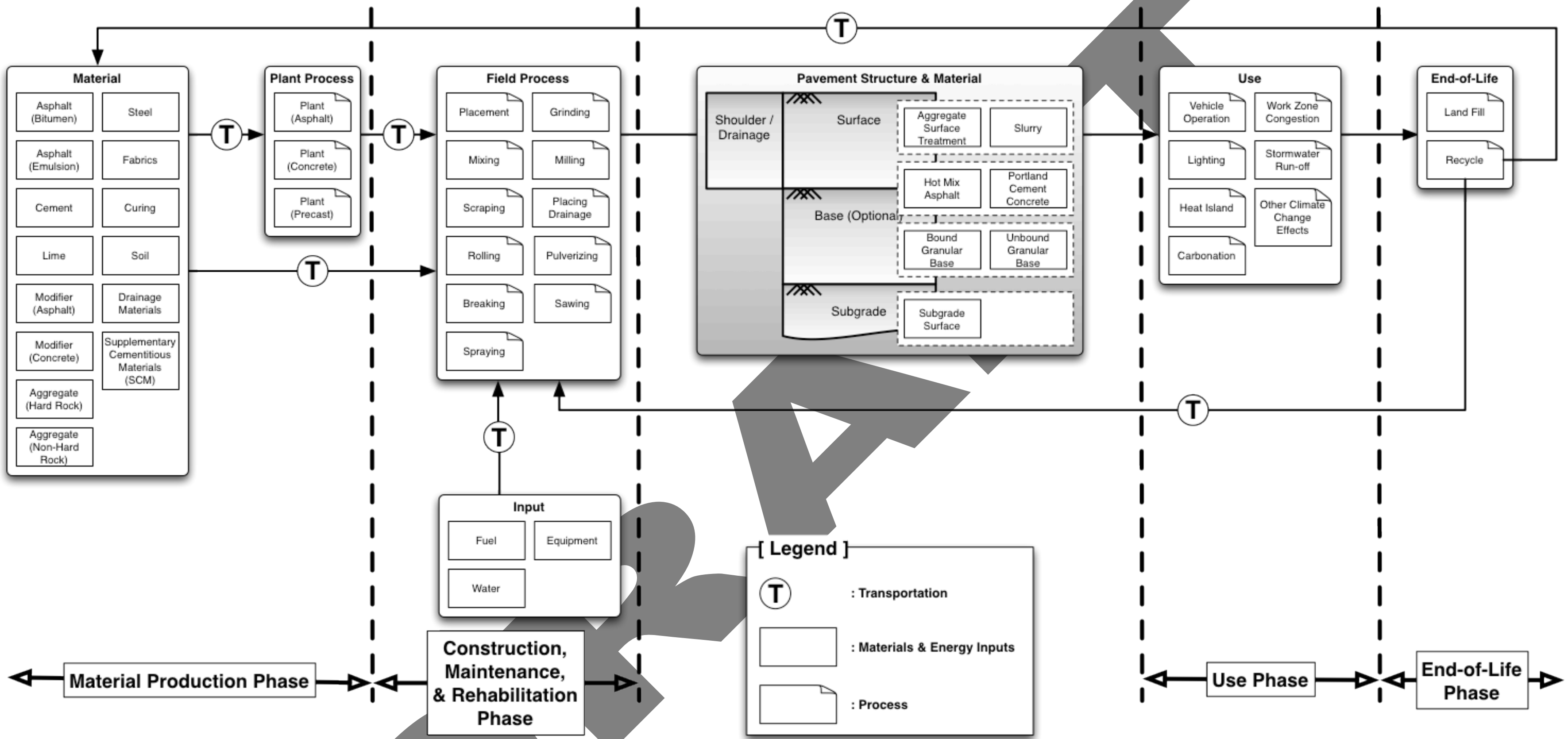
2) Resource depletion

   This translates the inventory of material flows into categories of consumption, such as non-renewable use or abiotic resource use.

3) Other impact categories, such as effects on human health, or environmental impacts categories, such as ozone depletion potential or acidification potential.

PROPOSED FRAMEWORK FOR PAVEMENT LCA

Prepared by the Pavement LCA Group at UC Davis



RECOMMENDED MODELS AND DATA SOURCES
(CALIFORNIA OR U.S. FOCUSED)

Prepared by the Pavement LCA Group at UC Davis (Kendall, Lee, Wang, Harvey, Santero)

This document provides more in-depth discussion of models and life cycle inventory (LCI) data sources for each life cycle phase of pavement, and provides examples relevant for California or the U.S. Guidelines for choosing the appropriate models and data sets are also provided so that equivalent tools in different regions can be selected. Gaps between current knowledge and analysis requirement are also listed where they have been identified, and these will be the foci for future work.

***Example* Materials and Processes Considered in Material Production Phase**[1]

1) Materials:

   Asphalt, asphalt emulsion, asphalt modifiers, portland cement, lime, cement modifiers, hardrock aggregate, non-hardrock aggregate, supplementary cementitious materials (SCMs, including slag, fly ash, silica fume, and calcined clay), steel, fabric/fibers, drainage material, and soil.

2) Plant process:

   Asphalt mixing, hydraulic cement concrete mixing, cement concrete precasting.

3) Pavement layer options:

Pavement Layer Options (Bonding and curing materials implied)	**Potential Use**
HMA	Surface or base
PCC	Surface or base
Bound granular base (cement-treated base, asphalt-treated base, etc.)	Base
Unbound granular base	Base
Aggregate surface treatment	Surface
Subgrade	Subgrade
Slurry	Surface

[1] This is not intended as a comprehensive or exhaustive list.

4) Field Processes:

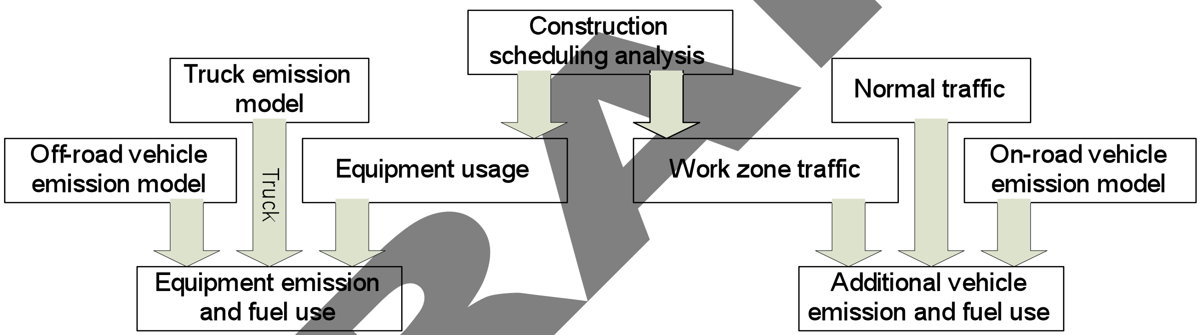
   Placement, rolling, grinding, pulverizing, breaking, mixing, milling, sawing, scraping, spraying, placing drainage

5) Since a specific layer (e.g., an HMA layer) could be considered as a surface layer in one construction event and then as a base in a future one, it is important to document the cross section of the pavement before each construction event. In a situation where the underlying layer is unclear, it is also important to document the "assumed" underlying structure.

6) The cross section of pavement must be defined before a construction activity.

Construction

Impacts to be considered during the construction stage include fuel use and emissions contributed by both construction equipment and construction-congested traffic. Fuel use must always consider total fuel cycle emissions. The following diagram shows the recommended analysis procedure.



1) ***Equipment emissions and fuel use***

The construction schedule, including the pattern of traffic closure and equipment utilization, can be modeled through *CA4PRS (Construction Analysis for Pavement Rehabilitation Strategies) [3]*, or a similar model. *CA4PRS* is a software tool that supports the integrated analysis of project alternatives for different pavement designs, construction logistics, and traffic operation options. It provides the activity of construction equipment, which then can be related to the emission factors obtained from an equipment emissions model, such as California's *OFFROAD* model *[4]*, and used to calculate the fuel consumption and emissions of construction equipment. *OFFROAD* is software used to generate emissions inventory data for off-road mobile sources (e.g., a paver or excavator). For states other than California, the US EPA's *NONROAD2005* model *[5]* can be used to calculate air pollutants from off-road equipment. For non-U.S. studies, equivalent models should be used.

Currently, *CA4PRS* can provide the work zone analysis for five types of rehabilitation work, including AC overlay, full-depth AC replacement, mill-and-fill AC rehabilitation, Continuous Reinforced Concrete Pavement (CRCP) rehabilitation, and Jointed Plain Concrete Pavement (JPCP) rehabilitation. Lane widening is under development.

Gap:

a) In general, construction processes that are not currently in *CA4PRS* or an equivalent construction schedule model require further investigation. Requesting diaries from similar projects is one option for simulating construction processes that are not already defined in a construction schedule model.

2) ***Additional emissions/fuel use from construction-related traffic***

Construction-related traffic includes the work zone traffic and network effect from construction congestion, such as detours. Currently only the work zone traffic is included for analysis.

Traffic behavior at the work zone, which is another output from work zone modeling and simulation, together with the background traffic information, is used as an input for modeling motor vehicle emissions/fuel consumption. The current model for on-road motor vehicle emission/fuel consumption in California is *EMFAC* (EMission FACtors) *[6]*. *EMFAC* can calculate emission/fuel consumption rates from all motor vehicles, from passenger cars to heavy-duty trucks, operating on highways, freeways, and local roads in California. For states other than California, the US EPA's *MOVES* (Motor Vehicle Emission Simulator) model *[7]* may be used for on-road mobile source emissions. The current version of *MOVES* is ver. 2010.

Gap:

a) *EMFAC* requires a speed spectrum to calculate the vehicle emissions; however, the work zone traffic analysis in *CA4PRS* doesn't calculate a speed distribution. Further information is needed to carry out the calculation.

b) *EMFAC* and *MOVES* only consider a static traffic speed; however, acceleration and deceleration of vehicles in congestion contributes to additional fuel consumption. This shortcoming would lead to an underestimation of fuel consumption in stop-and-go congestion.

c) The network effect from construction congestion could also lead to additional emissions and fuel use. This problem needs further investigation.

Use

1) ***Additional vehicle operation***

Currently only the fuel consumption in vehicle operation is proposed for analysis. The deterioration of pavements increases rolling resistance, and thus lowers fuel economy and increases the energy that traffic consumes. Pavement condition can be modeled and estimated through pavement performance modeling, and rolling resistance can be a parameter in estimating the fuel economy. In this way, additional fuel consumption due to deteriorated pavement can be evaluated through the change of pavement condition over the long run. One tool for evaluating this relationship is *HDM-4* (Highway Design and Maintenance Standards Model - ver.4), a model developed by PIARC (World Road Association) to conduct cost analysis for the maintenance and rehabilitation of roads *[8]*. It has an internal model to simulate the deterioration of pavement conditions and a mechanism to calculate vehicle energy consumption from IRI (International Roughness Index). The MIRIAM project will also produce further insights into this relationship between pavement condition and fuel economy.

Gap:

a) Our understanding of the relationship between pavement surface characteristics and vehicle fuel consumption is still in development. The current models require improvement.

b) Our understanding of differences in vehicle fuel consumption on different pavement types is still in development, and if significant differences exist, these need to be added to the models.

c) Tire wear and damage to freight and vehicles due to the deterioration of pavement condition need to be determined.

2) ***Urban heat island***

Two mechanisms have been identified as affecting urban heat island effects: albedo (solar reflection) and evaporative cooling. Differences in the albedo of pavements lead to different pavement temperatures, which then change air temperature. This change can result in additional energy use (such as increased use of air conditioning or greater energy needed for air conditioners to work because they intake warmer air) or energy offset in buildings or vehicles.

Nearly all pavements are impermeable, thus cutting off the soil beneath from the air, and reducing the evaporation of water from the soil into the near surface atmosphere. A new type of pavement, referred to as fully permeable pavement, where subgrade has contact with air through pavement (sometimes referred to as pervious pavements or porous pavements), may have less heat island effect than ordinary pavements because of evaporative cooling due to its high porosity and ability to pass evaporated water from the ground into the air.

The Heat Island Group at Lawrence Berkeley National Laboratory has conducted many studies on this topic and developed a semi-quantitative relationship which characterizes air and pavement temperatures *[9, 10]*. Future work would focus on how to convert the air temperature change to the related system-wide energy consumption change.

Gap:

a) The albedo is highly affected by pavement aging. The mechanisms controlling albedo and pavement aging are not fully developed. Further, new technologies affecting long-term albedo are under development.

b) More field tests are needed to determine the coefficient in the albedo/temperature relationship, and the result will be highly dependent on the air movement.

c) Currently there are limited studies on the evaporative cooling effect of pervious pavement. More studies are needed to address this issue.

3) ***Non-GHG climate change effect***

Currently only radiative forcing from albedo is considered.

High albedo contributes to the global cooling by reflecting a portion of the incoming radiation back to space, thus producing a negative radiative forcing. The Heat Island Group at Lawrence Berkeley National Laboratory has also made an attempt to quantify the relationship between changes in albedo and offset in CO_2 equivalents *[11]*.

Gap:

a) The study modeling the albedo-radiative forcing relationship at the Heat Island Group of the Lawrence Berkeley National Laboratory is still in an early stage and needs further development.

4) ***Water pollution from leachate and runoff***

Pollutants in groundwater may be modeled through *IWEM* (Industrial Waste Management Evaluation Model) *[12],* a software program developed by the Federal EPA to model the transport and fate of waste constituents through subsurface soils and groundwater to a well.

Gap:

a) There appears to be no equivalent model to *IWEM* for tracking the transport of pollutants to surface water. The pollution in surface water is often a more critical environmental compartment for many run-off events.

b) Different pavement designs have different effects on depositing and transporting pollutants in water and changing the water temperature. How to characterize the differences in pollutant movement among different pavement systems needs further investigation.

End-of-Life of Materials

When a material reaches its end of life, there are typically two options: recycle it or send it to a landfill.

1) ***Recycling***

Pavement materials may be recycled on-site or through an off-site recycling system. In either case, allocating the burdens of recycled materials to a specific pavement system is challenging. The following methods have been proposed in the LCA literature to address this challenge.

- One study *[13]* considered allocation of recycled materials and assumed that each construction event is responsible for the materials it uses. This implies that the construction event that uses virgin material is assigned all the environmental burdens for consuming that virgin material. Thus, all subsequent construction events that use recycled forms are only responsible for the recycling process and transport of the recycled materials.
- Another study *[14]* has proposed a 50/50 method that allocates half the burden of producing and disposing of virgin materials to the first construction event and half to the final construction event, which uses recycled forms of the virgin material. The environmental burdens of recycled forms of the material are allocated half to the first construction event and half to the construction event that follows the recycling process.

2) Landfilling

Impacts from landfilling include the burdens of transporting waste to the landfill site and leaching from waste once it is deposited in the landfill. However, most construction and demolition (C&D) waste is inert, so leachate is not likely to be a problem. The U.S. EPA conducted a study on water quality around the site of C&D landfills and found less than 1 percent of sites showed any water quality impacts *[12, 15]*. Therefore, the impacts from waste transport will likely be the dominant effect of the landfilling process.

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PAVEMENT LCA CHECKLIST

Prepared by Pavement LCA Group at UC Davis(Kendall, Lee, Wang, Harvey, Santero)

Draft version 04/15/2010

This checklist has been developed to help pavement life cycle practitioners prepare and organize essential information before conducting an analysis. It can also be used by LCA reviewers to identify differences in the basic elements of LCA (such as system boundary or data source) among different studies. A simpler and more graphical version of this list is being prepared for use by LCA reviewers and will be included with a future version of this document.

1 System Definition

1.1 Functional Unit

1.1.1 Physical dimension

Length: ____________km — Suggested: Max 100 km; Min 0.5 km

Width: ____________m

Number of lanes: ____________

Including shoulder: ☐

1.1.2 Performance requirements

Functional design life: __________years

Truck traffic (AADT): ____________

Climate: ____________

Subgrade type: ____________

Criteria for functional performance: ______________ , ______________ , ______________

1.2 Analysis Period

Method used to determine analysis period: ____________

Analysis period: __________years

1.3 Life Cycle Inventory

1.3.1 Primary energy: ☐

Clearly distinguish feedstock energy combusted energy: ☐

1.3.2 Greenhouse gases ☐

CO_2:	☐	CH_4:	☐
N_2O:	☐	Other:	______________

1.3.3 Material flows ☐

1.3.4 Air pollutants

O_3:	☐	PM_{10}:	☐
$PM_{2.5}$:	☐	SO_2:	☐
CO:	☐	Lead:	☐
Volatile organic compounds:	☐	NO_X:	☐

Others: ______________, ________________, ________________ *1.3.5 Water pollutants* ☐

1.3.6 Solid waste flows ☐

1.3.7 Other inventory categories ______________, ______________, ______________

1.4 Life Cycle Phases and Their System Boundary

1.4.1 Pavement design (for each system)

Surface:	☐	Shoulder:	☐
Base or Subbase:	☐	Drainage:	☐
Subgrade:	☐	Roadway lighting:	☐

1.4.2 Material production

1.4.2.1 *Raw material*

Material production: ☐
Feedstock energy: ☐
Transport of materials to site: ☐

1.4.2.2 *Engineered material*

Mixing in plant (HMA or PCC): ☐
Transport from/to plant: ☐
Transport of recycled material: ☐

1.4.3 Construction

Equipment usage: ☐
Water use: ☐
Work zone traffic congestion: ☐
Vehicle technology change: ☐
Traffic growth: ☐
Lighting energy, if at night: ☐
Movement of equipment: ☐
Equipment manufacturing: ☐
Factory or plant construction: ☐

1.4.4 Use

1.4.4.1 *Vehicle operation*

Impact to fuel economy from roughness:	☐	Damage to freight:	☐
Damage to vehicle:	☐	Vehicle tire wear:	☐
Traffic growth:	☐		
Change in vehicle technology:	☐		
Sensitivity analysis:	☐		

1.4.4.2 *Heat island* ☐

1.4.4.3 *Non-GHG climate change mechanism* ☐

1.4.4.4 *Water pollution from runoff* ☐

1.4.4.5 *Roadway lighting* ☐

1.4.4.6 *Carbonation* ☐

1.4.5 End of Life

1.4.5.1 *Recycling* ☐

Allocation: ☐

1.4.5.2 *Landfill*

Hauling of materials: ☐

Long-term water pollution: ☐

1.5 Impact assessment

1.5.1 Climate change

Global warming potential (GWP): ☐

Source : ☐ IPCC TAR ☐ IPCC AR4 ☐ Other ______

Time horizon (e.g. 100-yr, 20-year, etc.): ___________

1.5.2 Other

Other impact categories: ______________, ______________, ______________, ______________, ______________, ______________

2 Models and Data Sources

2.1 Material Production

2.1.1 Material LCI (List all the LCI Sources)

LCI Source #[1,2,…,n]: ___________

Type: ☐ LCI Tool ☐ LCI Study

Meet ISO standard? ☐

Data quality evaluation: ☐

Statistical analysis: ☐

2.2 Construction

2.2.1 Maintenance and rehabilitation schedule

Determined from: ___________

2.2.2 Equipment use ☐

Construction schedule analysis: ☐ Data source: ___________ Model: ___________

Equipment emission: ☐ Data source: ___________ Model: ___________

Equipment fuel use: ☐ Data source: ___________ Model: ___________

Truck emission: ☐ Data source: ___________ Model: ___________

Truck fuel use: ☐ Data source: ___________ Model: ___________

2.2.3 Construction-related traffic ☐

Work zone traffic analysis: ☐ Data source: ___________

		Model:	____________
Traffic network analysis:	☐	Data source:	____________
		Model:	____________
Additional emission:	☐	Data source:	____________
		Model:	____________
Additional fuel use:	☐	Data source:	____________
		Model:	____________

2.3 Use

2.3.1 Vehicle operation			
Pavement performance model:	____________	Data source:	____________
2.3.1.1 Impact to fuel economy	☐		
Pavement – fuel use model:	____________	Data source:	____________
2.3.1.2 Damage to vehicle	☐		
Pavement – vehicle model:	____________	Data source:	____________
2.3.1.3 Damage to freight	☐		
Pavement – freight model:	____________	Data source:	____________
2.3.1.4 Vehicle tire wear	☐		
Pavement – tire model:	____________	Data source:	____________
2.3.2 Urban heat island			
2.3.2.1 Albedo effect	☐		
Pavement aging – albedo model:	____________	Data source:	____________
Albedo – heat island model:	____________	Data source:	____________
Heat island – energy consumption relationship:	____________	Data source:	____________
2.3.2.2 Evaporative cooling	☐		
Evaporation – heat island relationship:	____________	Data source:	____________
Heat island – energy consumption relationship:	____________	Data source:	____________
2.3.3 Non-GHG climate change effects			
2.3.3.1 Albedo – radiative forcing	☐		
Albedo – radiative forcing model:	____________	Data source:	____________
Radiative forcing – GWP relationship:	____________	Data source:	____________
2.3.4 Leachate	☐		
Pollutant transport model:	____________	Data source:	____________
2.3.5 Carbonation	☐		
Carbonation model:	____________	Data source:	____________
2.3.6 Roadway lighting	☐		
Electricity use model:	____________	Data source:	____________

2.4 End-of-Life

2.4.1 Recycling	☐		
Method used to allocate input and output:	____________		
2.4.2 Landfill	☐		
2.4.2.1 *Truck use*			
Truck emission:	☐	Data source:	____________
		Model:	____________
Truck fuel use:	☐	Data source:	____________
		Model:	____________