CHAPTER 9. PAVEMENT SUSTAINABILITY WITHIN LARGER SYSTEMS

Introduction

Pavements can always be viewed as components of a larger system. Consider, for example, that transportation systems, highway corridors, neighborhoods, port terminals, pedestrian networks, stormwater treatment, and the local ecosystem are all larger systems that can influence or are influenced by a pavement system. The health, maintenance, improvement, restoration, or construction of these larger systems all have associated sustainability goals (which may or may not be explicitly stated) that will necessarily affect the sustainability goals of pavement subsystems. This could either encourage or exclude certain pavement sustainability practices. For instance, a larger corridor project may have a goal of minimizing GHG emissions from construction but may also specify a particular pavement type to match adjacent corridor sections for ease of maintenance and rehabilitation. In this case, recycled material use in pavements would be consistent with the project goals, but the pavement type with the lowest initial emissions may not be consistent with project goals.

This chapter describes how pavement systems can interact with larger system sustainability goals by highlighting several larger system efforts and metrics. Specific sustainability considerations that can arise from these interactions and example treatments are also presented.

Larger System Goals and Metrics

Larger systems within which pavements reside increasingly have sustainability goals and objectives to which the pavements subsystem contributes in some manner. This section provides examples to illustrate this concept and how it relates to the social and environmental components of sustainability, which are often undervalued or ignored when the focus is strictly on the pavement as the system in question.

> ***Major Issues:***
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> - ✓ *Inherent uncertainty in performance of materials specifically designed to meet aesthetic, environmental, or social criteria.*
> - ✓ *Higher cost of non-traditional approaches used to accommodate environmental and societal considerations.*
> - ✓ *Quality and performance of utility cuts.*
> - ✓ *Timing and quality of construction versus working in a prescribed window of operation.*

Sustainable Communities

Very generally, society is recognized by most as a large system that needs to function and grow in a sustainable manner. This includes how individuals, groups, industry, and infrastructure function together. This concept of an interacting population is often labeled "community." There are a number of efforts nationwide aimed at strengthening the role of community (and community values) in the development, operation, and maintenance of infrastructure (including roads). An example effort at the federal government level is the Partnership for Sustainable Communities, which is a partnership between the U.S. Department of Housing and Urban Development (USHUD), U.S. Department of Transportation (USDOT), and the Environmental Protection Agency (EPA), that aims to "…coordinate federal housing, transportation, and other infrastructure investments to protect the environment, promote equitable development, and help to address the challenges of climate change" (EPA 2012). According to the partnership agreement, the HUD, USDOT, and EPA commit to coordinate and identify strategies that (USHUD, USDOT, and EPA 2009):

- **Provide more transportation choices**. Develop safe, reliable and economical transportation choices in order to decrease household transportation costs, reduce the nation's dependence on foreign oil, improve air quality, reduce GHG emissions, and promote public health.
- **Promote equitable, affordable housing**. Expand location and energy efficient housing choices for people of all ages, incomes, races, and ethnicities to increase mobility and lower the combined cost of housing and transportation.
- **Increase economic competitiveness**. Enhance economic competitiveness through reliable and timely access to employment centers, educational opportunities, services, and other basic needs by workers as well as through expanded business access to markets.
- **Support existing communities**. Target federal funding toward existing communities to increase community revitalization, to improve the efficiency of public works investments, and to safeguard rural landscapes.
- **Leverage federal investment**. Cooperatively align federal policies and funding to remove barriers, leverage funding, and increase the accountability and effectiveness of all levels of government to plan for future growth.
- **Value communities and neighborhoods**. Enhance the unique characteristics of all communities by investing in healthy, safe, and walkable neighborhoods—rural, urban or suburban.

Pavement Integrated into a Sustainable Street: City of Chicago's Cermak/Blue Island Sustainable Streetscape.

The Chicago Department of Transportation (CDOT) advertises the first phase of a 2-mile stretch of Blue Island Ave. and Cermak Rd. in the Pilsen neighborhood as the "greenest street in America." It is a good example of how pavement is integrated into an overall approach to roadway sustainability. The $14 million project (completed in 2012) is helping to transform an industrial mixed-use stretch of street into one that can serve as a community focal point providing a sense of place, beautification, and ecological services.

The overall drivers for the project involve more than just pavements, although pavement features play a significant role.

Achievements of this project include:

- Reduced energy use by 42 percent.

- Wind/solar powered pedestrian lights.

- 76 percent local materials (manufactured within 500 mi (800 km) of the site).

- 131 percent increase in tree canopy cover.

- Education kiosks and an English/Spanish guidebook.

- New bike lanes.

Pavement contributions include:

- Warm-mix asphalt.

- Photocatalytic cement, largely used for its self-cleaning properties.

- Permeable pavements helping divert 80 percent of stormwater.

- Use of RCWMs including slag, shingles, and ground tire rubber.

More information is available at: *http://www.cityofchicago.org/dam/city/depts/cdot/CBISS_flier_2010.pdf*

Within this partnership context, pavements can play a significant role. Specifically, pavement construction, preservation, use, and reconstruction can be inferred to be a part of the strategies to (1) provide more transportation choices, (2) reduce GHG emissions, (3) increase mobility and lower the combined cost of housing and transportation, (4) expand business access to markets, (5) increase community revitalization, (6) increase the efficiency of public works investments, and (7) invest in walkable neighborhoods (USHUD, USDOT, and EPA 2009). These items also imply that pavement characteristics such as materials, geometry, design, and location can be influenced or controlled by things like aesthetics, historical context, and cultural identity. Other examples of larger system efforts to which pavements may contribute are:

- **National Complete Streets Coalition**. Part of Smart Growth America, the National Complete Streets Coalition is an advocacy group that assists organizations in creating and adopting policies that advocate for connected networks of multimodal access streets (Smart Growth America 2010) (http://www.smartgrowthamerica.org/complete-streets).
- **Walk Score**. A private company that uses algorithms to provide scores related to the walkability, transit service, and bike friendliness. Among other things, scores are linked closely with apartment and home searches (http://www.walkscore.com/).
- **National Scenic Byways Program**. This program, part of the FHWA, formally recognizes certain roads for their archeological, cultural, historic, natural, recreational, and scenic qualities (NSBP 2013) (http://byways.org/).
- **United States National Register of Historic Places**. The official list of U.S. historic places worthy of preservation. Authorized by the National Historic Preservation Act of 1966, the list is maintained by the National Park Service and contains over 6,800 transportation-related listings among its over 80,000 properties. For instance, listings include the first concrete street in Bellefontaine, OH; a proprietary R.S. Blome Granitoid Pavement in Grand Forks, ND; a Hessler Court Wooden Pavement in Cleveland, OH; and on original brick portion of the 1913 "Yellowstone Road" (NPS 1974) that went from Boston to Seattle (http://www.nps.gov/nr/).

Ecosystems

Very generally, ecosystems are communities of living organisms interacting with their surrounding non-living environment. This interaction involves complex systems such as nutrient cycles, food chains, and energy flows. As the full impact of human development on these systems becomes better recognized, a large number of national and international efforts have been undertaken to better understand these impacts and preserve complex ecosystems. An example effort by the U.S. DOT, called "Eco-Logical," defines what is called an "ecosystem approach to developing infrastructure projects" (Brown 2006).

Eco-Logical provides guidance on an approach to mitigating the effects of infrastructure with the larger surrounding ecosystem as the focal point of the effort. Instead of regulatory driven individual mitigation efforts done within narrowly defined project boundaries, an ecosystems approach seeks to define and optimize solutions for the larger impacted ecosystem. Generally, this requires coordination among multiple agencies and can ultimately lead to more efficient and meaningful mitigation efforts. Goals that drive the Eco-Logical effort include (Brown 2006):

- **Conservation**. Protect and even restore large-scale ecosystems.
- **Connectivity**. Reduce habitat fragmentation from infrastructure (including roads and their constituent pavements) projects.
- **Predictability**. Commitments made by all participating agencies will be recognized and honored.
- **Transparency**. Leverage better stakeholder (including the general public) involvement to improve public trust, credibility and streamline planning and development.

An ecosystems approach to mitigating infrastructure impacts on ecosystems can create a set of goals and objectives for the ecosystem that has significant interplay with pavement systems. For instance, a particular area's wildlife action plan can identify areas with high conservation needs, which may, in turn, influence the location of a temporary quarry for a roadway project. As a result, it may be that lesser quality aggregate is selected based on priorities of a wildlife action plan.

Other examples of efforts with an ecosystem focus include those by the Federal Lands Highway (FLH) Program's interaction with its partner agencies such as the National Park System, the U.S. Forest Service, and the U.S. Fish and Wildlife Service. These partner agencies are generally charged with the stewardship of larger ecosystems (e.g., Yosemite, Deschutes National Forest, Vieques Island National Wildlife Refuge) and tend to view roads and pavements within such ecosystems as secondary to the ecosystem itself. Consequently, when the FLH does work on roads and pavements with these partners, they frequently make design and construction decisions that conform to ecosystem goals and objectives that may not be optimized for pavements. For instance, many national parks and forests have aggressive invasive species programs that require imported aggregate be devoid of seeds from invasive weeds. This may require running the aggregate through the aggregate dryer portion of an asphalt plant to burn off weed seeds, resulting in a more energy-intensive pavement. Yet such a result is acceptable in light of the larger goal of controlling invasive species.

Strategies for Improving Sustainability

This section identifies some specific pavement features that have not been described previously in other sections of this document yet may be influenced by larger system goals. These pavement features are often not quantifiable by LCCA or LCA and may or may not be explicitly recognized in sustainability rating systems.

Aesthetics

"Aesthetics" refers to the nature and appreciation of beauty. In the context of infrastructure it refers to general appearance (typically meaning "visual appearance" but not necessarily excluding other senses) and usually implies a measure of beauty and harmony with the surrounding environment. There are limited opportunities to address the aesthetics of a pavement. To a large degree pavements are designed and materials selected for engineering reasons rather than artistic ones. However, there are situations where pavement aesthetics influence design; usually these influences are based on color or texture.

Color can be controlled by choice of aggregate and binder materials, either alone or in combination with stains, dyes, or pigments. An example of color-related aesthetics is the red cinder chip seal used in and around Zion National Park by the National Park Service and

> **Pavement Aesthetics**
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> *The Eastern Federal Lands Highway Division (EFLHD) used a transparent, amber-colored synthetic binder combined with salmon-colored granite and pink quartzite aggregate to achieve desired aesthetics for paving the portion of Pennsylvania Avenue in front of the White House in 2004 (EFLHD 2004).*
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> *Another example of aesthetics impacting pavement design is documented along the Gatlinburg Spur of the Great Smokey Mountains National Park Foothills Parkway. For this project, EFLHD was tasked with creating stabilized soil highway pull-offs for emergency use by motorists. Park aesthetics required that these pull-offs be grass surfaced (not paved) so EFLHD experimented with several different stabilization techniques that all proved successful (Hatcher 2004).*

Central Federal Lands Highway Division (CFLHD) (see figure 9-1). Pavement materials and type can also be changed in specific areas to create increased visibility, separating pedestrian and bicycle features based on color and texture (see figure 9-2).

Figure 9-1. Zion Park Blvd. in Utah (SR 9) with a chip seal surfacing that uses local red volcanic cinders to match the aesthetics of the surrounding environment and to be consistent with historical road surfacing (photo courtesy of Steve Muench).

Figure 9-2. Brick crosswalk in Charlotte, NC implemented as part of an intersection improvement (Hughes, Chappell, and Chen 2006).

For concrete pavements, their normal grey color can be made nearly white through the use of white cement, slag cement, pigments, or stains. Projects have also been constructed where white cement is coupled with photocatalytic titanium dioxide to help keep the surface clean, thus maintaining the light color while also treating nitrous and sulfur oxides in air pollution. Concrete can also be patterned to add aesthetic appeal. A similar effect can also be achieved through the use of interlocking concrete pavers. Figure 9-3 shows how a combination of colored interlocking concrete pavers and colored concrete is being used to add aesthetic appeal on U.S. 41 in a pedestrian-friendly historic downtown area of Houghton, Michigan.

Figure 9-3. Vehicular interlocking concrete pavers being placed in a pedestrian-friendly downtown area in Houghton, MI. Note the use of colored concrete for the pavers to provide a visual offset for the cross walk (photo courtesy of Thomas Van Dam).

Historical and Cultural Identity

Historical and cultural identities are often closely associated with aesthetics since aesthetics can help create such identities, enhance feelings of community, or maintain ties to the past. Several of the examples previously given (paving of Pennsylvania Avenue in front of the White House [see sidebar in page 9-4], Zion Park Boulevard in Utah, and U.S. 41 in Houghton, Michigan) are all aesthetic treatments done for historical or cultural identity. Indeed, one of the most common ways pavement contributes to such identity is the preservation of an old pavement type or material in an historical area (see, for example, figures 9-4, 9-5 and 9-6).

Figure 9-4. Old cobblestone pavement preserved and still in use on East Republican St., Seattle, WA (photo courtesy of Steve Muench).

Figure 9-5. Lombard Street in San Francisco during construction in 1922 (FoundSF 2013).

Figure 9-6. Lombard Street as it looks today with its brick pavement, kept for historical and cultural reasons (Wikipedia, public domain).

Utility Cuts

Utility cuts in pavements present a sustainability challenge because they breech the integrity of the pavement surface and their subsequent patches can result in weak points in the pavement structure through the existence of added joints, substandard pavement (figure 9-7), or inadequate subgrade repair. Some empirical work has been done to document these effects (e.g., City of Seattle 2000).

Figure 9-7. Poor quality patch in an existing concrete pavement (photo courtesy of Steve Muench).

Coordination Issues

In many instances paving and utility work schedules are not coordinated, which can result in utility cuts being made on newly paved surfaces. Many road owners have policies that forbid utility cuts for a specified time after paving (e.g., City of Spokane 2005; County of San Diego 2008); however, coordination between street paving and utility work can be difficult. Generally, those jurisdictions that actively coordinate such work use some form of electronic database that registers all projects and checks for conflicts (Trombka and Rubin 2013). Some jurisdictions even charge a "pavement degradation fee" associated with utility cuts, which is intended to recover the cost of associated long-term pavement damage (Trombka and Rubin 2013).

Repair Guidance

Most guidance on utility cut repair is directed at local agencies and focuses on traditional means including locating and marking existing utilities, traffic control, pavement cutting, excavation, backfill, surface restoration, and site cleanup (FHWA 1996). A key element to restoring long-term ride quality is to ensure that the backfill is adequately compacted. This is challenging in a long, narrow utility cut and thus the use of controlled low-strength materials (CLSM) to fill trenches is highly recommended.

Ongoing work continues in the development of modular/precast pavements specifically designed to provide ready access to underground utilities, allowing panel removal and replacement after utility work is completed. Considerable work has been done showing how interlocking concrete pavers can be reused to create relatively seamless and repeatable repairs, as shown in figure 9-8 (ICPI 2009). A French system using hexagonal panels is shown in figure 9-9 (Larrard, Sedran, and Balay 2012). While these methods are not new (see figure 9-10) they show promise in many instances.

Figure 9-8. Illustration of how existing concrete pavers can be removed to repair a gas line (a), and then the bedding recompacted (b), joint sand reapplied (c), and the final product which shows little sign of disturbance (d) (ICPI 2009).

Figure 9-9. Removal of French hexagonal modular pavement to access utility (Larrard, Sedran, and Balay 2012).

Figure 9-10. A utility cut in Rome, Italy shown with the excavation open and sampietrini (individual rounded black basalt stones) removed. Upon completion the cut is filled and sampietrini reinstalled (photo courtesy of Steve Muench).

Odor, Soot, and Particulate Matter

Although of greatest concern to construction workers, odors, soot, and particulate matter (PM) generated during construction and shortly thereafter are also of concern to the adjacent communities. All paving construction operations have the potential to negatively impact worker health and local communities through plant and construction equipment emissions and PM generated from soil disturbance and demolition activity (SMAQMD 2013). For example, a recent study cited increased level of exposure to submicron PM for workers in both paving and milling operations, listing multiple strategies to improve worker safety including improved maintenance of paver ventilation systems, diesel fume engineering controls, reduced idling, provision of cabs for the operators, and improved dust suppression systems on milling machines (Freund et al. 2012). Practices that can be used to help control construction generated emissions include (SMAQMD 2010):

- Fugitive dust can be controlled by watering all exposed unpaved surfaces twice daily, covering or maintain 2 ft (0.61 m) of free board space on haul trucks transporting loose material (all haul trucks using freeways or major roads should be covered), wet power vacuum paved surfaces daily, limiting vehicle speed on unpaved roads to 15 mi/hr (24 km/hr), and paving surfaces as soon as possible.
- Soot and other emissions from diesel-powered fleets can be reduced by minimizing idle time and maintaining all construction equipment in proper working condition.

In addition, as documented in chapter 3, the use of WMA technologies will reduce emissions and odors associated with the placement of asphalt materials.

Allowable Hours of Construction

It is very common in urban areas to have specified times in which delivery of materials and construction activities are allowed, being limited to certain times of the day, days of the week, or times of year. This is primarily to mitigate noise (e.g., in residential neighborhoods it is common for night construction to be prohibited) and minimize congestion during prime travel times. For example, in specifications used by the City of Azusa, California, construction is allowed between the hours of 7:00 a.m. to 6:00 p.m. Monday through Saturday and can be extended to 10:00 p.m. if approved by the City. For Sunday and national holidays, construction is only allowed if approved by the City, and is allowed only between the hours of 9:00 a.m. and 5:00 p.m.

Such restrictions are put in place to reduce the impact of construction on the community, yet they can impose difficult on contractors who often are working under tight schedules to complete the work as expeditiously as possible. Further, some construction activities are very sensitive to timing, and delays can cause serious damage and premature pavement failure. For example, concrete contraction joints must be sawed within a "sawing window" that is directly related to the properties of the mixture, the ambient temperature, and the length of time since mixing, among other factors. In general, joint sawing should be initiated within 4 hours and completed within 12 hours of paving, although specialized early-entry sawing equipment may allow sawing to begin within 1 to 2 hours of paving (Smith 2007). If paving is delayed and the sawing window falls at a time in which construction (e.g., sawing joints) is not allowed, the pavement can suffer random cracking and may require removal and replacement.

Strategies for Improving Sustainability

Most important to this chapter is that larger system goals, and specifically sustainability goals, can drive pavement sustainability choices. Most prominently, social and environmental goals of larger systems contain elements to which pavements can contribute. In some instances, the more sustainable solution for the larger system requires pavement choices that are less than optimal when viewed from the perspective of pavement alone. Some general approaches to improving pavement sustainability within larger systems are summarized in table 9-1.

Table 9-1. General strategies to improve pavement sustainability within larger systems.

Larger System Objective	Pavement Contribution	Economic Impact	Environmental Impact	Societal Impact
Enhance Roadway Aesthetics	Color, texture, and historical materials	Increased cost, single-sourced or scarce materials	Minimal	Improved sense of place, beauty, and integration with surroundings
Minimize/Eliminate Impacts of Utility Cuts Through Coordination and Repair	Better repair techniques, use of pavements that allow utility cuts without degrading pavement structure once repaired	Lower repair costs, less traffic disruption, longer pavement life	Reduction in needed material due to better repairs providing longer pavement life	Less disruption of transportation and services
Improve Worker and Community Health Through Reduction of Odors, Soot, and Particulate	Dust control, minimized idle time, warm-mix asphalt	Time and effort to train and implement new procedures	Less pollution that could adversely affect the environment	Improved worker and community health
Balance Approach to Allowable Hours of Construction	Faster construction and proper phasing of construction to conform to working hours	Increased construction costs (offset by impact savings) to accommodate community working hours	Improved environmental performance (e.g., reduced noise) during hours of non-work	Better accommodation of surrounding community needs and desires

Future Directions/Emerging Technologies

A few of the future directions and emerging technologies in this broad topic area are presented below:

- Photocatalytic pavement. Photocatalytic pavement can be made using photocatalytic cement or through the use of photocatalytic coatings. This innovation potentially offers an opportunity to create a surface that remains clean while treating air pollution through a photocatalytic reaction involving nanoparticles of titanium dioxide (TiO_2). In addition to its pollution-reducing quality, these materials are often lightly colored, having high albedo (reflectance). The technology has recently been implemented on a limited basis in the U.S. Additional information on photocatalytic cement can be found in chapters 3 and 6.

However, titanium dioxide has recently been classified by the International Agency for Research on Cancer (IARC) as a possible carcinogen to humans (IARC 2006). The effects of nanostructured titanium dioxide on the environment are also not fully known; some initial studies show significant effects on microbial communities in surface waters (Battin et al. 2009).

- Energy production. Pavements may provide a venue to produce electric power through use of pressure, vibration, embedded solar photovoltaic (PV) devices, or simply by harvesting heat from sun exposed surface with embedded tubing. Research is ongoing in this arena, with numerous promising ideas populating the worldwide web. No idea has yet taken root, but it is likely that at some point energy harvesting from pavement will become a reality.
- Translucent concrete. Translucent concrete may be a viable material in urban environments for use in delineating crosswalks or bicycle crossings (PCA 2013). Made from orientated optical fibers, the concrete literally glows and if accompanied with sensors, can light up a crosswalk as a pedestrian approaches the intersection. The technology can be used to show predefined messages.
- Precast pavement systems. This technology continues to evolve, and new methods are being developed that offer the potential to allow ready removal and replacement of the surface to access underground utilities. This "snap in, snap out" approach is still in early stages of development, but if implemented, will provide an answer to municipal agencies that are confronted with seeing the integrity of newly placed pavement being compromised as it is cut into pieces for utility access. An overview of precast concrete pavement systems is provided by Tayabji, Ye, and Buch (2012).

Concluding Remarks

This chapter describes how pavements interact with larger system sustainability goals and objectives, and highlights a number of key pavement-related sustainability considerations not directly covered elsewhere. There are a number of potential issues and trade-offs that are inherent when considering sustainable pavements within the context of these larger systems, including:

- Uncertainty in performance of materials specifically designed to meet aesthetic, environmental, or social criteria.
- Cost is often higher for non-traditional approaches to pavement design, materials, and construction including meeting historical or cultural identity.
- Depending on local policy, utility cuts are often executed by utilities that are not focused on the quality or long-term performance of the repair. This will require education and accountability to improve the state-of-the-practice.
- Timing and quality of construction versus being allowed to work only within prescribed hours of operation. This is most acute in urban areas where construction often is prohibited during nighttime hours (e.g., 6:00 p.m. to 7:00 a.m.).
- Specific features designed to accommodate wildlife can be expensive, and their effectiveness not well demonstrated.

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