Concrete Pavement Recycling Series

QUANTIFYING THE SUSTAINABILITY BENEFITS OF CONCRETE PAVEMENT RECYCLING

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Introduction

For environmental, economic, and societal reasons, the use of recycled concrete in rehabilitation and new construction is an important step in the development of a more sustainable infrastructure. Much of the existing concrete infrastructure is already comprised of the best available materials, so the reuse and recycling of existing concrete pavements is an important sustainability strategy for highway agencies.

Concrete can be recycled in a variety of ways in pavement applications. Recycled concrete aggregate (RCA) can be used as a substitute for virgin aggregates in new concrete pavements and in foundation layers. Existing concrete pavements can be recycled in place using crack-and-seat, rubblization, on-grade crushing and processing, and as a stabilizer in full-depth reclamation (FDR) techniques. The Construction and Demolition Recycling Association estimated that, as of 2014, approximately 140 million tons of concrete is recycled on an annual basis (CDRA 2016).

As state highway agencies increasingly view RCA as an economical, sustainable pavement material that provides satisfactory performance, opportunities exist to increase the volume of concrete repurposed in new infrastructure in the coming decades. Recently, the FHWA has expended considerable effort to advance the application of sustainability

Figure 1. Stockpile of broken concrete to be recycled (Photo courtesy of Jerod Gross, Snyder & Associates, Inc.)

principles to pavements through the Sustainable Pavements Program (FHWA 2015). This program maintains a website that provides a clearinghouse of pavement sustainability-related information, including references, technical briefs, publications, and recorded webinars.

Several publications exist that describe the tools and techniques that can be utilized to quantify the sustainability benefits (economic, environmental, and societal) of recycling, to assist in weighing alternatives, and to support decision-making. The purpose of this tech brief is to provide guidance concerning the use of these tools in quantifying the sustainability benefits of concrete recycling in pavement applications. Case studies of projects in which concrete recycling was performed and benefits were quantified using these tools are highlighted.

Benefits Associated with Concrete Recycling

The many economic, environmental, and societal benefits of concrete recycling are well documented (Behera et al. 2014), and the recycling of existing concrete pavements is generally considered to be one of the most sustainable end-of-life options for concrete pavements (Van Dam et al. 2015, Snyder 2016). The benefits associated with concrete recycling have been the subject of a number of studies and include the following:

- Lower reliance on virgin quarried aggregates
- Reduced energy consumption
- Reduced use of landfill space
- Reduced greenhouse gas emissions
- Time savings associated with haul time reductions
- Recaptured value of prior investments in concrete paving materials

The economic benefits of concrete pavement recycling are relatively easy to estimate but may not be sufficient to justify the process. Therefore, it may be necessary to consider other (environmental and societal) factors in determining the most sustainable option for a given project.

Assessment Tools and Techniques

In selecting project alternatives, decisions are often made based upon initial cost. The recent focus on more sustainable practices and changes in legislation have resulted in increased interest in other metrics to evaluate and select projects. Quantification of the environmental and societal benefits of concrete recycling can assist stakeholders in making the decision to use recycled concrete.

Assessment tools that incorporate considerations associated with concrete recycling are available to support decision making, and increased use of these tools will result in a more sustainable highway system. These assessment tools can be broadly classified into economic analysis, environmental assessment, and rating systems. Critical to the successful use of these tools is the gathering of data and the identification of appropriate assumptions to support the analyses.

The exact information required to perform each analysis will differ based on the tool utilized, the end goal of the analysis, project characteristics, alternatives to be compared, and other considerations. A partial list of typical information required to support these tools is provided in Table 1 on the following page.

Economic Analysis

Economic analysis decision support tools can be used to effectively evaluate the costs of different alternatives over the project lifetime. The most common approach to economic analysis, life-cycle cost analysis (LCCA), is ". . . a process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user costs, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment," as defined by the Transportation Equity Act of the 12st Century (U.S. DOT 1998). The Federal Highway Administration (FHWA) encourages the use of LCCA to support decisions. A widely accepted LCCA tool, RealCost, is available as free software (RealCost 2011).

Potential sources of cost savings associated with the use of recycled concrete include the following:

- Lower initial costs for recycled aggregates
- Lower hauling costs
- Increased efficiency for the contractor's execution of a project, resulting in lower bid costs
- Reduced landfill tipping fees

Concrete recycling can also be considered as part of the "salvage value" used as the end-of-life value for a project in an economic analysis, although care must be taken not to double count the benefits of recycling as both a salvage value at the end of one life cycle and a reduction in initial costs at the beginning of the next. All of these potential economic benefits can lead to the selection of pavement project options that incorporate recycled concrete materials through the use of economic analysis.

Table 1. Typical Considerations for Sustainability Assessment Tools

	Economic Analysis	**Environmental Assessment**	**Rating Systems**
General considerations	➢ Agency costs • Pavement costs • Non-pavement costs such as safety, engineering, inspection, testing ➢ User costs • Vehicle operating costs • Travel delay costs • Crash costs ➢ "Equivalent" designs ➢ Rehabilitation options and schedules • Time to first activity • Activity life • Cost of activities ➢ Analysis period ➢ Discount rate (inflation) ➢ End of Analysis (Residual) Value • Remaining service life • Salvage value • Value as recycled materials • Demolition costs and landfill tipping fees	➢ Functional unit ➢ System boundaries ➢ Inputs of raw materials, feedstock, and energy ➢ Outputs of waste and pollution ➢ Impacts of transport ➢ Evaluations over the following phases: • Raw material acquisition • Material processing • Manufacturing • Construction • Use • End-of-life	➢ Most consider pavement as a contributing subsystem to a larger system or project such as • Infrastructure project • Roadway project • Site development project • Agency sustainability effort ➢ Factors considered often include • Ecological impact • Community impact • Connectivity • Aesthetics ➢ Rating systems differ by • Grouping of performance criteria • Delineation and computation of metrics • Thresholds for obtaining points and ratings status • Certification methodology (self-certification or third-party certification)
Specific considerations for recycling activities	➢ Economic costs of alternatives to recycling: • Purchase and hauling costs for virgin material • Landfill tipping fees for disposal of existing material ➢ Economic costs of recycling: • Hauling costs • Crushing/grading equipment (onsite or offsite) • Contractor efficiency • Production efficiency	➢ Fuel consumption ➢ Emissions ➢ Non-renewable resource use ➢ Freshwater use ➢ Hazardous and non-hazardous waste generation ➢ Local impacts such as noise and dust	➢ Amount of materials reused (mass or volume percentage) ➢ Method of recycling utilized ➢ Use of recycled materials in new mixtures ➢ Emissions reductions ➢ Noise reductions ➢ Planning initiatives ➢ End-of-life considerations

Life-cycle cost analysis tools can provide consideration of only those factors that can be accurately quantified monetarily; thus, LCCA is not generally used to quantify or assess the potential environmental or societal benefits associated with the use of recycled concrete. This limitation of LCCA has resulted in an increased emphasis on the use of other assessment tools (described in subsequent sections) in addition to LCCA.

Environmental Assessment

A commonly used environmental assessment tool is the life-cycle assessment (LCA). Developed in the 1960s and recently standardized by the International Standardization Organization (ISO) under ISO 14040 and ISO 14044, an LCA is utilized to quantify the impact of a product or process on the environment in terms of mass or energy use, along with waste and emissions produced during the life cycle. The use of LCA in pavement projects provides a quantitative approach for comparing the environmental impacts of competing alternatives and can assist in making decisions that lower the environmental impact of a pavement over its life cycle. In addition to quantifying environmental impacts, an LCA can also be used to some extent to evaluate or quantify the societal and economic impacts of the product or process.

The LCA process generally consists of four phases: the goal and scope definition phase, the inventory analysis phase (life cycle inventory, or LCI), the impact assessment phase (life cycle impact assessment, or LCIA), and the interpretation phase. In recent years, calls have been made for development of a pavement-specific LCA framework for pavements and non-proprietary LCI inputs and environmental product declarations (EPD) to support LCA for pavements. To promote implementation of LCA, the FHWA has recently supported development of a pavement life cycle assessment framework, which provides guidance tailored to the pavement community on the LCA approach, methodology, and system boundaries (Harvey et al. 2016).

Currently, LCAs are typically performed using software programs supporting an LCA model. These programs include the following:

- Athena (Athena 2013)
- SimaPro (Pré 2011)
- TRACI (EPA 2012)

Other programs developed specifically for LCA of pavements and roadways are available, such as

- Pavement Life Cycle Assessment Tool (PaLATE) (Horvath 2007)
- Building Environmentally and Economically Sustainable Transportation-Infrastructure Highways (BE^{2}ST-in-Highways) (Lee et al. 2013)
- Illinois Tollway LCA (in development) (Harrell et al. 2016)

Often these models provide data and options for common materials to support an LCA, although it is important to verify that the tool is maintained and that the associated databases are current. Also, some tools utilize a hybrid LCA approach, considering only portions of a more robust LCA. An example of this is the PaLATE tool, which considers energy use, air emissions, and leachate and may require an update of data to be appropriately utilized (Van Dam et al. 2015).

Key to consideration of recycled concrete in an LCA is its definition as a waste or a product. Treatment of a waste flow as a material with value (or as a material that can become valuable after additional processing) requires consideration in a manner that both accounts for economic and environmental impacts and avoids double counting in the analysis. As indicated previously, impact categories in LCA are typically defined as energy use, resource use, emissions, toxicity, water, and waste. Use of concrete recycling can be incorporated into a number of LCA impact categories, as detailed in Table 1.

Rating Systems

Rating systems promote innovation in design and construction and provide an avenue for communicating sustainability achievements. During recent years, several rating systems have emerged that facilitate the rating of pavement projects based on LCCA, LCA, and other environmental and sustainability metrics. These systems each provide means of evaluating and differentiating between projects, and many ultimately provide an avenue for recognizing stakeholders (i.e., providing award or certification levels). In addition to identifying, evaluating, and ranking the environmental impacts of projects, many of these systems address other metrics, such as community (social) and economic benefits. For pavement projects, rating systems currently include the following:

- INVEST (Infrastructure Voluntary Evaluation Sustainability Tool)
- Greenroads®
- Envision™
- GreenLITES (Leadership in Transportation and Environmental Sustainability)

Although each of these rating systems differs in the grouping of performance criteria, delineation and computation of metrics, and thresholds for obtaining points and ratings status, the approach of each tends to be similar. From the standpoint of concrete recycling, credits and points can often be earned via performance criteria related to the items presented in Table 1. A summary of some of the ways in which concrete recycling can be considered in each of these rating systems is provided below.

INVEST

Supported by the FHWA, INVEST is available on the web for use as a self-evaluation and self-certification tool for transportation services and projects. Modules included in the tool include those for System Planning (SP) on both regional and state levels, Project Development (PD), and Operations and Maintenance (OM). Use of recycled concrete is specifically addressed in INVEST (v1.2) Project Development module using *PD-20: Recycle Materials*. The impacts of use of processes that reduce the need for virgin material, or reuse a material or byproduct from another industry, are addressed in INVEST in *PD-19: Reduce, Reuse, and Repurpose Materials*. Opportunities for additional points exist in other areas, such as *PD-23 Reduced Energy and Emissions in Pavement Materials* and *PD-26 Construction Equipment Emission Reduction*. Additional information on each INVEST module and scoring criteria can be found at the INVEST website (INVEST 2016).

Greenroads®

The Greenroads® rating system was developed as a third-party rating system for roadway projects and is owned by the Greenroads Foundation, which is based at the University of Washington. Similar to most rating systems discussed here, Greenroads® provides tools for multiple levels of use, including planning, design, construction, operations, and maintenance.

The Greenroads® website provides information regarding the program and additional details regarding means for obtaining recognition of projects (Greenroads 2016a). Concrete recycling activities are addressed in the mandatory *PR-6 Waste Management Plan*, in which a plan to divert construction and demolition (C&D) waste from a landfill is required. Other voluntary credits associated with concrete recycling can be obtained as part of the Construction Activities (CA) categories (*CA-2 Environmental Training* and *CA-3 Site Recycling Plan*), Materials & Resources (MR) categories (*MR-2 Pavement Reuse* and *MR-4 Recycled Materials*), and other areas.

Envision™

Developed to fill the need for a "holistic" rating system capable of rating the sustainability of a broad range of infrastructure projects, the Institute for Sustainable Infrastructure's Envision™ provides a means for rating a variety of projects, such as pavements, water treatment systems, pipelines, dams, and airports. An overview of this rating system, along with details regarding the system framework and means for projects to achieve recognition, is provided at the Institute for Sustainable Infrastructure website (Envision 2016).

Points for the use of recycled concrete can be earned for several credit criteria associated with Resource Allocation (such as *RA1.3 Use recycled materials, RA1.5 Divert waste from landfills, RA1.6 Reduce excavated materials taken off site,* and *RA1.7 Provide for deconstruction and recycling*). Other areas where activities associated with recycling can earn points include credits in categories such as Quality of Life (*QL2.2 Minimize noise and vibration*), Leadership (*LD3.1 Plan for long-term monitoring and maintenance*), and Climate & Risk (such as *CR1.1 Reduce greenhouse gas emissions* and *CR1.2 Reduce air pollutant emissions*).

GreenLITES

Developed by the New York State Department of Transportation (NYSDOT), GreenLITES provides a self-certification tool for project design and operations. Tailored to the ongoing initiatives and organizational structure of NYSDOT, the GreenLITES rating system offers two certifications (Project Design Certification and Operations Certification), with details provided on the NYSDOT website (NYSDOT 2016).

Portions of Section M-1 of the GreenLITES Project Design criteria are suited for incorporating concrete recycling. Specifically, *M-1d Specify rubblizing or crack and seating of portland cement concrete*, *M-1e Reuse of pervious pavement as subbase during full-depth reconstruction*, *M-1f Arranging for the reuse of excavated material, asphalt millings, old concrete*, and *M-1g Specify the process of demolished concrete to reclaim scrap metals* allow for consideration of the benefits of concrete recycling in this rating system.

Case Studies

Following are brief case studies, two regarding the use of LCCA/LCA in Illinois and Wisconsin, and two regarding the use of rating systems in Wyoming and Washington State.

LCCA and LCA

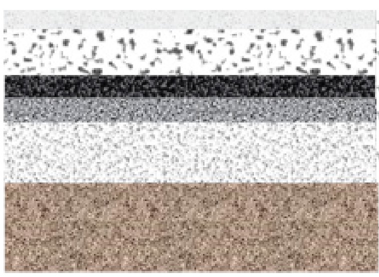
Illinois Tollway, I-90 Jane Addams Memorial Tollway

Over the past decade, an objective of the Illinois Tollway "has been to maximize the amount of existing pavements that are recycled into newly reconstructed pavements" (Gillen and Vavrik 2016). The Tollway has extensively utilized LCCA to measure the impact of a number of its sustainability efforts, including concrete recycling, as part of Move Illinois, a 15-year, $12.1 billion program.

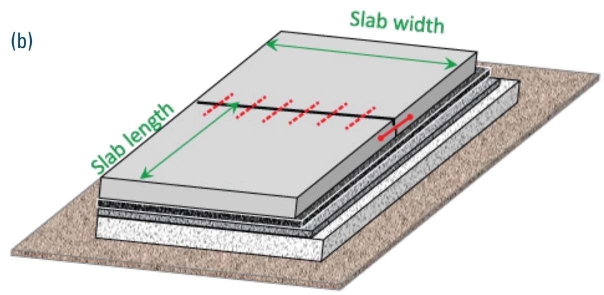
Life-cycle costs analysis was used to identify $50 million in savings (through 2014) by using recycled concrete aggregate, rather than virgin aggregate, in pavement bases (Gillen and Vavrik 2016). In 2015 alone, the Tollway recycled almost 775,000 tons of concrete, with 466,283 tons of recycled concrete utilized on the I-90 Jane Addams Memorial Tollway in 2014 (Illinois Tollway 2015, 2016). Demolished concrete was obtained from various sources and was crushed to provide RCA for base material (including porous base) and backfill. Waste concrete from off-site locations used to produce RCA met specification provisions requiring documentation that the concrete was obtained from an Illinois DOT or other agency project.

Life-cycle cost analysis has also been utilized to justify use of two-lift concrete pavements that include recycled aggregates, as shown in Figures 2a and 2b (Gillen 2013). Ongoing work is being performed to develop and proof-test a customized LCA tool that can be integrated with the existing LCCA software as well as the INVEST rating system. This tool will heavily rely on the impact data from the SimaPro database, with the ability to include customizable, locally sourced data. The tool is designed to use contract pay items as the primary input for the LCA to ease integration into existing Tollway processes, as well as to allow contractors to provide data in a readily useable format (Gillen 2015, Harrell et al. 2016).

(a)



(b)



Figures 2(a) and 2(b). I-90 concrete pavement section details (from Gillen 2013)

Beltline Highway, Madison, Wisconsin

A 1.5-mile segment of the Beltline Highway in Madison, Wisconsin, was reconstructed using a variety of recycled materials, including recycled concrete aggregates. The existing concrete pavement at the site was crushed and graded on site in a closed area of the work zone to produce RCA (Figure 3). Approximately 9,870 cubic yards of RCA was produced on site during the initial phase of the project and included in the LCA and LCCA (Bloom 2016). Additional RCA was sourced from nearby suppliers, who typically received concrete demolition waste from other local roadway projects and other local sites.

The RCA was typically utilized in base course or embankment fill materials. Spreading of the RCA for base material is shown in Figure 4. The RCA produced from off-site concrete waste material was qualified for use using provisions outlined in WisDOT specifications for crushed materials used for aggregate bases. WisDOT's specifications for acceptance of RCA produced from off-site sources include AASHTO T96 abrasion resistance testing, which is waived for RCA produced from concrete sourced from within project limits.

The LCCA and LCA analyses were performed using the PaLATE tool (Horvath 2007). A novel approach to this LCA included real-time data collection in order to avoid issues with post-construction data gathering, such as generalizations of mixture designs and market-price averaging. For example, weigh tickets were a critical component used in data collection, along with other key site-specific WisDOT and subcontractor reports. These reports provided detailed information on the sources of materials (including RCA) such as quantity and origin, allowing for accurate accounting of economic costs and environmental impacts of production, transportation, and installation.

To complete the LCCA and LCA analyses, characteristics of the actual project were compared to a reference design that utilized only virgin materials. The LCCA analyses indicated a cost savings of approximately $130,000 at initial construction for use of RCA from both on-site and off-site sources, and a total savings of "about $250,000 from the use of all recycled material over the project's lifetime" (Bloom et al. 2016a, 2016b). The results of the LCA analysis quantified lifetime environmental impact reductions in all LCA criteria for the as-built project, including energy use (13 percent reduction), water consumption (12 percent reduction), CO_2 emissions (13 percent reduction), and hazardous waste (9 percent reduction) (Bloom et al. 2016a).

Figure 3. Onsite crushing operations at the Beltline Highway project (Photo courtesy of Steven Theisen, WisDOT)

Figure 4. RCA spread for base course (Photo courtesy of Eleanor Bloom, Recycled Materials Resource Center)

Rating Systems

INVEST: North Park Road, Grand Teton National Park, Wyoming

The Western Federal Lands (WFL) Highway Division has extensively utilized the INVEST rating system to evaluate the sustainability of its projects and to provide recognition for efforts to incorporate sustainable practices. Since 2012, between seven and seventeen projects per year were scored and ranked using INVEST (Armstrong 2016), and an Annual Sustainability Award winner was selected. The 2013 Annual Sustainability Award winner, the North Park Road Project, consisted of widening and improving a 13-mile stretch of road extending between the Jackson Lake Lodge and Leek's Marina in the Grand Teton National Park, Wyoming (INVEST 2016b). This project received the highest score for *PD-20: Recycle Materials* in the INVEST rating system due to the reuse of both concrete and asphalt materials. Concrete recycling on the project included on-site crushing of a large pile of concrete demolition waste (Figure 5) that had been accumulating on park maintenance grounds for several years. The recycled concrete aggregate produced (approximately 3,500 tons) (Figure 6) was utilized as pavement subbase in frost-susceptible areas (Crockett 2016).

Figure 5. Pile of waste concrete prior to crushing into RCA (Photo courtesy of Phillip Lamoureux, FHWA WFL)

Figure 6. RCA produced for North Park Road Project (Photo courtesy of Phillip Lamoureux, FHWA WFL)

GreenROADS: James Street Bridge Replacement and Road Improvements, Bellingham, Washington

The Greenroads™ project most heavily utilizing recycled concrete to date is the James Street Bridge Replacement and Road Improvements, owned by the City of Bellingham, Washington. The 0.5-mile long project included approach pavement reconstruction to support replacement of two 95-year-old timber bridge structures with a single 80-ft concrete structure, with supports located outside of the flood plain of the creek. The project included 23.5 percent recycled content, including 15 percent RAP in warm-mix asphalt and approximately 320 tons of recycled concrete, helping it to earn 16 of 23 possible points in the Greenroads™ *Materials & Resources* scoring category (Greenroads 2016b). The recycled concrete was sourced from demolition waste from other infrastructure and was crushed off site in a local industrial redevelopment area (Figure 7). Recycled concrete aggregate was used in new concrete in sidewalks and curb and gutter and as a partial replacement for natural aggregate in the bridge deck concrete (Anthony 2016, Mueller 2016). The complete project (Figure 8) received GreenROADS Silver certification.

Figure 7. RCA produced and stockpiled off-site for James Street Bridge Replacement (Photo courtesy of Freeman Anthony, City of Bellingham)

Figure 8. Completed James Street Bridge Replacement with Greenroads™ Scorecard (Photo courtesy of Greenroads™)

Summary

The sustainability benefits of recycling concrete pavements can be quantified using LCCA, LCA, and rating systems. The approach, assumptions, and analysis techniques used by each tool are different but, when utilized singularly or in concert, various aspects of sustainability can be quantified. The goals of stakeholders should be carefully considered prior to selecting one or more approach. Overall, as outlined in Van Dam et al. (2015), these tools are defined as follows:

- LCCA is an economic analysis technique that is principally used to quantify the economic component of sustainability.
- LCA is most suitable for analyzing and quantifying the environmental impacts of a specific project or strategy over a life cycle.
- Rating systems rely heavily on providing incentives (points and recognition) for addressing a broad set of sustainability best practices.

Each of these types of tools provides one or more means of incorporating recycling-related activities and materials choices into the analysis and evaluation, providing guidance and potentially reward (recognition). As outlined in the case studies presented, these tools have been successfully used by several agencies to justify and support concrete recycling activities. More extensive utilization of these tools could provide incentive to stakeholders to utilize concrete recycling more frequently in pavement construction, moving towards a more sustainable highway infrastructure.

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The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technoogy through research, tech transfer, and technology implementation.