A Report on the Workshop to Address Infrastructure Life Cycle Inventory Data Needs: Supporting Sustainable Decision-Making for Civil Infrastructure Using Environmental Product Declarations

September 13-15th, 2016

Ann Arbor, MI

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November 17, 2016

This workshop was conducted under Federal Highway Administration's Contract# DTFH61-11-D-00009 awarded to Engineering & Software Consultants, Inc. (ESCINC) and hosted by the Michigan Tech Transportation Institute under a subcontract from ESCINC.

Introduction

The goal of this workshop was to assess the prospects and obstacles for production of Environmental Product Declarations (EPD) by industry, and their use by public and private owners. The objectives of this workshop were:

- Globally benchmark the ability of industry to produce EPDs, and the use of EPDs by owners
- Identify institutional barriers, technical gaps, human resource and level of expertise capacity limitations, and cost constraints in developing uniform standards and approaches for collecting, organizing and documenting data inventories in keeping with data quality standards outlined in ISO 14025, and its implementation in the European EN 15804 standard, and recently published FHWA Pavement LCA guidelines.
- Work together to produce a vision for future production and use of EPDs, including solutions for standardization, strategies to overcome barriers and gaps, and ideas for constraining costs.

The underlying questions that this workshop addressed fall into two categories: technical and organizational, recognizing that these are closely coupled.

The workshop consisted of invited plenary presentations to frame the issues and pose the questions to be answered, followed by participatory workshop sessions to discuss and develop answers (and sometimes more questions), and on the final day, the outline of a draft road map for a way forward was discussed. The schedule for the meeting can be found in Appendix 1: Meeting Agenda. The list of attendees can be found in Appendix 2: Meeting Attendees

Summary of Discussions on Day 1:

On Day 1 various presentations were made as summarized in Appendix 3: Summary and Minutes from Day 1. The presentations were followed by robust discussion that can be classified into three sections which are expanded on in this section. The first section addressed the technical questions around the development of Product Category Rules (PCR), the data used to conduct Life Cycle Assessment (LCA) to support EPDs, and the technology frameworks that support the use of EPDs. The second covered challenges to integrating the use of EPDs into current business processes such as procurement and the necessary policy support and frameworks. The third section considered the challenges to integrating EPDs in the decision-making process.

Technical Questions

This section outlines the discussion on issues inherent to the technical aspects of developing PCRs and conducting LCAs that support the EPD development process.

The State of PCRs:

In the last few years, multiple industries in the United States have become program operators and introduced PCRs for their products. The construction materials industry is among this group: The National Ready Mix Concrete Association and the National Asphalt Pavement Association have become program operators for concrete and asphalt mixtures, respectively. As these relatively loosely coordinated efforts have begun, there has been recognition that multiple components of a PCR apply broadly across different products and processes. For example, data quality assurance requirements could be applied uniformly

across all products. Similarly, there has risen the need for coordination to ensure that PCRs are harmonized and are using consistent principles for allocation of impacts to co-products and recycled materials.

Speakers at the workshop representing European countries (Netherlands, Spain and Sweden) reported that some of the member countries have developed or are in the process of developing national PCRs managed by single national program operators who are associated with the national government. Meanwhile, there were efforts at developing a Europe-wide PCR that may supersede the national PCRs.

This led to the discussion of whether there needs to be single PCR for the United States that could be potentially governed by a consortium. A common PCR would identify the majority of rules (possibly 80%) that apply across all products and processes, and develop special requirements for the factors that are product specific. The process of developing a common PCR could help identify discrepancies across PCRs for related produces and harmonize them. The PCR would be akin to the core requirements definition for all construction and building materials as outlined in EN 15804. In keeping with the Part B specifications in EN 15804 that are specific to different products, the PCR could allow special provisions to cater to specific products.

The following new questions were raised in the discussion:

1. Should the infrastructure materials industries adopt a "core PCR" that allows special provisions for a wide variety of materials?
2. Who would be the operator for the program?

System Boundary Definition:

The current FHWA effort in developing the Framework for Sustainable Pavements has identified the life cycle system boundary for the entire pavement system. While this is a very useful guide, there are still questions to be addressed regarding possible exclusion, or double counting of impacts when developing the sub-system boundaries for products and co-products that are part of the pavement system. The following additional questions were raised in discussion:

1. When declared units are defined by mass, should they be normalized to reflect specific gravity of the material?
2. How would an EPD be developed for a material with 100% recycled content?
3. For pavement products and co-products, what is the appropriate definition of a "gate"? For example, if the gate for asphalt binder is set to be the petroleum refinery, then there is a possibility of excluding the impacts of the terminals where the binder is transported to before making it to the asphalt plant. Similar dilemmas are relevant for products that are recycled-in-place, or are pre-cast or processed off-site.
4. Should capital equipment in plants that produce construction materials be included explicitly in the system boundaries defined in the product PCRs?

Databases:

Establishing data quality and assurance standards, and ways of communicating data reliability and transparency, in keeping with standards such as ISO 14025 is a critical goal of this effort. The presentations raised questions regarding the current state of reliable and transparent life cycle inventory databases available for infrastructure materials. The challenges exist for both foreground and background

data. Data for a process that is directly observed, and reported in an LCA supporting an EPD is referred to as foreground data. For example, the energy reported (kWh of electricity, MJ of natural gas, gallons of diesel), in an asphalt plant, that is used to estimate impacts of an asphalt mixture can be considered foreground data. By comparison, the inventories that are used to estimate the well-to-refinery impacts of crude oil extraction, transportation and refining are often based on industry averages and/or databases that are provided by third parties. Datasets that pertain to upstream impacts of products and processes that are within the system boundary of an LCA but are not directly observed as part of the study, are referred to as background data. The workshop had various discussions regarding ways of ensuring reliability and transparency of background datasets, and the reporting of foreground data.

Currently there are a few commercial providers of background data (such as Thinkstep), and one US public life cycle inventory (NREL). While the former promises higher quality and completeness, it is usually proprietary and can be expensive. Public sources on the other hand are free to use and transparent, but often incomplete. This creates a dilemma for industry operators when specifying background databases in their PCR. On the one hand, state DOTs, who are often major customers for the infrastructure materials industry, are looking for greater transparency in the use of upstream databases and also want low cost solutions. The high cost of upstream databases can be a deterrent to adoption of EPDs for industry. On the other hand, if industry operators do not specify the use of specific inventories, there is a risk of EPDs being produced using widely different and unreliable upstream data. In this context, it was reported that in the Netherlands, LCA consultants created a single national database, funded equally by industry and government. The best available data was used when available, with an emphasis on using supplier reported data. In the absence of supplier reported data, very conservative industry average and third party reported data are used to indirectly penalize, and encourage the suppliers to provide better data. Questions were raised regarding the suitability of similar situations in the US context.

There are similar challenges in reporting foreground data. Uncertainty in the observed data must be reported, with careful characterization of variability across a significant number of observations. For example, average electricity use for a specific process must be reported with region specification and confidence intervals from more than a specified number of observations. Also, the sources of uncertainty should be sorted into their types: uncertainty resulting from lack of knowledge (called epistemic), or uncertainty resulting from inherent randomness (called aleatory). Efforts should also be made to correlate trends in data with underlying causal relationships that define processes. For example, the trend of regional variations in energy and electricity used to dry aggregate and the correlation with ambient temperature and moisture.

Besides foreground and background data, LCAs also use modeled data in some instances. This is particularly relevant to use-phase considerations that relate impacts to modeled changes in system/product performance, e.g., the rate of change of vehicle fuel efficiency with respect to changes in pavement surface characteristics. Guidelines should be developed regarding how data from supporting models should be used, and the necessary validation and documentation necessary to support such models.

In the course of the above discussion the following were considered to be beneficial:

1. Develop rules for reporting and using upstream background data across all industries. This is particularly important for upstream producers who are outside the immediate supply chain, e.g., upstream impacts of fuels, additives and other chemicals.

2. Encourage collaboration with allied industries (e.g., the chemical manufacturing industry) to develop transparent, reliable and low cost inventories.
3. Strongly encourage use of the same "proxy" datasets for all LCAs when using upstream datasets that are incomplete.
4. Develop guidelines for characterization of uncertainty in reported data.
5. Develop guidelines for reporting data from models and establish necessary validation and documentation necessary to support such models.
6. Develop benchmarks for processes to standardize across available databases and reported datasets.

Business and Organizational Processes

This section addresses the discussions regarding the challenges in delivering EPDs, including using novel technological frameworks and integrating them into existing construction industry business processes.

Information Technology Frameworks

There is a need to identify suitable information technology (IT) frameworks and platforms that can be used to integrate processes for creating EPDs and processes for using EPDs in the design, procurement, construction, and maintenance processes. For instance, in Sweden, as reported in the presentation, a custom made software system that takes the bill-of-materials as an input is used. The information is directly extracted from the design documents and loaded into standardized templates that are compatible with an LCA calculation engine. The LCA is conducted using a built-in standardized LCA engine using the EPDs as inputs. This produces an easily verifiable standardized report that provides a project level view of the LCA impacts.

The following delivery possibilities were discussed:

1. Have standardized software templates reflecting PCR categories, so that EPDs can be easily uploaded and archived.
2. Make available to local government simplified systems for tracking flows including materials used, distances travelled in transporting them, and project level procurement. These tools could be useful for tracking flows through current business processes providing decision-makers an initial way to engage in life cycle thinking.
3. Develop EPD delivery tools tied to standardized databases and PCRs. These platforms would allow suppliers to keep their EPDs up to date using a verified, user-friendly software interface. The interface would allow them to change and update their EPDs easily and economically, as they change the list of ingredients and proportions per declared unit.

The discussion emphasized the need for good IT design that allows for integration with existing design and construction management software.

Critical Review Frameworks and Qualifications

There are several rounds of third party review when developing an ISO 14025 compliant EPD program, and subsequently for producers creating program compliant EPDs,. The PCR must be reviewed and commented upon, as does the LCA supporting the EPD to ensure its compliance with the PCR. The review process is critical to the reliability of EPDs as a way of communicating the environmental impacts of a

product, yet currently there is no standard best practice to define the review process. In this context the following issues were discussed:

1. The necessity of possible minimal requirements to be a critical reviewer.
2. The need for a standardized critical review process for EPDs.
3. The need for a mechanism to ensure that if the procurement process were to use EPDs, there would be a way to vet the reviewers and/or create a list of verified reviewers to be used.
4. The possibility of automated verification of EPDs using software, as part of the technology frameworks discussed above.

Use of EPDs in Procurement

There is potential for EPDs being used by owners and agencies during the procurement phase. This can be limited to requiring EPDs on an informational basis to estimate the impacts of the materials being used in design and construction. This can be extended to consideration of EPDs in the selection of materials in a design-bid-build (low-bid) environment where the designer does not know the supplier of the material, and consideration of LCA of pavement structures using material EPDs as input in a design-build environment. The California High Speed Rail Commission is asking for EPDs from material suppliers, but limiting their use for information purposes only. However, they have set a goal for using EPDs for procurement purposes in three years, to be provided by suppliers at the time of delivery (not bidding). Within this context, the discussion considered the following challenges for state agencies using EPDs in the procurement process.

1. Limited LCA experience in agencies and no best practices in reviewing the expertise involved in critical reviews of EPDs and the PCRs under which they were produced, particularly with respect to identifying differences in the scope, etc. of EPDs for materials produced with under different PCRs (as discussed above).
2. It is not clear if making EPDs a requirement could lead to discrimination against small businesses. If so, could there be government supported programs to level the playing field?
3. The success of EPD programs will depend on the availability of reliable and transparent LCI databases. Should a government agency fund a targeted effort to fill gaps in public LCIs?
4. There are currently no best practices around certification of EPDs for materials produced in other countries – this could become relevant for projects with international bidders.
5. Materials EPDs only extend to the gate of the producer, and do not consider construction, use and end-of-life stages. ISO rules state that EPDs should not be used for comparison without consideration of the full life cycle. The full life cycle of a pavement material is highly dependent on how it is used in the structure, the traffic, and climate and other variables affecting performance, thus the use stage cannot be considered based on the materials properties alone. Materials with lower impacts in the materials production stage may actually produce greater impacts over the rest of the life cycle, and vice versa. Therefore, selection of materials within type and especially between different types based on material EPDs alone could actually result in increased impacts over the life cycle without consideration of the information that comes from design of the pavement structure and prediction of its performance in the use stage and its end-of-life.

In summary, while the use of EPDs in procurement would provide much greater incentive for their use, it may be too early, given the above challenges. Requiring material EPDs which can be used as input to evaluation of pavement structure designs is a more likely early goal.

Decision-Making

Ultimately the goal of EPDs is to produce better information to support the decision-making process and move decisions towards more sustainable outcomes. The role of decision-makers in improving the long-term sustainability of infrastructure is important at all levels: local, state and federal. The workshop attendees provided perspectives from all three levels. While at the federal level there are efforts at influencing best practices and informing policy, the states can provide leadership in benchmarking and implementing LCAs in projects. At the local level (city and municipality), the scope of sustainable decision-making is quite broad with decision-makers encountering many situations that can be better informed by life cycle thinking (comparison of flows from the inventory phase of LCA rather than full impact assessment). At the local level the performance of pavement systems is also often affected by other infrastructure such as storm water system and utility maintenance

The dilemma lies in appropriately using EPDs during the decision-making process. All indicators reported in an EPD may not have the same scope, and depending on the level at which decisions are being made, the weighting may vary. For instance, while Global Warming Potential (GWP) is of universal concern, local indicators such as eutrophication, smog formation and water use may carry different weights in different locations. In addition, as these indicators are summed across the life cycle of a product or process, it may be difficult to establish the geographical scope of the impacts. The economic aspect of decision-making must also be considered and there are potential challenges with monetizing impacts.

Summary of Activities on Day 2

The second day was dedicated to group work. Groups were formed to reflect the diversity of the stakeholders. Each team was assigned a facilitator and a scribe. The four teams were:

Team 1: Joep Meijer (Facilitator), Ali Azhar Butt (Scribe), Thomas P. Wilson Chaitanya Bhat, Alicia Pitlik, Jim Mack, Heather Dylla

Team 2: Jeremy Gregory (Facilitator), Benjamin Ciavola (Scribe), Cesar Bartolome, Jenny Li, Edward Poppitt, Barry Descheneaux, Mark Buncher

Team 3: Kurt Smith (Facilitator), Hasan Ozer (Scribe), Emily Lorenz, Ken Darby, Gina Ahlstrom, Daniel DeGraaf, Brian Killingsworth

Team 4: John Harvey (Facilitator), Arash Saboori (Scribe), Ron Sines, Elias Kurani, Senthilmurugan Thyagarajan, Larissa Strömberg, Curtis Bleech

The LCA Checklist from the FHWA LCA Guideline Document (attached in Appendix 4: LCA Checklist – From FHWA LCA Guidelines Document) was provided as a reference for discussion. The groups discussed and responded to a set of questions that were technical, organizational and pertaining to decision-making. The questions and the group responses are listed below.

Summary from Group Discussion on Day 2:

The summary of group reports can be found in **Appendix 5: Summary of Group Reports from Day 2.** The following summary shows the key outcomes from the responses from all of the groups under each question put to them.

Technical Questions

Question T1: What factors should be kept in mind when developing a checklist/guideline for EPD data collection and organization?

- A checklist is necessary for pavement LCAs. While the FHWA checklist, originally developed at the UCPRC workshop has been useful, it needs to be redesigned. One suggestion is to reorganize it to reflect the EN 15804 framework.
- Data collection should be organized by life cycle stages and material suppliers and contractors should be incentivized to develop EPDs. Data collection and organization should be considered within the context of network, project and design/execution levels.

Question T2: How do EPDs integrate at different levels: the conceptual - program description, and at the project and network levels?

- When implementing EPDs at the project level all EPD related information should be managed through the prime/general contractors.
- There should be greater emphasis on collecting material flow data at the local government level.
- Information technology frameworks are necessary for seamless reporting of EPDs across project delivery systems.

Question T3: Roadmaps, Challenges and Gaps

- Significant data gaps were identified in life cycle inventories for upstream impacts of (including but not limited to) project level material flows, aggregates, additives (various), polymers, fibers, lime, transportation and asphalt binder. There is also a need for further guidelines on handling capital equipment impacts. Recycled material handling also needs further guidance.
- Increase knowledge in the industry regarding PCRs and EPDs: Identify how they can best be produced and develop rules and best practices for use.
- Determine where the gaps and conflicts are in PCRs and EPDs: Find common areas, conflicts (lateral and vertical) and prioritize gaps
- Develop a funding plan for curating transparent and reliable public datasets.
- Continue to update the FHWA LCA Framework through improved information, consensus on best practice, eventually leading to requirements instead of just recommendations
- Produce guidelines for agencies: How to manage and use EPDs through management of Information and benchmarking quantities and impacts, use in design, procurement and interpretation in decision-making.

Question T4: Would this be the first step to a "single PCR"?

- A single PCR can be developed for materials but there are uncertainties associated with the development of single PCR for the complete pavement system.
- A phased approach should be considered starting with PCRs for individual products, followed by PCRs for each life cycle stage before merging into single PCR in the long run. Through this process, as more stakeholders get more experience in handling EPDs, the "single PCR" development process will be smooth.

Organizational Questions

What are the recommendations for collecting and organizing data?

- In the long run create single governmental (or government controlled) operator, or an effective consortium of industry operators.
    - Appeal to ISO for a change so that procurers can select the PCR they want to use, to prevent small unqualified organizations from staking a claim with a PCR and everyone has to wait until it expires even though it is an incomplete or poorly prepared PCR.
    - May be at state level or consortium of lead states and local governments if no federal mandate for national.
- There is a need and a demand to develop a centralized comprehensive, easily accessible, reliable and transparent database, which might come from collaboration of allied industry and agency groups.
- A governing body comprising of people from industry, academia, state transportation agencies and the Federal Highway Administration should be formed to examine the critical review process. Reviewers should have some years of experience in the field of LCA. There should be uniformity in the process followed by PCR program operators.
- When developing rules relating to EPD implementation, consider how they will drive behavior and evaluate potential for unintended consequences.
- Outline types of tools needed tied to IT
    - Standard templates for pulling data into EPDs, tied to existing pay and other tracking systems; for local government need tools for tracking flows
    - Standard reporting templates for EPDs so can be pulled into LCA tools and other database and reporting tools.
    - Tools for producing EPDs as proportions of basic ingredients and additives change. (List of standard materials in my photographed notes).

Decision-Making Questions

What steps should be taken to understand uncertainty in data (variability and epistemic) and its impact on decision-making?

- Uncertainty analysis should be considered in case of significant variability in the results obtained. Sensitivity analysis should be carried out in most of the life cycle stages, however more data is needed before these analyses can really be performed; there is no point in doing sensitivity analysis if there is no data regarding variability.

- It is desirable to consider all the impact indicators specified by the FHWA framework (TRACi from US EPA) but in most cases it is practical to consider the indicators that are significant to the decision-making organization.

Summary of Discussion on Day 3

A round table discussion was conducted on day 3 from 8:00 am to 11:00 am. The highlights of the discussion raised a need for the following:

1. Understand, review and harmonize existing and newly developing PCR efforts.
2. Understand the role of the ISO 21930 working group, which has the goal of producing a single industry wide PCR, as it takes shape.
3. Identify and fill knowledge gaps in databases: what data needs to be collected, what are the standards for data quality assurance?
4. Identify how each of the organizational and technical challenges aligns with decision-making workflows.

The next step that has been identified is to try and benchmark a project with a lead state DOT to understand the scope of the challenges of using EPDs as input in the design phase of a project. That experience will provide information regarding challenges in the use of EPDs for procurement.

Recommended Implementation Plan and Roadmap

The following is a recommended three stage implementation plan for agencies in the use of EPDs:

1. Develop rules and then require reporting, move towards standardization of EPDs (1-2 years)
    a. Pilot project for requirements for EPDs for information purposes (Caltrans).
    b. Pilot project for using EPDs for various purposes (not yet to procurement, Caltrans).
    c. Take lessons learned and provide information to other lead states.
    d. Identify alternative plans for steps 2 and 3 below, and gaps for each.
2. Require use of standardized PCRs (3 to 5 years)
    a. Need single operator or consortium identified in 1-2 years.
    b. Produce a single PCR with appendices for additional requirements for specific materials
    c. Fill gaps in public databases.
    d. Develop how processes to handle characterization of performance, must have for procurement.
    e. Implement reward system similar to Dutch for quality (plant specific data versus use of industry averages) of EPDs submitted.
    f. Use this better information in pavement design.
3. If desirable and have made sufficient progress, consider using for procurement
    a. EPDs of materials, if design-bid-build.
    b. LCAs of pavements, to laid, if design-build.
    c. LCAs of full life cycle, if design-build-maintain.

At the end of this implementation plan future research direction will be identified.

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Appendix 1: Meeting Agenda

Session and Time	Topic
Tuesday 13th	Introduction Session
08:00 am – 09:30 am	Welcome and Keynote: Howard Lazarus, City of Ann Arbor FHWA Sustainable Pavements Program: Gina Ahlstrom Framework for Sustainability: John Harvey, UC Davis Broad outline of goals and objectives of workshop: Amlan Mukherjee
	State of LCI Data: Agency Practices Near and Afar – US DOTs
09:30 am – 10:45 am	Michigan DOT – Curtis Bleech Texas DOT – Jenny Li Panel discussion on gaps, needs and opportunities
	State of LCI Data: Agency Practices Near and Afar - Abroad
11:00 am – 12:15 am	Netherlands: Joep Meijer Sweden: Larissa Stromberg LCE4Roads: Cesar Bartolome, IECA Panel discussion on trends in practices abroad & lessons to be learned
	Lunch
	State of LCI Data: Broader Infrastructure
01:15 pm – 02:30 pm	City of Detroit (Chicago) – Janet Attarian City of Austin – Ed Poppit California High Speed Rail – Meg Cederoth, Parsons Brinkerhoff Panel discussion on broader goals of infrastructure sustainability
	Current Practices around Data Reporting
02:45 pm – 04:15 pm	Challenges with EPD program development – Heather Dylla, NAPA Use of LCA in Decision-Making – Thomas Wilson, ARA Delivery of LCI databases – Jeremy Gregory, MIT Discussion of challenges around data collection and inventory
	Prep for Day 2
04:30 pm – 05:00 pm	Summary – break-out sessions and group work
Wednesday 14th	
08:30 am – 10:00 am	Interactive work (5-6 groups, 5-6 per group, 3 question/group)
10.30 am – 12:00 pm	Interactive work (rotate the questions)
01:30 pm – 02:30 pm	Interactive group work on a PCR
03:00 pm – 05:00 pm	Presentations and discussion
Thursday 15th	Organization team wrap-up
08:30 am – 12:00 pm	Protocol and institutional framework development

Appendix 2: Meeting Attendees

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Appendix 3: Summary and Minutes from Day 1

Following is a summary of the presentations and discussions in each session. MS PowerPoint slides of the presentations are available upon request.

Day 1: Session 1: Introduction Session

Howard Lazarus - Funding Process for Infrastructure projects, City of Detroit

There are many challenges associated with funding for infrastructure projects. The uncertainties mainly exist with the money to be borrowed by public agencies for infrastructure projects. There is a need to provide a quality project within economic constraints. As public expectations of the quality of service provided by the government keeps increasing disproportionately compared to resources available, Lazarus shared that most projects focus on least cost, and tend to not emphasize on sustainability. His message was that while sustainability is important, decision-makers are often forced to focus on life cycle costs rather than life cycle environmental impacts.

Gina Ahlstrom - Federal Highway's Sustainability Program

Limited guidance is currently available regarding the management of data collected. There exists a lack of knowledge to check the reliability of "green products". Ahlstrom mentioned about the USDOT's Sustainability Policy Statement. Every stage of the life cycle can contribute towards sustainability. The presenter stated the goals of the FHWA's Sustainable Pavement Program. Recycling alone doesn't guarantee movement towards sustainability. FHWA believes in stakeholder involvement. FHWA has developed a document that will act as a technical guidance to incorporate sustainability in infrastructure projects. FHWA has also developed a document that provides a framework to carry out LCA for various infrastructure projects. The speaker also discussed the contribution of LCA towards decision-making. FHWA's next goal is to develop guidelines for data identification and collection for pavement LCA. FHWA is interested in pursuing a direction that will lead to the creation of a centralized database that will provide free, reliable and transparent data to support LCA.

John Harvey - Framework for Sustainability

There is a need to differentiate between LCA, Life Cycle Cost Analysis (LCCA) and Sustainability Rating Systems. LCA is a best approach to measure environmental impact associated with a project. LCA has four key stages namely, goal and scope definition, life cycle inventory assessment, impact assessment and interpretation. Harvey presented a generic model to carry out a cradle to grave LCA study. Recycling of materials may not always be advantageous. The presenter specified that more focus must be given on collecting good data rather than focusing on the software tools to conduct LCA, and that there are major data gaps for pavement LCA. These include missing data for some important pavement materials, regionally applicable data and updating of old data. There are gaps in other stages of the pavement life cycle as well, although a number of those are being filled or will be soon in the use stage. Organization of database will help to identify the applicability of the data. PCR is a set of rules that needs to be followed to obtain an EPD. The speaker specified the steps necessary to obtain to conduct PCR. S. David Freeman initiated the implementation of environmental policies in the infrastructure projects. There is a need to establish one national standard for environmental policies as present in Europe.

Amlan Mukherjee - Goals and Objectives of Workshop

The speaker presented a roadmap of the activities involved for incorporating sustainability in infrastructure projects. He also mentioned the technical and organizational challenges associated with the delivery of life cycle inventory database. He specified that the long-term objective is to provide a comprehensive, inexpensive, reliable and transparent life cycle inventory database for construction materials. It is necessary to discuss the level of detail of data to be collected, organized and presented.

Day 1: Session 2 State of Life Cycle Inventory Data: United States

Curtis Bleech - Michigan Department of Transportation

The speaker defined the terms LCCA, LCA, Life Cycle Inventory data and EPD. He mentioned the state of Michigan has a state law for LCCA and conducts LCCA for projects whose total life cycle costs exceed $1 million. Pavement type selection is based on least equal uniform annual cost. MDOT uses software called PASER to evaluate the condition of the pavement. Currently LCA results are not used for the procurement purposes in the design-bid-build project delivery system. There is a need for more regional data. He mentioned that MDOT developed its own database through the research project Carbon Footprint for HMA and PCC Pavements, which is currently hosted at Michigan Technological University within the Project Emissions Estimator (PE-2) website. He concluded by suggesting the need for LCA in future for decision-making within state departments of transportation, and FHWA's role in providing guidelines to do so.

Abroad

Joep Meijer - Netherlands

The speaker mentioned that LCA is used as a decision making tool in the Netherlands. In the beginning stages, agencies used LCA as additional information and were not using it in decision-making. Later the agencies gathered information from the contractors regarding their knowledge of sustainability. Life cycle costing analysis gained much importance before LCA did. Europe has set goals to reduce 20% of CO_2 emission, based on 1990 levels, by 2020. It has been made mandatory for public authorities to apply for green procurement on all purchases as of 2015. A tool named DuboCalc is being currently used to conduct LCA by both agencies as well as contractors during the bidding process. Using this tool the environmental impact is converted into an economic value. A national database was created in 1999 by the association of LCA consultants. There were funding problems associated with data collection. Finally, merging several databases such as Rijkswaterstaat, and Ecoinvent formed a national database named Nationale Milieudatabase.

Larissa Stromberg - Sweden

The speaker mentioned that sustainability gained importance in Sweden due to the competition between various industries producing green products. She specified that the Swedish EPD is prepared according to EN 15804:2014-17. Sweden uses commercial software plug-in produced by thinkstep (Germany) in a joint project with Norway to develop an automatic EPD for bridges and roads. Microsoft Excel sheets listing the Bill of Materials (BoM) were created to calculate the amount of carbon and energy for bridges and roads. Data from each construction activity was collected separately. The complete database was developed by combining commercial datasets from Gabi, and data from local plants. A roadmap was followed to verify the quality of data collected. The usefulness of the software has been tested through the projects carried

out by four contractors from both Sweden and Norway. The results revealed that the BoM approach produced excellent results according to EN standards and PCRs. The software also proved to be cheap and was flexible to input supplier specific data information. The speaker identified that there is a need for a universal PCR for all infrastructure projects. A new version of software is being developed for the future studies.

Discussion led by Joep Meijer

Meijer gave a brief idea about the development of LCA in Europe. LCA gained importance in Europe from mid 1990s to 2000. He mentioned that 80% of things are common in all PCRs. In the Netherlands the program operator exists at the national level. Meijer expressed the possibility for all industries operate together under a common PCR. He mentioned that in the Netherlands LCA consultants created the single database that everyone uses and the software. There is 50/50 funding for EPD program between government and industry. Best available data used. If data not very good (industry average) then data are weighted to be conservative which penalizes those not producing their own data.

Question: Who is in the certification process in Europe? What level of expertise is required to be a reviewer?

Answer: People with some years of experience in the field of LCA are considered for the post of reviewer. A person from the EPD committee will also be present in the review committee. The quality of data collected from different commercial databases like Gabi, Ecoinvent is the same.

Cesar Bartolome - Spain

The speaker talked about the development of LCE4roads in Spain. LCE4roads was funded by European Commission to develop the EPD for road. Various databases gave different results for environmental impacts associated with the same road. These uncertainties encouraged the industry to develop its own database. He specified that the industries will use the database that gives them favorable results if a standard rule is not made. Database should be revised every 5 years and should be collected region-specific. He mentioned the challenges associated with the addition of new materials, process of allocation, data collection and environmental impacts to be considered. In Spain, PCR is developed based on the guidelines present in ISO 21930 and EN 15804. European countries tend to use a national PCR, which will continue to be in use unless an EU PCR is available. National level PCR development takes time as it requires unanimous consensus. The speaker mentioned that the final objective is to obtain comparable results from different databases. He urges that method for conducting LCA should be standardized globally.

Day 1: Session 3: Broader Infrastructure

Janet Attarian - City of Detroit

The speaker specified that there is a lack of Knowledge on LCA among city government officials. She mentioned that the current organizational structure of local governments doesn't support LCA. There is limited guidance on sustainability for solving technical problems. It is often linked to Livable Streets. City governments have their own policy for data collection that aims at improving quality-of-life for citizens without depleting the natural resources. Hence, innovation for government means more operational solutions like permeable roads, increase in the use of recycled materials, and waste material management. Reduction in the storm-water runoff is the only aspect that is considered for green streets.

While, state department of transportations are really slow in implementing innovations, at the level of local government innovative use of micro-thin concrete clay, photocatalytic, permeable and high albedo pavements can help implement sustainability. She mentioned that her department partnered with Vulcan Materials Company with the purpose of constructing sustainable pavements.

Ed Poppit - City of Austin

The speaker mentioned that the demand for LEED certification for buildings led to the development of EPDs for buildings. He expressed the need to incorporate sustainability in transportation projects. The office of sustainability in the City of Austin aims at educating the departments that are not yet aware of the developments in the field of sustainability. Current design-bid-build practices give more importance to the quality of pavements neglecting various other the aspects of sustainability but future efforts must include both sustainability and quality. The speaker specified that the main objective of his department is to provide durable, safe and aesthetically pleasing utilities and services for citizens. He felt that research must focus on monetizing environmental impacts and adding it to life cycle costs. LCA should be included in the planning stage rather than the decision making stage. Practical effort at sustainability has focused more on operational decisions such as using products like recycled asphalt, and warm-mix asphalt. Crushed glass was also used as a replacement for fine aggregate in concrete but the results were not favorable.

The speakers Poppit and Attarian, both observed that while not directly involved in LCA, local governments are often capable of collecting material flows data directly while also being in a position to directly impact the life cycle impacts through operational level decisions. While they may not directly engage in LCA, they benefit significantly from life cycle thinking.

Margaret Cederoth - California High Speed Rail (HSR)

The speaker stated that sustainability is the core mission of the State of California. LEED's initiative proved to be the driving force towards sustainability. High-speed rail was required to increase mobility for the increasing population. California aims at reducing CO_2 consumption by 2,500,000 MT before 2030. 25% of fly ash concrete is used in 119 miles of construction. When making decisions, agencies look at sustainability in a comprehensive manner, focusing on outcomes rather than delving into details of LCA methodology. Hence, there is a need to develop high level internal agency data sources for construction materials that will help estimate environmental impacts to support decision-makers. However, database and inventory development is really expensive, particularly if proprietary databases such as Gabi are used. Hence, EPDs were considered to be a useful communication tool that is provided by suppliers. At this time EPDs are being used for disclosure only. They are not certain that the data is high enough quality and that they know how to use it for procurement yet. They have set a goal of using for procurement in three years. The EPD is required at time of delivery, not during bidding. The speaker feels that PCRs must be simple and should provide same grounds for comparison. When using EPDs for decision-making, the idea of considering global warming as the single representative of environmental impacts was rejected by HSR.

Day 1: Session 4: Current Practices around Data Reporting

Heather Dylla - National Asphalt Pavement Association

The speaker addressed the challenges associated with the development of an EPD program. LEED version 4.0 proved to be the driving force for the development of the EPD program for asphalt. The National

Asphalt Pavement Association (NAPA) started its own EPD program in 2014 that concentrates on the cradle-to-gate life cycle stages. The program expects the EPD to reflect the environmental impacts of asphalt mixtures in a way that can be considered to be fair, reviewed by third party, credible and comparable. The main challenges associated with data collection were the methods to obtain secondary data and whether to use public data or private data. NAPA chose to use public data because open and low cost, but it is limited. Private data sources were not used because they cost more and are not disclosable on broadcast basis. The speaker feels that current process of developing EPD is expensive and time consuming and this may be a barrier to adoption in the industry.

Jeremy Gregory - Massachusetts Institute of Technology

The costs and credibility associated with LCA methodology depend on the life cycle inventory data collected. Gregory stated that the ultimate goal is to develop a flexible life cycle inventory database to support a robust LCA methodology. The variations and uncertainties associated with the life cycle inventory data must be quantified. Two types of uncertainties namely aleatory (random) and epistemic uncertainty (lack of knowledge) must be studied and characterized. The model parameters that are used to generate the quantity of inventory parameters must also be clearly defined. The speaker concluded by saying that interoperability between various commercial and public databases will help to create a transparent life cycle inventory data for Northern America.

Thomas Wilson - Illinois Tollway

Illinois Tollway uses LCA methodology as a decision making tool in addition to FHWA's INVEST 1.0 that was implemented. Illinois Tollway is moving towards greener roads through the MoveIllinois program. The speaker stated that they are in the process of implementing an LCA tool for evaluating the Tollway projects. The inventory data was collected through interviews and questionnaires even though, the responses from stakeholders varied widely and has promise for improvement. In conclusion, the speaker reported that sustainability efforts at the Tollway had saved approximately $250M over the period of 11 years.

Appendix 4: LCA Checklist – From FHWA LCA Guidelines Document

APPENDIX A. PAVEMENT LCA CHECKLIST

1 Goal and Scope Definition

1.1 Goal Definition

Study level (Choose one):	☐ Network level ☐ Project level	
LCA type (Choose one):	☐ Single stand-alone LCA ☐ Comparative LCA	
If "Comparative LCA" is selected, state the components that are assumed to be the same across systems:		

1.2 Functional Unit

1.2.1 Physical dimension

Lane length:	_____km	Suggested: Max 100 km; Min 0.5 km
Lane width:	_____m	
Number of lanes:		
Including shoulder:	☐	
If lane length, width, and number are not applicable, use total area:	_____m^2	Such as parking lots, airports, or intersections.

1.2.2 Performance requirements

Functional design life:	_____years	
Truck traffic (AADT):		
Climate:		
Subgrade type:		
Criteria for functional performance:	_____ [a]	_____ [a]

1.3 Analysis Period

Method used to determine analysis period:	Analysis period: _____years

Appendix 5: Summary of Group Reports from Day 2

This is a summary of discussions as reported by groups on Day 2. The group presentations can be provided upon request.

Question: 1 Technical Questions

Question T1: What factors should be kept in mind when developing a checklist/guideline for EPD data collection and organization?

Group 1:

- Manufacturers will be motivated to provide EPDs if sufficient incentive is provided to them. Agency should consider making obligatory rules for the manufacturers to provide EPD.
- Separate EPDs are recommended for each life cycle stage such as material production, mix design and construction.
- In the current scenario EPDs for materials and mix design can be produced but it is too ambitious to expect EPDs for construction and use stages.

Group 2:

- The EN15804 document provides clearer framework as compared to the framework prepared in UCPRC workshop. Hence there is a need to reorganize the framework. Identify scope, data, model sources for each element based on reorganization
- Checklist should be prepared based on the inputs from agencies, contractors and suppliers.
- Life cycle inventory should be present in the output part of the checklist and not in the input section.
- Sources: Agency documents, general contractor, suppliers

Group 3:

- The data collection should be carried out depending on the life cycle stages.
- It is the responsibility of the state, agencies and contractors to provide data regarding the materials used during the construction activities. Such data collected can be expected to be generic in nature.
- The data for material production can be obtained through EPDs and commercial databases.
- The upstream data related to fuel and electricity can be obtained from the existing commercial databases.

Group 4:

- The functional unit: similar unit should be used by different suppliers of the same materials. Based on contract bid items? Dimensional unit should also be similar to facilitate comparison.
- Section 1.2 in FHWA Checklist: Functional unit is not applicable to materials EPDs only applicable to pavement
- Section 1.4 in FHWA Checklist: The indicators should only be TRACI 2.0.
- To be considered for PCR 2.0: regional impacts of different components in the material; maybe for PCR 2.0.

Question T2: How do EPDs integrate at different levels: the conceptual - program description, and at the project and network levels?

Group 1:

- The group developed a framework at two levels (Network and Project) and categorized it by two stages (Early Planning and Design/Execution). Specific product/material EPDs will be required at the design stage at the project level where contractors will be required to provide plant specific and material specific data, as the design will have determined what materials/mix design will be used. On the other hand, at the network level as well as the early project stage, when the specific information is not available and project specific information is not certain, average EPDs can be used. Additionally, specific material EPDs that are selected in the design stage can also be used.
- The group also recommended that the design/execution stage to be further divided into 20%, 50% and 80% completion as for each level, data will be required based on decisions that are made or changed along the completion of the project. At the network and early planning stage, two ranges can be used; National Averages and Agency Specific (such as mix design). And instead of reporting one number, a range should be provided as nothing is certain but one knows about local material EPDs and its ranges.

Question T3: Roadmaps, Challenges and gaps

Group 1:

- Ask for environmental related information/surveys from the material producers/manufacturers.
- Incentivize suppliers who provide EPDs. This is important as, material producer/contractor will have to justify the extra cost of producing EPDs. Eventually, submission of EPDs should become mandatory once an agency is well informed of the system.
- EPDs should be separated out for each stage such as materials, mix design, construction and pavement use.
- There is current readiness to develop PCRs for mix design, whereas for construction and use stages, more information is required before such readiness is reached.
- Additionally, EPD system can be implemented for all the life cycle stages at the National level except for the use phase that may require regional customization.

Group 3:

- The challenges associated with data collection are that not enough data is present for material flow (project-specific data).
- There is no central database for background data. There exists a lack of understanding regarding the responsibilities for data collection.
- The data should be collected specific to a region.

- The commercial databases contain data of high quality but are costly to access. Hence a centralized database that will be free to use must be developed. But the challenge associated with centralized database is the responsibility to develop and maintain it.
- There should be EPDs for geogrids and fabrics.

Group 4:

- Significant data gaps in inventories for asphalt binder, polymers, other additives, warm mix additives, PPA, fibers and lime.
- Differences in mix types (HMA v. WMA) should also be considered.
- Aggregates: an EPD is in the process of being developed. Need to differentiate between natural and crushed aggregates, considering the production efficiency and wastes.
- There are data gaps for material transportation for different modes (truck, rail, barge).
- General contractor should gather the information from the suppliers. And subs need to have EPDs so that the GC could evaluate them.
- Electronic submittal form for the EPDs should be explored.
- There should be the ability to compare EPDs produced under the same PCR and the same functionality.
- The definition of the gate. What is the boundary of the gate? Find the boundary between material production and constructions.
- Gaps in impacts for upstream demolition that produce the reclaimed material either for PCC or HMA.
- Significant gaps in inventories for slag, ground limestone, fly ash, polymers, steel, epoxy, curing compound, admixtures, and water.
- Significant gaps in inventories for processes like cast in place concrete, slipped form, precast concrete, production of geotextiles fiber mats, concrete piping, stabilization materials such as lime
- HMA: How RAP is handled. CIR and cold in-plant mixing.
- Inclusion of capital equipment in the EPD: plant infrastructure and the equipment used for raw material acquisition. Nobody will include the capital equipment unless everyone has to include it.
- How EPD for materials that are 100% recycled should be handled?

Question T4: Would this be the first step to a "single PCR"?

Group 1:

- The group thinks that it is too early to come up with a single PCR at this time as this may cause industry and other stakeholders to back out. In order to encourage them to write PCRs and produce EPDs, it is better to systematically develop several PCRs for different products and processes, organized by life cycle stages. Standards such as SETAC, ISO etc. which could be followed to write guidelines can help the material producers/industry to develop PCRs. As more and more knowledge is gained from different material PCRs, a single PCR could be later developed that has similar/common information in the main document and an appendix for more specific material information/requirements.

Group 2:

- It should be clearly stated whether the single PCR is to be prepared at the structural level or for different types of materials since there are many uncertainties associated with using a single PCR. It is also not clear how a structure-level PCR would be useful/who would use it/how it would be better, than following the FHWA guidelines.

Group 3:

- A PCR must be divided into two parts. The first part should be standard to all PCRs and the second part must contain specific information about the material.
- It is difficult to implement a single PCR for construction materials. However it will be useful if a single PCR is present since it will bring industry and research groups together in discussing keen issues such as allocation and embodied energy.

Question 2: Organizational Question:

What are the recommendations for collecting and organizing data?

The discussions were driven by the following sub-questions:

- Question O1: What is the best way to develop and make available data inventories from suppliers outside the immediate supply chain?
- Question O2: Identify existing data collection procedures that can be used to collect flow data at the local government level.
- Question O3: How to manage multiple PCRs?
- Question O4: How should we manage the certification and review process?

Group 1:

- The formation of a governing body is necessary which is comprised of members from industry, academia, state agencies, FHWA and contractors.
- Academia can help to communicate latest developments in the research and it will be the job of industry to provide EPDs.
- The involvement of agencies is important since they provide funding to implement the practice.
- The role of this governing body will be to organize data collected and to review and approve PCRs. The governing body will not be involved in the collection of the data.

Group 2:

- The agencies and department of transportations should consider requesting suppliers to provide EPDs by providing them incentives for the data provided.
- The ultimate goal is to prepare the EPDs which will cover all the phases of life cycle. Incentives can be provided with preference given to the products with directly observed foreground data.
- The standard PCR that sets the rules for preparing EPDs should be developed. This will promote transparency in the data collection process.
- It is the responsibility of the agencies and the department of transportations to follow the framework prepared by FHWA to mitigate environmental impacts.
- The data should be directly transferred from the supplier to the consumer and it should also be stored in the database as secondary data.

- The databases could be prepared for construction and maintenance.
- The incentives for construction and maintenance databases can be provided at local department of transportation levels.
- The PCRs can be used based on their geographical distribution or based on the product.
- The current PCRs can be used as they are. The revisions to PCRs can be requested in case of conflicts.
- Some sort of formal authority should be considered to overview the reviewing process. But the certification process can be costly.
- The best way to reduce costs is to build checks into EPD process itself. The certification process should be considered while designing a PCR.

Group 3:

- Currently there are no standards for reviewing LCA studies. In the future, agencies must make certification compulsory for the reviewers in order to maintain the quality of reviewing process.
- FHWA and states should use a licensing fee procedure to provide access to data.
- The products to be included can be checked for the environmental impacts and only those products should be considered which have significant environmental impacts.
- A standard template should be considered by agencies to collect data. The data collection should start from the current time since the data regarding the past can be difficult to collect. This difference can be eliminated by creating a standard procedure for development of EPDs in all states.

Group 4:

- The suppliers can be motivated to provide the upstream and downstream data. The level of detail in which the data to be collected should be defined.
- There is a need to update the impact assessment factors every 5 years.
- A pseudo PCR can be used where a PCR doesn't exist and develop EPD.
- The gaps in the existing data systems must be identified.
- Data collection depends on the contract and pay codes. Hence it is advisable to create a generalized template where pay code can be tied to the EPD items. Data should be collected specific to a region.
- It is the responsibility of the owner to choose a particular PCR for preparing an EPD.
- The program operator should also be selected by the owner. A quality check should be performed on the working of a program operator.

Question 3: Decision Making Questions

What steps should be taken to understand uncertainty in data (variability and epistemic) and its impact on decision-making?

Group 1:

- Many uncertainties will be associated with both foreground and background data. These uncertainties can be isolated by analyzing each life cycle stage of a product individually.

- As more experience, more data, and more knowledge is gathered through the EPD development process the ability to characterize uncertainty will improve.
- Currently LCA practitioners are spending a majority of their time in collecting and analyzing data with limited emphasis on the interpretation phase. One way of dealing with uncertainty could be to consider each data set within the context it is being used in and then revisiting the source to identify reasons for counterintuitive outcomes. Performing more sensitivity analysis to understand how a dataset affects a system is also crucial.

Group 2:

- When there are a lot of uncertainties associated with the input data Monte-Carlo simulation can be performed to characterize uncertainty.
- Sensitivity analysis for foreground input data should be performed at the PCR development stage. It can also be performed during the LCA of a pavement to understand the drivers of results. If there are any uncertainties present during the sensitivity analysis phase, "most likely" scenarios must be chosen.
- Monetization of multiple indicators can be carried out. Midpoint indicators can be used with appropriate normalization.
- Decisions should be made based on the utility of an indicator and its relevance to the decision-making context and monetization should be considered.

Group 3:

- The parameters such as co-product allocation, end of life allocation, input variability which are necessary to perform sensitivity analysis should be identified first.
- An approach similar to ME design parameters can be employed.
- Uncertainties will become less with the increase in the number of LCA studies.
- The use of uncertainty in pavement selection is more viable after it is completely understood.
- The impact indicators could be considered based on the region in which the project is taking place. Proper guidance is needed in considering the impact indicators. The PCRs must indicate critical indicators.

Group 4:

- Sensitivity Analysis could be carried out only if variability is significant. The level of detail of carrying out sensitivity analysis will depend upon the extent of information available.
- Sensitivity analysis is just a support to make decision and it doesn't ensure foolproof results.
- Sensitivity analysis can be applied in all the life cycle stages and is not limited to interpretation phase alone.
- The impact indicators can be analyzed in three ways. The first option is to monetize the dollar value of the impact indicators. The second option is to include the indicators specific to a region. The third option is to use a cascading decision-making approach were the indicators are included according to their priorities.