Developing a LEED specification for design and construction of flexible pavements

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There is a growing recognition that highway construction and maintenance have major environmental impacts. Despite the lack of a clear protocol for designing and constructing an environmentally-friendly highway, the industry had experienced with sustainable alternatives since the 1970s. With an ultimate goal to develop sustainable guidelines for highway construction processes, this paper presents a general framework for the design and construction of sustainable flexible pavement system. This framework follows a similar approach to the Leadership in Energy and Environmental Design (LEED™) methodology by employing a point system to award a rating that quantifies the sustainability of the structure. The proposed framework divides factors related to highway design and construction into six major categories: sustainable sites (eight points), energy efficiency (five points), site air quality (four points), materials (ten points), water efficiency (four points), and innovative and design process (three points). The developed rating framework may be used to award a LEED™ certification for highway design and construction. Different levels of certification may be awarded depending on the total earned credits from the six categories (Platinum, Gold, Silver, and Certified). A maximum score of 34 may be achieved under the aforementioned categories. It is proposed that a highway construction that satisfies the prerequisites and achieves a passing score of 10 be awarded a certified rating.

Keywords: LEED, highway construction, sustainable construction, flexible pavement

Introduction

For the viability of national, state, and local economies, efficient operation of the U.S. highway network is critical. The U.S. is served by the world's largest highway system, including 6.3 million kilometers of streets, roads, and highways, as well as more than 570,000 bridges. This road network consists of 83% classified as flexible pavements (pavement with an asphalt mixture top surface) and the remaining shared between rigid (pavement with a concrete top surface) and aggregate pavements. Annually, this transportation system carries—at a level of $775 billion—over four trillion passenger miles of travel and 3.8 trillion ton miles of domestic freight, close to 11 percent of the Gross Domestic Product (GDP) (FHWA 2000).

Despite the importance of the national transportation network, there is a growing recognition that highway construction and maintenance have major environmental impacts (EPA 1994; World bank 1996). Some of these environmental impacts include damage that occurs during the construction, the operational, and the maintenance phases. During the construction phase, impacts on sensitive ecosystems occur due to vegetation removal, erosion and sedimentation, soil compaction, noise and visual disturbance, contamination and toxicity, and many others (Harrington 2000). Highway construction materials also impact the environment, the cost, and the energy use associated with these processes. As no slowdown in freight transportation growth is in sight in the near future, it is imperative that innovative technologies that can reduce the environmental impacts of highway construction be introduced.

With the recent increase in energy prices and the gradual depletion of natural resources, there is a pressing need to conserve energy in highway construction activities and to adopt methodologies that would be beneficial to the environment, to the users, and to the industry. The building construction industry is currently experiencing with a process known as sustainable construction, which supports using recycled material and natural products as well as developing systems that are more energy-efficient. In 1998, the Leadership in Energy and Environmental Design (LEED™) Green Building Rating System was developed by the U.S. Green Building Council (USGBC) to establish a "common standard of measurement" for "green" buildings (Kibert 2005). To date, LEED™ buildings represent a conservative estimate of 4% of the new construction market. However, because the rate of new buildings seeking certification increases rapidly, these figures will also increase.

In spite of LEED's success as a tool to implement sustainable construction, there are no LEED™ guidelines available for highway construction. Despite the lack of a clear protocol for designing and constructing an environmentally-friendly highway, this industry had experienced with sustainable alternatives since the 1970s. This had led to experimentation with various construction techniques that are thought to reduce the environmental impacts of highway construction. With an ultimate goal to develop sustainable guidelines for highway construction processes, this paper presents a general framework for the design and construction of environmentally-friendly flexible pavement system. This framework follows a similar approach to the LEED™ methodology by employing a point system to award a rating that quantifies the sustainability of the structure. For illustration purpose, this study identifies successful alternatives that may be used to reduce the environmental impacts of highway construction. At this stage of research, this framework is only applicable to flexible pavement systems.

Background

A flexible pavement consists of a layered system with the better quality materials placed at the top (where the stress is high) and lower quality materials placed at the bottom (where the stress is low). To achieve this design, a typical pavement consists of the surface course, underlying bases, and subbase courses. This design makes use of a wide array of construction materials including hot-mix asphalt (a mixture of asphalt binder and high quality aggregates), granular materials, and stabilized aggregates. Hot-mix asphalt (HMA) is the most important component of flexible layered systems since it carries the greatest level of stresses and is used to provide a smooth surface for road users. A number of modifiers (polymers, rubber, anti-stripping additives) are also widely used in the production of HMA to improve pavement performance.

The production of asphalt binder is part of the petroleum refining process, a high energy-intensive manufacturing process (EIA 2002). Energy consumption during production is used in the extraction, hauling, heating, distillation, cooling, and final processing. During production of HMA, energy is used for heating of asphalt binder, drying of aggregates, heating of the mixture, and transportation to the construction site. Hot-mix asphalt requires a very high temperature during production (in excess of 150^{o}C). Recent research has shown that 48% of needed energy extracted from fossil fuels is used during production of HMA and 40% is used during production of asphalt binder (Zapata 2005). With the recent increase in energy prices, the cost of a ton of HMA had increased by as much as 50%. One state agency reported that over the past three years, the price of hot mix asphalt (HMA) increased from $68 a ton in 2004 to $104 a ton in 2007, which represents an increase of 53%. The scarcity of high-quality raw aggregates for use in HMA and granular layers is also a major challenge facing the highway industry.

LEED™-New Construction

The Leadership in Energy and Environmental Design (LEED™) Green building Rating System, developed by the U.S. Green Building Council, is a set of building assessment standards to rate environmentally sustainable construction (LEED 2002). LEED-New Construction (NC), which was originally developed for office building, is the most popular of these standards. This rating system is structured into six major categories that address the following areas:

- Sustainable sites (14 points);
- Water efficiency (5 points);
- Energy and atmosphere (17 points);
- Materials and resources (13 points);
- Indoor environmental quality (15 points); and
- Innovation and design process (5 points).

Each of these categories is assigned a number of scoring points that describe the sustainability of the building. The total score, calculated by adding the points in each category, is used to determine a building rating. A maximum achievable score is 69 points. LEED™-NC rates sustainable buildings as platinum, gold, silver, and certified. In general, silver and certified ratings can be achieved without significant additional investments while platinum and gold ratings are fairly expensive to achieve.

Since its inception in 1998, the application of LEED™ in commercial and institutional buildings has substantially grown and numerous projects in 28 countries have chosen to get LEED certification. Over the past years, the number of buildings designed and built according to this assessment system has increased drastically each year as shown in Figure 1. There are currently nearly 1,100 certified projects in the US and more than 6,000 registered projects (LEED 2007). The advantage of this system over other assessment methods is that it provides a simple but logical approach to quantifying sustainability. It was also developed with continuous inputs from the green building industry. Despite these advantages, LEED™ has not been extended to cover horizontal construction. In recent years, major construction projects such as the O'Hare Airport Modernization Program have expressed interests in adopting a sustainable approach in the construction process but had to develop their own set of guidelines given the lack of standards for this type of construction (Andolino 2006). There are also other perceived deficiencies in the LEED-NC^{TM} certification system including high fees for registration and that credits are not soundly distributed to reflect the environmental impacts of construction and operation processes (Schendler & Udall 2005).

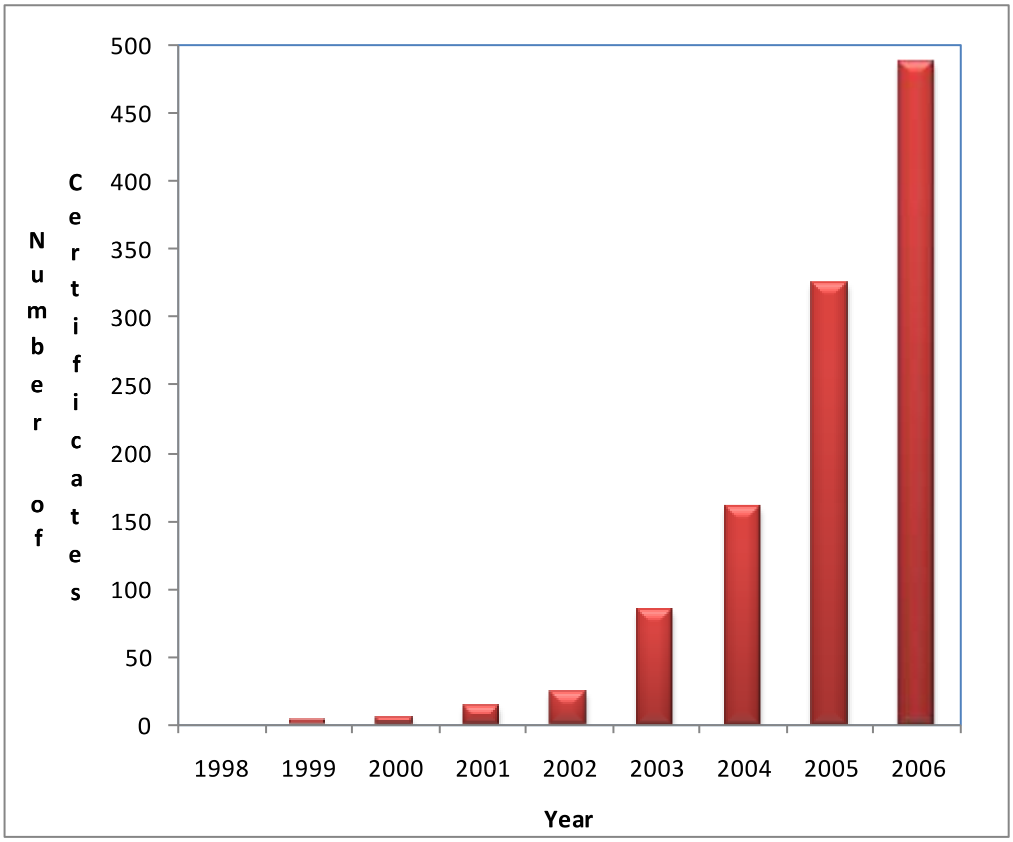

Figure 1. Annual Cumulative Number of LEED^{TM} Certified Buildings (Sector Strategies 2006)

Overview of the proposed framework

Highway construction can result in many adverse effects on the surrounding environment. It is, therefore, the objective of this framework to minimize these impacts and award points for actions taken to mitigate these effects. The developed framework follows a similar approach to the LEED^{TM} system for new construction (LEED^{TM}-NC). This would facilitate implementation into existing methodologies and ensure familiarity with the concepts proposed in this framework. Factors addressed by this framework are divided into six major categories: sustainable sites, energy, site air quality, materials, water efficiency, and innovation and design process (see Figure 2).

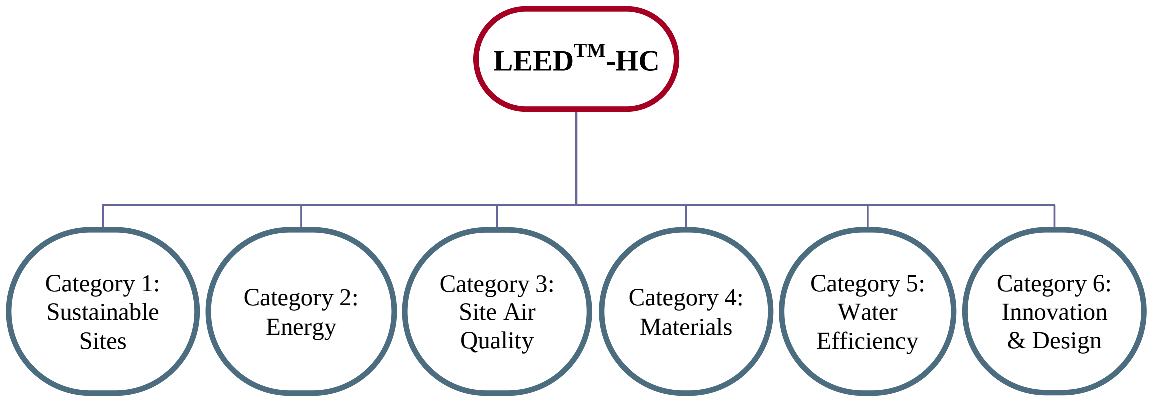

Figure 2. Overview of LEED-HC Categories

Sustainable Sites (Eight Points)

This group is similar to the LEED™-NC category named "sustainable sites and landscaping" and addresses the use of land to build a highway in a way that minimizes disruption of the existing ecological system. Highway systems have been referred to in the past as "disruption corridors" since they may cause significant fragmentation of habitats and dramatic disruption to the original ecological system (Barrett 1991). However, the impact of highway construction on the existing ecological system can be significantly minimized. In the planning and design phases of an environmentally-friendly highway system, a designer would consider the site's geology, topography, and ecological system in selecting the corridor route. In addition and as recommended in LEED™-NC, the following guidelines are suggested:

- Control erosion and sedimentation of soils during the construction process.
- Minimize earthmoving operations (i.e., cut and fill) by following the site natural topography.
- Minimize the highway imprint during construction operations.
- Minimize the destruction, fragmentation, and degradation of natural habitats.
- Build on land that had previously been developed and redevelop heavily-impacted lands.
- Preserve wetlands and other valuable ecological systems.
- Minimize land contamination with pollutants.
- Avoid building in flood-zone due to the potential of disasters and possible reconstruction.

To control erosion and sedimentation during construction, many practices have been successfully implemented (IAMU 2005). Maintaining a vegetation cover during the construction process is the most effective of these practices. Other effective practices include compost (a soil amendment consisting of decomposed organic waste) and mulch applications. It is also imperative to minimize wind erosion by using sand or wind fences as a barrier for soil movement in areas of high wind. To control sedimentation, straw bales and silt fences are widely used. Geotextiles are also used to control sedimentation by allowing the flow of water while retaining sediments and fine soil particles. A number of state highway agencies also require that a contractor interested in performing Erosion and Sedimentation Control (ESC) activities must obtain training from an approved ecological training provider (WDOT 2005). This is a recommended practice that was included in the proposed framework for sustainable highway construction.

Table 1 presents an eight-point system suggested to rate a highway construction in terms of sustainable site. Erosion control and selection of a corridor route away from wetlands and sensitive ecological systems are prerequisites in the proposed framework due to their importance in minimizing the environment impact of highway construction. A prerequisite means that a highway cannot be considered sustainable if it does not meet this precondition. However, a sustainable highway does not have to meet all scoring criteria.

Table 1

Sustainable Sites Eight-Point System

ID	Description	Points
PR1	Erosion and sedimentation control plan − Contractor must obtain training in ESC	N/A
PR2	Avoid wetlands and sensitive ecological systems in selected corridor route	N/A
SS1	Site selection: − Minimize earth moving operations − Minimize destruction, fragmentation, and degradation of natural habitats − Redevelop heavily-impacted lands − Provide easy access to the outdoors around the constructed highway	4
SS2	Minimize highway imprint during construction	1
SS3	Minimize land contaminant with pollutants during construction	1
SS4	Restore ecosystem after construction: − Provide wildlife corridor around the constructed highway − Plant native plants in the disturbed ecosystem	2

PR: Prerequisite – no points are associated with a prerequisite since it is a precondition for a highway to be rated by the proposed standard.

Energy Efficiency (Five Points)

As it was previously mentioned, the impact of energy consumption on highway construction operations is significant. With the recent rise in energy cost, sustainable highway construction should adopt technologies proven to reduce the consumption of nonrenewable energy. Recent estimates predict that the current energy crisis will escalate at the end of the current decade, at which a rollover point will be reached (Kibert 2005). At this point, the increase in the demand rate will surpass the rate of oil extraction and a sharp increase in energy price is expected. Energy consumption associated with highway construction is mainly related to two activities: material production and transportation, and equipment operation. To minimize the energy impacts of highway construction, the following observations are noted:

- Recent advances in construction equipment have led to the introduction of fuel-efficient diesel engines, which can improve fuel efficiency by as much as 30% (Equipment world 2004). Biodiesel fuel (a mix of soybean oil and petroleum-based diesel fuel) has also been successfully used to power dump trucks. In addition, hybrid technology was recently introduced to power heavy vehicles such as trucks and construction equipments. This technology is expected to improve fuel efficiency by as much as 35% (Green fuel 2007).
- A new class of asphalt mixtures has been recently introduced to minimize energy consumption and reduce emissions during production. More details about this class of materials are presented in the following sections.
- Selection of the route corridor in the vicinity of production plants and quarries would minimize energy consumption during hauling and transportation. Using portable plants in the construction process may also be a feasible option.

Table 2 presents a five-point system suggested to rate a highway in term of energy efficiency. Depending on the percentage of fuel-efficient construction equipments used in a specific project, a sustainable practice may be awarded up to three points for this category.

Table 2

Energy Efficiency Five-Point System

ID	Description	Points
EE1	Employ fuel efficient construction equipment^ – Use at least 25% fuel-efficient construction equipment – Use at least 50% fuel-efficient construction equipment – Use at least 75% fuel-efficient construction equipment	3
EE2	Minimize hauling distance	1
EE3	Utilize energy-efficient HMA mixtures	1

^: Based on fuel consumption that may be obtained from monitoring consumption or manufacturer information

Site Air Quality (Four Points)

The Environmental Protection Agency (EPA) estimated that non-road diesel engines generate about 10% of the nation's Nitrogen Oxide (NOx – a chemical compound causing lung and liver cancer) with greater rate in the neighborhood of large U.S. cities with air quality problems. It is also predicted that these equipments may increase their contribution to NOx by as much as 25% by 2010. In addition, these engines are a major source of diesel Particle Matters (PM). EPA envisions that, without new standards, as much as three-quarters of all diesel PMs will come from non-road engines by 2010 (EPA 2003). To minimize the energy impacts of highway construction, the following guidelines are suggested:

- Employ low-emission construction equipments during construction. In 2006, ultra-low sulfur diesel (ULSD) fuel became available nationwide, providing an immediate 10% reduction of fine particle emissions. In addition, a new class of fuel-efficient engines scheduled to be available by 2010 is expected to decrease emissions by as much as 90% (Equipment world 2004).
- Minimize the emissions of ozone-depleting chemicals during production and construction. As a positive sign, the Environment Protecting Agency (EPA) has removed asphalt plants from its record of major sources of hazardous air pollutants in 2002. Moreover, asphalt plants in the U.S. increased production by more than 250% over the past 40 years while reducing total emissions by 97% (Beyond Roads 2007).

Table 3 presents a four-point system suggested to rate highway construction in term of site air quality. Depending on the percentage of low-emission construction equipments used in a specific project, a sustainable practice may be awarded up to three points for this category.

Table 3

Site Air Quality Four-Point System

ID	**Description**	**Points**
SA1	Employ low-emission construction equipment:^ – Use at least 25% low-emission construction equipment – Use at least 50% low-emission construction equipment – Use at least 75% low-emission construction equipment	3
SA2	Develop a control plan to minimize airborne dust during construction	1

^: Based on manufacturer's information on emissions as a fraction of total equipment hours used

Materials (Ten Points)

Construction materials are the most important aspect of highway construction. The selection of appropriate materials affects the cost, energy use, sustainability, and pavement performance. The gradual depletion of natural resources has encouraged the industry to develop a number of sustainable alternatives. It is worth noting, however, that the terms sustainable when referring to highway construction can only be used relatively due to the petroleum nature of HMA (nonrenewable construction materials). To reduce the environmental impact of highway construction, the following alternatives are suggested (more details are presented in the following sections):

- Use of reclaimed (recycled) asphalt pavement allows reducing the consumption of natural resources in highway construction.
- Utilization of a new class of asphalt mixture (warm-mix asphalt) will result in reducing energy consumption and emissions during construction.
- A number of residual materials can be recycled into pavement systems instead of placing them into landfills. At current waste generation rate, this approach is critically needed to avoid overfilling of existing landfills. In many cases, these residual materials were found to improve pavement performance. Examples of residual materials include crumb rubber from scrap tires, furnace slag from metal manufacturing, and fly ash from coal-fired power plants.

Table 4 presents a ten-point system suggested to rate a highway in terms of materials sustainability. Similar to LEED-NC, minimizing construction waste can be credited a maximum of 2 points depending on the rate of diversion.

Table 4

Materials and Resources Ten-Point System

ID	**Description**	**Points**
MR1	Reduce construction waste^ • By a diversion rate of 50% • By a diversion rate of 75%	2
MR2	Reclaimed asphalt pavement content • Use of RAP by a minimum content of 15% • Use of RAP by a minimum content of 25% • Use of RAP by a minimum content of 45%	3
MR3	Use of warm-mix asphalt • In surface course • In surface and base course	2
MR4	Use of residual materials in highway construction • One type of residual material • Two types of residual material • Three types of residual material	3

^ Contractor must demonstrate by sound calculations the quantity of materials that was diverted and the method of diversion.

Water Efficiency (Four Points)

The green movement strongly advocates the need for water conversation, as water is one of the most important resources needed for survival. In spite of that, water has been significantly depleted in the last three decades. Highway construction can contribute to the effective preservation of this resource by adopting innovative technologies in the design and construction process. Pavement contributes to water runoff, which results in pollution of water streams. This type of pollution is referred to as non-point source pollution. To reduce the environmental impact of highway construction on the hydrologic cycle, the following alternatives may be used:

- A new class of asphalt mixture (open-graded friction course) that provides quick surface drainage capability. In the event of heavy rain, there is minimum standing water on the surface, which minimizes water run-off and sharply improves safety conditions during driving. This would reduce pollution of water running on impermeable pavement.
- A drainage layer is a treated-permeable base used to drain water beneath the pavement surface. The use of a drainage layer underneath the surface and base courses would facilitate water movement to the side drainage system, and therefore, reduce water loss.

Table 5 presents a four-point system used to rate a highway in terms of water efficiency. Due to the relatively high investment associated with these alternatives, two points are awarded for each credit. However, additional safety benefits may be achieved by adopting these alternatives.

Table 5

Site Air Quality Four-Point System

ID	Description	Points
WE1	Use Open-Graded Friction Course	2
WE2	Use of a treated drainage layer	2

Innovation and design process (Three Points)

This category rewards innovative actions taken by the designer to facilitate future maintenance and rehabilitation activities. This includes utilization of recyclable material, design for adaptation, repair, and future uses. This category provides a maximum of three points based on a detailed plan that demonstrates that innovative actions were taken to facilitate future repair and use of the pavement structure. An example of innovative actions includes the use of quiet pavements, which were shown to reduce noise pollution to neighborhood habitats to highway systems.

Points Required for LEED-HC Certification

The developed rating framework may be used to award a LEED-HC certification for highway construction. A maximum score of 34 may be achieved under the aforementioned categories. It is proposed that a highway design and construction practices that satisfy the prerequisites and achieves the following credits be awarded a certain level of certification:

- Platinum: 26 points or more.
- Gold: 21 – 25 points
- Silver: 16 – 20 points
- Certified: 10 – 15 points

These ratings were selected based on an estimation of achievable scores based on different levels of investments. It is envisioned that a certified rating is achievable with minimum additional investments to conventional construction processes.

ENVIRONMENTALLY-FRIENDLY TECHNOLOGIES

This section presents illustrative technologies that have been used successfully to minimize the environmental impacts of highway construction.

Reclaimed Asphalt Pavement

Recycling of asphalt material results in a reusable mixture of aggregate and asphalt binder known as reclaimed asphalt pavement (RAP). Recycling of asphalt pavements is a very valuable approach for technical, economical, and environmental reasons (Kennedy, Tam & Solaimanian 1998). With the increasing costs of asphalt, coupled with the scarcity of quality aggregates and the pressuring needs to preserve the environment, the use of RAP has been favored against virgin materials. Many State agencies have also reported significant savings when RAP is used (Page & Murphy 1987). In addition, the use of RAP allows decreasing the amount of produced waste and helps to resolve the disposal problems of highway construction materials especially in the neighborhood of large cities. In 1996, it was estimated that about 33% of all asphalt pavement in the U.S. was recycled into HMA (Sullivan 1996). After more than 30 years since its first trial in Nevada and Texas, it appears that the use of RAP will not only be a beneficial alternative in the future but will also become a necessity to ensure economic competitiveness of asphalt pavement construction. However, concerns remains with respect to the number of times HMA can be recycled before it can no longer meet the specifications.

Warm-Mix Asphalt

In 1997, European countries started experiencing with a new mix technology known as warm mix asphalt (WMA). The concept of warm mix asphalt is based on the fact that substantial energy is spent to heat HMA to temperatures in excess of 150^{o}C during production and compaction. By reducing the heating temperature during production by 15 to 40^{o}C lower than with typical HMA, warm mix asphalt may provide significant energy savings to the asphalt industry. Warm mix asphalt uses specific mechanical and chemical means to reduce the shear resistance of the mixture, which allows to process and compact the mat at lower temperatures. Compared to regular mixtures, WMA reduces fuel energy consumption at the plant by as much as 30% (Asphalt Pavement association 2003). In addition, WMA reduces emissions at the plant, widens the winter paving season, and reduces mixture aging. By reducing emissions at the plant, WMA would also reduce health problems, complaints of odor, and fumes in the vicinity of all paving workers.

Crumb-Rubber Modifier

Approximately 850 million to 3 billion scrap tires are disposed of in landfills, stockpiled, or illegally dumped around the U.S., a number that increases by 250 million tires every year (Reisman 1997). To address the disposal problem associated with this material, crumb rubber modifier (CRM) has been used in flexible pavement construction since the early 1960s. The use of this modifier was shown to significantly improve pavement performance (Roberts, Mohammad, Qin, & Huang 2003). Crumb rubber can be added to the asphalt binder during refining (wet process) at a percentage ranging from 15 to 25% or added as a source of aggregate (dry process) during preparation of HMA. The use of crumb rubber in HMA was also shown to reduce traffic-generated noise during operation (Better Roads 2005). One of the issues that need to be investigated is the recycling process of HMA containing crumb rubber. Concerns were raised that a RAP containing asphalt rubber may be too absorptive or may increase blue smoke emission during production (Better Roads 2005).

Summary

The objective of this study was to develop a general framework for the design and construction of sustainable flexible pavement system. This framework follows a similar approach to the LEED™ methodology, which employs a point system to award a rating that reflects the number of predefined criteria that the design and construction practices meet. The proposed framework divides factors related to highway design and construction into six major categories: sustainable sites (eight points), energy efficiency (five points), site air quality (four points), materials (ten points), water efficiency (four points), and innovative and design process (three points). The developed rating framework may be used to award a LEED™ certification for highway design and construction. Different levels of certification may be awarded depending on the total earned credits from the six categories. A maximum score of 34 may be achieved under the aforementioned categories. It is proposed that a highway construction that satisfies the prerequisites and achieves a passing score of 10 be awarded a certified rating.

Based on the developed framework in this study, further research is recommended and is currently conducted to validate and implement the proposed guidelines into highway design and construction:

- A peer panel of experts from related industries and highway agencies will be solicited to validate categories, ratings, and certification levels.
- Many of the proposed innovative technologies may not be applicable to all highway construction practices and all climatic and pavement conditions. Therefore, the designer must ensure that the selected methodology would not

adversely affect pavement performance, and therefore, increase maintenance needs in the future.

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