Sustainability Consideration for Highway Facilities

Yuhong Wang, Ph.D., PE
East Carolina University
Greenville, North Carolina

The construction industry has gradually started to incorporate sustainability considerations into its conventional practices. For instance, the industry has witnessed increasing interests in green building projects in recent years. However, in other construction sectors, the goals and scope of sustainability remain to be defined. The purpose of this paper is to discuss sustainability considerations for highway facilities, which can be used to assess and improve the current practices on highway planning, design, construction, and maintenance. In addition, these considerations can be used to enrich the pedagogical content of construction education, especially in the area of heavy construction. This paper has developed sustainability indicators for highway facilities and organized them according to major stages of the facility's life cycle. Based on these indicators, measurable objectives can be created by highway agencies to evaluate sustainability practices of project participants.

Keywords: Sustainable Development, Highway, Sustainability Indicator, Sustainability Metrics, Project Life-cycle

Introduction

Background

Sustainability is often used interchangeably with sustainable development. Although there are many definitions on sustainability, the most frequently cited one is 'meeting the needs of the present without compromising the ability of future generations to meet their own needs,' provided by 'United Nations World Commission on Environment and Development (WCED, 1987)'. Another frequently cited document on sustainability is Agenda 21, which specifies the framework of sustainability, as well as the policies, objectives, and activities in order to achieve it (UN, 1992). The United Nations also provides other documents on this issue through its Division for Sustainable Development, Department of Economic and Social Affairs (Web site: http://www.un.org/esa/sustdev/csd/review.htm). These documents primarily deal with sustainability issues at the national and the international levels.

In the UN documents, transportation is regarded as one of the key factors that promote economic and social development, and also a factor that significantly influences atmosphere, use of resource, and consumption of energy (UN, 1992). An important component of the transportation system is highways. The highway network plays an important role in supporting social and economic development. However, the development and operation of highways also create various issues that impact the sustainable development of a society, such as excessive land consumption, reliance on nonrenewable energy, generation of harmful emissions, and others. For example, highway transportation consumes a great amount of fossil fuel, which is not only nonrenewable, but also causes air pollution and potentially global warming. Although these issues have been widely discussed, it remains a question how they can be effectively addressed through better highway operational practices.

Existing Practices

Sustainable development can only be achieved when major business practices are sustainable. There is an increasing interest of sustainability in different fields. It seems that the most active areas are where specific indicators and metrics of sustainability have been well defined, so that industry practices can be assessed against the present standards. For instance, one effort to promote sustainability in the building industry is the certification of "green buildings." Standards have been developed to assess sustainability of individual buildings in design, construction, and operation. The BRE environmental assessment method (BREEAM) has been used to assess the environmental performance of some 600 major office buildings (BRE, 2006). In the US, there is a dramatic increase of interest in obtaining leadership in energy and environmental design ($LEED_{®}$) certification from the U.S. Green Building Council (USGBC). Since it started in 2000, more than 2000 new construction and major renovations projects had registered for $LEED_{®}$ certification (USGBC, 2006). One critical factor that contributes to the success of these programs is that they have a comprehensive yet detailed rating system. Additionally, the target of rating is an individual project or a building facility, so it is more measurable and implementable.

There are also many studies on sustainability indicators and metrics for the whole transportation system. Litman from the Victoria Transport Policy Institute (VTPI) summarized existing research on sustainable transportation indicators and recommended his own (Litman, 2005). Jeon and Amekudzi reviewed and summarized 16 worldwide initiatives on sustainable transportation systems and provided a long list of sustainability indicators (Jeon and Amekudzi, 2005). These are just two examples out of numerous efforts in developing sustainability indicators in transportation. However, these studies do not focus on assessing individual transportation projects or facilities. Various sustainability issues have also been addressed through highway practices, although sometimes under different names. For example, many social and environmental issues are considered under context sensitivity solutions by many US state highway agencies (Newman et al, 2002). Several research projects were funded under the National Cooperative Highway Research Program (NCHRP) 25-25, Research for the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on the Environment, to investigate social and environmental issues in transportation. As part of the project, NCHRP study 25-25(04) presents a valuable compendium of environmental stewardship practices in highway planning, design, construction, and maintenance, primarily based on information from US state departments of transportation (DOT) and other practitioners (Venner Consulting and Brinckerhoff, 2004). However, the existing practices do not systematically cover all the dimensions of sustainability. There are also wide discrepancies among state DOTs on what environmental stewardship practices to choose and how to implement them. Unlike the commercial evaluating tools $LEED_{®}$ and BREEAM, no systematic documentation has been found to guide, monitor, and promote sustainability for highway projects and facilities.

Objectives of the Study

The purpose of this study, as presented in the paper, is to identify and propose sustainability indicators and metrics specific for highway projects and facilities. It is expected that the indicators and metrics can be used to guide highway agencies to make policies to promote sustainable practices. They also provide a set of issues to consider for highway practitioners when they perform design, construction, and maintenance activities. Additionally, they provide college educators a framework of sustainability topics to be incorporated in highway construction related curriculum, so that future constructors or engineers are prepared with the relevant body of knowledge.

Method of Identifying Sustainability Indicators

Comparing to other civil infrastructures, highway facilities have many unique characteristics: Highways generally influence a large geographic area and demarcate the piece of land they cross. Most sections of highways are publicly funded and used by the public; therefore, there are a lot of stakeholders involved. During construction, there is normally a great amount of earthwork involved, which may cause erosion and impact the existing ecosystem. Some projects are carried out in rural settings and environmental sensitive areas. These are just some examples of a wide range of unique issues, which make highways have different sustainability concerns than other infrastructural facilities.

To develop sustainability indicators for highways, one needs to identify the general requirements of sustainability, which can then be refined and adapted for highway practices. According to UN's commission on sustainable development (CSD) — theme indicator framework, sustainability is categorized into four dimensions: social, environmental, economic, and institutional. Under these dimensions, there are 15 themes, 38 sub-themes, and 58 indicators, which are based on voluntary national testing and expert group consultations (UN, 2005). According to World Bank, sustainable transportation must satisfy three main requirements: economic and financial, environmental and ecological, and social (World Bank, 1996). The VTPI also divided sustainability considerations into three groups: economic, social, and environmental, which is agreed by a lot of other literature (Litman, 2005). This study adopted the three dimension approach.

There are great variations on what constitutes sustainability under these dimensions. For example, the Canadian Center for Sustainable Transportation recommends 14 sustainable transportation indicators (Gilbert and Tanguay, 2000), while the VTPI proposed 16 most important ones, 10 helpful ones, 5 specialized ones, and others (Litman, 2005). In this study, a step-by-step process was followed to find sustainability indicators for highways.

1. Major components of the highway system were identified.
2. General transportation sustainability indicators from existing research were summarized and specialized for highways.
3. Current highway practices that promote sustainability were summarized.
4. Indicators and practices from Step 2 and 3 were reorganized according to the major stages of the life-cycle of the highway facility.
5. Indicators and practices from Step 4 were mapped to the 15 themes in the UN CSD theme indicator framework. Gaps were filled between the themes and practices if certain themes relevant to highway were not adequately covered.

The major components of the highway system are shown in Figure 1 by a breakdown structure. In the system, there are certain building types of facilities like service stations, buildings at rest area, and buildings at maintenance stations. For these facilities, sustainability evaluation criteria for “green buildings” may be applied. But the majority of the facilities are ‘horizontal’ nature, such as pavements, bridges, walls, fences, etc, which are the focus of the sustainability review in this paper.

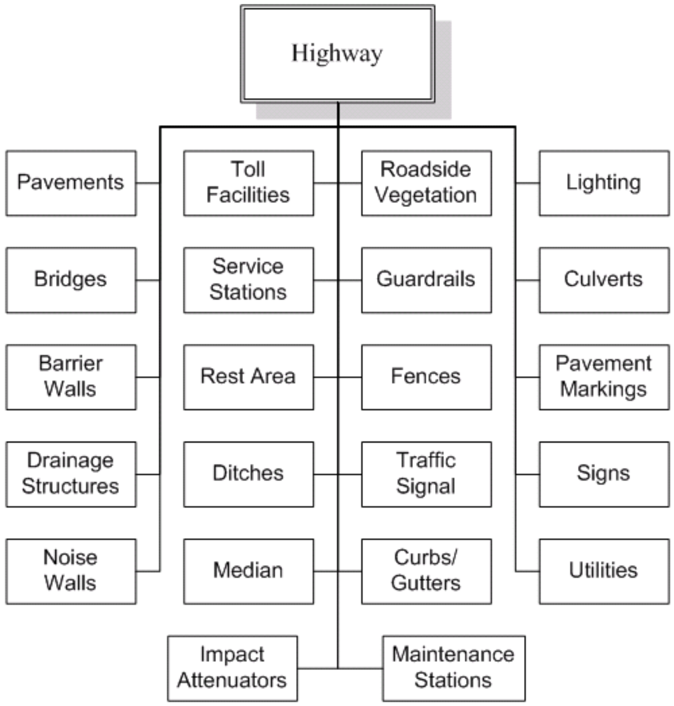

Figure 1. Breakdown structure of major highway facilities.

An extensive literature review was conducted by this study to identify highway related sustainability indicators. Besides the previously mentioned literature, there is also a lot of research addressing specific sustainability issues. For instance, Zapata and Gambatese reviewed and compared energy consumption of asphalt and reinforced concrete pavement materials and construction (2005). Hassan et al compared the effects of runway deicers on pavement materials and environment (2002). Wada et al estimated the environmental impacts of highway runoff pollution (2002). Park et al assessed the environmental impacts on life cycle of highways (2003). These are several examples of existing studies considered when the set of indicators were developed.

The study also reviewed the current practices of promoting sustainability by highway agencies, especially US DOTs. Some of the information was obtained from DOT’s websites, while others from various NCHRP reports. Different concerns addressed by these practices were summarized when developing the set of sustainability indicators.

Highways, like other infrastructure facilities, have a finite life span. At the different stage of the life-cycle of the facility, emphasis on sustainability may be different. At the planning stage, one may need to justify the construction of the highway and compare it with other transportation modes. Also, important decisions are made regarding its major components and their sustainability goals. At the design stage, the goals at the planning stage are transformed into design documents and one needs to select design features to meet specific sustainability requirements. Additional sustainability considerations may be applied to construction as well as operation and maintenance. Since there are different organizations involved, another reason to divide stages is to clarify these organizations' responsibility and assess their individual efforts toward sustainability.

Starting from project planning, indicators were developed for each stage. Some of them were based on existing literature or practices, while others were added by this study to map the 15 themes of UN CSD theme indicator framework. When justifying these indicators, three criteria were used: first, they contribute to the 15 themes of the UN document; secondly, they are under the authority of highway agencies; and thirdly, they can be specialized to measurable objectives.

Sustainability Indicators at Different Stage of Facility Life-cycle

Sustainability Considerations at Planning Stage

Sustainability indicators and their descriptions for the planning stage are listed in Table 1. Certain indicators may be viewed as both economic and social. For example, 'mobility' is not only important to economy by promoting trade and production, but also helpful in poverty reduction. In Table 1 and the following tables, sustainability indicators that may cover more than one dimension are listed under one group only.

Table 1. Evaluation of Sustainability at Planning Stage

INDICATORS	DESCRIPTION
ECONOMIC	
Mobility	Increase of mobility, measured by the estimation of passenger kilometers and freight ton-kilometers, added length of highways, traffic volumes on the planned road, etc.
Accessibility	Clear definition of user groups; Accessibility of different user groups to the planned highway.
Transportation system integration	Integration of the planned highway with other transportation modes (aviation, railroad, etc.).
Alternative transportation mode	Comparison of function and cost of the planned highway with alternative transportation modes; Feasibility of the planned highway being replaced by more environmentally friendly transportation mode.
Quality of transportation related economic data	Quality and extent of economic information that can assist planning of the facility, such as demography, road user cost, congestion cost, construction cost of existing similar facilities, etc.
Congestion cost	Reduction of congestion cost due to the planned highway.
Growth potential	Increase of real estate value and business opportunities along the planned facility.
Job opportunities	Increase of job opportunities because of the project.
Life-cycle cost	Conceptual life-cycle cost of the planned highway and the comparison of it with other transportation modes.
Availability of parking spaces	For urban highways, the availability of parking spaces at important locations along the highway and the cost of building them.

Project financing	Availability of public and private funds to build, operate, and maintain the facility; Priority of the planned project compared with other public projects.
Travel efficiency	Reduction of average commute time or average home-work trip distance; Reduction of travel time of other purposes because of the planned road.
Benefit/cost of environmentally friendly features	Benefit and cost of the added features to the basic function that will improve the social and environmental values of the project.
User cost	User cost of the planned highway and the comparison of it with other transportation modes.

Table 1. Evaluation of Sustainability at Planning Stage (continued)

INDICATORS	DESCRIPTION
SOCIAL	
Aesthetics	Effects of visual impact of the planned facility on its environmental context.
Community impacts & disruption	Impacts and disruptions of the facility to nearby communities during its construction and operation.
Pedestrian & bicycle	Planned highway features that facilitate walkers and bicyclers.
Environmental justice	Compliance of the planned highway with environmental laws and regulations.
Management process integration	Integration of project management processes in planning so that transportation and environmental issues can be analyzed simultaneously.
Involvement of stakeholders	Involvement of stakeholders in making planning decisions and the extent of the stakeholders' opinions are reflected.
Mixed development	Avoidance of fragmentation of human society caused by separation of highways, different land use, and real estate property values.
Preservation of cultural & historical resources	Effort of preserving cultural, historical, archeological resources and creating livable communities.
Proximity of highway facility to points of interest	Identification of points of interest and special areas (e.g., commercial area, recreational area, animal outlook, scenic views, etc.); Closeness of the highway facility to these special locations.
Mobility services to disadvantaged residents & non-auto users	Quality (including accessibility, price, etc.) of transportation services for the poor, people with special mobility needs, and non-auto users.
Safety	Reduction of traffic accidents because of the planned project and

	the addition of safety features.
Transit stops & stations	Closeness of public transit stops/stations to future user groups.
User benefit equity	Equality of benefits of the facility to users with different income levels, ages, and races.

Table 1. Evaluation of Sustainability at Planning Stage (continued)

INDICATORS	DESCRIPTION
ENVIRONMENTAL	
Renewable Energy	Reduction of non-renewable energy consumption by transportation policies (e.g., carpool) and facilities (e.g., service stations providing non-fossil fuel).
Contaminated site remediation & risk management	Remediation of known contaminated sites within the scope of the planned project; Risk management plan for unexpected contaminated sites.
Critical slopes & sliding areas	Protection of critical slopes and sliding areas along the planned highway; Using environmentally friendly techniques for slope protection.
Emissions of greenhouse gas & pollutants	Reduction of emissions of greenhouse gas and airborne pollutant by policies and facilities.
Fragmentation of ecosystems & habitat loss	Avoidance of potential fragmentation and loss of habitat of the ecosystem caused by the highway facility and planned features; Reduction of negative impacts like animal collisions and fish passage obstructions.
Green area	Creation of green areas along the planned facility.
Light pollution	Reduction of light pollution for people who live nearby the facility.
Noise pollution	Reduction of noise pollution for people who live nearby the facility.
Restoration & creation of sustainable stream	Restoration and creation of sustainable streams along the right-of-way and at highway crossings.
Sitting of maintenance facilities	Evaluation of sitting locations of maintenance facilities based on environmental sensitivity of the surrounding area.
Stormwater treatment & flood Control	Treatment of stormwater and mitigation of flood risk caused by the planned facility.
Toxic materials & hazardous waste	Avoidance and reduction of toxic materials and hazardous waste such as asbestos, lead, volatile organic compounds (VOC), etc.
Urban sprawl	Control of urban sprawl by cautious transportation planning.
Use of land	Evaluation of the area of land occupied by transportation facilities; Reduction of land use by smart engineering design.

Waste reduction & recycling	Application of waste reduction and recycling program on the planned facility.
Water pollution	Reduction of water pollutants and chemicals.
Wetland protection	Protection of wetland along the planned highway.

Sustainability Considerations at Design Stage

Sustainability indicators and their descriptions for design stage are listed in Table 2. Many of the factors are similar to those in the planning stage. However, even for the same indicator, the measurements are different. Planning may provide general concept with word descriptions, while design implements these concepts and formalizes them through contract documents such as drawings and specifications

Table 2. Evaluation of Sustainability at Design Stage

INDICATORS	DESCRIPTION
ECONOMIC	
Benefit/cost of environmentally friendly features	Benefit and cost analysis of the added features to the basic design that will improve the social and environmental values of the project, based on design documents.
Cost, benefits, and risks of using waste and recycled materials	Benefit/cost and risk analysis of using waste and recycled materials in the designed facility.
Quality of highway related economic data	Quality and extent of economic information for the designed facility such as right-of-way, construction cost, etc.
Life-cycle cost	Life-cycle cost of the facility with different design alternatives.
User cost	User cost influenced by different design alternatives.
SOCIAL	
Aesthetics	Aesthetic considerations in design including the harmony of the project with the surrounding environment.
Community impacts & disruption	Use of special design features to minimize disruptions of the facility to nearby communities during its construction and operation.
Pedestrian & bicycle	Designed highway features that facilitate walkers and bicyclers.
Environmental justice	Compliance of design documents with environmental laws and regulations.
Management process integration	Integration of project management processes in design so that transportation and environmental issues can be analyzed simultaneously.
Involvement of stakeholders in making design decisions	Involvement of stakeholders in making design decisions and the extent of the stakeholders' opinions are reflected in design documents.
Mixed use of land	Design features to avoid fragmentation of human society caused by highway separation, different land use, and real estate property values.
Preservation of cultural,	Efforts of preserving cultural, historical, archeological resources

historical, archeological resources	and creating livable communities during design process.
Mobility services to disadvantaged residents & non-auto users	Design features that provide convenience for people with special mobility needs and non-auto users.
Safety	Design considerations to reduce traffic accidents.
Transit stops & stations	Design considerations to provide convenience to travelers at transit stops and stations.

Table 2. Evaluation of Sustainability at Design Stage (continued)

INDICATORS	DESCRIPTION
ENVIRONMENTAL	
Contaminated site remediation	Identification of technology and procedure for remediation of specific contaminants on site.
Critical slopes & sliding areas	Design features to protect critical slopes and sliding areas along the planned highway.
Snow removal	Design features to reduce the amount of snow accumulation on highways and assist snow removal.
Emissions of greenhouse gas & pollutants	Reduction of emissions of greenhouse gas and airborne pollutants in design by specifying materials and construction methods.
Fragmentation of ecosystems and habitat loss	Engineering design features to avoid fragmentation of ecosystems and habitat loss.
Green area	Inclusion of green areas in design.
Impervious surfaces	Reduction of impervious surfaces in designed facility such as rest areas.
Light pollution	Design features to reduce light pollution during highway operation.
Noise pollution	Design features to reduce noise pollution for people who live near the facility.
Restoration & creation of sustainable stream	Design features that restore and create sustainable streams along the right-of-way and at highway crossings.
Stormwater treatment & flood control	Design features for treating stormwater and mitigating flood risk caused by the facility.
Toxic materials & hazardous waste	Selection of environmentally friendly materials to avoid and reduce toxic materials and hazardous waste such as asbestos, lead, volatile organic compounds (VOC), etc.
Use of land	Reduction of land consumption by smart engineering design.
Waste reduction& recycling	Application of waste and recycled materials in the designed facility.
Water pollution	Reduction of water pollutants and chemicals in design.
Wetland protection	Design features to protect wetland along the highway.

Sustainability Considerations at Construction Stage

Sustainability indicators and their descriptions for construction stage are listed in Table 3. The majority of the indicators are different than those from the planning and design stages. In planning and design, sustainability considerations are the impacts of the highway facility, while in construction stage, only impacts of construction operations are interested. In this stage, sustainability is generally the constructor's responsibility, even though the requirement may be specified by highway agencies.

Table 3. Evaluation of Sustainability at Construction Stage

INDICATORS	DESCRIPTION
ECONOMIC	
Assistance to small & disadvantaged business	Availability of a program to assist small and disadvantaged business in contract awarding.
Justice in acquiring right-of-way	Fairness and justice in appraising and acquiring the right-of-way; Availability of an effective dispute resolution procedure.
Labor payment	Implementation of laws and regulations to ensure workers' wage to be paid in full amount and promptly.
Minimizing construction impacts on traveling public & surrounding business	Measures used in construction, including methods, temporary facilities, and scheduling (duration & sequencing) to reduce the negative impacts of the project to traveling public and surrounding business.
Owner's construction cost control	Control of actual construction cost to complete the project within the budget.
Prevention of corruption in construction	Availability and implementation of laws, regulations, and procedures to effectively prevent corruption during bidding, contract awarding, payment, and quality acceptance, etc.
SOCIAL	
Community impacts & disruption	Reduction of impacts and disruptions of the facility to nearby communities during its construction.
Environmental justice	Compliance with environmental laws and regulations during construction.
Construction / environment integration management	Availability of an environment management program on the construction project; Integration of environment management with other project management processes.
Involvement of stakeholders in construction	Involvement of stakeholders (especially nearby neighborhood, business, frequent road users) in construction planning.
Preservation of cultural & historical resources	Effort of preserving cultural, historical, and archeological resources during construction.
Public awareness of construction activities	Increasing public awareness of construction activities and detours through bulletin board, broadcasting, internet, etc.
Safety	Protection of workers in work zone and protection of passengers.
Working conditions of workers	Quality of sanitary, first aids, and temporary living facilities for workers.

Table 3. Evaluation of Sustainability at Construction Stage (continued)

INDICATORS	DESCRIPTION
ENVIRONMENTAL	
Consumption of nonrenewable energy	Improvement of energy efficiency during construction; Reduction of nonrenewable energy consumption in construction.
Contaminated site remediation & risk management	Remediation of known contaminated site, if encountered by the project; Construction risk management plan for unexpected contaminated site.
Critical slopes & sliding areas	Protection of critical slopes and sliding areas during construction, preferably through environmentally friendly techniques such as bioengineering.
Emissions of greenhouse gas & pollutant	Reduction of emissions of greenhouse gas and airborne pollutants during construction.
Light pollution	Reduction of light pollution to passengers and nearby neighborhood during construction.
Noise pollution	Reduction of noise pollution during construction.
Preservation & protection of aquatic resources	Preservation of riparian areas of a stream during construction. Protection of aquatic resources during construction through cautious selection of construction timing and techniques.
Protection of sensitive wildlife habitat or plant areas	Protection of sensitive wildlife habitats or plant areas during construction through fencing and cautious selection of construction timing and techniques.
Restoration & creation of sustainable stream	Restoration and creation of sustainable streams in construction.
Reuse of water	Reuse of water generated from dewatering process and other construction operations.
Prevention of spillage of vehicle fluid & fuel; washwater control	Prevention of the spillage of vehicle fluid and fuel; Control of vehicle washwater.
Topsoil preservation	Preservation and protection of topsoil during construction.
Toxic materials & hazardous waste	Management of toxic and hazardous materials generated/used in construction.
Use of native plants for road side vegetation	Use of native plants when planting road side vegetations.
Waste reduction& recycling	Reduction of construction waste; Use of waste and recycled materials in construction.
Water erosion & sedimentation control	Effectiveness of water erosion and sedimentation control in construction.
Water pollution	Reduction of water pollutants and chemicals during construction.
Wetland protection	Protection of wetland during construction.
Wind erosion, dust and mud control	Reduction of wind erosion; Control of dust and mud from construction site.

Worksite sanitation	Worksite sanitation of the construction project.

Sustainability Considerations at Operation/Maintenance Stage

Sustainability indicators and their descriptions for operation/maintenance stage are listed in Table 4. After construction, the responsibility of the highway facility is handed over to the highway agency. This is the longest stage of the life-cycle and affects both road users and community along the highway. Many activities in this stage can be carried out in a sustainable way.

Table 4. Evaluation of Sustainability at Operation / Maintenance Stage

INDICATORS	DESCRIPTION
ECONOMIC	
Vehicle sharing	Availability and effectiveness of a vehicle sharing program during the operation of the highway.
Cost effectiveness of maintenance options	Cost and benefit analysis of different maintenance options (e.g., crack sealing vs. thin overlay).
Impacts of pavement performance on vehicle operation cost	Performance of pavement and estimated user cost due to pavement roughness and distress (e.g., potholes on damage of tires, rough road on vehicle operation cost, etc.).
Impact of maintenance activities on traveling public & surrounding business	Measures taken in highway maintenance operations to reduce their negative impacts on traveling public and surrounding business (e.g, timing of the operation).
Preventative maintenance	Preventative maintenance activities of bridges and pavements and their cost effectiveness
SOCIAL	
Environmental justice	Compliance of maintenance and operation activities with environmental laws and regulations.
Public awareness of maintenance activities	Increasing public awareness of maintenance activities, lane closures, detours, and other information through bulletin board, broadcasting, internet, etc.
Safety	Protection of workers in road maintenance and protection of passengers.
Snow removal & deicing	Promptness of snow removal; Effectiveness of deicing operations.
User satisfaction	Overall user satisfaction of the highways, measured by user surveys
ENVIRONMENTAL	
Consumption of nonrenewable energy	Improvement of energy efficiency and reduction of nonrenewable energy consumption during maintenance and operation of highway facilities.
Critical slopes & sliding areas	Continuously monitoring and maintenance of critical slopes along the highway.
Emergency plan on spillage of hazardous materials from transport	Availability of emergency plan on spillage of hazardous materials from transport vehicles; Implementation of the emergency plan.

vehicles	
Erosion, sedimentation, and spillage control of maintenance materials	Erosion, sedimentation, and spillage control of regular and winter maintenance materials at the maintenance facilities.
Integrated roadside vegetation management	Availability of an integrated roadside vegetation management program.
Maintenance of streams	Maintenance of streams along the right-of-way and at highway crossings
Mitigation of environmental impact of snow & ice control	Selection of appropriate snow and ice control materials to mitigate their negative environmental impacts.
Fish & wildlife habitat enhancement	Mitigation of impacts on fish and wildlife during maintenance of bridges and culverts; Creation and maintenance of bird habitats below bridge decks.
Recycling	Use of recycled materials during highway operation and maintenance.
Stormwater treatment	Treatment of runoff from highway, rest areas, and other facilities.
Toxic materials & hazardous waste	Avoidance and reduction of toxic materials and hazardous waste during highway operation and maintenance.
Waste management	Implementation of waste management plan in maintenance facilities; Removal of animal carcass, garbage, and debris from highways.

Sustainability Metrics

The indicators developed in the previous section represent a wide spectrum of possible sustainability considerations for highway facilities. In order to encourage or enforce their applications, additional steps are required, which include identifying a subset of indicators, developing measurable objectives, evaluating actual practices, and synthesizing the evaluation results.

Local highway agencies need to identify a set of indicators that are most applicable to their social, environmental, and economic context. For example, in areas that have been developed and densely populated for a long time, wild animals are very rare, if existing at all. Animal collisions on highways may not be a big concern. Therefore, it may not be selected as a sustainability indicator, while in other areas, this is a serious problem. Another example is payment to labors. In the US, laborers who work on highway projects funded through the federal government are protected by the Davis-Bacon Act of 1931, which established the requirement for paying prevailing wages. In places where late pay and pay below the minimum wage are rampant, the indicator 'labor payment' may be included to promote social equity and development of the poor.

The indicators also need to be specified to measurable objectives. For example, 'increase of mobility' is a sustainability indicator in the planning stage when different transportation modes and capacities are compared. The indicator must be measured through data such as the estimated increase of passenger kilometers, freight ton-kilometers, or added traffic volumes, etc. To further verify that the planned highway facility meets the objectives, actual data may be collected after the highway opens to traffic.

Based on the measurable objectives, highway projects and facilities can be evaluated. Since different project participants are responsible at different stages of the life-cycle, their efforts toward sustainability should be evaluated separately. For example, at the planning and design stage, the highway agency and engineering firms that provide design service may be evaluated, while at the construction stage, the constructor may be evaluated. The parties being evaluated are responsible to provide necessary documents.

Finally, the evaluation results need to be synthesized. In the LEED® green building rating system, in order to be certified, a building project must meet certain prerequisites and performance credits within each category. The credits are not weighed. The project can be awarded to certified, silver, gold, or platinum certification, depending on the number of credits they achieve (USGBC, 2005). In some other environmental evaluation systems, e.g., the environmental impact scores of Building for Environmental and Economic Sustainability (BEEs®), the evaluation scores can be weighed (Lippiatt, 2002). For highway facilities, it depends on the local agency whether to weigh the sustainability score or not. The advantage of weighing is that the relative importance of each objective can be considered. The whole evaluation process, from project planning to operation and maintenance, are summarized in Figure 2.

Summary and Recommendations

Sustainable development of a society can only be achieved when its individual business process is operated in accordance with sustainability principles. Specific objectives and metrics are essential to guide the business process toward this goal. There have been many studies on general sustainability indicators for transportation, while this study concentrates on how they can be specialized for highway projects and facilities, an important component of the transportation system. Sustainability indicators were developed by reviewing the existing literature and practices primarily from the state departments of transportation in the US. Then, they are reorganized according to stages of the life cycle of the highway facilities so that not only they can be assessed progressively, the efforts of different participants can be evaluated.

The indicators represent a wide spectrum of possible sustainability considerations for highway facilities. Different countries or areas may have their own particular emphases. In practice, a highway agency can identify a subset of indicators, develop measurable objectives, evaluate the practices of responsible parties, and finally synthesize the evaluation results. It is expected that the indicators and metrics will assist the agency improving its current practices, which further contribute to sustainable development of the transportation section and the whole society. In addition, the indicators developed in this study can serve as a framework of sustainability topics for construction education. This may assist the educators in identifying the contents of sustainability related classes.

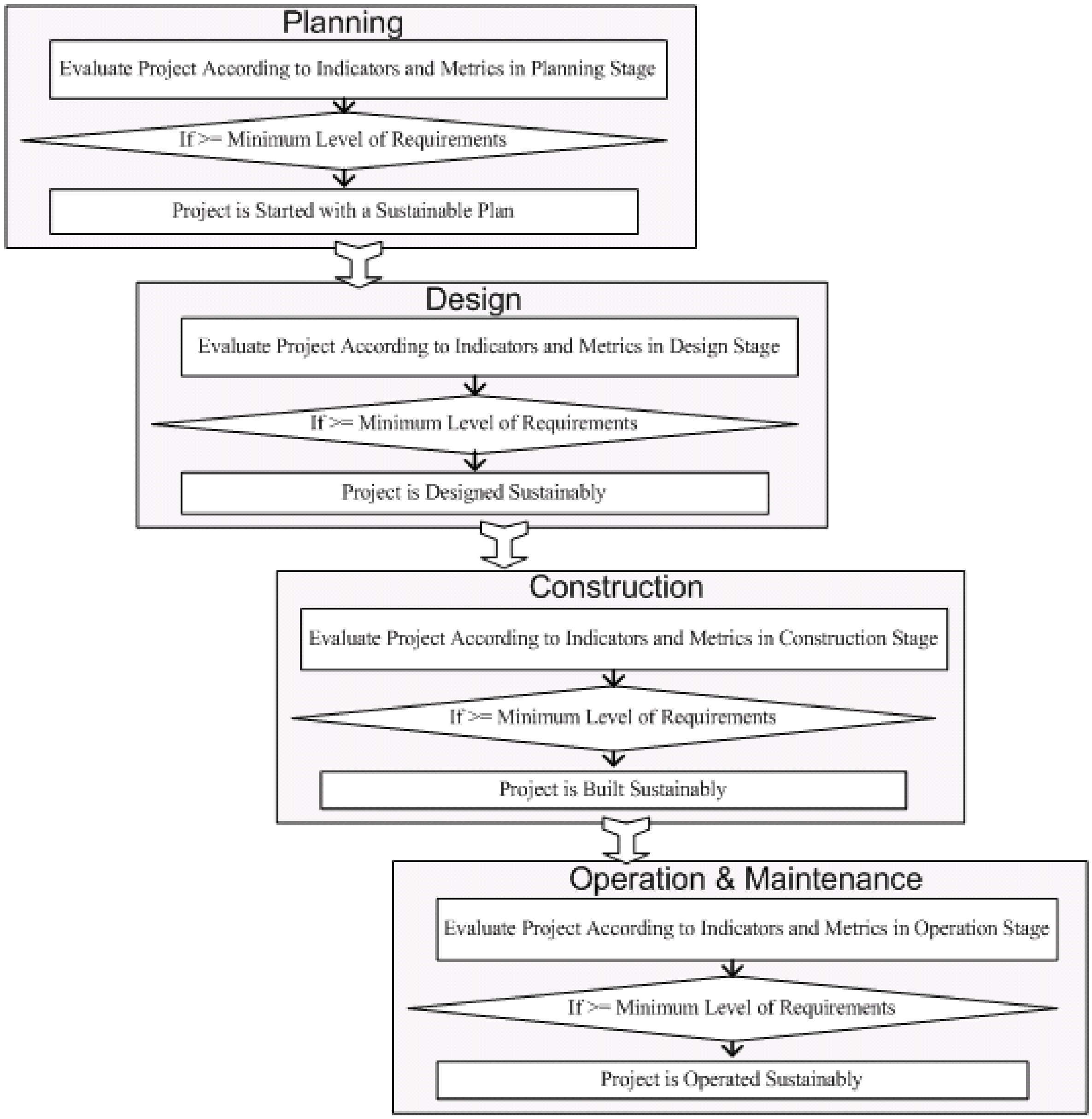

Figure 2. Summary of sustainability evaluation process.

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