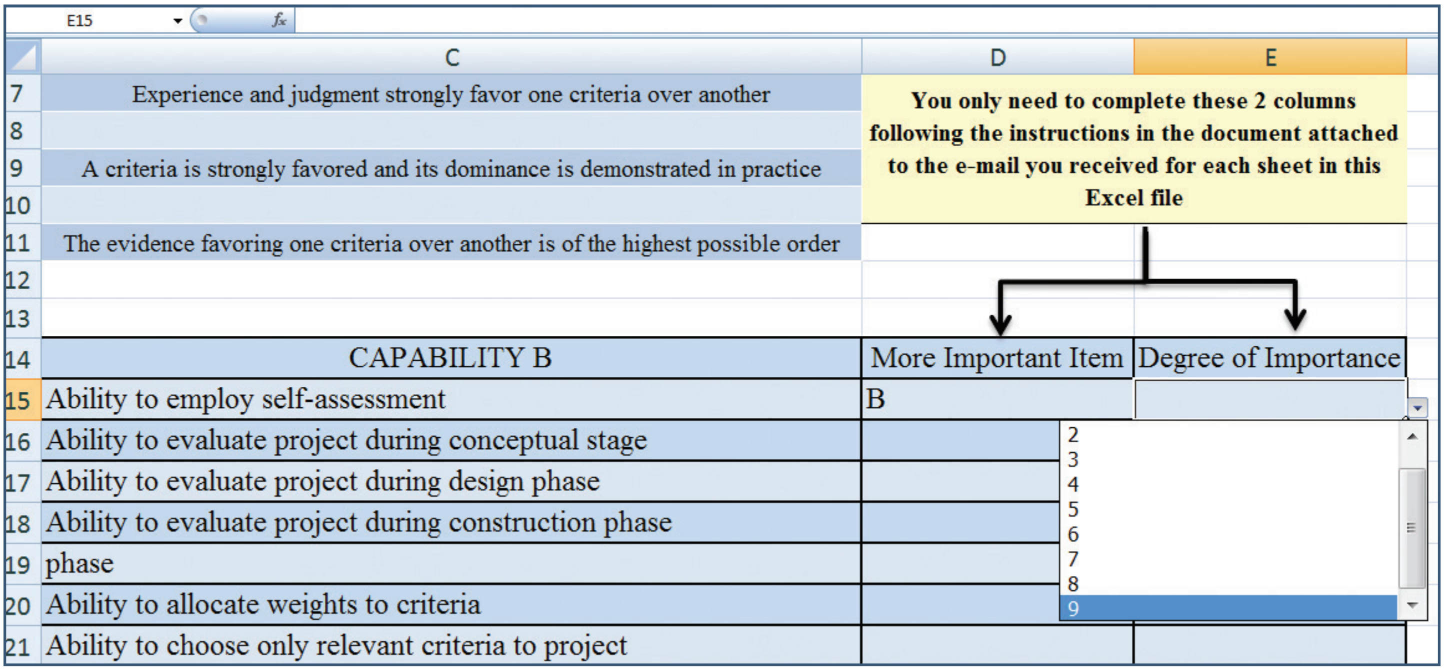
MOUNTAIN-PLAINS CONSORTIUM

MPC 14-268 | Sherona Simpson, Mehmet Ozbek, Caroline Clevenger, and Rebecca Atadero | MAY 2014

A Framework for Assessing Transportation Sustainability Rating Systems for Implementation in U.S. State Departments of Transportation



MPC MOUNTAIN-PLAINS CONSORTIUM

A University Transportation Center sponsored by the U.S. Department of Transportation serving the Mountain-Plains Region. Consortium members:

Colorado State University
North Dakota State University
South Dakota State University
University of Colorado Denver
University of Denver
University of Utah
Utah State University
University of Wyoming

A Framework for Assessing Transportation Sustainability Rating Systems for Implementation in U.S. State Departments of Transportation

Sherona P. Simpson
Graduate Research Assistant

Mehmet E. Ozbek, PhD
Assistant Professor

Caroline M. Clevenger, PhD
Assistant Professor

Rebecca A. Atadero, PhD
Assistant Professor

Department of Construction Management and
Department of Civil and Environmental Engineering
Colorado State University, Fort Collins

May 2014

Acknowledgements

The funding for this research was provided by a grant from the Mountain-Plains Consortium (MPC). This support is gratefully acknowledged.

Disclaimer

EXECUTIVE SUMMARY

Sustainability has increased in popularity as a key indicator for planning transportation projects. With that movement, evaluating the sustainability of transportation projects has become necessary for state departments of transportation (DOTs). Transportation Sustainability Rating Systems (TSRS) have been adopted for this purpose; however, different TSRSs employ different methods for determining or quantifying sustainability, and emphasize different sustainability factors. Given the number, variability, and specificity of TSRSs available, an evaluation and pairing exercise of available systems is needed to help state DOTs select a system by determining to what extent a given system suits each state DOT's preferences.

This thesis presents a four-step framework that identifies the most important capabilities in a TSRS as preferred by a state DOT and then facilitates weighting of those capabilities via a well-established methodology, the Analytical Hierarchy Process. The thesis also presents the implementation of this framework for Colorado DOT (CDOT), South Dakota DOT (SDDOT), Utah DOT (UDOT) and Wyoming DOT (WYDOT). The framework resulted in the identification of INVEST to be the most suitable TSRS for CDOT and WYDOT, GreenLITES as the most suitable TSRS for SDDOT, and the results for UDOT were inconclusive. The framework developed for assessing TSRSs was proven to be a viable means for determining rank and suitability of TSRS for DOTs.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Background

Over the past decade, green construction has been gaining popularity in the United States, particularly for buildings (Yudelson 2008), but also for transportation projects (Oswald 2010). This growth is attributable to various causes that can be traced as far back as the late 1700s (CEM 2008a). The Romantic Movement, which had at its core the abhorrence of the industrial revolution, revered nature and man's connection to the environment. In subsequent years, several monumental events have mapped the road toward the "green revolution." The Town and Country Planning Act (UK) came into force in 1947 followed by the Clean Air Act (US) of 1956. Greenpeace was formed in 1971; and two years later, in 1973, the first energy crisis occurred. This was due to the export embargo placed on oil over the Arab-Israeli war by the Organization of the Petroleum Exporting Countries (OPEC) (CEM 2008a).

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environmental Programme (UNEP) to investigate climate change every five to seven years and present its findings to the world's political leaders (CEM, 2008a). In 1992, the United Nations Conference on Environment and Development (UNCED) was convened in Brazil and as an outcome of the meeting the Kyoto Protocol (CEM, 2008a) which is an amendment to the U.N. Framework Convention on Climate Change of 1994 was adopted by 170 countries (Yudelson 2008). The United States signed the first Kyoto Protocol agreement but did not ratify it. Subsequently in 2012 the second phase of the Kyoto Protocol was ratified by majority of the countries who had previously adopted it; the United States, however, did not change its stance (Yudelson 2008). On May 10, 2013, the most damning report to date was published by the National Oceanic and Atmospheric Administration (NOAA); "Carbon Dioxide at NOAA's Mauna Loa Observatory reaches new milestone: Tops 400 ppm"(NOAA 2013). The article stated that according to measurements taken at Hawaii's Mauna Loa Observatory, the ratio of carbon dioxide in the earth's atmosphere had surpassed 400 parts per million (ppm). This is significant as climate scientists have predicted that an increase to above 400 ppm of carbon dioxide in the earth's atmosphere could mean an increase of 2° Celsius or 3.6° Fahrenheit in global temperatures (Banerjee 2013). In 1958, the recording of carbon dioxide in the atmosphere was 318 ppm (Banerjee 2013), meaning that over the last 55 years there has been an increase of 82 ppm of carbon dioxide in the atmosphere. According to the NOAA, the rate of increase has increased from 0.7 ppm per year in the late 1950s to 2.1 ppm per year in the last decade. Other models predict that carbon readings in 2030 will surpass 450 ppm, which would result in further global temperature increases (EPA 2013) if nothing is done to reduce carbon emissions.

In addition to these growing concerns, the United Nations (UN) Millennium Ecosystem Assessment has acknowledged that over the past 40 years, the speeds at which current generations are consuming natural resources are not conducive to their renewal to meet the needs of future generations (CEM 2008b). The construction industry accounts for 30% of the energy consumed in the United States, while contributing 6% of the greenhouse gas emissions in the United States (Gambaste 2005). Other estimates are not so conservative and indicate that the construction industry contributes between 27% (Faisal Awadallah 2012) - 30% of greenhouse gas emissions (Yudelson 2008). Based on these estimates, it is evident that the construction industry cannot go on with business as usual and will need to adopt sustainable development in a bid to reduce its environmental, social, and economic impact.

1.2 Benefits of Sustainable Development

Sustainable development is defined as the ability to meet the needs of the present generation without compromising the ability of future generations to meet their needs (CEM 2008a). Some researchers argue that construction (in particular, transportation systems) can never be sustainable based on its very nature (Oswald 2010). For example, the processes of producing construction materials, as well as the construction process, are energy intensive, utilizing considerable amounts of natural resources. Buildings account for 30% of raw material usage, 12% of fresh water usage, and 30% of greenhouse gas emissions; transportation of materials and other sundry tasks account for a further 18% of greenhouse gas emissions, 45% to 65% of waste to landfills, 71% of electricity consumption and 31% of mercury in solid waste (Yudelson 2008).

It has, however, been established that the construction industry, by reusing end-of-life resources and maintaining existing structures instead of building from the ground up, can reduce waste and resource consumption (Kibert 2002). It has also been noted that with the available stock of virgin material diminishing and the availability of by-products increasing, it makes economic and environmental sense to reuse by-products in the construction process (RMRC 2012b). By implementing such measures, construction projects have proven to be sustainable.

The US Green Building Council (USGBC) states that green buildings can offer a 30% energy saving, 30% to 50% water saving, 50% to 90% reduction in construction waste, and a 20% to 35% reduction in greenhouse gas emissions (McKinsey 2007; Yudelson 2008), which is equivalent to one-fourth of the reduction necessary to keep atmospheric carbon emissions below 450 ppm in 2030.

Another added benefit of green building is the improved air quality for occupants of indoor spaces. Occupants may spend up to 90% of their time indoors and, as such, any contaminants in buildings could affect the health of building users (CEM 2008a). Therefore, it is important to build green, limiting the amount of potentially harmful substances that may be incorporated into the end products of construction projects.

1.3 Sustainable Transportation Systems

Another area that greatly contributes to climate change is the transportation sector. The transportation of goods and people has increased in demand in recent years as it has become necessary for social and economic prosperity. However, the demand for transportation has resulted in high congestion, more frequent accidents, higher transportation costs, excessive energy usage, and pollution (Colin Booth 2012). Road transport accounts for 81% of the transportation sectors' total greenhouse gas emissions, and the transport sector itself contributes 31% of the U.S. total greenhouse gas emissions. Considering the United States is the largest producer of greenhouse gases in the world and the fact that the transportation sector contributes significantly to this number, it is safe to conclude that sustainable transportation would go a long way in mitigating climate change (Colin Booth 2012).

A sustainable transportation system is defined as one that will allow the basic access needs of individuals to be met safely while ensuring the health of the ecosystem and equity between and within generations, is affordable and offers a choice of transport modes, and is efficient and supports a vibrant economy while minimizing emissions and waste to a level that is easily absorbed by the environment. It also minimizes the use of nonrenewable resources, encourages recycling in its construction, and minimizes noise pollution and the use of land (Black 2010; Colin Booth 2012).

The approach to developing a sustainable transportation system should include policy making, project implementation, and appraisal (Colin Booth 2012). A clearly defined plan has to be made and implemented, and the progress or performance of the system determined through an appraisal process. Traditionally, transportation systems were planned around indicators commonly referred to as indicator-based planning. Most of the transportation system planning of the 20th century was based on the issue of congestion (Black 2010). The result was networks designed to relieve the problem of congestion. In recent times, however, sustainability has been deemed to be a more significant issue than congestion and has become the indicator around which transportation systems are planned (Black 2010). In planning for sustainable transportation projects, it is imperative that sustainability planning be included in every stage of the process; this means that sustainability has to be considered during the planning, design, construction, and implementation, as well as operations and maintenance phases of a project (Zietsman 2011).

Several agencies are responsible for the delivery and maintenance of the U.S. transportation infrastructure. At the national level are: the Federal Highway Administration, Congress and the executive branch, the U.S. Department of Transportation (USDOT), and the Federal Transit Administration; at the state level: state DOTs and independent state toll authorities; and at the regional level: metropolitan planning organizations (MPOs), public transit agencies, local level toll authorities, and local public works and transportation departments (Zietsman 2011). Because there are so many agencies involved in the process, it is imperative that sustainability performance be tracked to provide feedback on the performance of projects for all concerned. The focus of this thesis is on state DOTs in particular and how best they can select a transportation sustainability rating system (TSRS) to assess the sustainability of highway projects undertaken by each state DOT.

1.4 The Development of Sustainability Rating Systems

As the construction industry has become more interested in sustainable development (Reeder 2010) the need to evaluate and measure the performance of projects with respect to sustainability has emerged. To meet this need, sustainability rating systems have been widely adopted and endorsed by the construction industry. The most prominent rating system used in the United States is the LEED sustainability rating system for building projects.

Sustainability rating systems allow design teams and constructors to set sustainable priorities while providing stakeholders a method of analyzing sustainability performance (Reeder 2010). Rating systems typically measure sustainability efforts using five categories: use of resources, energy, transport, water, and waste (CEM 2008b). The use of rating systems, however, has been slow in coming for infrastructure works and the transportation sector in particular (Krekeler, Nelson, Gritsavage, Kolb, & McVoy 2010).

Research has identified infrastructure projects as presenting significant opportunity to promote sustainability since they are large in scope, usually last a very long time, and contribute immensely to greenhouse gas emissions (Colin Booth 2012). Factors contributing to sustainability of infrastructure projects include cost, energy consumption, resource requirements, capacity, service quality, safety, impacts on society, and impacts on the environment (Lee 2011; Martland 2012).

Recently, several systems have been developed or are under development to measure the sustainability of transportation projects. These systems employ different methods of determining sustainability emphasizing different sustainable factors (Martland 2012). The 10 prominent systems that have been identified as applicable to transportation projects are BEST-in-Highways, Envision, Green Guide for Roads, Green Leadership in Transportation and Environmental Sustainability (GreenLITES), GreenPave, Greenroads, Illinois Livable and Sustainable Transportation (I-LAST), Infrastructure Voluntary Evaluation Sustainability Tool (Invest), Sustainability Assessment and Awards for Civil Engineering, Infrastructure, Landscaping and the Public Realm (CEEQUAL), and Sustainable Transportation Analysis rating System (STARS). These systems will be reviewed in depth in chapter two of this thesis to highlight their main characteristics and capabilities.

1.5 Problem Definition and the Research Need

With the current movement in sustainable development, there exists a need to evaluate the sustainability performance of projects undertaken by state DOTs in order to ensure that projects are actually being executed sustainably. There is a proliferation of transportation sustainability rating systems (TSRS) available for use throughout the United States; however, not all are suited to the different geographic regions of the United States based on climate, population density, resource availability, core business of state DOTs, and other issues. Furthermore, different TSRSs employ different methods for determining or quantifying sustainability, and emphasize different sustainability factors (Martland 2012). Given the number, variability, and specificity of TSRSs available, an evaluation and pairing exercise of available systems is needed to help state DOTs select a system by determining to what extent a given system suits state DOTs' preferences.

1.6 Research Objective and Contribution to the Body of Knowledge

The purpose of this study is to develop a specific framework to assess existing TSRSs for implementation in individual state DOTs across the United States. The framework supports identification of the most important capabilities in a TSRS as preferred by a state DOT and then facilitates weighting of those capabilities via a well-established methodology, the Analytical Hierarchy Process (AHP). Finally, results derived from the AHP evaluation can be used to determine which existing TSRS is best suited for adoption by the state DOT by determining the extent to which preferred capabilities are satisfied by each system. The contribution of this research is to provide a framework that can be implemented by any state DOT to assist in the selection of "best fit" TSRS.

1.7 Scope

This framework will be developed via a case study approach involving four Mountain-Plains Consortium (MPC) DOTs: Colorado (CDOT), South Dakota (SDDOT), Utah (UDOT), and Wyoming (WYDOT). At the study's conclusion, a recommendation will be made with regard to which existing TSRSs should be adopted by each of the above-named state DOTs. The methodology developed will be applicable to all state DOTs.

This research is based solely on existing TSRSs and will not include the development of a TSRS to suit each of the state DOTs included in this study. The existing TSRSs will not be amended by the researchers to include any capability desired by state DOTs but will be evaluated as they were developed to be utilized.

2. LITERATURE REVIEW

2.1 Background on Sustainability Rating Systems

As the construction industry has become more interested in sustainability as a planning indicator, the need to evaluate and measure the performance of projects has become apparent. To meet this need, sustainability rating systems have been widely adopted and endorsed by the vertical building industry. Rating systems allow design teams and constructors to set sustainable priorities while providing stakeholders a method to analyze performance (Reeder 2010).

Systems used to assess the "greenness" of vertical projects include Building Research Establishment's Environmental Assessment Method (BREEAM), Comprehensive Assessment Systems for Building Environmental Efficiency (CASBEE), Leadership in Energy and Environmental Design (LEED), Green Globes, GBTool, and the Living Building Challenges Net Zero Housing system (Kubba 2010; LBC 2013). The most widely used system is LEED, with over 40,000 domestically and internationally certified projects to date (Kubba 2010; USGBC 2013). By contrast, the development of rating systems has been relatively slow for infrastructure works and the transportation sector (Krekeler et al. 2010). Numerous systems have been developed recently to measure the sustainability of transportation projects. Many of these systems, however, were developed by or for specific agencies with a focus on specific, local environmental needs or context (Hirsch 2011). Currently, the prominent TSRSs include BEST-in-Highways, Envision, Green Guide for Roads, Green Leadership in Transportation and Environmental Sustainability (GreenLITES), GreenPave, Greenroads, Illinois Livable and Sustainable Transportation (I-LAST), Infrastructure Voluntary Evaluation Sustainability Tool (INVEST), Sustainability Assessment and Awards for Civil Engineering, Infrastructure, Landscaping and the Public Realm (CEEQUAL), and Sustainable Transportation Analysis Rating System (STARS).

2.2 Infrastructure Sustainability Rating Systems

2.2.1 BE^{2}ST-In-HighwaysTM

Developed by the Recycled Materials Resource Center (RMRC) based at the College of Engineering at the University of Wisconsin, Building Environmentally and Economically Sustainable Transportation-Infrastructure-Highways (BE^{2}ST-In-Highways) is a sustainability rating system whose main focus is to quantify the sustainability impact of using recycled materials in pavements (Edil, Lee, Benson, & Tinjum 2010). In scoring projects, the rating system utilizes Pavement Life-Cycle Assessment Tool for Environmental and Economic Effects PaLATE and the Life Cycle Cost Analysis (LCCA) RealCost software program (RMRC 2012a). In addition, it uses Mechanistic-Empirical Pavement Design Guide (MEPDG) to measure service life, Traffic Noise Model LookUp (TNM-Look) to assess traffic noise, and International Roughness Index (IRI) simulation to determine life of pavement (Edil 2012; Staiano 2008). Projects are analyzed based on a comparative analysis of a reference design (base design), which has no sustainable features but fulfills statutory and social requirements with designs (measured against base design) that satisfy statutory and social requirements as well as incorporating sustainable design features (Edil et al. 2010). By comparing the two designs, an accurate, transparent, and replicable measurement, which takes into consideration tradeoffs of the proposed project, can be taken to garner how well the new project performs (Edil 2012).

When implementing this rating system, project teams make the reference design with alternate design options (Edil et al. 2010). All options are screened in the Mandatory Screening Layer to ensure that they conform to statutory and project-specific criteria. Design options, which pass the Mandatory Screening Layer, are evaluated in the Judgment Layer. At this layer, projects are evaluated based on nine sub-criterion: Greenhouse Gas Emission, Energy Use, Waste Reduction (including ex situ materials), Waste Reduction (recycling in situ materials), Water Consumption, Hazardous Waste, Life Cycle Cost, Traffic Noise, and Social Cost of Carbon Saving (Edil 2012). The default weight for each criterion in BE^{2}ST-In-Highways is 1 point (Lee 2011) (see Figure 2.1). Stakeholders have the option of assigning weights to each sub-criterion based on their importance and potential to contribute to the project. Weights can be assigned through the use of the Analytical Hierarchy Process (AHP), although this is not mandatory (Lee 2011).

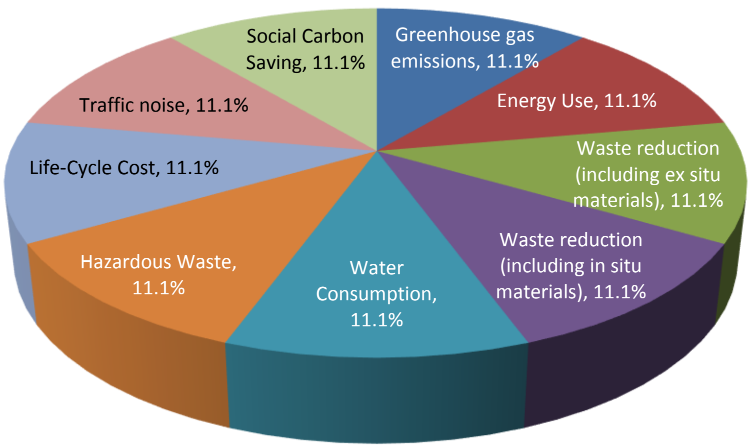


Figure 2.1 Percentage of total credit points allocated per category for BE^{2}ST-in-Highways Sustainability Rating System

Score percentages are presented in comparison to the reference design and prorated to an equivalent score in accordance with the weight for each sub-criterion. A percentage of the actual score over the maximum possible score is calculated according to the following levels: bronze (50%), silver (75%), and gold (90%). The system is applicable to highway projects during the design phase, is entirely web based, and offers third-party verification as well as voluntary participation alternatives (RMRC 2012a). BE^{2}ST-in-Highways rating system allocates an even 11% of its credits across all nine categories contained in the rating system (see Figure 2.1).

2.2.2 Envision™

Envision, developed by the Institute for Sustainable Infrastructure (ISI) in partnership with the Zofnass Program for Sustainable Infrastructure based at the Harvard Graduate School of Design (ISI 2012b), can be used to rate infrastructure works associated with water storage and treatment, energy generation, landscaping, transportation, and information systems (e.g., broadcast towers) (ISI 2012a). The ISI was formed from a group of three organizations: the American Public Works Association (APWA), the American Society of Civil Engineers (ASCE), and the American Council of Engineering Companies. All three organizations were on their way to developing a sustainability rating system individually, but acknowledged that there needs to be consensus on what sustainable infrastructure is and how it is rated. As such, they came together, partnering with Zofnass in 2010 to create Envision™ (ISI 2012b). The program encourages the use of life-cycle analysis in planning, designing, construction, and operation to improve infrastructure project sustainability performance (ISI 2012c). Design teams and owners of infrastructure are recognized for their efforts to incorporate sustainable practices throughout their project life cycle (ISI 2012a).

Under Envision, there are 60 credits (ISI 2012a) distributed under five categories: Quality of Life, Leadership, Resource Allocation, Natural World and Climate, and Risk (ISI 2012d, 2012f). Quality of Life embodies social aspects of sustainability such as the appropriateness of a project, its effect on the community holistically, and whether it improves the community's mobility or access to facilities. Leadership measures actual performance of stakeholders in areas such as collaboration, management, and planning (ISI 2012d). Resource Allocation applies to the sustainable use of materials, water, and energy in the project. Quantifying impact in the Natural World category relates to land issues. Siting of project, and understanding, preserving, and restoring natural ecosystems where necessary are the foundation of this category. Lastly, the Climate and Risk category, which addresses emissions and resilience, looks at quantifying the impact of the project as it relates to harmful emissions and the longevity of the infrastructure (ISI 2012d).

Envision is a two-stage assessment tool. Stage 1 is a Self-Assessment Checklist and Stage 2 entails Third Party Verification and Public Recognition. Both tools can be used concurrently or independently. Four Envision certifications exist: Bronze Award (20% of total points achievable under the rating system), Silver Award (30% of total points achievable under the rating system), Gold Award (40% of total points achievable under the rating system), and Platinum Award (50% of total points achievable under the rating system) (ISI 2012f). Stage 1 requires that an Envision credentialed employee be on the project team. An application fee of $1,000.00 must be paid before the checklist can be accessed for on-line generation of the checklist for the project (ISI 2012f). The project team consults the Self-Assessment Checklist in order to identify areas in which points may be gained. The credentialed employee will log onto the Envision website in order to register the project for rating. The five categories under which points may be received will appear on the screen and the credentialed employee will select the categories, answering questions about his or her project as they appear (ISI 2012f). Some questions are mandatory for any project to be certified by Envision; however, there are other optional questions. The credentialed employee will also have to indicate the type of evidence that will be provided to substantiate achievement for particular questions. The team will work through the spreadsheet for the duration of the project, and the spreadsheet can be updated as many times as necessary before it is reviewed by a third-party verifier. Once the project design and construction has been completed, the project is submitted for third-party verification along with the evidence to prove a project's worthiness for credits in each category (ISI 2012f).

The Envision Sustainability Rating System is heavily weighted in the Natural World and Resource Allocation categories containing 32% and 29%, respectively, of the credits achievable under the rating system. Quality of Life, Leadership, and Climate contain 18%, 13%, and 8%, respectively (see Figure 2.2)[1].

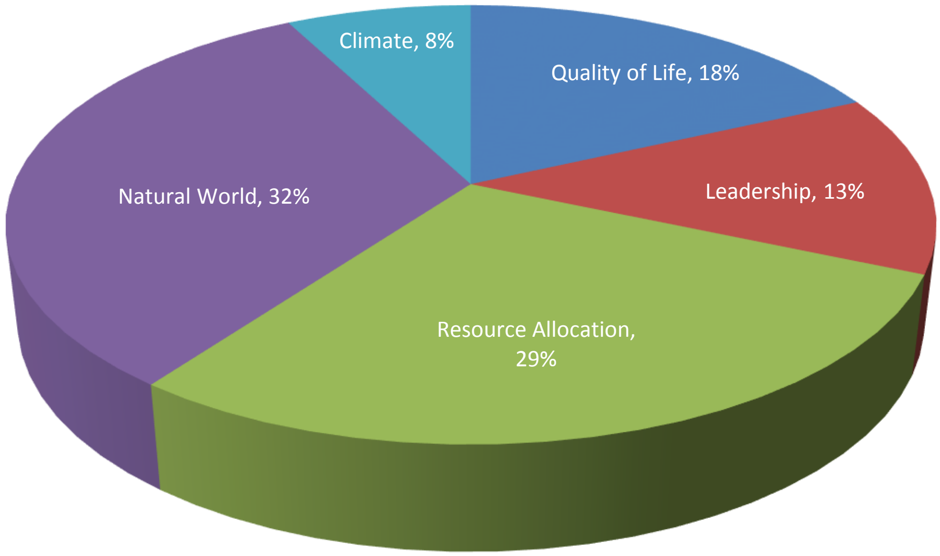


Figure 2.2 Percentage of total credit points allocated per category for Envision Sustainability Rating System

2.2.3 Green Guide for Roads

Green Guide for Roads was developed in 2008 by Stantec, primarily as a marketing tool to demonstrate Stantec's commitment to the sustainability initiative of the global community and to indicate that it is a market leader in sustainable development. Stantec also hoped that through this sustainability rating system it would be able to share industry best practices and that the system would eventually be adopted into the Leadership in Energy and Environmental Design (LEED) rating system. In fact, the rating system was modeled from the LEED rating system to facilitate ease of adoption (Clark et al. 2009).

In 2009 a new Green Guide for Roads was drafted collaboratively by Stantec and a group of students in partial fulfillment of their BS degree at Worcester Polytechnic Institute. The previous version of the Green Guide for Roads evaluated projects under seven categories:

1. Mobility for All
2. Transportation Efficiency
3. Safety
4. Energy and Atmosphere
5. Materials and Resources
6. Community Impact
7. Innovation in Design Process

The revised Green Guide for Roads was generated after a review of other established sustainability rating systems, such as Greenroads and GreenLITES, to include items that were previously missing from the rating system. Green Guide for Roads is still broken down into seven categories but Safety is no longer a major category. Instead, environmental impact has been included and Transportation Efficiency has been renamed Transportation Planning. In addition to the name changes of the categories, other major changes were seen in the distribution of weights across the categories (Clark et al. 2009). In the previous version, 82 points were the maximum achievable, as opposed to 100 in the revised version. The credit weightings were also redistributed across the categories with major changes being noted in the Energy and Atmosphere and Materials and Resources category. There was more than a 200% increase in the credits allocated for the Energy and Atmosphere category, moving from 4 to 15 total points, or a 5% allocation to 15% (see Figure 2.3 below). There was also an increase from 6 credit points to 18 points being allocated for the Materials and Resource category. The table below shows the percentage point distribution across all categories for the original Green Guide for Roads manual (Clark et al. 2009).

Each category is broken down into prerequisites and voluntary credits. All prerequisites must be fulfilled before certification can be granted for a project seeking Green Guide for Roads certification. Criteria that offer credit points are optional and are included in a project at the discretion of the project team. Credits comprise an intent section, which briefly explains what the credit is trying to accomplish; a requirement section, which highlights the necessary measures or actions that must be done toward achieving a score; and a submittals section, which states the documents or the evidence that needs to be presented as proof the credit was achieved and points should be awarded (Clark et al. 2009).

The Green Guide for Roads awards scheme follows the format of LEED awards with a score of:

1. 40% or more of the core credits earning a Green Guide for Roads Certified award
2. 50% or more of the core credits earning a Green Guide for Roads Silver award
3. 60% or more of the core credits earning a Green Guide for Roads Gold award
4. 80% or more of the core credits earning a Green Guide for Roads Platinum award

The manual does not address the cost of certification, whether the assessment is meant to be conducted via self-evaluation, or whether third-party verification is to be used in validating scores. The rating system appears to be under development and further versions may address some of the shortfalls of the system (Clark et al. 2009). However, based on the fact that the TSRS was modeled to be integrated into LEED, the researchers assumed for the purposes of this study that the TSRS employs a third-party assessment process in keeping with LEED. The Green Guide for Roads sustainability rating system has relatively distributed its credits equitably across seven categories (see Figure 2.3). Mobility for All has the highest percentage of credits allocated, standing at 22%. Closely following are Materials and Resources, Energy and Atmosphere, and Transportation Planning with 18%, 15%, and 15%, respectively. Environmental Impact has a credit allocation of 13%, Community Impacts has 11%, and Innovation and Design has 6% (see Figure 2.3).

2.2.4 GreenLITES - Green Leadership in Transportation and Environmental Sustainability

Developed by the New York State Department of Transportation (NYSDOT), GreenLITES assesses project performance in several key areas while encouraging sustainability best practices (NYSDOT 2009). It encourages development with no negative environmental effects and very little disruption to society (NYSDOT 2010). Secondly, it encourages appropriateness of design, the provision of safe multimodal means of transportation, and the construction of low-cost or no-cost maintenance highways (Krekeler et al. 2010). Thirdly, it provides a medium for the dissemination of information as well as funding for research. The system is grounded in the triple bottom line of sustainability, and includes five categories under which points can be earned: Sustainable Sites, Water Quality, Material and Resources, Energy and Atmosphere, and Innovation. A total of 175 credits exists across five categories (NYSDOT 2008). The system offers transparency in NYSDOT’s operation to state government and other stakeholders, and provides the following award levels: GreenLITES Certified, GreenLITES Silver, GreenLITES Gold, and GreenLITES Evergreen awards. GreenLITES is a mandatory tool for NYSDOT on all highway projects (Krekeler et al. 2010).

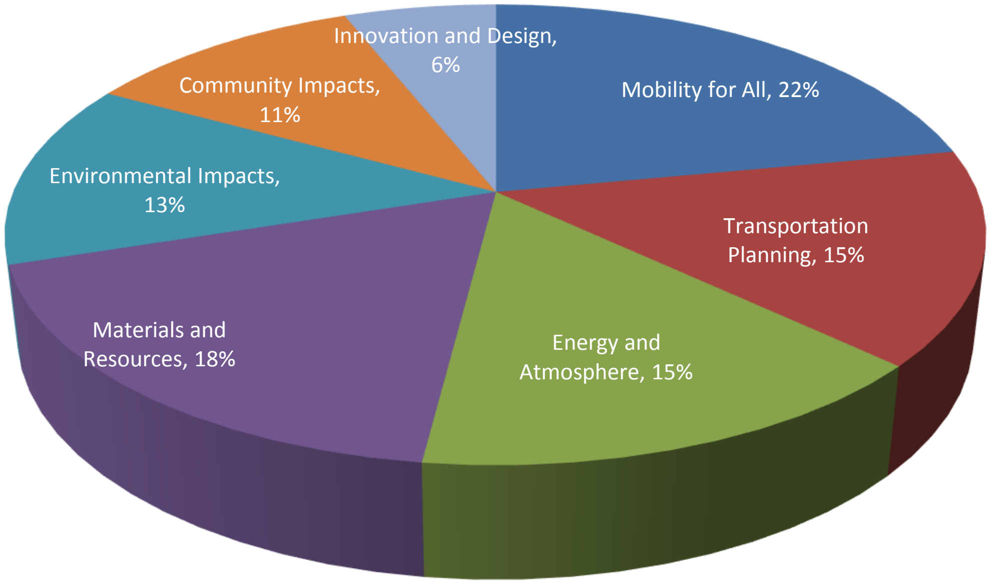


Figure 2.3 Percentage of total credit points allocated per category for the Revised Green Guide for Roads Sustainability Rating System

Projects are assessed under GreenLITES Design during the conceptual and design phase (NYSDOT 2008). Stakeholders and the project team review the GreenLITES scorecard to determine which items to include in the design. The project team next undertakes design while maintaining dialogue with the stakeholders to ensure proposed designs fulfill societal, transportation, and sustainability goals. Once plans, estimates, and specifications are complete, the project is reviewed and given one of four awards as appropriate (NYSDOT 2008).

Additional GreenLITES systems that investigate other phases of the projects have also been developed. GreenLITES Operation was developed to solve issues of greenhouse gases and water quality (NYSDOT 2012). It allows sustainable practices to be implemented in everyday maintenance activities for infrastructure works. Divisions such as Transportation Maintenance, Traffic, Safety and Mobility, etc. use this rating system as a tool for measuring performance, and to help identify high points and areas of improvement (Krekeler et al. 2010). This system serves as a distribution channel for innovative ideas on best practices. GreenLITES Planning was developed for new works. The system allows for planning of new works in a way that involves all stakeholders, and ensures that projects meet the needs of the community (NYSDOT 2012). The planning tool may be used at the local or capital expenditure and solicitation level for long-term projects. Finally, NYSDOT is developing a Pilot GreenLITES Regional Assessment Tool to rate projects using the triple bottom line (NYSDOT 2010). The GreenLITES sustainability rating system is more heavily weighted in the Energy and Atmosphere, 33%; Sustainable Sites, 27%; and Materials and Resources, 23%, categories. The Water Quality and Innovation/Unlisted categories have 9% and 8%, respectively, of the credits available under the system (see Figure 2.4)[2].

[2] First Copyright is held by the Associated Schools of Construction (ASC). Original publication in the International Proceedings of the 49th Annual Conference of the ASC (April 2013). Reprint permission granted on October 30, 2013.

2.2.5 GreenPave

Developed by the Ontario Ministry of Transportation, GreenPave is a sustainability rating system that was modeled after the University of Washington's Greenroads and NYSDOT's GreenLITES sustainability rating systems (Lane 2003, 2010). The primary difference, however, is that GreenPave was developed specifically for Ontario and is only applicable to the pavement component of work and not the whole road (Lane 2003). In developing the system, reference was drawn from the LEED rating system and Alberta's Green Guides for Roads conceptual rating system (Lane 2003, 2010).

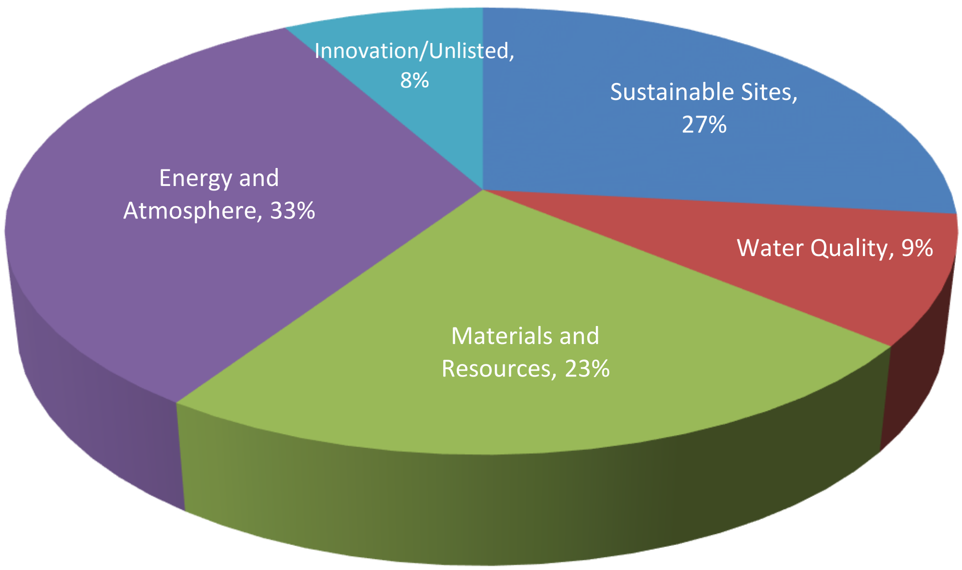


Figure 2.4 Percentage of total credit points allocated per category for GreenLITES Sustainability Rating System

GreenPave, was developed to be applicable to the conditions in Ontario, and was meant to be easily understood and to provide a means of quantifying the "greenness" of a roadway. Similar to other rating systems, it is also meant to share best practices across projects and to encourage sustainability in projects (Lane 2003, 2010).

GreenPave takes the form of a computerized checklist, which is broken down into four main categories: Pavement Design Technologies (PT), Material and Resources (MR), Energy and Atmosphere (EA), and Innovations and Design Process. A total of 36 points can be gained across these four categories, which are further broken down into four credits each for PT, MR, and EA and two credits for Innovation and Design Process (Lane 2003, 2010).

Under pavement technology, a project is assessed on the following criteria:

1) Long-life pavement (4 points)
2) Permeable pavement (1 point)
3) Noise mitigation (2 points)
4) Cool pavement (2 points)

Materials and Resources addresses project issues with regard to the following criteria:

1) Recycled content (6 points)
2) Reuse of pavement (3 points)
3) Local materials (3 points)
4) Construction quality (2 points)

Energy and Atmosphere also addresses sustainability concerns through the following criteria:

1) Reduce energy consumption (3 points)
2) GHG emissions reduction (2 points)
3) Pavement smoothness (1 point)
4) Pollution reduction (3 points)

Innovation in Design awards two points for Innovation in Design and two points for exemplary process. Important to note is that three criteria are applicable only to constructed pavements: these are Pavement Smoothness, Pollution Reduction, and Construction Quality (Lane 2003, 2010).

The GreenPave sustainability rating system is applicable to the design and construction of new pavements (both flexible and rigid), and the reconstruction, rehabilitation, and preservation management of pavements (flexible and rigid) (Lane 2010).

The rating system acts as a guide to the development process and is presented in a user-friendly manner. The criteria are broken down into three sections. First, an "objective" of the criteria is given. An example of an objective is "to encourage reusing existing pavement materials in the new pavement structure." This is found under the Reuse of Pavement criteria. Second, it explains the applicability of the criteria in terms of the type of project work to which the criteria is applicable. For the criteria in the example above, the "applicability" example would be "rehabilitation projects that leave a portion of the pavement structure undisturbed and new construction projects that make use of cut material as fill material within the right of way." Finally, it states what has to be achieved in order to gain points for the particular criteria. This section specifies the exact results that would merit a point being awarded to the project (Lane 2003).

A project rated using the GreenPave sustainability rating system could gain one of four awards;

1. GreenPave certified Bronze (7-10 points)
2. GreenPave certified Silver (11-14 points)
3. GreenPave certified Gold (15-19 points)
4. GreenPave certified Trillium (20 + points)

The rating system is still under review, and as of December 2012, the most recent documentation that could be found on this system dated back to 2010. A true reflection of its usability and method of assessment was undetermined at the time of this review.

The credit distribution in the GreenPave sustainability rating system is heavily weighted toward the Materials and Resources category, which contains 39% of the credits achievable under the rating system. Pavement Technologies and Energy and Atmosphere contain 25% each, and Innovation and design contains 11% (see Figure 2.5).

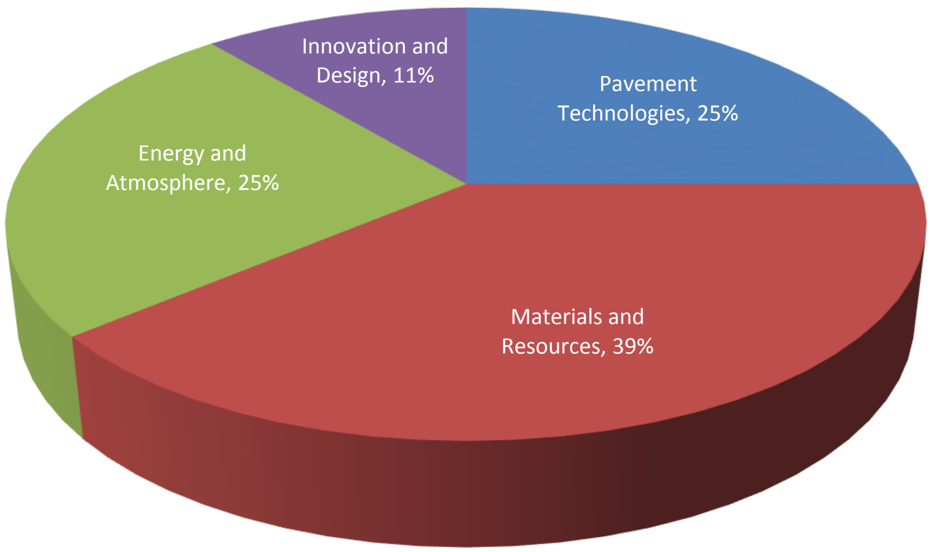


Figure 2.5 Percentage of total credit points allocated per category for the GreenPave Sustainability Rating System

2.2.6 Greenroads™

The Greenroads sustainability rating system was developed by CH2M HILL and the University of Washington in 2009 (Greenroads 2012a). Greenroads stimulates sustainability in highway construction by awarding credits to projects that have successfully incorporated sustainable best practices. It provides a holistic means of considering and evaluating roadway sustainability (for new construction, reconstruction, and rehabilitation) through a quantitative method that informs decision making by project stakeholders (Greenroads 2012a). It also addresses operations and maintenance through an Operations and Maintenance plan, which is evaluated when the project is scored. The system does not apply to day-to-day maintenance of highways (Greenroads 2011).

The criteria under the Greenroads sustainable rating system are broken down into two categories: required and voluntary (Greenroads 2012a). Each project must meet 11 project requirements: Environmental Review Process, Lifecycle Cost Analysis, Lifecycle Inventory, Quality Control Plan, Noise Mitigation Plan, Waste Management Plan, Pollution Prevention Plan, Low Impact Development, Pavement Management System, Site Maintenance Plan, and Educational Outreach (Greenroads 2012c). Most of the criteria under project requirements are derivatives of codes or laws, and as such do not present an additional burden to the project team. In addition, there are six voluntary credit categories. They include: Environment and Water (8 criteria), Access and Equity (9 criteria), Construction Activities (8 criteria), Materials and Resources (6 criteria), Pavement Technologies (6 criteria), and Custom Credits (2 criteria) (Greenroads 2012b). All criteria are meant to inspire action toward a higher standard of construction sustainability to the extent achievable using current technology and tools. After project requirements are fulfilled, voluntary credits are selected, documented, and submitted to Greenroads for a third-party review (Greenroads 2012b). Each credit is weighed by Greenroads on a scale of 1-5 depending on its potential to influence the sustainability of projects. (Greenroads 2011).

Four award levels exist for the Greenroads system: Bronze (32-42 voluntary credit points), Silver (43-53 voluntary credit points), Gold (54-63 voluntary credit points), and Evergreen (64-plus voluntary credit points) (Greenroads 2011). The tool may be used on highways and conceptually on bridges, tunnels, and other structures associated with similar works. It is web-based and can be used throughout the life cycle of the project (Greenroads 2012a). Greenroads is unique in that the majority of its credits are allocated toward social concerns, with Access and Equity containing 25% of the achievable credits. Credits are equitably distributed across Materials and Resources, Environment and Water, and Pavement Technologies at 19%, 18%, and 17%, respectively. Custom Credits account for the remaining 8% of the credits achievable under this rating system. Important to note is that although no credits are achievable under Project Requirements, all projects have to fulfill the criteria contained within this category in order to achieve a Greenroads Award (see Figure 2.6).[3]

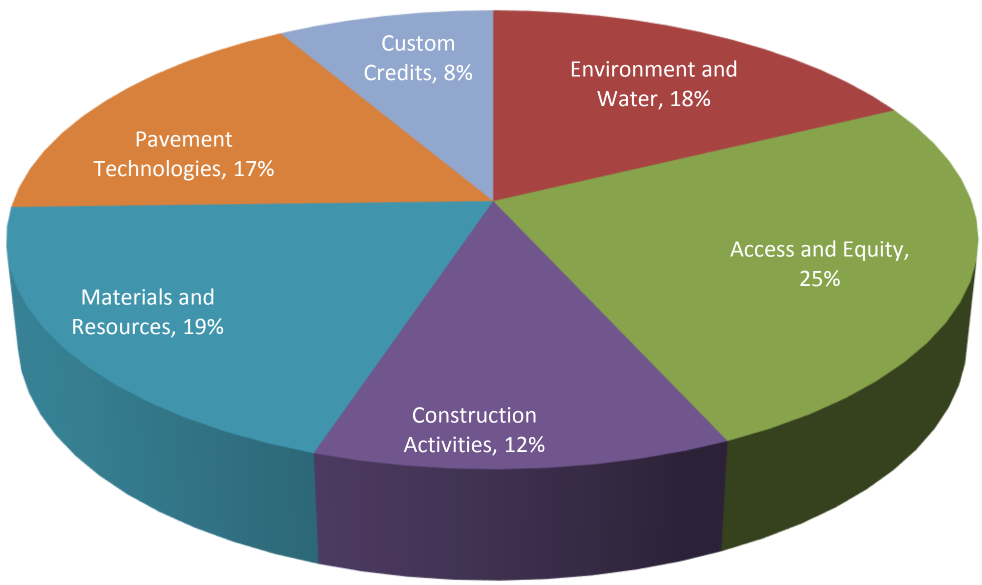


Figure 2.6 Percentage of total credit points allocated per category for Greenroads Sustainability Rating System

2.2.7 I-LAST – Illinois Livable and Sustainable Transportation

The aim of I-LAST is to encourage sustainable practices in highway construction and to evaluate sustainability using simple methods. The system is voluntary, paper-based, applicable to highways, and employs self-assessment (IDOT & IJSG 2010). It was developed out of a collaborative effort between the Illinois Department of Transportation (IDOT), the American Consulting Engineers Council (ACEC), and the Illinois Road and Transportation Builders Association (IRTBA). Participation is voluntary and the system consists of a guidebook that allows the project team to review criteria, select which ones are

---

[3] First Copyright is held by the Associated Schools of Construction (ASC). Original publication in the International Proceedings of the 49th Annual Conference of the ASC (April 2013). Reprint permission granted on October 30, 2013.

applicable, and score them (Knuth & Fortmann 2011). I-LAST can be used throughout the conceptual phase (Phase I, which is the Planning phase), design (Phase II, which is the Final Design phase), and is also applicable to future construction phases (Phase III).

Eight major categories exist under this rating system: Planning, Design, Environmental, Water Quality, Transportation, Lighting, Materials, and Innovation. In combination, all categories have 153 sustainable criteria, which fall into 17 broader criteria headings (IDOT & IJSG 2010). Certification documentation is not required. Rather, the system employs self-scoring using a hierarchy methodology where 1-3 points are awarded per criterion. There are no calculations, just a yes/no award by the self-evaluator. A maximum of 233 points can be gained across the 153 sustainable best practices. The percentage of points earned is calculated as the ratio of points awarded divided by points achievable (IDOT & IJSG 2010). Development of an awards system is pending feedback from the users of the rating system.

The I-LAST sustainability rating system has eight categories across which credit points can be gained. Environmental has the highest percentage of credits allocated standing at 22%. Closely following are Transportation, Materials, and Water Quality with 18%, 18%, and 15%, respectively. Design has a credit allocation of 11%, Planning 8%, Lighting 7%, and Innovation and Design 1% (see Figure 2.7).

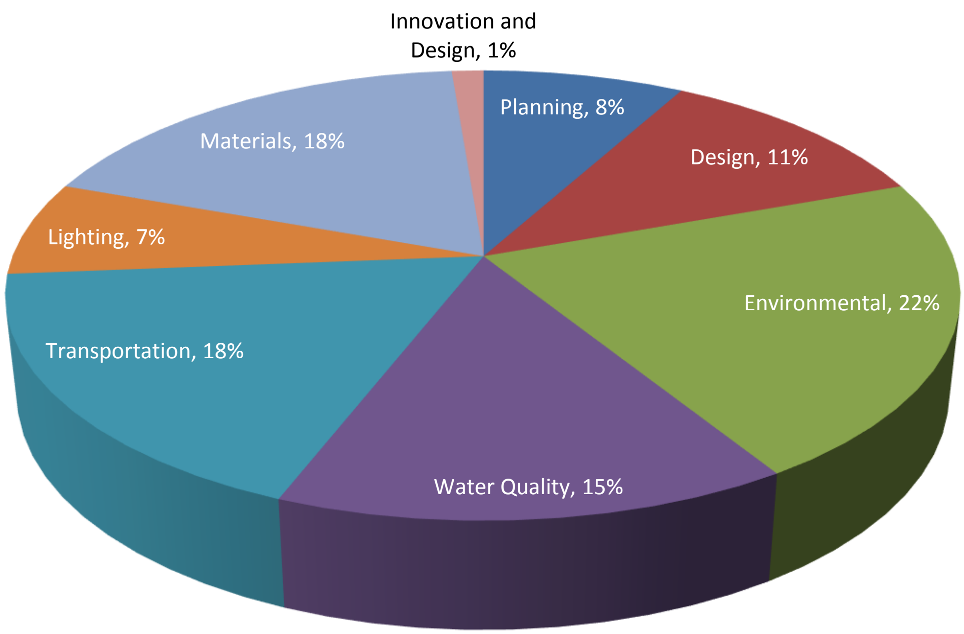


Figure 2.7 Percentage of total credit points allocated per category for I-LAST Sustainability Rating System

2.2.8 INVEST-Infrastructure Voluntary Evaluation Sustainability Tool

INVEST was developed by the Federal Highway Administration (FHWA) with the help of CH2M Hill and launched in 2012 (FHWA 2012a). It was designed to be user-friendly and uses a free, web-based interface. It is broken down according to the following project phases: systems planning, project development, and operations and maintenance (FHWA 2012d). The system provides scorecards for

Paving, Basic Rural, Basic Urban, Extended Rural, Extended Urban, and Custom (FHWA 2012c). The custom scorecard applies to situations where a project does not fit into the pre-defined scorecards. Stakeholders are allowed to design a project-specific scorecard.

Criteria under the INVEST rating system are defined according to sustainable best practices. They fall under one of three headings: project delivery and system planning and processes (17 criteria), project development (20 or 29 criteria depending on whether basic or extended scorecard is used), and operations and maintenance (14 criteria) (FHWA 2012d). The criteria in project development are weighted based on their relative sustainable impact. All criteria in Operations and Maintenance and Systems Planning are equally weighted at 15 points each, except for the bonus criteria contained in Systems Planning, which nets a maximum of 10 points (FHWA 2012b). The system generates questions that require answers from the project administrator when the project evaluation tool is being used. Based on the answers given, the project is awarded a score for each criterion and the overall score is tallied in order to rate the project. The project is awarded a Bronze, Silver, Gold, or Platinum based on its performance. Due to the lack of a third-party evaluator, this award merely serves as unofficial recognition by the FHWA (FHWA 2012e).

The credit distribution in the INVEST sustainability rating system is heavily weighted toward the planning phase of projects, with Systems Planning containing 43% of the credits achievable under the rating system, Operations and Maintenance containing 36%, and Project Development containing 22% (see Figure 2.8)[4].

2.2.9 Sustainability Assessment and Awards for Civil Engineering, Infrastructure, Landscaping and the Public Realm (CEEQUAL)

The Sustainability Assessment and Awards for Civil Engineering, Infrastructure, Landscaping and the Public Realm (CEEQUAL) TSRS, formerly the Civil Engineering Environmental Quality Assessment and Awards Scheme, was developed out of a need to encourage sustainability in civil engineering projects and to award project teams that successfully surpass the legal minima in projects as they relate to environmental issues (CEEQUAL 2011b). The rating system was developed by the Institution of Civil Engineers (ICE) and is supported by the institution's Research and Development Enabling Fund and the United Kingdom (UK) government. CEEQUAL is now operated by CEEQUAL Ltd., which is owned and operated by 14 organizations that were instrumental in the development of the scheme. Among the 14 organizations are the Association for Consulting and Engineering (ACE), the Chartered Institution of Water and Environmental Management (CIWEN), and the Civil Engineering Contractor's Association (CICA) (CEEQUAL 2012b). As the name suggests, CEEQUAL is applicable to a wide range of project types; for example, marine and offshore projects, electrical and mechanical projects, roadwork, landscaping, water treatment infrastructure, infrastructure associated with building developments, etc. (CEEQUAL 2011b).

[4] First Copyright is held by the Associated Schools of Construction (ASC). Original publication in the International Proceedings of the 49th Annual Conference of the ASC (April 2013). Reprint permission granted on October 30, 2013.

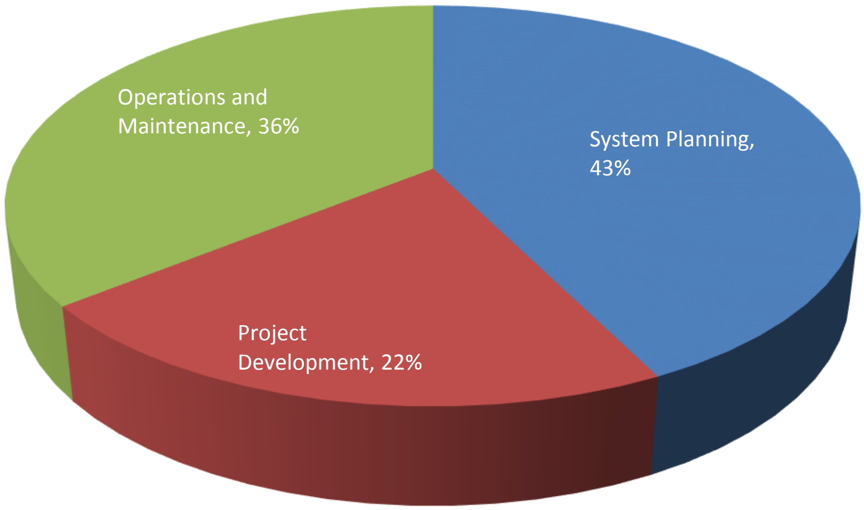


Figure 2.8 Chart showing the percentage of total credit points allocated per category for Invest Sustainability Rating System

The rating system is available in two forms: CEEQUAL for Projects and CEEQUAL for Terms Contracts. CEEQUAL, in its initial stages, was developed for the UK but has since seen revisions that make it applicable internationally (CEEQUAL 2011b). As such, CEEQUAL for Projects has been expanded to include two separate forms: CEEQUAL for UK and Ireland Projects and CEEQUAL for International Projects. Both forms of CEEQUAL for Projects, however, contain the same question sets in nine categories:

1. Project Strategy
2. Project Management
3. People and Communities
4. Land use (above and below water) and Landscape
5. The Historic Environment
6. Ecology and Biodiversity
7. Water Environment (fresh and marine)
8. Physical Resources Use and Management
9. Transport

All nine categories offer a commentary on the main issues in which the questions contained therein seek to address. The questions themselves are also broken down into different sections. First, an explanation of the question is given followed by guidance on "scoping out," i.e., whether or not the question should be included in the assessment. It next offers the range of possible scores allocated for the question, followed by guidance on how the assessment of the issue should be conducted. Last, it gives examples of evidence that may be presented to substantiate the scores being sought in relation to the question (CEEQUAL 2012b, 2012c).

Project Strategy is new to Version 5 and is an optional category aimed at evaluating a project's contribution to the wider sustainability goals of the community. It also evaluates the project's contribution to sustainability best practices in the civil engineering profession to sustainable development in general (CEEQUAL 2011b, 2012b, 2012c). The main goal of this category is to ensure that the client and the project team not only look at their interests, but also those of the civil engineering profession as well as those of the community where the project is being constructed (or the communities the project serves).

The Project Management category looks at how environmental and sustainability issues are addressed in the management of the project. This category also aids in ascertaining the impact of the social issues that arise as a result of the project (CEEQUAL 2012b, 2012c). It accomplishes this by assessing what is being built and how it is being built; and, as such, it is relatively easy to determine the environmental and social issues that could arise from construction methodologies.

The People and Communities category evaluates a project's positive and negative effects on the people who are affected in a community. It looks at nuisances generated as a result of the work, employment, legal requirements, and other related issues, and how they are addressed (CEEQUAL 2012b, 2012c). This category is geared toward getting a project team to not only look at serving its own interest, but to make project decisions that also consider the interests of the people and the community.

The Land Use (above and below water) and Landscape categories look at assessing the sustainable use of land, the improvement of land in cases of contamination, remediation work, the conventional use of land, and the like (CEEQUAL 2012b, 2012c). This category ensures that the use of land in a project will not cause any deterioration of the land and in some cases will improve the state of the land before the commencement of the project.

The Historic Environment category looks at the preservation of historical artifacts and features that may be found during the project. Examples of such finds include shipwrecks, old Roman jetties, ancient civilization or evidence of their existence, and the like (CEEQUAL 2012b, 2012c). Essentially, anything that is of great historical value should be preserved and the efforts exerted by a project team to do so are assessed and points awarded.

The Ecology and Biodiversity category looks at assessing the preservation of ecosystems and the encouragement of biodiversity in areas where a project could potentially cause harm to the environment or natural habitats of local species (CEEQUAL 2012b, 2012c). Essentially, this category encourages project teams to think of the effects of a project on local species or on the potential of a project to support different life forms.

The Water Environment category facilitates the evaluation of a project's impact on water sources and environments and, in some cases, will address water enhancement measures.

The Physical Resources Use and Management category addresses the effects of the materials used in civil engineering works. Issues such as the use of recycled materials, selection of timber, de-construction, minimizing water usage, and waste management are addressed in this category.

The Transport category evaluates a project's proximity to transport infrastructure (CEEQUAL 2012b, 2012c). It essentially looks at the ease with which users of the final product of the project or the workers on the project are able to access transportation.

New to Version 5 is whether the project forms a part of an existing transportation network, a destination that causes additional burdens on other networks, whether it provides and/or encourages multimodal access, among other issues (CEEQUAL 2011b, 2012b).

The major differences in the CEEQUAL for UK and Ireland Projects and the CEEQUAL for International Projects manuals are in the level of guidance that is provided and in the weighting factor for each question (CEEQUAL 2011a). CEEQUAL acknowledges that sustainability criteria contained within the manual will have differences in significance in different geographic regions. As such, CEEQUAL has included the weighting as used in the UK and Ireland as guidance. However, users in different geographic regions are encouraged to embark on a weighting exercise aimed at categorizing the criteria into appropriate weightings relative to their location (CEEQUAL 2011a).

CEEQUAL for Projects recognizes projects and project teams that have successfully incorporated sustainability principles into projects. There are six awards which can be sought under CEEQUAL for Projects: Whole Project Award (WPA), Whole Project Award with an Interim Client and Design Award, Client and Design Award, Design Only Award, Design and Build Award, and Construction Only Award (CEEQUAL 2011b, 2012b). The WPA award can be jointly applied for by the client, the designer, and the principal contractor and is only granted after the completion of the project. The Whole Project Award with an Interim Client and Design Award again is sought by the client, the designer, and the principal contractor. The difference in this case is that the client and the designer can apply for The Interim Client and Design Award prior to a contractor being appointed and before the construction phases begin. However, the granting of a WPA award afterward would supersede the interim award that was previously granted for the project. The Design Only Award can be sought in the event that the designer and the client are not interested in seeking a CEEQUAL award. The Design and Build award is available for a constructor and his designer in the event that the client is not interested in seeking a CEEQUAL award. Finally, a Construction Only Award is available for the principal contractor in the event that the client and the designer are not interested in seeking a CEEQUAL award (CEEQUAL 2011b, 2012b).

CEEQUAL for Terms Contracts is used for the assessment of civil engineering and public realm contracts that are meant to be undertaken over a period of time (CEEQUAL 2012a). Terms contracts are integral to the British construction industry and are used whenever contractors are to execute work over a period of time. The contractor signs a contract to undertake all the work within agreed parameters for a period or term, usually 18 to 24 months or even several years. For these types of contracts, CEEQUAL for Terms Contracts is useful in determining the sustainability issues over a protracted period of time. Examples of works that may fall under a terms contract are highway maintenance, railway maintenance, railway track realignments, etc. (Seely 1997).

CEEQUAL is evidence-based and its assessment questions/checklist is fundamentally established on the triple bottom line of sustainability and social, environmental, and economic principles. The scheme has associated manuals to be read in conjunction with the CEEQUAL online assessment tool, which is to be maneuvered by a CEEQUAL assessor who has been trained in the CEEQUAL Version 5 Sustainability rating tool. Assessors who were trained in Version 4 can access an online training module at no cost or may attend a half-day training seminar, also at no cost, in order to upgrade to Version 5 qualification standards (CEEQUAL 2011b, 2012b).

All project teams seeking CEEQUAL certification as of November 1, 2012, will have to analyze their project under the new Version 5 tool (CEEQUAL 2011b). In order to have a project certified by CEEQUAL, the project team will first have to decide on the award they will be applying for. After this is agreed, the team can register their project with CEEQUAL in order to have it assessed. The project team will hire a CEEQUAL assessor who will become a member of the project team and will offer guidance on sustainability best practices. The assessor will then navigate the online assessment tool to fill out the form with regard to the applicable questions to the project. Questions that do not apply to the project will be neglected (scoped out) and the project will be scored only on the basis of those questions for which it sought points. In choosing questions that should be included, the assessor must take care to include questions that apply to the project even if no measures are being put in place to address associated issues in the execution of the project. Once the assessor has completed the online form, i.e., inserting the scores, uploading the supporting evidence, and submitting the form for review, a verifier who is directly engaged by CEEQUAL will assess the form and the evidence in order to ratify the score of the assessor or assign a new score based on the evaluation of the evidence presented. Based on the score of the project, an award may be granted for the project. A score of more than 25%, more than 40%, more than 60%, and more than75% is equivalent to a pass, good, very good, or excellent, respectively (CEEQUAL 2012b).

The cost to have a CEEQUAL award for a project is determined by value of the project, the geographic location of the project, and the type of award being sought.

CEEQUAL does not evaluate whether a project should be constructed or not, but it assesses whether a project employs sustainability measures, whether it encourages a sustainable lifestyle by the community, as well as its contribution to overall sustainability goals. CEEQUAL encourages and promotes sustainability best practices and has been noted to be beneficial to project teams that seek CEEQUAL awards. Benefits reported by users include cost saving on projects, cohesiveness of project team, great PR opportunities in terms of reputation building, improved project performance in terms of energy savings, and the like (CEEQUAL 2011b, 2012b).

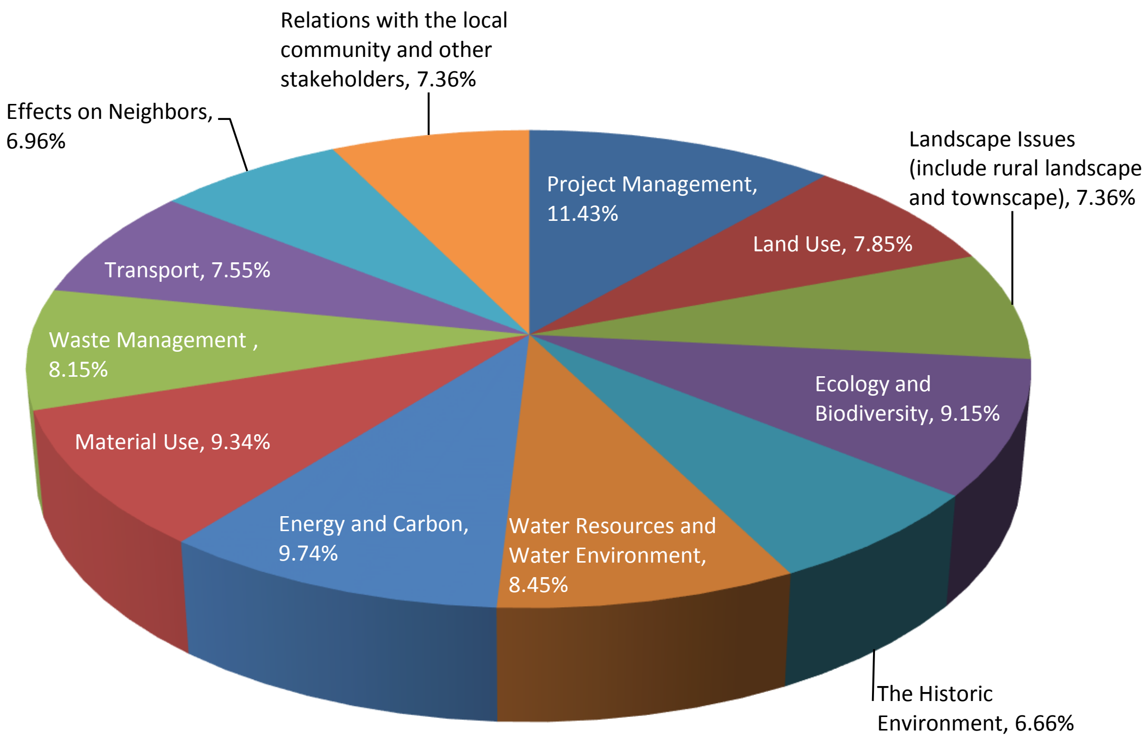


Figure 2.9 Percentage of total credit points allocated per category for CEEQUAL Sustainability Rating System

CEEQUAL boasts the most equitable distribution of credits across its categories. Project Management has the highest allocation of credits standing at 11%. Energy and Carbon comes a close second at 10%, followed by Ecology and Biodiversity and Material Use at 9% each. Land Use, Water Resources and Water Environment, Waste Management, and Transport have a credit allocation of 8% each. Lastly, Landscape Issues, The Historic Environment, Effects on Neighbors, and Relations with the Local Community and other Stakeholders have a credit allocation of 7% each (see Figure 2.9).

2.2.10 Sustainable Transportation Analysis Rating System (STARS)

The Sustainable Transportation Analysis Rating System (STARS) was developed by the North American Sustainable Transportation Council (STC), a nonprofit group formed in 2009 (Commission 2011; N. A. S. T. Council, n.d.). The group collaborated with LEED professionals, the Portland Bureau of Transportation, the Santa Cruz Regional Transportation Commission, CH2M Hill, Parsons Brinckerhoff, Confluence Planning, ECONorthwest, David Evans and Associates, Brightworks, National Peer Reviewers, Green Building Services, TriMet, City of Vancouver, Metro and WSDOT Commute Trip Reduction in a bid to develop credits (N. A. S. T. Council 2010). The developers hope that through the application of STARS to projects, communities and planners will be able to systematically identify and accomplish livability goals in transportation projects.

STARS was developed in order to evaluate transportation project sustainability based on the three tenets of sustainability. The developers of the system have, however, defined the three tenets of sustainability as environment, economy, and access, redefining the social aspect of sustainability with access (Commission, 2011). This they deemed to be necessary as transportation is not an end by itself but is indeed a means of access to other essential services. As such, great emphasis is placed by the rating system on the different modes of access afforded to individuals in a community, including the disadvantaged populace such as the poor and disabled.

Essentially, STARS was developed to evaluate access rather than mobility, and this is based on the premise that the needs of a community can be met without travel being necessary. As such, STARS evaluates transit, virtual communication, compact communities, and driving (Commission 2011). In doing so, STARS promotes a blend of transportation and land use strategies geared at meeting the needs of residents and businesses for access to goods, services, and information (N. A. S. T. Council, 2010). STARS is performance-based and not prescriptive as it encourages the users to define and achieve clearly stated goals while being guided by the credits contained in the various versions. It is also an entirely voluntary rating system that encourages integrated planning by the stakeholders of projects (N. A. S. T. Council 2010).

The rating system can be used throughout the life cycle of a project; however, greater emphasis is placed on the evaluation of the operations and maintenance phases of projects as the developers believe that more consequences are felt by communities during the OM phase than during the design and construction phases. The system is in different stages of development aimed at accomplishing life cycle analysis with four versions applicable to different project phases being unveiled: STARS-Plan, which is currently being pilot tested; STARS-Project, also currently being pilot tested; STARS Certification, on which development commenced in fall of 2012; and STARS Safety, Health and Equity Credits, which is currently in use as a separate tool (N. A. S. T. Council 2010). In the future, the current Health, Safety, and Equity credits will be incorporated into the STARS-Project tool, and new Health, Safety and Equity credits will be developed to be incorporated into the STARS-Plan tool (N. A. S. T. Council 2012). After pilot testing, the developers hope to consolidate all versions into one system, which will be the STARSPlanning, Evaluation and Rating System. The new system will include a points system with weighted credits and awards, which will be achievable under the system. Further credit development is also projected to continue based on feedback from the pilot projects and developing trends in transportation sustainability. For now, the system encourages sustainable best practices but does not serve as a means of measuring or rewarding the sustainable performance of projects (N. A. S. T. Council 2010).

STARS-Project, which was unveiled in November 2010, is geared toward the evaluation of transportation projects. It is still in the development stages and does not offer credit weighting, scoring, or awards. This is projected to be included in subsequent versions of the rating system. STARS-Projects consist of 29 credit categories, 12 of which have been developed to date. The remainder will continue to evolve with the continued efforts of the developers and research results. Credits are included in projects based on their applicability, and not all credits will be applicable to all projects (N. A. S. T. Council 2010).

Project credits are broken down into six categories: Integrated Process, Access, Climate and Energy, Ecological Function, Cost Effectiveness Analysis, and Innovation. The first credits in the first five categories are required with the remainder being optional. The required credits are performance-based and require that the project team establish certain fundamental goals related to the category (N. A. S. T. Council 2010). The rating system does not establish these goals for the team, it only exists to guide the project team on what areas they need to focus on. The voluntary credits, on the other hand, are more goal specific, guiding the team on specific goals that may be included under the broader category. However, it does not specify percentages or numbers and, to date, does not weight the categories in order of importance. As such, the project team is free to do what it sees best for a project and the surrounding communities. Credits are organized into goals, objectives, and performance measures; i.e., a goal is established that is a statement of aspiration. Next, objectives, which act as a road map toward attaining the goal, are established. The performance measure takes the form of a metric which aids in establishing how well the objective chosen actually helps in the achievement of the goal established (N. A. S. T. Council 2010).

STARS-Plan is geared toward the evaluation of transportation planning at the regional level. This tool allows communities and jurisdictions to evaluate various options to see if the current and future needs of a community and end users can be met by the project. STARS-Plan has credits distributed under eight broader categories: Integrated Process, Community Context, Access and Mobility, Safety and Health, Economic Benefit, Cost Effectiveness, Climate Pollution and Energy Use, and Ecological Function. Each category only has one credit; however, the credit is still broken down in the same way that credits are broken down in STARS-Project. The credits are again organized in terms of goals, objectives, and performance measures (N. A. S. T. Council 2010).

The STC, collaborating with the Multnomah County Health Department and Upstream Public Health, developed some safety, health, and equity credits for the STARS rating system. This formed the basis of STARS - Safety, Health and Equity, a sustainability rating tool, which is used to guide the integration of health, safety, and equity concerns in transportation projects (N. A. S. T. Council 2012). This measure was deemed necessary by the developers as they believe that transportation projects affect the health and safety of communities. They cited automobile transportation as being the main culprit, as it reduces the opportunities for physical activities and increases the likelihood of traffic accidents. It also amplifies poverty and inequity as the disadvantaged are unable to drive and resort to walking, cycling, or taking public transportation in order to access services (Association 2009).

Based on these statistics, the developers of STARS saw the need for measures in transportation planning geared toward reducing these numbers and have sought to address the issues through the STARS-Safety, Health and Equity tool. The tool is broken down into three large categories: Safety, Health, and Equity. Under this tool, each category may have more than one goal, again followed by objectives and performance measures (N. A. S. T. Council 2010, 2012). The major difference with this tool is that STARS has elected to define the goals, objectives, and acceptable performance measures for each goal, taking the ability to decide from the team opting to use the tool. Teams that use the STARS-Project tool and the STARS-Plan tool are expected to also use the STARS-Safety, Health and Equity tool (N. A. S. T. Council 2010). The STARS-Safety Health and Equity tool was, however, developed to be a stand-alone tool and may be used by itself by project teams to incorporate health, safety, and equity concerns in their construction projects (N. A. S. T. Council 2012).

2.3 Comparison of the Sustainable Infrastructure Rating Systems

Table 2.1 Key of symbols used in tables

KEY	
✓	Does meet Criterion
○	Under development
✓/-	Meets Criterion with Exception(s)
-	Does not meet Criterion
∞	Represented elsewhere

Table 2.2 Project phases relevant to each rating system

APPLICABILITY - Phase of Projects				
Rating System	**Planning**	**Design**	**Construction**	**Operations and Maintenance**
BE2ST-IN-HIGHWAYS	□	□	-	-
ENVISION	□	□	□	□
GREEN GUIDE FOR ROADS	□	□	-	-
GREENLITES	□	□	□	□
GREENPAVE	□	□	□	□
GREENROADS	□	□	□	-
I-LAST	□	□	○	-
INVEST	□	□	□	□
CEEQUAL	□	□	□	□
STARS	□	□	□	□

The 10 rating systems reviewed have various similarities and differences. The above tables highlight some of the distinguishing and defining characteristics of the ten systems. Table 2.1 provides the key for the symbols used in the tables that follow.

As can be seen in Table 2.2, all 10 sustainability rating systems are applicable to the design phases of projects. Seven are applicable during the construction phase (Envision, GreenLITES, STARS, CEEQUAL, GreenPave, Greenroads, and INVEST) and six during the operations and maintenance phase of a project (STARS, CEEQUAL, GreenPave, Envision, GreenLITES, and INVEST). Note that I-LAST is currently developing a system applicable to the construction phase. In general, the majority of systems are applicable from planning through operation. Tables 2.2 and 2.3 list the various project phases and types applicable to each rating system.

As can be seen in Table 2.3, Envision and CEEQUAL are applicable to different types of infrastructure works. The other rating systems reviewed, however, are only applicable to highway projects. Greenroads does incorporate pathways and landscaping related to highways, however, only in the capacity that they are being constructed at the same time as the highway.

Table 2.3 Project types relevant to each rating system

APPLICABILITY - Types of Infrastructure						
Rating System	**Highways**	**Water Storage**	**Water Treatment**	**Energy Generation**	**Landscaping**	**Information Systems**
BE2ST-IN-HIGHWAYS	☐	-	-	-	-	-
ENVISION	☐	☐	☐	☐	☐	☐
GREEN GUIDE FOR ROADS	☐	-	-	-	-	-
GREENLITES	☐	-	-	-	-	-
GREENPAVE	☐	-	-	-	-	-
GREENROADS	☐	-	-	-	☐/-	-
I-LAST	☐	-	-	-	-	-
INVEST	☐	-	-	-	-	-
CEEQUAL	☐	☐	☐	☐	☐	☐
STARS	☐	-	-	-	-	-

Tables 2.4–2.7 highlight similarities and differences of the 10 rating systems according to four major categories relevant to the majority of systems. Numerous other categories exist but have limited applicability across the systems reviewed. It should be noted that the total points achievable for Envision, Green Guide for Roads, GreenLITES, GreenPave, Greenroads, I-LAST, INVEST, and CEEQUAL are 143, 100, 86, 36, 118, 236, 586, and 2012, respectively. STARS currently does not award points for achieving criteria under the rating system. BE^{2}St-in-Higways has a default of 9 points total; however, project teams reserve the right to allocate a desired weighting to each criteria under the rating system.

Table 2.4 Summary of sub-criteria related to the environment category for each rating system

ENVIRONMENT CATEGORY - POINTS PER SUB-CATEGORY COMPARISON FOR EACH RATING SYSTEM																	
Rating System	**Environmental Management Systems**	**Site Vegetation/Trees and Plant Communities**	**Protect Enhance or Restore Wildlife (Habitat Restoration)**	**Ecological Connectivity**	**Environmental Training**	**Improve Air Quality by Improving Traffic Flow**	**Improving Bicycle and Pedestrian Facilities**	**Noise Abatement**	**Integrated Planning Natural Environment**	**Siting**	**Basic Principles**	**Legal Requirements**	**Monitoring and Maintenance**	**Reflective/Cool Pavement**	**Pollution Reduction**	**Biodiversity**	**Percentage of system**
BE2ST-IN-HIGHWAYS	**Points determined by project team**																
ENVISION	-	∞	∞	∞	∞	∞	∞	∞	∞	22	-	-	∞	∞	∞	14	25%
GREEN GUIDE FOR ROADS	∞	∞	∞	∞	-	∞	∞	6	∞	∞	-	-	∞	3	∞	∞	9%
GREENLITES	-	∞	∞	∞	-	6	6	4	∞	∞	-	-	∞	∞	∞	∞	6%
GREENPAVE	-	-	-	-	-	-	-	2	-	-	-	-	-	2	3	-	19%
GREENROADS	2	3	3	3	1	∞	∞	∞	∞	∞	-	-	∞	∞	∞	∞	10%
I-LAST	-	21	20	∞	-	∞	∞	10	∞	∞	-	-	∞	∞	∞	∞	22%
INVEST	5	3	3	∞	1	15	∞	2	15	∞	-	-	∞	∞	∞	∞	8%
CEEQUAL	70	∞	44	∞	∞	22	∞	∞	∞	∞	36	42	20	∞	∞	42	12%
STARS	**No Points under system**																

Table 2.5 Summary of sub-criteria related to the water quality and use category for each rating system

WATER QUALITY AND USE - POINTS PER SUB-CATEGORY COMPARISON FOR EACH RATING SYSTEM													
Rating System	**Stormwater Treatment / Management**	**Reduce runoff and treat stormwater runoff**	**Runoff Flow Control**	**Runoff Quality**	**Stormwater Cost Analysis**	**Reduce Impervious Areas**	**Construction Practices to Protect water Quality**	**Basic Principles**	**Legal Requirements**	**Water Efficient Landscaping**	**Permeable Pavement**	**Water/Tracking**	**Percentage Allocated for Water Quality**
BE2ST-IN-HIGHWAYS	**Points determined by project team**												
ENVISION	2	∞	∞	8	-	∞	-	-	-	-	∞	15	17%
GREEN GUIDE FOR ROADS	8	∞	∞	-	-	∞	-	-	-	2	∞	-	10%
GREENLITES	3	5	∞	∞	-	∞	-	-	-	-	∞	-	3%
GREENPAVE	∞	-	-	-	-	∞	-	-	-	-	1	-	3%
GREENROADS	∞	∞	3	3	1	3	-	-	-	-	∞	2	10%
I-LAST	10	∞	∞	∞	-	14	11	-	-	-	∞	-	15%
INVEST	9	∞	∞	∞	-	∞	-	-	-	-	∞	-	2%
CEEQUAL	∞	71	∞	24	-	∞	-	30	12	-	∞	33	8%
STARS	**No Points under system**												

Table 2.6 Summary of sub-criteria related to the energy category for each rating system

ENERGY CATEGORY - POINTS PER SUB-CATEGORY COMPARISON FOR EACH RATING SYSTEM																
Rating System	**Energy and Fuels/Emissions Monitoring**	**Lighting/Energy Efficiency**	**Reduce Electrical/Energy Consumption**	**Reduce Petroleum Consumption**	**Stray Light Reduction**	**Renewable Energy Consumption**	**Basic Principles**	**Energy and performance on site**	**Paving Energy Reduction**	**Paving Emission Reduction**	**Volatile Organic Compounds**	**Pavement Smoothness**	**Resilience**	**Infrastructure Energy Efficiency**	**Percentage Allocated for Energy**
BE2ST-IN-HIGHWAYS	**Points determined by project team**														
ENVISION	3	∞	3	∞	1	2	-	-	∞	4	-	-	7	-	6%
GREEN GUIDE FOR ROADS	4	2	∞	-	3	∞	-	-	3	2	2	-	-	2	14%
GREENLITES	∞	∞	3	6	3	∞	-	-	∞	∞	-	-	-	-	4%
GREENPAVE	2	-	3	-	-	-	-	-	∞	∞	-	1	-	-	11%
GREENROADS	∞	5	∞	-	3	∞	-	-	∞	∞	-	-	-	-	7%
I-LAST	∞	∞	12	∞	4	∞	-	-	∞	∞	-	-	-	-	7%
INVEST	15	11	15	∞	∞	∞	-	-	∞	∞	-	-	-	-	7%
CEEQUAL	∞	∞	60	∞	10	∞	66	70	∞	∞	-	-	-	-	10%
STARS	**No Points under system**														

Table 2.7 Summary of sub-criteria related to the materials category for each rating system

MATERIALS CATEGORY - POINTS PER SUB-CATEGORY COMPARISON FOR EACH RATING SYSTEM																		
Rating System	**Reuse of Materials**	**Recycled Content/Materials**	**Locally Provided/Regional Material**	**Bioengineering Techniques**	**Hazardous Material Minimization**	**Life Cycle Assessment/Costing**	**Pavement reuse**	**Basic Principles**	**Minimizing material use and waste/Management**	**Responsible sourcing of materials**	**Timber**	**Durability and Maintenance/Long Life Pavements**	**Future de-construction or disassembly**	**Construction Site Footprint**	**Earthwork Balance**	**Energy Efficiency**	**Construction Quality**	**Percentage Allocated for Materials**
BE2ST-IN-HIGHWAYS	**Points determined by project team**																	
ENVISION	∞	2	7	-	∞	-	∞	-	6	∞	-	∞	3	-	-	∞	∞	13%
GREEN GUIDE FOR ROADS	-	6	2	-	∞	3	∞	-	∞	∞	-	4	-	3	-	∞	∞	18%
GREENLITES	7	2	2	3	6	-	∞	-	-	∞	-	∞	-	-	-	∞	∞	7%
GREENPAVE	-	6	3	-	∞	-	3	-	-	∞	-	∞	-	-	-	∞	2	33%
GREENROADS	∞	5	5	-	∞	2	5	-	-	∞	-	∞	-	-	1	5	∞	19%
I-LAST	∞	22	6	-	∞	-	12	-	-	∞	-	∞	-	-	-	∞	∞	17%
INVEST	∞	31	3	-	∞	8	15	-	-	∞	-	∞	-	-	∞	∞	∞	10%
CEEQUAL	-	28	-	-	20	-	∞	18	42	24	24	10	22	-	-	∞	∞	9%
STARS	**No Points under system**																	

Table 2.4 evaluates the focus of each sustainability system regarding environmental factors when assessing the sustainability of projects. Envision allocated the highest percentage of its available credit to environmental issues, which stands at 25%. I-LAST is second at 22% with GreenPave allocating the third highest at 19%. Although the percentage allocated for environmental issues was lower for Greenroads, CEEQUAL, Green Guide for Roads, GreenLITES, and INVEST, environmental issues were dealt with extensively in terms of policy guidelines in each of these rating systems in comparison with the other systems.

With regard to water quality shown in Table 2.5, both potable and storm water, Envision again has the highest percentage, standing at 17%. I-LAST, Greenroads, Green Guide for Roads, CEEQUAL, GreenPave, GreenLITES, and INVEST, came in at 15%, 10%, 10%, 8%, 3%, 3%, and 2%, respectively. Envision, CEEQUAL, and Greenroads were, however, the only systems to track potable water usage during construction. Greenroads was the only system to address the analysis of the cost of handling storm water.

Table 2.6 highlights that the highest percentage allocation for energy was 14% by Green Guide for Roads and the lowest at 4% by GreenLITES. GreenPave, CEEQUAL, Greenroads, I-LAST, INVEST, and Envision stand at 11%, 10%, 7%, 7%, 7%, and 6%, respectively. Common issues covered under this category included light pollution, energy consumption, and fuels.

With regard to the percentage allocation for each system toward the selection of materials shown in Table 2.7, GreenPave, Greenroads, Green Guide for Roads, I-LAST, Envision, INVEST, CEEQUAL, and GreenLITES allocate the following percentage, respectively: 33%, 19%, 18%, 17%, 13%, 10%, 9%, and 7%. Great emphasis was placed on recycling efforts across all systems.

2.4 Discussion

While the rating systems share a number of commonalities, they also have unique features. The following discussion highlights the distinctions between systems.

INVEST differentiates between different levels and type of work and acknowledges that not all projects are able to achieve all sustainability criteria (FHWA 2012c). It allows project teams to identify which credits are attainable at the beginning of the project and to customize scorecards. INVEST breaks the criteria of the rating system into a logical sequence and distinguishes between work in rural or urban areas, small scale or large scale work, paving only jobs, or custom jobs. The final score is calculated relative to the total points that were identified as attainable by the project team.

I-LAST serves primarily as a guidebook for roadwork project teams. It does not offer awards currently, but development of an awards system is pending feedback from the users of the rating system (IDOT & IJSG 2010).

Greenroads is the system that is the most encouraging of innovation. It awards a maximum of 10 points for innovation (compared with 1-2 points by other systems). It breaks innovation into two criteria, giving project teams the opportunity to incorporate more than one innovative attribute to their project (Greenroads 2012a). There is also a mechanism for project teams to document their sustainability efforts for inclusion in future versions of Greenroads.

Envision and CEEQUAL incorporate the widest range of infrastructure projects. In addition to roadways, Envision and CEEQUAL are applicable to water treatment and storage systems, energy generation, landscaping, and information systems (ISI 2012a). These systems also require that a credentialed employee be on the project team of projects seeking Envision or CEEQUAL certification and are the only rating systems that award points for leadership (CEEQUAL 2012c; ISI, 2012e).

BE^2ST-in-Highways is unique because it quantifies the sustainable aspects of a project in comparison with a base design with no sustainable attributes. To compare the project against this benchmark, it applies established methods and tools such as Life Cycle Cost Analysis (LCCA) using RealCost software, Life Cycle Assessment (LCA) using PaLATE software, TNM-Look to assess traffic noise, International Roughness Index (IRI) predictions, and Analytical Hierarchy Process (AHP) in the selection of criteria weighting (RMRC 2012a). BE^2ST-in-Highways is heavily weighted toward materials and resources.

GreenPave is unique in that it is the only horizontal sustainability rating system that assesses project sustainability based on the pavement only aspects of the project. Like BE^2ST-in-Highways, GreenPave is heavily weighted toward materials and resources.

STARS is unique in its approach to assessing sustainability in that it redefines the social aspect of sustainability, paying particular attention to it in terms of access for all. STARS acknowledges that the human component of horizontal projects is determined in the access to services it grants to its users. As such, emphasis is placed on the operations and maintenance phase of projects.

Although reference was sought from the LEED sustainability rating system in the development of some horizontal rating systems, Green Guide for Roads was the only horizontal sustainability rating system developed specifically to be adapted into the LEED rating system.

GreenLITES was developed for domestic use by the NYSDOT to track its sustainability performance. It is applied during the planning and maintenance phases of NYSDOT highway projects, but awards the project a rating based on design intent and specifications (NYSDOT 2009). While it is attracting some interest from other state DOTs, it was not originally intended to be adopted by other DOTs or project teams[5].

Each sustainability rating system was evaluated to identify the distribution of credits across the triple bottom line of sustainability (society, economy, and environment) as shown in Figure 2.10.

GreenLITES was found to have the highest distribution of credits for environmental concerns at 76%. I-LAST and Envision both allocate more than 60% of their credits to evaluating environmental concerns. GreenPave, Greenroads, CEEQUAL, and Green Guide for Roads all allocate between 45% - 55% of their credits to environmental concerns. Invest had the least number of credits allocated to environmental assessment, standing at 35%.

Green Guide for Roads was observed to have the highest allocation of credits toward social concerns, standing at 45%. I-LAST, Invest, Envision, GreenPave, Greenroads, CEEQUAL, and GreenLITES all allocated between 12% - 29% of their credits to assessing social concerns.

The highest allocation of credits for economic concerns is 37% by GreenPave, closely followed by Invest at 36%. I-LAST, Envision, Greenroads, CEEQUAL, GreenLITES, and Green Guide for Roads all allocated between 10% - 29% of their credits to assessing economic concerns. STARS has no weighting structure currently and as such could not be evaluated using the same methodology employed by the other rating systems evaluated throughout this literature review.

[5] First Copyright is held by the Associated Schools of Construction (ASC). Original publication in the International Proceedings of the 49th Annual Conference of the ASC (April 2013). Reprint permission granted on October 30, 2013.

Another potential way systems differ is according to their ease of use. Direct observation and documentation of ease of use is left to future research. The following discussion reports the level of use as documented by the literature. Greenroads has been used to evaluate more than 120 projects nationally and internationally (Greenroads 2012). The majority of use has occurred in the United States. More than 20 projects have been registered in five states and 5-10 projects are pending registration in nine states. Greenroads is also working with several countries to develop and expand the rating system (Greenroads 2012).

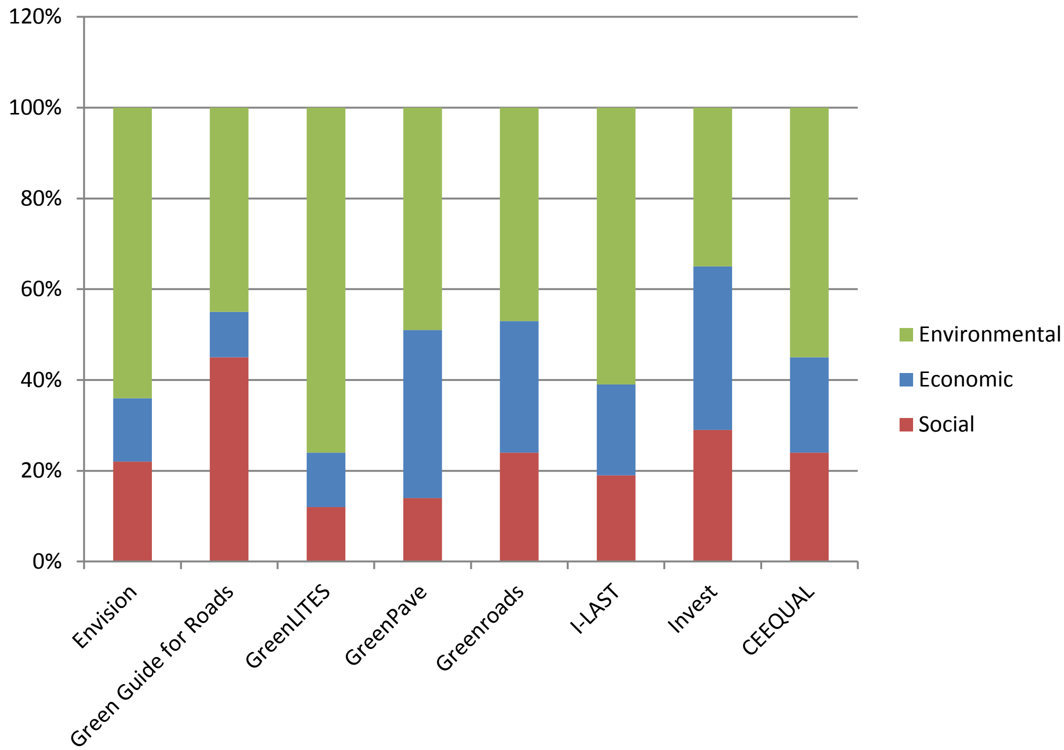


Figure 2.10 Summary of distribution of credits across the Triple Bottom Line of Sustainability

GreenLITES has been used to evaluate a total of 221 projects (NYSDOT 2012). Of the projects evaluated, 39% were not certified, 36% were GreenLITES certified, 16% earned GreenLITES Silver, 5% earned GreenLITES Gold, and 5% earned GreenLITES Evergreen.

INVEST has been pilot tested on four projects across the United States. The North Central Texas Council of Governments (NCTCOG) used INVEST's system planning module to evaluate its long-term plan, Mobility 2035; the Ohio Department of Transportation (ODOT) used the INVEST project development extended scorecard to evaluate the sustainable performance of the Innerbelt Bridge; Utah DOT evaluated its current operations and maintenance program using the INVEST operations and maintenance module; and the INVEST scorecard was used to evaluate the Western Federal Lands Going-to-the-Sun-Road Rehabilitation Project (FHWA 2012b).

BE^{2}ST-in-Highways has been pilot tested on the Baraboo Bypass in Wisconsin (Lee 2011). Envision has been pilot tested on four Colorado projects: the Academy/Woodmen Road interchange in Colorado Springs, Little's Creek in Littleton, Gold Camp Tunnel in Teller County, and the Aspen Rio Grande Recycling Project (Hirsch 2012).

More than 200 companies have adopted the CEEQUAL TSRS on their projects and contracts. Some companies, such as Thames Water, London Underground and Crossrail, and Welsh Assembly government, now specify the use of CEEQUAL on large-scale projects. Additionally, some clients now select contractors based on their experience working on CEEQUAL projects (CEEQUAL 2013).

STARS has been used in California, Oregon, and Washington across a total of seven counties. In California, STARS was used to inform the updates to the Regional Transportation Plan of the Santa Cruz County Regional Transportation Council, as well as by the Transportation Agency for Monterey County, to determine the economic implications of a highway project (S. T. Council 2013). In Oregon, it was used by the City of Eugene to establish goals for its transportation plan as well as to assess the sustainability of its bicycle and pedestrian infrastructure, by Multanomah County to assess the sustainability of its bicycle and pedestrian infrastructure, and by the City of Gersham to assess neighborhood's connections to a proposed bicycle path that would run adjacent to a major transit route (S. T. Council 2013). In Washington, STARS was used by the Clark County Transit Agency (C-TRAN) to assess the economic and environmental impacts of different options of a bus rapid transit along Fourth Plain Boulevard (S. T. Council 2013).

GreenPave has been used to assess 91 projects, 89 of which were purely pavement design projects. Of the 89 pavement design projects assessed, 45% were found to be sustainable with 37 obtaining GreenPave Bronze certification and two GreenPave Silver certification (Chan, Bennet, & Kazmierowski 2013). No statistical information was available on the past use of Green Guide for Roads at the time this thesis was being written.

The review of the 10 sustainable rating systems for transportation projects reveals that all the rating systems support sharing, encouragement, and recognition of sustainable best practices. Each system differs, however, in how it analyzes and evaluates such practices, whether through comparison to a base design, quantitative methods, the use of experts in the form of third-party validation, or self-assessment. Regardless of analysis method, the objective to analyze and recognize project performance is accomplished according to the unique processes and implementation requirements of the various rating systems. To what extent sustainability is achieved remains uncertain since consensus does not exist as to the definition of sustainability for highway and infrastructure projects.

Similarities are identified between rating systems for issues related to water, energy, materials, and the environment. However, the weights given to each factor vary across systems that have different sustainability objectives. Such objectives differ according to stakeholder and project. Further research is recommended to explore the implications of such similarities and differences in greater detail and to make recommendations about the merits and shortcomings of various sustainability rating systems for transportation projects.

3. METHODOLOGY

The framework hereinafter proposed for the assessment of TSRSs for implementation by state DOTs is based on a mixed method research approach (qualitative and quantitative), which was implemented by the researcher in four case studies. The case studies were conducted to demonstrate the repeatability of the study (Creswell 2003) and were done with the assistance of the Colorado DOT (CDOT), South Dakota DOT (SDDOT), Utah DOT (UDOT), and Wyoming DOT (WYDOT). The framework consists of four main steps:

1. a literature review of available TSRSs for use in the United States to determine capabilities
2. an interview with the state DOT to determine which capabilities are desired in a TSRS
3. the development of a secondary survey instrument based on the AHP methodology to allow the assignment of weights to the desired capabilities as identified in step 2
4. an assessment of TSRSs to identify the most suitable TSRS for implementation in the state DOT using the results of the AHP survey

3.1 Qualitative, Quantitative and Case Study Research Methods

Qualitative research methods are used in situations where a researcher intends to explore and understand the meanings ascribed by individuals or groups to a social or human problem. The researcher builds from a central question or the broadest question that can be asked, which is used in order to avoid limiting the research, up to several sub-questions geared toward finding more definitive and varied explanations (Creswell 2003). This approach is taken in this study by the researcher through interview questions geared to determine the meanings ascribed by state DOT decision makers to sustainability issues and specifically to the desires of the DOT as they relate to the ideal capabilities of TSRSs.

Quantitative research methods, on the other hand, are geared at determining the relationship between two variables. The variables are usually measurable and result in numbered data, which can be analyzed using statistical methods (Creswell 2003). Quantitative research is usually grounded on a hypotheses or quantitative research questions posed by the researcher. The researcher essentially makes a prediction about the expected outcome of the research and, through a quantitative methodology, proves or disproves the theory (Creswell 2003). In this study, the Analytic Hierarchy Process, which is a mathematical process used in multi-criterion decision making, is used.

Finally, four case studies are used to demonstrate the usefulness of the framework herein proposed. This research method was included to demonstrate that the results can be replicated using the framework and lends validity to the framework (Creswell 2003; Yin 2003). The case studies facilitated an in-depth and up-close look at the performance of the framework in a real-world context, thereby establishing the feasibility of the framework (Yin 2003).

Quantitative, qualitative, and case study research all have their strengths and weaknesses. Mixing methods is commonly referred to as mixed method research and allows each method to complement the other's weaknesses, thereby strengthening the results garnered from the study (Creswell 2003).

3.2 Conducting a Literature Review

The literature review phase is in all likelihood the most significant phase in this framework as it sets the stage for the remainder of the study. The literature review is conducted for two main reasons: first, it facilitates the identification of TSRSs, which are available for use in the United States; second, it aids in the identification of the capabilities of each TSRS. At the time of the development of this framework, there was very little published data in peer reviewed journals on TSRSs, so the developers' websites served as the main reference for each TSRS.

While conducting the literature review, information on the applicability of each TSRS to different types of projects as well as the different phases of projects, the rating mechanisms of each and any unique capabilities should be noted. This list is not meant to be exhaustive; essentially everything notable about each TSRS should be documented. Tables and charts may be used to categorize, summarize and compare the information gleaned from the literature review (Galvan 2009).

A literature review was conducted at the commencement of this study. Tables and charts were used to categorize, summarize, and compare each TSRS. Based on the information gleaned from the literature review, 10 TSRSs available for use within the United States were identified: BEST-in-Highways, Envision, Green Guide for Roads, GreenLITES, GreenPave, Greenroads, I-LAST, Invest, STARS, and CEEQUAL. Additionally, after a thorough review of the 10 systems, 16 capabilities were identified. They are as follows:

1. **Ability to assign a score or an award**: Projects are assessed using a scoring system. Certain scores are awarded levels of achievement (similar to a LEED Certified, Silver, Gold, Platinum).
2. **Ability to employ self-assessment**: Project assessment (scoring or otherwise) is performed internally by a team member(s) involved in the project (i.e., state DOT).
3. **Ability to evaluate project during conceptual stage**: The rating system facilitates consideration of decisions or activities that occur during the conceptual phase of a project when assessing the sustainability of the project.
4. **Ability to evaluate project during design phase**: The rating system facilitates consideration of decisions or activities that occur during the design phase of a project when assessing the sustainability of the project.
5. **Ability to evaluate project during construction phase**: The rating system facilitates consideration of decisions or activities that occur during the construction phase of a project when assessing the sustainability of the project.
6. **Ability to evaluate project during operations and maintenance phase**: The rating system facilitates consideration of decisions or activities that occur during the operations and maintenance phase of a project when assessing the sustainability of the project.
7. **Ability to allocate weights to criteria**: The rating system facilitates the assignment of weights to various criteria when assessing the sustainability of the project.
8. **Ability to choose only relevant criteria to project**: The rating system permits a team member(s) to determine whether or not given criteria are relevant to the project and whether they should or should not be used in the assessment.
9. **Ability to offer a checklist customized to particular types of projects**: The rating system facilitates a checklist customized to differing scenarios. For example, it may have a checklist customized to a rural setting, an urban setting, pavement only jobs, new works, etc.
10. **Ability to award points for innovation**: The rating system facilitates award of credits or points for the implementation of innovative techniques used to promote sustainability.
11. **Ability to offer prescriptive measures towards achieving credits**: The rating system prescribes and credits specific decisions or activities as certain to promote sustainability.

12. **Ability to offer performance measures towards achieving credits**: The rating system identifies and credits certain goals to promote sustainability, but does not prescribe specific decisions or activities to achieve these goals.
13. **Ability to compare different project options side by side**: The rating system facilitates side-by-side comparison of whole projects while assessing sustainability.
14. **Ability to offer an award for the designer, client, and contractor**: The rating system facilitates award(s) for or acknowledgement of specific team members based on project sustainability.
15. **Alignment with state DOT's preferred distribution of credits**: Alignment of the rating system's distribution of credits across the triple bottom line of sustainability (i.e., social, economic, and environmental concerns) with the state DOT's preferred distribution of credits.
16. **Ability to employ third-party verification**: Project assessment (scoring or otherwise) is performed externally by a TSRS member(s) (i.e., project application and documentation submitted to external body for review and scoring).

It is important to note that the capabilities were shared among the TSRSs; no one system had all capabilities common to it.

When this framework is being adopted, it is imperative that the literature review herein contained be expanded as TSRSs are constantly evolving. A check should first be conducted to determine whether any new TSRSs have developed subsequent to this thesis being generated to ensure that these are the only systems available for use. Any new systems identified should be reviewed to determine if they qualify to be included in the study. The qualifying criterion for this review was any system available for use in the United States. Other qualifying markers may be added at the discretion of the researchers in the adoption of this framework.

It is also necessary to review the TSRSs to identify the capabilities of each system; it is expected that the capabilities of TSRSs will be consistent with the capabilities identified in this study. However, note that there may be changes in each system based on the evolving nature of sustainability and transportation construction methods, which may give rise to new capabilities being included in a TSRS or even the exclusion of capabilities from a TSRS. In essence, the identification of all possible capabilities of TSRSs is important to the results of an assessment exercise, as the results may be compromised in light of any omission of capabilities.

3.3 INTERVIEWS

3.3.1 Drafting Interview Questions

Once all capabilities of TSRSs have been identified, a document of possible interview questions should be prepared. This is highly recommended as it lends some structure to the interview process. It is important that the interviewer be flexible and leave room for additional questions that may become necessary based on the responses of the interviewee (Creswell 2003).

The interview should be structured in three separate sections. The first section should include open-ended questions geared at determining the role of the interviewee with the state DOT, the state of sustainability knowledge of the interviewee and the state DOT, the role of the state DOT in highway development and maintenance, and the state of sustainable development at the state DOT (Creswell 2003). By assessing the level of sustainability knowledge and the role of the interviewee, the researcher will be ensuring that the interviewee has the requisite knowledge to address the questions fielded throughout the remainder of the interview as well as the authority to speak on behalf of the state DOT. By garnering information on the state of sustainability knowledge in the state DOT, the interviewer will have a better feel for the receptiveness of the organization to the implementation of a TSRS. In investigating the role of the state

DOT in highway development and maintenance, the researchers will be able to identify practices currently part of the state DOT's duties, which are defined as "sustainable practices" but are not recognized as "sustainable practices" by the state DOT. This will enable the researchers, after analyzing all the data, to match these sustainable practices with any missed opportunities to fulfill criteria previously deemed unattainable or undesired. Lastly, in determining the state of sustainable development at the state DOT, the researcher will get a broader understanding of the usefulness of a TSRS to the state DOT and the level of training required for potential users of a TSRS if implemented at the state DOT.

With the exception of two questions, the second phase of the interview should be a list of closed-ended questions which are directly related to each capability as identified through the literature review (Creswell 2003). The exceptions to this rule are the following two questions:

1. How do you generally incorporate sustainable strategies in the development of highway projects?
2. What are some of the main characteristics that a sustainability rating system should have?

These two questions will help the researcher gain a better understanding of what types of sustainability practices are being undertaken by the state DOT that are outside the scope or capabilities of the TSRSs available for use in the United States. Again, these two questions are not meant to be exhaustive, and additional open-ended questions may be added by the researcher when adopting this framework. It is important to note, however, that a lengthy interview is not recommended in research as interviewees may become bored and the quality and validity of answers may deteriorate. This may result in the interviewee supplying any answer just to have the interview concluded (Creswell 2003).

The remaining questions in the second phase of the interview should directly ask the interviewee to respond "yes" or "no" with regard to desired capabilities. The following is an example of a question used in phase two of the interview for the case studies with the state DOTS: "Would the 'blank' state DOT prefer to use a sustainability rating system that awards points for Innovation?" The interviewee would be required to respond with a "yes" or "no" and that response will be catalogued by the interviewer.

Last but not least, the third phase of the interview should address any additional concerns that may influence the results of the study. These questions can be open-ended or closed-ended and should concentrate on determining what other factors outside of the direct capabilities of each TSRS may affect a state DOT's choice to adopt and use a TSRS (Creswell 2003). The following is an example of a question used in phase three of the interview for the case studies with the state DOTS: "How intensive a training exercise do you foresee being necessary in your organization for the use of a rating system?" Appendix I of this thesis includes the interview questions used in the case studies.

3.3.2 Conducting Interviews

Once the interview questions are drafted, the researcher should test the questions before conducting the actual interviews (Creswell 2003). This will aid in the correction or omission of any questions or phrasing that may be redundant to the research or misunderstood by the interviewee. Additionally, the completion of the questions for the interview means the researcher can then identify the person(s) to be interviewed from the state DOT. This individual should be in a position of authority and be authorized to speak on behalf of the state DOT. If the implementer does not have an established relationship with the state DOT, and therefore does not possess intimate knowledge of whom to contact, a good place to start would be the state DOT website. The state DOT website typically lists its managers and their responsibilities; a good starting point would be to look for a sustainability manager, sustainability department, or project development engineer. Once contact is made with the state DOT, the individual should verify that they are indeed qualified to speak on the matter and, in the event they are not, to refer the implementer to someone within the organization who is qualified to address the interview questions.

Once the contact is made, it is imperative that consent to the interview be received from the interviewee, and this may be done via a signed document or a verbal consent (best if recorded). A date and time for the interview should be arranged between both parties. Before the interview is conducted, it is also recommended that a copy of the interview questions be submitted to the interviewee for review. The document, however, should not include section two of the interview questions in order to prevent the generation of biases for a particular system before the interview is conducted. In the section of the questionnaire where section two of the interview should be, it should be clearly stated that those questions will be provided at the time of the interview.

It is recommended that the interview be tape recorded, as well as notes taken during the interview by a secondary researcher, in order to ensure that two methods of data collection are used for validity purposes. The use of the secondary researcher will ensure that the primary researcher (fielding interview questions) is able to fully concentrate on asking questions and responding to interviewee queries while the secondary researcher is able to fully concentrate on documenting responses (Creswell 2003). Additionally, having two methods of data collection can facilitate a check-and-balance system to ensure that all information collected was correct and not misrepresented.

At the beginning of the interview, if verbal consent is given or if no consent was given to record on the consent form, consent to record should be requested by the researcher. Once this consent is received, the researcher can proceed with recording the interview. Notes should be taken of the responses received from the interviewee during the interview (Creswell 2003). Even after pilot testing the interview, it may still be necessary to clarify some questions and terms in the interview; be prepared to answer questions from the interviewee.

Once the interview is completed, transcripts of the interview should be prepared and a copy sent to the interviewee for approval. The interviewee should be allowed to review the transcripts and confirm, refute, or revise his or her responses in the document. The aim is to have a correct representation of the interviewee's responses before the next step of the process is undertaken.

Based on the responses received from the interview and the confirmation of the transcript, the researcher can then develop the secondary survey instrument, which is based on the Analytical Hierarchy Process (AHP) methodology.

For the four case studies presented in this thesis, the interview questions once completed were pilot tested to determine whether they needed reformatting. The state DOT websites were next consulted to determine an appropriate point of contact for the research. Contact was made and an interview date set. Consent forms were submitted by the state DOTs to the researchers and the interview questions were presented to the interviewee for review before the interviews were conducted. The interviews were conducted in the presence of at least two researchers, with one functioning in the capacity of primary researcher and the other as secondary researcher (as previously described). The interviews were also tape recorded with the consent of the state DOTs. After completion of the interviews, transcripts were made of the interviews and submitted to the state DOTs for the interviewee to review and confirm. All transcripts were confirmed by the state DOTs. The researchers then developed the secondary survey instrument based on the AHP methodology.

3.4 Developing and Administering Secondary Survey Instrument – Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a decision-making method designed to help individuals use intuition and rational thinking in selecting the best option from a number of alternatives that are evaluated based on multiple criteria (Saaty & Vargas 2001). The decision maker will essentially go through pairwise comparisons of each criterion during which the preferred criteria will be ranked numerically in order of preference over the rejected criteria. Based on a mathematical calculation, the options will be placed in a hierarchy with the highest ranked being at the top and the lowest ranked at the bottom of the hierarchy (Saaty & Alexander 1989).

AHP is, in essence, a well-structured quantitative multi-criteria decision analysis theory of measurement developed by Thomas Saaty for dealing with economic, socio-political, and complex technological problems (Saaty & Vargas 2001). AHP assists people to organize their thoughts and judgments to make effective decisions through a mathematical calculation that can identify the subjective and personal preferences present in decision making (Saaty & Vargas 2001). The rationale behind the use of AHP is that it is fairly simple for individuals to view two alternatives and decide which is preferred. However, this process gets slightly more complex when there are several items to compare or numerous criteria/capabilities of each alternative (Saaty & Vargas 2001). The AHP methodology aids in this type of dilemma in that it facilitates the breakdown of alternatives into all its criteria and makes pairs of each criteria to be compared. An example will be used to illustrate the mechanism of the AHP process as well as its usefulness in decision making. An Excel spreadsheet used in the demonstration was the tool used in developing the AHP survey instrument for this survey. It is important to note, however, that there are many AHP software packages available for use in the event the Excel spreadsheet becomes difficult to replicate.

Let us say Greg, a graduate student at Colorado State University, loves pizza but is not sure which pizza to buy. After a careful study of several pizza options and their qualities he decides on five qualities or things he desires in a pizza most. The five qualities are:

1. Taste
2. Texture
3. Cheesiness
4. Tomato paste richness
5. Spiciness

These five qualities are shared among the different options with no one pizza having all qualities. As such, Greg will have to be willing to give a little in order to make a decision. But how will he go about deciding which quality is least important or which combination of qualities is best for him? The AHP method is ideal for such scenarios and will be used to demonstrate how such a problem may be solved using the process.

The five qualities chosen will be represented in a table format developed in Excel, and which matches each capability against the four other capabilities identified (see Table 3.2). The objective of the decision maker, once he receives the survey, will be to work through the spreadsheet systematically and decide which of the qualities paired is preferred and on what scale it is preferred. The scale, which ranges from 1 - 9, was developed by Saaty and is illustrated in Table 3.1.

The spreadsheet below facilitated the choice of options by way of a drop-down menu from which the decision maker can choose either option “A” or “B” and then move on to choose the scale that best fits the capability chosen. The decision maker will work through the whole document repeating the process as depicted in the example above (Table 3.2).

The calculations are then done in a separate sheet within the spreadsheet based on references made to the sheet completed by the decision maker. On the separate sheet, a matrix was developed with references that were automatically populated once the information was filled in by the decision maker on the first sheet. For example, "taste" was chosen over texture and the value 2 assigned to taste. This means that taste was deemed to be slightly more important than texture. Automatically, when this choice is made, the cell comparing taste to texture in the matrix was populated with the numerical weighting assigned to the preferred item. At the same time, another input was made. By virtue of the matrix, each quality is compared to the other qualities twice. As such, another reference was made to automatically populate the other cell where the same comparison was being made. When texture was again compared to taste, texture was chosen as the preferred quality and assigned a score of ½ or 0.5, which is the reciprocal of the first choice made when the same two qualities were compared (highlighted in yellow in Table 3.3).

Table 3.1 The Fundamental Scale of Absolute Numbers (Saaty & Vargas 2013)

Degree of Importance	Definition	Explanation
1	Equal Importance	Two criteria contribute equally to the objective
2	Weak	
3	Moderate Importance	Experience and judgment slightly favor one criteria over another
4	Moderate Plus	
5	Strong Importance	Experience and judgment strongly favor one criteria over another
6	Strong Plus	
7	Very Strong or demonstrated Importance	A criteria is strongly favored and its dominance is demonstrated in practice
8	Very, Very Strong	
9	Extreme Importance	The evidence favoring one criteria over another is of the highest possible order

Table 3.2 Pairwise comparison table for qualities of pizza

QUALITY A	**QUALITY B**	**More Important Item**	**Degree of Importance**
Taste	Texture	A	2
Taste	Cheesiness	A	5
Taste	Tomato paste richness	A	5
Taste	Spiciness	A	8
Texture	Cheesiness	A	5
Texture	Tomato paste richness	A	5
Texture	Spiciness	A	8
Cheesiness	Tomato paste richness	A	1
Cheesiness	Spiciness	A	5
Tomato paste richness	Spiciness	A	5

Table 3.3 Comparison matrix for pizza qualities

Criteria	Taste	Texture	Cheesiness	Tomato Paste Richness	Spiciness
Taste	1.000	2.000	5.000	5.000	8.000
Texture	0.500	1.000	5.000	5.000	8.000
Cheesiness	0.200	0.200	1.000	1.000	5.000
Tomato Paste Richness	0.200	0.200	1.000	1.000	5.000
Spiciness	0.125	0.125	0.200	0.200	1.000

Once the survey instrument is completed by the decision maker and the matrix populated, several calculations need to be completed in order to generate the results. First, the number derived in each row will be multiplied to get a row product. For row "Taste," the row product is derived by 1 x 2 x 5 x 5 x 8 = 400 (see Table 3.3 and 3.4). The row product is then raised to the n^{th} power (n being the number of qualities being compared). This will be repeated for the remaining four rows and the values derived summed (Table 3.4). Once the values derived are summed, the normalized eigenvector can be calculated, which in essence is a ratio exercise for the quality in the row. Each figure derived by multiplying the row product to the n^{th} root will be divided by the total sum of the numbers derived by multiplying the row product to the n^{th} root to come up with the normalized eigenvector (see Table 3.4). All the ratios added together should give a value of 1. By calculating the ratios the hierarchy of preference is established.

Table 3.4 Preliminary numbers for normalized eigenvector calculations for pizza example

Criteria	Row Product	n^{th} Root of Row Product	Normalized Eigenvector
Taste	400.000	3.314	0.442
Texture	100.000	2.512	0.335
Cheesiness	0.200	0.725	0.097
Tomato Paste Richness	0.200	0.725	0.097
Spiciness	0.001	0.229	0.030
		7.505	**1.000**

Another important calculation is the consistency ratio, which signifies how consistent the decision maker is being with his choices. Consider, for example, options A, B, and C are being compared. If the decision maker chooses option A over option B and ranks A at a 2 and then chooses option C over option B and ranks B at 3, it follows that when A is compared to C, A should be ranked as the preferred option and given a weighting of 6. This, however, may not be the case as the decision maker is not making calculations in his ranking but is subjectively assigning a weight to each preferred option. This process gets even more complex with increased numbers of options. It is impossible to remove inconsistency in the AHP process. However, a score above 10% is not desirable. The acceptable limit for the consistency ratio should be at or below 10% for the result to be deemed truly valid (Saaty & Vargas 2013).
The consistency ratio is calculated by first taking the sum of each column and then multiplying by the normalized eigenvector (see Table 3.5). The second step involves taking the sum of all the SUMPV figures from which Lambda-max is derived. Third, the consistency index (CI) is calculated using the formula:

$$\frac{(\text{Lambda-Max} - n)}{(n - 1)}$$, where n is equal to the total number of variables in the matrix being analyzed.

The final step in the process is taking the random index (RI) number per Saaty's random index table (Saaty 1980) developed for matrices of different sizes as shown in Table 3.6 and dividing into the CI. The following depicts the calculation of the consistency ratio using the pizza example.

Table 3.5 Preliminary numbers for consistency ratio calculations for pizza example

Criteria	Taste	Texture	Cheesiness	Tomato Paste Richness	Spiciness	Normalized Eigenvector
Taste	1.000	2.000	5.000	5.000	8.000	**0.442**
Texture	0.500	1.000	5.000	5.000	8.000	**0.335**
Cheesiness	0.200	0.200	1.000	1.000	5.000	**0.097**
Tomato Paste Richness	0.200	0.200	1.000	1.000	5.000	**0.097**
Spiciness	0.125	0.125	0.200	0.200	1.000	**0.030**
Sum	**2.025**	**3.525**	**12.200**	**12.200**	**27.000**	**1.000**
Sum PV	0.894	1.180	1.178	1.178	0.823	
Lambda-Max	5.253					

Each column is first summed: the sum of the first column is (1.000+0.500+0.200+0.200+0.125 = 2.025) as shown in the Table 3.5. The process is repeated for all other columns. The next step of multiplying by the weight for the appropriate quality is then undertaken (2.025 x 0.442 = 0.894). Again the process is repeated for all other columns. The Sum PV row in the table shows all the values obtained when all the calculations are completed. The next step is to sum all the numbers in the SUM PV row and from this Lambda-Max is derived (0.894+1.180+1.178+1.178+0.823) = 5.253. The CI is then calculated by using the formula:

$$\frac{(\text{Lambda-Max} - n)}{(n - 1)} \qquad . \qquad CI = \frac{(5.253 - 5)}{(5-1)}$$

$$CI = \mathbf{0.063}$$

The final step includes taking the random index number as shown in Table 3.6 and dividing into the CI. The number of item in the Pizza Analysis matrix is 5; therefore, the random index to be used is 1.12.

$$C.R. = \frac{C.I.}{R.I.}$$

$$C.R = (0.063 / 1.12) \times 100$$

$$C.R. = 5.6\%$$

Based on the AHP analysis, it can be determined that Greg in his pairwise comparison was consistent and that his preferred quality in pizza is Taste followed by Texture; Cheesiness and Tomato Paste Richness tie for third, and Spiciness ranks last as a desired quality.

Table 3.6 Random Index (R.I) according to matrix size (n) (Saaty 1980)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.36	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

3.5 Assessing TSRSs for Implementation in State DOTs

In this framework, AHP is the proposed decision-making tool that will be used to assess the suitability of TSRS for implementation in state DOTs across the United States. The following chapter will present the findings of a case study based on the framework herein presented. AHP was used to derive weights for the capabilities under investigation, indicating their perceived importance by making pairwise comparisons between two factors at a time. Every criterion was compared against all other possible criteria whether they are from the same TSRS or not, and weights were given to each criterion performing the above mentioned mathematical calculations in order to establish which criteria are most important. Then these criteria were matched back to the alternatives to which they belong. Based on the results of this mathematical approach, a recommendation was then made with regard to which alternative should be chosen (Saaty & Vargas 2001).

4. FRAMEWORK IMPLEMENTATION AND FINDINGS

This section presents the findings of four case studies conducted using the four-step methodology that was presented in Chapter 3. The methodology proposed for assessing the suitability of TSRSs was applied to CDOT, SDDOT, UDOT, and WYDOT, and the results are documented herein.

The researcher first conducted a literature review from which TSRSs available for use within the United States were identified. Each system identified was then reviewed to determine the mechanism of each system and their capabilities. A total of 16 capabilities were identified across all 10 systems (see Table 4.1). No system offers all the capabilities identified; however, there were shared capabilities between TSRSs. It is important to note that, for the capability shown in red text in Table 4.1, based on each state DOT's response to step two of the framework, the capability of "Alignment with State DOT's preferred distribution of credits" will apply to a different system in each case study. In fact, "Alignment with State DOT's preferred distribution of credits" is not considered a capability of the rating system but an additional consideration that may influence a DOT's decision to adopt a TSRS.

Once the capabilities of each system were identified, a set of interview questions geared at identifying which capabilities were desired by each state DOT was developed (see Appendix I). The interview questions were structured in three sections: the first containing open-ended questions geared at determining the state of sustainability at the DOT, the second geared at identifying which capabilities were desired by the state DOT, and the third geared toward identifying any additional considerations that may influence a DOT's decision to adopt a particular TSRS.

The next phase of the implementation plan called for the identification of a decision maker within each state DOT. The respective websites of each state DOT included in this study were consulted to determine a suitable contact for addressing issues of sustainability. Once an individual was identified, contact was made via email seeking the individual's consent to participate in the study. Once consent was obtained, an interview was scheduled with each of the four state DOTs included in the study. A copy of the interview questions less section two was sent to each decision maker for their perusal. Section two of the document contained the phrase "will be provided at the time of the interview" in order to make the decision maker aware that there were additional questions not included in the document.

The following sections present the findings with respect to all four state DOTs included in this study based on the interviews conducted (primary survey instrument) and the AHP survey instrument (secondary survey instrument).

4.1 CDOT Implementation

4.1.1 Framework Implementation

Based on an interview conducted with CDOT, of 16 capabilities identified during the literature review, 15 capabilities were desired in a TSRS by CDOT (see Tables 4.2 and 4.4). A transcript of the interview was subsequently prepared and sent to the decision maker at CDOT for confirmation. A secondary survey instrument was then developed using the AHP methodology based on the capabilities identified as being desired (See Appendix II for an example of the instructions for the secondary survey). The survey instrument contained a total of 105 pairwise comparisons to be made by the decision maker. Once the survey was completed, it was returned to the researcher and the mathematical calculations performed to determine the results of the survey.

Table 4.1 Capabilities of transportation sustainability rating systems

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	BEST-in-highways	Envision	GreenLITES	Greenroads	I-LAST	INVEST	Green Guide for Roads	GreenPave	STARS	CEEQUAL
Ability to employ self-assessment	x	☑	☑	x	☑	☑	x	x	☑	x
Ability to evaluate project during conceptual stage	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to evaluate project during design phase	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to evaluate project during construction phase	x	☑	☑	☑	☑	☑	x	☑	☑	☑
Ability to evaluate project during operations and maintenance phase	x	☑	☑	☑	x	☑	x	☑	☑	☑
Ability to allocate weights to criteria	☑	x	☑	x	x	x	x	x	x	x
Ability to choose only relevant criteria to project	x	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to offer a checklist customized to particular types of projects	x	x	x	x	x	☑	x	x	x	x
Ability to award points for Innovation	x	x	☑	☑	☑	x	x	☑	☑	x
Ability to offer prescriptive measures towards achieving credits	☑	x	☑	☑	☑	☑	☑	☑	x	x
Ability to offer performance measures towards achieving credits	x	☑	x	x	x	x	x	x	☑	☑
Ability to compare different project options side by side	☑	x	x	x	x	x	x	x	x	x
Ability to offer an award for the designer, client and contractor	x	x	x	x	x	x	x	x	x	☑
Alignment with State DOT's preferred distribution of credits	**DEPENDS ON THE RESPONSE RECEIVED FROM THE STATE DOT IN STEP 2 OF THE FRAMEWORK**									
Ability to assign a score or an award	☑	☑	☑	☑	☑	☑	☑	☑	x	☑
Ability to employ third party verification	☑	☑	x	☑	x	x	☑	☑	x	☑

(☑ - TSRS has capability, x - TSRS does not have capability)

Table 4.2 Capabilities of transportation sustainability rating systems desired by CDOT

CHARACTERISTICS DESIRED IN A SUSTAINABILITY RATING SYSTEM	***YES***	***NO***
Ability to assign a score or an award	☑	
Ability to employ self-assessment	☑	
Ability to evaluate project during conceptual stage	☑	
Ability to evaluate project during design phase	☑	
Ability to evaluate project during construction phase	☑	
Ability to evaluate project during operations and maintenance phase	☑	
Ability to allocate weights to criteria	☑	
Ability to choose only relevant criteria to project	☑	
Ability to offer a checklist customized to particular types of projects	☑	
Ability to award points for Innovation	☑	
Ability to offer prescriptive measures towards achieving credits	☑	
Ability to offer performance measures towards achieving credits	☑	
Ability to compare different project options side by side	☑	
Ability to offer an award for the designer, client and contractor	☑	
Alignment with State DOT's preferred distribution of credits	☑	
Ability to employ third party verification		☑

The consistency ratio for CDOT was 14.55%, which falls slightly outside the recommended limit of 10% as specified by Saaty (Saaty & Vargas 2013). This was, however, expected because of the number of pairwise comparisons that were being made. The higher the number of pairwise comparisons being made the higher the consistency ratio will be (Saaty & Vargas 2001). Another factor that added to these results was that single person AHP was chosen for this study instead of the group AHP method. A better result could have been arrived at had group AHP been the method chosen for this study as individual preferences could be aggregated and made cardinal instead of ordinal, thereby giving a more balanced result (Saaty & Vargas 2013). Based on the results received from CDOT, the capability that is most desired is the "Ability to employ self-assessment" as this capability received a weighting of 0.186, followed by the "Ability to offer a checklist customized to particular types of projects" (see Table 4.3).

Based on the weightings received by each capability, a summary was conducted to determine the scores of each TSRS. This was done by populating Table 4.4 with the scores of each capability. The weighting assigned to each capability by CDOT was inserted in the corresponding cells that had a tick (☑). The sum was then taken of each column in order to determine the total score of each TSRS. Based on the results of this exercise, as shown in Table 4.5, the TSRSs obtained the following ranks in order of CDOT's preferences: 1st – Invest, 2nd – STARS, 3rd – Envision, 4th – GreenLITES, 5th – I-LAST, 6th – CEEQUAL, 7th – GreenPave, 8th – Greenroads, 9th – Best-in-Highways, and 10th – Green Guide for Roads. Based on the analysis, Invest was found to be the most suitable TSRS for CDOT gaining a weighting of 77% from CDOT. Second was STARS at 70%, and third was Envision at 69%.

Table 4.3 Normalized eigenvector (weights) of the capabilities of transportation sustainability rating systems for CDOT

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	Normalized Eigenvector
Ability to assign a score or an award	0.044
Ability to employ self-assessment	0.186
Ability to evaluate project during conceptual stage	0.015
Ability to evaluate project during design phase	0.146
Ability to evaluate project during construction phase	0.145
Ability to evaluate project during operations and maintenance phase	0.027
Ability to allocate weights to criteria	0.011
Ability to choose only relevant criteria to project	0.031
Ability to offer a checklist customized to particular types of projects	0.161
Ability to award points for Innovation	0.054
Ability to offer prescriptive measures towards achieving credits	0.010
Ability to offer performance measures towards achieving credits	0.097
Ability to compare different project options side by side	0.029
Ability to offer an award for the designer, client and contractor	0.034
Alignment with State DOT's preferred distribution of credits	0.011

4.1.2 Other Considerations

Based on the results of the AHP methodology, Invest is the most suitable TSRS to be adopted for implementation by CDOT. Other considerations expressed by CDOT in the interview process that could not be quantified using the AHP methodology may, however, affect the suitability of Invest for adoption by CDOT. CDOT expressed a concern for the establishment of a baseline by the TSRS, as it was noted to be a difficult task for the DOT to do on its own. Invest establishes a baseline through the minimum amount of points needed in order to receive an award under the system, as well as through the setting out of goals at the beginning of each criteria.

Another concern expressed by CDOT was the "why" factor. It is the wish of CDOT that the TSRS being adopted would have an intent specified for each criteria included in a project. Invest addresses this concern through the inclusion of a sustainability linkage section in which it presents each criterion, therefore establishing a "why" for each action to be taken in a project.

Finally, it was expressly stated in the selection of the capabilities desired that CDOT does not desire a TSRS that employed a third-party assessment. In this one area, Invest is unsuitable for CDOT as it employs third-party assessment. CDOT could opt, however, to adapt the Invest TSRS to be one of self-

Table 4.4 Capabilities desired by CDOT across transportation sustainability rating systems

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	BEST-in-highways	Envision	GreenLITES	Greenroads	I-LAST	INVEST	Green Guide for Roads	GreenPave	STARS	CEEQUAL
Ability to assign a score or an award	☑	☑	☑	☑	☑	☑	☑	☑	x	☑
Ability to employ self-assessment	x	☑	☑	x	☑	☑	x	x	☑	x
Ability to evaluate project during conceptual stage	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to evaluate project during design phase	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to evaluate project during construction phase	x	☑	☑	☑	☑	☑	x	☑	☑	☑
Ability to evaluate project during operations and maintenance phase	x	☑	☑	☑	x	☑	x	☑	☑	☑
Ability to allocate weights to criteria	☑	x	☑	x	x	x	x	x	x	x
Ability to choose only relevant criteria to project	x	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to offer a checklist customized to particular types of projects	x	x	x	x	x	☑	x	x	x	x
Ability to award points for Innovation	x	x	☑	☑	☑	x	x	☑	☑	x
Ability to offer prescriptive measures towards achieving credits	☑	x	☑	☑	☑	☑	☑	☑	x	x
Ability to offer performance measures towards achieving credits	x	☑	x	x	x	x	x	x	☑	☑
Ability to compare different project options side by side	☑	x	x	x	x	x	x	x	x	x
Ability to offer an award for the designer, client and contractor	x	x	x	x	x	x	x	x	x	☑
Alignment with State DOT's preferred distribution of credits	x	x	x	x	x	x	x	☑	x	x

(☑ - TSRS has capability, x - TSRS does not have capability)

Table 4.5 Ranking of transportation sustainability rating systems based on the summed weighting of the capabilities for CDOT

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	Normalized Eigenvector	BEST-in-highways	Envision	GreenLITES	Greenroads	I-LAST	INVEST	Green Guide for Roads	GreenPave	STARS	CEEQUAL
Ability to assign a score or an award	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	x	0.044
Ability to employ self-assessment	0.186	x	0.186	0.186	x	0.186	0.186	x	x	0.186	x
Ability to evaluate project during conceptual stage	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Ability to evaluate project during design phase	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146
Ability to evaluate project during construction phase	0.145	x	0.145	0.145	0.145	0.145	0.145	x	0.145	0.145	0.145
Ability to evaluate project during operations and maintenance phase	0.027	x	0.027	0.027	0.027	x	0.027	x	0.027	0.027	0.027
Ability to allocate weights to criteria	0.011	0.011	x	0.011	x	x	x	x	x	x	x
Ability to choose only relevant criteria to project	0.031	x	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
Ability to offer a checklist customized to particular types of projects	0.161	x	x	x	x	x	0.161	x	x	x	x
Ability to award points for Innovation	0.054	x	x	0.054	0.054	0.054	x	x	0.054	0.054	x
Ability to offer prescriptive measures towards achieving credits	0.010	0.010	x	0.010	0.010	0.010	0.010	0.010	0.010	x	x
Ability to offer performance measures towards achieving credits	0.097	x	0.097	x	x	x	x	x	x	0.097	0.097
Ability to compare different project options side by side	0.029	0.029	x	x	x	x	x	x	x	x	x
Ability to offer an award for the designer, client and contractor	0.034	x	x	x	x	x	x	x	x	x	0.034
Alignment with State DOT's preferred distribution of credits	0.011	x	x	x	x	x	x	x	0.011	x	x
TOTAL	**1.000**	**0.254**	**0.692**	**0.669**	**0.472**	**0.631**	**0.765**	**0.246**	**0.483**	**0.701**	**0.540**
Ranking		**9**	**3**	**4**	**8**	**5**	**1**	**10**	**7**	**2**	**6**

assessment. Otherwise, the second best TSRS, STARS, as established through the AHP methodology, could be adopted as it does not employ third-party evaluation.

It must be noted that STARS may eventually employ self-assessment, as the system is currently under development to include scoring and assessment. Envision, which placed third, also employs third-party evaluation but is also developed to be used for self-assessment.

4.1.3 Recommendation

Based on the findings of this study, it is the recommendation of the researcher that CDOT adopt and adapt Invest TSRS in the assessment of sustainability of its projects. Overall, it is the most suitable option based on the AHP methodology as well as the other considerations expressed by CDOT. Further research into the suitability of the Invest TSRS is recommended before the adoption of the system.

4.2 SDDOT Implementation

4.2.1 Framework Implementation

Based on the interview conducted with SDDOT, of 16 capabilities identified during the literature review, 12 capabilities were desired in a TSRS by SDDOT (see Tables 4.6 and 4.8). A transcript of the interview was subsequently prepared and sent to the decision maker at SDDOT for confirmation. A secondary survey instrument was then developed using the AHP methodology based on the capabilities identified as being desired. The survey instrument contained a total of 66 pairwise comparisons to be made by the decision maker. Once the survey was completed, it was returned to the researcher and the mathematical calculations were assessed to determine the results of the survey.

The consistency ratio for SDDOT was 14.32%, which also falls slightly outside the recommended limit of 10% as specified by Saaty (Saaty & Vargas 2013). Based on the results received from SDDOT, the capability most desired is the "Ability to employ self-assessment" as this capability received a weighting of 0.187 (see figure 4.7). The weightings received by each capability facilitated the development of a summary aimed at determining the scores of each TSRS. This was done by populating Table 4.8 with the scores of each capability. The weighting assigned to each capability by SDDOT was inserted in the corresponding cells that had a tick (☑). The sum was then taken of each column in order to determine the total score of each TSRS (see Table 4.8).

Based on the results of this exercise, as shown in Table 4.9, the TSRSs obtained the following ranks in order of SDDOTs preferences: 1st – GreenLITES, 2nd – Invest, 3rd – STARS, 4th – I-LAST, 5th – Envision, 6th – Best-in-Highways, 7th – Greenroads and GreenPave, 9th – CEEQUAL, and 10th – Green Guide for Roads (see Figure 4.7). GreenLITES was found to be the most suitable TSRS for SDDOT, gaining a weighting of 72% from SDDOT, with STARS second at 70% and Envision third at 59%.

4.2.2 Other Considerations

Based on the results of the AHP methodology, GreenLITES is the most suitable TSRS to be adopted for implementation by SDDOT. Other considerations expressed by SDDOT in the interview process that could not be quantified using the AHP methodology may, however, affect the suitability of GreenLITES for adoption by SDDOT. SDDOT expressed a desire to have a system that offered some level of flexibility and was tailored to the rural conditions of South Dakota; in particular, it made a direct comparison to the conditions in New York State as a benchmark for urban conditions.
GreenLITES was developed by the New York State DOT and as such is more tailored to an urban region with coastal areas. Although the system was developed specifically for New York, there are certain

features that enable the adaption of the system for rural settings. First, one capability of the TSRS is that it allows the user to allocate a weighting to the criteria contained in the system. As such, the user can rank the relative importance of criteria through the assignment of weights based on the setting of the project being assessed. For example, in a less populated area, social concerns may not be as important as environmental concerns. As such, an environmental criterion may be ranked higher in an area where there are more environmental concerns than social considerations.

Second, the system allows the exclusion or inclusion of criteria to a project. The user is at liberty, within reason, to include only those criteria deemed necessary to the assessment exercise for projects being assessed using the GreenLITES TSRS. As such, criteria that are unsuitable to the rural conditions of South Dakota projects can be excluded from project assessments.

Based on the AHP results, Invest TSRS is the second suitable system to be adopted by SDDOT. Areas in which it did not fulfill the requirements of SDDOT are in the TSRS's inability to allow the allocation of a weighting to criteria as well as its inability to award points for innovation. The system does, however, offer two key capabilities that may sway SDDOT's decision. First, Invest TSRS allows the user the ability to choose relevant criteria through its custom checklist feature where a checklist may be developed for each project. The user may go through the criteria offered under the system and include or exclude them from a project.

Table 4.6 Capabilities of transportation sustainability rating systems desired by SDDOT

CHARACTERISTICS DESIRED IN A SUSTAINABILITY RATING SYSTEM	**YES**	**NO**
Ability to assign a score or an award		☑
Ability to employ self-assessment	☑	
Ability to evaluate project during conceptual stage	☑	
Ability to evaluate project during design phase	☑	
Ability to evaluate project during construction phase		☑
Ability to evaluate project during operations and maintenance phase		☑
Ability to allocate weights to criteria	☑	
Ability to choose only relevant criteria to project	☑	
Ability to offer a checklist customized to particular types of projects	☑	
Ability to award points for Innovation	☑	
Ability to offer prescriptive measures towards achieving credits	☑	
Ability to offer performance measures towards achieving credits	☑	
Ability to compare different project options side by side	☑	
Ability to offer an award for the designer, client and contractor	☑	
Alignment with State DOT's preferred distribution of credits	☑	
Ability to employ third party verification		☑

Table 4.7 Normalized eigenvector weights of the capabilities of transportation sustainability rating systems for SDDOT

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	Normalized Eigenvector
Ability to employ self-assessment	0.187
Ability to evaluate project during conceptual stage	0.127
Ability to evaluate project during design phase	0.056
Ability to allocate weights to criteria	0.138
Ability to choose only relevant criteria to project	0.166
Ability to offer a checklist customized to particular types of projects	0.127
Ability to award points for Innovation	0.035
Ability to offer prescriptive measures towards achieving credits	0.012
Ability to offer performance measures towards achieving credits	0.016
Ability to compare different project options side by side	0.100
Ability to offer an award for the designer, client and contractor	0.016
Alignment with State DOT's preferred distribution of credits	0.018

Second, it has predesigned custom checklists that may be selected based on the types of projects or location of projects being undertaken. In particular, it has a rural checklist, which could be adopted by SDDOT. If the rural checklist still includes criteria deemed to be irrelevant, the predesigned checklist could serve as a baseline in the development of a "custom" checklist.

4.2.3 Recommendation

Based on the findings of the AHP survey, it is the recommendation of the researcher that SDDOT adopt and adapt the GreenLITES TSRS in the assessment of sustainability of its projects. Overall, it is the most suitable option based on the AHP methodology as well as the other considerations expressed by SDDOT. Further research into the suitability of the GreenLITES TSRS is recommended before the adoption of the system.

Table 4.8 Capabilities desired by SDDOT across transportation sustainability rating systems

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	BEST-in-highways	Envision	GreenLITES	Greenroads	I-LAST	INVEST	Green Guide for Roads	GreenPave	STARS	CEEQUAL
Ability to employ self-assessment	x	☑	☑	x	☑	☑	x	x	☑	x
Ability to evaluate project during conceptual stage	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to evaluate project during design phase	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to allocate weights to criteria	☑	x	☑	x	x	x	x	x	x	x
Ability to choose only relevant criteria to project	x	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to offer a checklist customized to particular types of projects	x	x	x	x	x	☑	x	x	x	x
Ability to award points for Innovation	x	x	☑	☑	☑	x	x	☑	☑	x
Ability to offer prescriptive measures towards achieving credits	☑	x	☑	☑	☑	☑	☑	☑	x	x
Ability to offer performance measures towards achieving credits	x	☑	x	x	x	x	x	x	☑	☑
Ability to compare different project options side by side	☑	x	x	x	x	x	x	x	x	x
Ability to offer an award for the designer, client and contractor	x	x	x	x	x	x	x	x	x	☑
Alignment with State DOT's preferred distribution of credits	x	x	x	x	x	☑	x	x	x	x

(☑ - TSRS has capability, x - TSRS does not have capability)

Table 4.9 Ranking of transportation sustainability rating systems based on the summed weighting of the capabilities for SDDOT

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	Normalized Eigenvector	BEST- in-highways	Envision	GreenLITES	Greenroads	I-LAST	INVEST	Green Guide for Roads	GreenPave	STARS	CEEQUAL
Ability to employ self-assessment	0.187	x	0.187	0.187	x	0.187	0.187	x	x	0.187	x
Ability to evaluate project during conceptual stage	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.127
Ability to evaluate project during design phase	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
Ability to allocate weights to criteria	0.138	0.138	x	0.138	x	x	x	x	x	x	x
Ability to choose only relevant criteria to project	0.166	x	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166
Ability to offer a checklist customized to particular types of projects	0.127	x	x	x	x	x	0.127	x	x	x	x
Ability to award points for Innovation	0.035	x	x	0.035	0.035	0.035	x	x	0.035	0.035	x
Ability to offer prescriptive measures towards achieving credits	0.012	0.012	x	0.012	0.012	0.012	0.012	0.012	0.012	x	x
Ability to offer performance measures towards achieving credits	0.016	x	0.016	x	x	x	x	x	x	0.016	0.016
Ability to compare different project options side by side	0.100	0.100	x	x	x	x	x	x	x	x	x
Ability to offer an award for the designer, client and contractor	0.016	x	x	x	x	x	x	x	x	x	0.016
Alignment with State DOT's preferred distribution of credits	0.018	x	x	x	x	x	0.018	x	x	x	x
TOTAL	**1.000**	**0.433**	**0.553**	**0.721**	**0.396**	**0.583**	**0.694**	**0.361**	**0.396**	**0.588**	**0.382**
Ranking		**6**	**5**	**1**	**7**	**4**	**2**	**10**	**7**	**3**	**9**

4.3 UDOT Implementation

4.3.1 Framework Implementation

Based on the interview conducted with UDOT, of 16 capabilities identified during the literature review, 15 capabilities were desired in a TSRS by UDOT (see Table 4.10 and 4.12). A transcript of the interview was subsequently prepared and sent to the decision maker at UDOT for confirmation. A secondary survey instrument was then developed using the AHP methodology based on the capabilities identified as being desired. The survey instrument contained a total of 105 pairwise comparisons to be made by the decision maker. Once the survey was completed, it was returned to the researcher, and the mathematical calculations were assessed to determine the results of the survey.

Table 4.10 Capabilities of transportation sustainability rating systems desired by UDOT

CHARACTERISTICS DESIRED IN A SUSTAINABILITY RATING SYSTEM	YES	NO
Ability to assign a score or an award	☑	
Ability to employ self-assessment	☑	
Ability to evaluate project during conceptual stage	☑	
Ability to evaluate project during design phase	☑	
Ability to evaluate project during construction phase	☑	
Ability to evaluate project during operations and maintenance phase	☑	
Ability to allocate weights to criteria	☑	
Ability to choose only relevant criteria to project	☑	
Ability to offer a checklist customized to particular types of projects	☑	
Ability to award points for Innovation	☑	
Ability to offer prescriptive measures towards achieving credits	☑	
Ability to offer performance measures towards achieving credits	☑	
Ability to compare different project options side by side	☑	
Ability to offer an award for the designer, client and contractor	☑	
Alignment with State DOT's preferred distribution of credits	☑	
Ability to employ third party verification		☑

The consistency ratio for UDOT was 40.05%, which falls far outside the recommended limit of 10% as specified by Saaty (Saaty & Vargas 2001). As a result of the large consistency ratio, the results of the AHP methodology are deemed to be inconclusive. Large consistency ratios are common in AHP exercises that have larger numbers of pairwise comparisons. One method used to remedy this problem is the use of the group AHP method, which allows the averaging of results (Saaty & Vargas 2013). Due to the time constraints, however, this method was not used in this survey. Another method that could be used to reduce the chances of arriving at a high consistency ratio is software that highlights the consistency ratio while the decision maker is completing the survey. This would provide a direct check-and-balance system that would highlight to the decision maker the decisions that lead to a high consistency ratio and allow the correction of these errors before the survey is submitted to the researcher.

Another method recently developed to address high consistency ratios is the Improved AHP methodology (IAHP), which was published in the *Journal of Construction Engineering and Management* in March 2013 (Zhang 2013). It proposes the use of ranking and sorting methodology that seeks the selection of the highest ranked item from the list of available options; and it is first compared to the other items in the list. Once that criterion has been compared, it is moved from the list as the most important, and the others are compared using the same process (Zhang 2013). This research project was developed before the findings of the IAHP were published and as such, the researcher was unaware of a new AHP method suitable for multi-criteria decision making. It is the recommendation of the researcher that the improved IAHP method be employed in situations where there are larger quantities of pairwise comparisons being made.

Table 4.11 Normalized eigenvector weights of the capabilities of transportation sustainability rating systems for UDOT

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	Normalized Eigenvector
Ability to assign a score or an award	0.020
Ability to employ self-assessment	0.075
Ability to evaluate project during conceptual stage	0.014
Ability to evaluate project during design phase	0.262
Ability to evaluate project during construction phase	0.058
Ability to evaluate project during operations and maintenance phase	0.093
Ability to allocate weights to criteria	0.029
Ability to choose only relevant criteria to project	0.046
Ability to offer a checklist customized to particular types of projects	0.155
Ability to award points for Innovation	0.097
Ability to offer prescriptive measures towards achieving credits	0.027
Ability to offer performance measures towards achieving credits	0.062
Ability to compare different project options side by side	0.023
Ability to offer an award for the designer, client and contractor	0.018
Alignment with State DOT's preferred distribution of credits	0.020

Although the results of the AHP methodology for UDOT are inconclusive, they will be discussed in the following sections. For UDOT, the capability most desired is the "Ability to evaluate project during the design phase" as this capability received a weighting of 0.262 (see Table 4.11). The weightings received by each capability facilitated the development of a summary aimed at determining the scores of each TSRS. This was done by populating Table 4.12 with the scores of each capability. The weighting assigned to each capability by UDOT was inserted in the corresponding cells with a tick (☑). The sum was then taken of each column in order to determine the total score of each TSRS.

Based on the results of this exercise, as shown in Table 4.13, the TSRSs obtained the following ranks in order of UDOT's preferences: 1st – Invest, 2nd – GreenLITES, 3rd – STARS, 4th – GreenPave, 5th – Envision, 6th – Greenroads, 7th – I-LAST, 8th – CEEQUAL, 9th – Best-in-Highways, and 10th – Green Guide for Roads.

4.3.2 Other Considerations

Based on the results of the AHP methodology, Invest is the most suitable TSRS to be adopted for implementation by UDOT. However, it is important to note that the results were inconclusive based on the consistency ratio of the AHP survey. UDOT previously pilot tested the Operations and Maintenance checklist of the Invest TSRS and the results were published in the launch of the Invest 2.0 program. According to the report, UDOT successfully incorporated the Invest Operation and Maintenance tool into its project assessment process. This is indicative of the suitability of Invest for UDOT project sustainability assessment.

4.3.3 Recommendation

Based on the findings of the AHP survey, it is the recommendation of the researcher that further research be conducted into the suitability of a particular TSRS for UDOT using the Improved AHP methodology or a group AHP methodology. The IAHP can be substituted into the AHP framework to assess the suitability of a TSRS for implementation at UDOT. Given the discussion previously presented, no conclusive recommendation can be made with regard to a specific TSRS for adoption by UDOT based on the results of this study.

Table 4.12 Capabilities desired by UDOT across transportation sustainability rating systems

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	**BEST- in-highways**	**Envision**	**GreenLITES**	**Greenroads**	**I-LAST**	**INVEST**	**Green Guide for Roads**	**GreenPave**	**STARS**	**CEEQUAL**
Ability to assign a score or an award	x	☑	☑	x	☑	☑	x	x	☑	x
Ability to employ self-assessment	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to evaluate project during conceptual stage	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to evaluate project during design phase	x	☑	☑	☑	x	☑	x	☑	☑	☑
Ability to evaluate project during construction phase	☑	x	☑	x	x	x	x	x	x	x
Ability to evaluate project during operations and maintenance phase	x	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to allocate weights to criteria	x	x	x	x	x	☑	x	x	x	x
Ability to choose only relevant criteria to project	x	x	☑	☑	☑	x	x	☑	☑	x
Ability to offer a checklist customized to particular types of projects	☑	x	☑	☑	☑	☑	☑	☑	x	x
Ability to award points for Innovation	x	☑	x	x	x	x	x	x	☑	☑
Ability to offer prescriptive measures towards achieving credits	☑	x	x	x	x	x	x	x	x	x
Ability to offer performance measures towards achieving credits	x	x	x	x	x	x	x	x	x	☑
Ability to compare different project options side by side	x	x	x	x	x	x	x	☑	x	x
Ability to offer an award for the designer, client and contractor	☑	☑	☑	☑	☑	☑	☑	☑	x	☑
Alignment with State DOT's preferred distribution of credits	☑	☑	x	☑	x	x	☑	☑	x	☑

(☑ - TSRS has capability, x - TSRS does not have capability)

Table 4.13 Ranking of transportation sustainability rating systems based on the summed weighting of the capabilities for UDOT

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	Normalized Eigenvector	BEST-in-highways	Envision	GreenLITES	Greenroads	I-LAST	INVEST	Green Guide for Roads	GreenPave	STARS	CEEQUAL
Ability to assign a score or an award	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	x	0.020
Ability to employ self-assessment	0.075	x	0.075	0.075	x	0.075	0.075	x	x	0.075	x
Ability to evaluate project during conceptual stage	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Ability to evaluate project during design phase	0.262	0.262	0.262	0.262	0.262	0.262	0.262	0.262	0.262	0.262	0.262
Ability to evaluate project during construction phase	0.058	x	0.058	0.058	0.058	0.058	0.058	x	0.058	0.058	0.058
Ability to evaluate project during operations and maintenance phase	0.093	x	0.093	0.093	0.093	x	0.093	x	0.093	0.093	0.093
Ability to allocate weights to criteria	0.029	0.029	x	0.029	x	x	x	x	x	x	x
Ability to choose only relevant criteria to project	0.046	x	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
Ability to offer a checklist customized to particular types of projects	0.155	x	x	x	x	x	0.155	x	x	x	x
Ability to award points for Innovation	0.097	x	x	0.097	0.097	0.097	x	x	0.097	0.097	x
Ability to offer prescriptive measures towards achieving credits	0.027	0.027	x	0.027	0.027	0.027	0.027	0.027	0.027	x	x
Ability to offer performance measures towards achieving credits	0.062	x	0.062	x	x	x	x	x	x	0.062	0.062
Ability to compare different project options side by side	0.023	0.023	x	x	x	x	x	x	x	x	x
Ability to offer an award for the designer, client and contractor	0.018	x	x	x	x	x	x	x	x	x	0.018
Alignment with State DOT's preferred distribution of credits	0.020	x	x	x	x	x	x	x	0.020	x	x
TOTAL	**1.000**	**0.375**	**0.630**	**0.721**	**0.617**	**0.599**	**0.750**	**0.369**	**0.637**	**0.707**	**0.572**
Ranking		**9**	**5**	**2**	**6**	**7**	**1**	**10**	**4**	**3**	**8**

4.4 WYDOT Implementation

4.4.1 Framework Implementation

Based on the interview conducted with the Wyoming State DOT, of 16 capabilities identified during the literature review, 13 capabilities were desired in a TSRS by WYDOT (see Table 4.14). A transcript of the interview was subsequently prepared and sent to the decision maker at WYDOT for confirmation. A secondary survey instrument was then developed using the AHP methodology based on the capabilities identified as being desired. The survey instrument contained a total of 78 pairwise comparisons to be made by the decision maker. Once the survey was completed, it was returned to the researcher and the mathematical calculations assessed to determine the results of the survey.

The consistency ratio for WYDOT was 13.88%, which also falls slightly outside the recommended limit of 10% as specified by Saaty (Saaty & Vargas 2013). Based on the results received from WYDOT, the capability most desired is the "Ability to offer performance measures towards achieving credits" as this capability received a weighting of 0.184 (see Table 4.15). The weightings received by each capability facilitated the development of a summary aimed at determining the scores of each TSRS. This was done by populating Table 4.16 with the scores of each capability. The weighting assigned to each capability by WYDOT was inserted in the corresponding cells with a tick (☑). The sum was then taken of each column in order to determine the total score of each TSRS.

Table 4.14 Capabilities of transportation sustainability rating systems desired by WYDOT

CHARACTERISTICS DESIRED IN A SUSTAINABILITY RATING SYSTEM	YES	NO
Ability to assign a score or an award		☑
Ability to employ self-assessment	☑	
Ability to evaluate project during conceptual stage	☑	
Ability to evaluate project during design phase	☑	
Ability to evaluate project during construction phase		☑
Ability to evaluate project during operations and maintenance phase	☑	
Ability to allocate weights to criteria	☑	
Ability to choose only relevant criteria to project	☑	
Ability to offer a checklist customized to particular types of projects	☑	
Ability to award points for Innovation	☑	
Ability to offer prescriptive measures towards achieving credits	☑	
Ability to offer performance measures towards achieving credits	☑	
Ability to compare different project options side by side	☑	
Ability to offer an award for the designer, client and contractor	☑	
Alignment with State DOT's preferred distribution of credits	☑	
Ability to employ third party verification		☑

Based on the results of this exercise, as shown in Table 4.17, the TSRSs obtained the following ranks in order or WYDOTs preferences: 1st – Invest, 2nd – STARS, 3rd – GreenLITES, 4th – Envision, 5th – CEEQUAL, 6th – Best-in-Highways, 7th – Greenroads and GreenPave, 9th – I-LAST, and 10th – Green Guide for Roads. Invest was found to be the most suitable TSRS for WYDOT receiving a weighting of 52% from WYDOT, with STARS second at 49% and GreenLITES at 48%.

Table 4.15 Normalized eigenvector weights of the capabilities of transportation sustainability rating systems for WYDOT

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	Normalized Eigenvector
Ability to employ self-assessment	0.046
Ability to evaluate project during conceptual stage	0.017
Ability to evaluate project during design phase	0.075
Ability to evaluate project during operations and maintenance phase	0.094
Ability to allocate weights to criteria	0.111
Ability to choose only relevant criteria to project	0.053
Ability to offer a checklist customized to particular types of projects	0.027
Ability to award points for Innovation	0.022
Ability to offer prescriptive measures towards achieving credits	0.063
Ability to offer performance measures towards achieving credits	0.184
Ability to compare different project options side by side	0.152
Ability to offer an award for the designer, client and contractor	0.016
Alignment with State DOT's preferred distribution of credits	0.141

4.4.2 Other Considerations

Based on the results of the AHP methodology, Invest is the most suitable TSRS to be adopted for implementation by WYDOT. Other considerations expressed by WYDOT in the interview process that could not be quantified using the AHP methodology may, however, affect the suitability of Invest for adoption by WYDOT. WYDOT's main concern relates to the rural nature of Wyoming and the fact that not all sustainability measures will be applicable to Wyoming. For example, the main mode of transportation in Wyoming is motor vehicles because of the long distances that residents travel. As such, bicycle lanes would be a wasted resource as it is not a practical mode of transportation. Invest is ideal for such situations as it has a rural checklist, which can be adopted for project sustainability assessment in areas with a larger proportion of rural to urban areas. The checklist is designed to address issues such as the best modes of transportation among other concerns that would arise in a rural area. There is also the option of developing a custom checklist based on the type of project being assessed by the state DOT. The state DOT can choose the criteria deemed to be relevant on a project-by-project basis and exclude those that are irrelevant, all within reason. The system, however, does not offer the assignment of weights to criteria, and project teams will have to accept the predefined weights assigned to criteria by the developers of the system.

4.2.3 Recommendation

Based on the findings of the AHP survey, it is the recommendation of the researcher that WYDOT adopt and adapt the Invest TSRS in the assessment of sustainability of its projects. Overall, it is the most suitable option based on the AHP methodology as well as the other considerations expressed by WYDOT. Further research into the suitability of the Invest TSRS is recommended before the adoption of the system.

Table 4.16 Capabilities desired by WYDOT across transportation sustainability rating systems

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	BEST- in-highways	Envision	GreenLITES	Greenroads	I-LAST	INVEST	Green Guide for Roads	GreenPave	STARS	CEEQUAL
Ability to employ self-assessment	x	☑	☑	x	☑	☑	x	x	☑	x
Ability to evaluate project during conceptual stage	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to evaluate project during design phase	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to evaluate project during operations and maintenance phase	x	☑	☑	☑	x	☑	x	☑	☑	☑
Ability to allocate weights to criteria	☑	x	☑	x	x	x	x	x	x	x
Ability to choose only relevant criteria to project	x	☑	☑	☑	☑	☑	☑	☑	☑	☑
Ability to offer a checklist customized to particular types of projects	x	x	x	x	x	☑	x	x	x	x
Ability to award points for Innovation	x	x	☑	☑	☑	x	x	☑	☑	x
Ability to offer prescriptive measures towards achieving credits	☑	x	☑	☑	☑	☑	☑	☑	x	x
Ability to offer performance measures towards achieving credits	x	☑	x	x	x	x	x	x	☑	☑
Ability to compare different project options side by side	☑	x	x	x	x	x	x	x	x	x
Ability to offer an award for the designer, client and contractor	x	x	x	x	x	x	x	x	x	☑
Alignment with State DOT's preferred distribution of credits	x	x	x	x	x	☑	x	x	x	x

(☑ - TSRS has capability, x - TSRS does not have capability)

Table 4.17 Ranking of transportation sustainability rating systems based on the summed weighting of the capabilities for WYDOT

CAPABILITIES OF TRANSPORTATION SUSTAINABITY RATING SYSTEMS (TSRSs)	Normalized Eigenvector	BEST-in-highways	Envision	GreenLITES	Greenroads	I-LAST	INVEST	Green Guide for Roads	GreenPave	STARS	CEEQUAL
Ability to employ self-assessment	0.046	x	0.046	0.046	x	0.046	0.046	x	x	0.046	x
Ability to evaluate project during conceptual stage	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
Ability to evaluate project during design phase	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
Ability to evaluate project during operations and maintenance phase	0.094	x	0.094	0.094	0.094	x	0.094	x	0.094	0.094	0.094
Ability to allocate weights to criteria	0.111	0.111	x	0.111	x	x	x	x	x	x	x
Ability to choose only relevant criteria to project	0.053	x	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
Ability to offer a checklist customized to particular types of projects	0.027	x	x	x	x	x	0.027	x	x	x	x
Ability to award points for Innovation	0.022	x	x	0.022	0.022	0.022	x	x	0.022	0.022	x
Ability to offer prescriptive measures towards achieving credits	0.063	0.063	x	0.063	0.063	0.063	0.063	0.063	0.063	x	x
Ability to offer performance measures towards achieving credits	0.184	x	0.184	x	x	x	x	x	x	0.184	0.184
Ability to compare different project options side by side	0.152	0.152	x	x	x	x	x	x	x	x	x
Ability to offer an award for the designer, client and contractor	0.016	x	x	x	x	x	x	x	x	x	0.016
Alignment with State DOT's preferred distribution of credits	0.141	x	x	x	x	x	0.141	x	x	x	x
TOTAL	**1.000**	**0.417**	**0.469**	**0.480**	**0.323**	**0.275**	**0.515**	**0.207**	**0.323**	**0.491**	**0.439**
Ranking		**6**	**4**	**3**	**7**	**9**	**1**	**10**	**7**	**2**	**5**

5. CONCLUSIONS

5.1 Summary of Research

The purpose of this study was to develop a framework that can be used by state DOTs in the United States for assessing Transportation Sustainability Rating Systems (TSRS) for adoption. TSRSs have become critical planning indicators for DOTs; however, the capabilities of existing TSRSs vary widely. In addition, the preferences of individual DOTs with regard to TSRS capabilities also vary considerably. A need exists to assist DOTs to establish which TSRS is best suited to their preferences. The framework facilitates the identification of the most preferred capabilities in a TSRS for a state DOT and matches available capabilities of existing TSRSs to that state DOT's preferences. The framework was deemed necessary as it has become common practice to develop highway projects sustainably, paying attention to the societal, environmental, and economic impact of projects. Sustainability rating systems have been widely accepted as a way of quantifying how sustainable construction projects are; and several systems have in recent years been developed to assess the sustainability of highway projects. Not all systems will be suitable for all state DOTs; and as such, an assessment into the suitability of each system is necessary before one is adopted by a given state DOT.

The scope of this project was limited to assessing existing TSRSs available for use within the United States and not the development of an entirely new TSRS.

The development of the framework was based on qualitative and quantitative methods and consisted of the following steps:

1. a literature review of available TSRSs for use in the United States to determine capabilities
2. an interview with the state DOT to determine which capabilities are desired in a TSRS
3. the development of a secondary survey instrument based on the AHP methodology to allow the assignment of weights to the desired capabilities as identified in step 2
4. an assessment of TSRSs to identify the most suitable TSRS for implementation in the state DOT using the results of the AHP survey

5.2 Implementation Examples

The framework was implemented for four state DOTs: CDOT, SDDOT, UDOT, and WYDOT. The objective was to determine the most suitable TSRS for each state DOT using the developed framework. The implementation of the framework is briefly summarized below for each state DOT included in the implementation case study.

Step 1 - A literature review was conducted that yielded 10 TSRSs available for use in the United States: BEST-in-Highways, Envision, GreenLITES, Greenroads, I-LAST, Invest, CEEQUAL, Green Guide for Roads, GreenPave, and STARS. A review of each of the 10 systems revealed the 16 capabilities of TSRS; they are:

1. Ability to assign a score or an award
2. Ability to employ self-assessment
3. Ability to evaluate project during conceptual stage
4. Ability to evaluate project during design phase
5. Ability to evaluate project during construction phase
6. Ability to evaluate project during operations and maintenance phase
7. Ability to allocate weights to criteria
8. Ability to choose only relevant criteria to project

9. Ability to offer a checklist customized to particular types of projects
10. Ability to award points for innovation
11. Ability to offer prescriptive measures toward achieving credits
12. Ability to offer performance measures toward achieving credits
13. Ability to compare different project options side by side
14. Ability to offer an award for the designer, client, and contractor
15. Alignment with state DOT's preferred distribution of credits
16. Ability to employ third-party verification

Step 2 - Interviews were next conducted with each state DOT to determine which of the 16 capabilities were desired in a TSRS by each respective state DOT. The number of capabilities desired by each state DOT is as follows: CDOT – 15, SDOT – 12, UDOT – 15 and WYDOT – 13.

Step 3 – Based on the results of the interviews, an AHP survey instrument was developed for all four state DOTs. CDOT and UDOT had a total of 105 pairwise comparisons to be made by the decision maker in the AHP survey. SDDOT had a total of 66 pairwise comparisons while WYDOT had 78 pairwise comparisons to be made by the decision maker. The surveys were completed and returned to the researcher and the results assessed.

Step 4 - Based on the analysis, Invest was found to be the most suitable TSRS for CDOT with a 77% from CDOT. Second was STARS at 70% and third was Envision at 69%. GreenLITES was found to be the most suitable TSRS for SDDOT, gaining a weighting of 72% from SDDOT, with STARS second at 70% and Envision third at 59%. Invest was found to be the most suitable TSRS for WYDOT, receiving a weighting of 52% from WYDOT, with STARS second at 49%, and GreenLITES at 48%. No conclusive result was arrived at for UDOT as the consistency ratio was significantly outside the recommended limit for AHP analyses. Further research would have to be conducted for UDOT before a recommendation can be made.

A more detailed explanation of the results of the studies is presented in Chapter 4 of this paper. Taking into consideration the findings of the study, it was recommended that CDOT and WYDOT adopt Invest TSRS and SDDOT adopt GreenLITES for project sustainability assessment.

5.3 Concluding Remarks

In conclusion, the framework developed for assessing TSRSs for implementation in state DOTs was proven to be a viable means of determining rank of suitability according to preferred capabilities as identified by the state DOT. A limitation of the study was that, in each case, the consistency ratio was slightly outside the upper limit of what is recommended for AHP studies. This was likely the result of the large number of capabilities being assessed in each case study.

Another limitation of the study was the time constraint on the part of the researcher and the decision makers at the DOTs. This was a one-year study, and information that may have assisted with this study was not available during the time the methodology was being developed. In particular, information on the Improved Analytic Hierarchy Process (IAHP) was published in March 2013, after the results of the AHP survey was received by the researcher from the state DOTs.

Nevertheless, the results of the study are a strong indication that the methodology can assist in the assessment of TSRS and, with its use, a suitable TSRS can be identified for adoption for state DOTs across the United States.

5.4 Future Research

The results of this study have indicated that the framework herein proposed is a viable means of assessing TSRSs being considered for implementation in U.S. state DOTs. The framework is primarily based on the AHP methodology developed by Thomas Saaty. The AHP methodology is suitable in situations where decisions are being made based on multiple criteria. It can, however, be problematic in situations where the number of criteria compared exceeds nine (Saaty & Vargas 2001). An Improved AHP (IAHP) has been proposed for use in situations where there are more than nine criteria on which an analysis is being made (Zhang 2013). As such, further research should be geared toward establishing whether using the IAHP method in lieu of the traditional AHP methodology would address the consistency issue (by reducing the consistency ratio) in situations where there are more than nine capabilities chosen by state DOTs. This would be particularly beneficial, especially for UDOT, which recorded a high consistency ratio, thereby rendering the information garnered inconclusive.

Another method that can be used to improve the consistency is through group decision making. Instead of using a single representative from the DOT, a group of persons who have the authority to make sustainable decisions could participate in steps 2 and 3 of the framework. The results garnered in both steps can be aggregated, thereby making individual choices cardinal as opposed to ordinal (Saaty & Vargas 2013).

Additional research is also recommended to investigate the impact of decision makers' understanding of terms related to sustainability since another possible explanation for the slightly high consistency ratios might be decision makers' confusion over terms used when comparing capabilities.

Additionally, the state DOTs included in this study could be asked to pilot test the TSRS that is recommended based on the findings of this study. In essence, they could test to see how well the TSRS satisfies the needs of the DOT within the ambit of the capabilities desired by the DOT. This would also aid in assessing whether the proposed methodology was a success in identifying the most appropriate TSRS for a given DOT with respect to the suitability of that TSRS for implementation in that state DOT.

In addition, the level to which each TSRS measures true sustainability is undetermined. In future, it will be imperative to determine the extent to which each TSRS measures the sustainability of transportation projects. This can be achieved by looking at the performance of projects that have been rated using these TSRSs.

Finally, based on the results of this survey, Invest proved to be the preferred system for three state DOTs if the consistency ratio for UDOT is disregarded. This begs the question of whether Invest is the front runner or most robust TSRS. Further studies could be conducted with other state DOTs to ascertain if this may be a recurring trend, and if in fact it would be best to disregard all other TSRSs and focus on adopting and adapting Invest as the preferred TSRS for U.S. state DOTs. This, of course, is pending the result of further research.

REFERENCES

Association, A. P. H. (2009). At the Intersection of Public Health and Transportation Retrieved

December, 2012, from http://www.apha.org/NR/rdonlyres/43F10382-FB68-4112-8C75-49DCB10F8ECF/0/TransportationBrief.pdf

Banerjee, N. (Producer). (2013, May 21). Carbon dioxide in the atmosphere crosses historic threshold. *Los Angeles Times - Science*. Retrieved from http://www.latimes.com/news/science/sciencenow/la-sci-sn-carbon-atmosphere-440-ppm-20130510,0,6498056.story

Black, W. R. (2010). *Sustainable Transportation Problems and Solutions*. New York: The Guilford Press.

CEEQUAL. (2011a). CEEQUAL International Retrieved December 2012 from http://www.ceequal.com/pdf/CEEQUAL%20International%20Leaflet%20A4%20portrait%20web%20version.pdf

CEEQUAL. (2011b). CEEQUAL Sustainability Assessment and Awards for Civil Engineering, Infrastructure, Landscaping and the Public Realm - Introduction and What's New in Version 5 Retrieved December 2012 from http://www.ceequal.com/manual_download.php

CEEQUAL. (2012a, March 2012). CEEQUAL for Terms Contracts Retrieved December 2012 from http://www.ceequal.com/term_contracts.html

CEEQUAL. (2012b). CEEQUAL Sustainability Assessment and Awards for Civil Engineering, Infrastructure, Landscaping and the Public Realm - Scheme Description CEEQUAL for Projects (Version 5) Retrieved December 2012 from http://www.ceequal.com/pdf/CEEQUAL%20Scheme%20Description%20for%20Projects%20(Version%205)%20-%20MAY%2012.pdf

CEEQUAL. (2012c, 2012). CEEQUAL Version 5 Methodology Retrieved October 2012 from http://www.ceequal.com/structure.html

CEEQUAL. (2013). CEEQUAL Improving Sustainability; About CEEQUAL - Who can use CEEQUAL, 2013, from http://www.ceequal.com/about.html

CEM. (2008a). *Sustainability and the built environment*. United Kingdom: The College of Estate Management.

CEM. (2008b). *Sustainability and the Built Environment* (First ed.). London, England: College of Estate Management

Chan, S., Bennet, B., & Kazmierowski, T. (2013). *Implementation of Ontario's Pavement Sustainability Rating System - GreenPave*. Paper presented at the Airfield and Highway Pavement 2013: Sustainable and Efficient Pavements ASCE 2013. http://ascelibrary.org/doi/pdf/10.1061/9780784413005.003

Clark, M., Pauli, C., Tetreault, Z., Thomas, J., Hart, F., & Mallick, R. (2009). Green Guide for Roads Rating System

A Major Qualifying Project Report fo rthe Stantec Sustainable Design Project Site Retrieved December, 2012, from http://www.wpi.edu/Images/CMS/CEE/Green_Guide_for_Roads_Rating_System.pdf

Colin Booth, F. H., Jessica Lamond, David Proverbs. (2012). *Solutions to Climate Change Challenges in the Built Environment*. Oxford: Blackwell Publishing Ltd. .

Commission, S. C. C. R. T. (2011). STARS (Sustainable Transportation Access Rating System) Fact Sheet Retrieved December 2012 from http://sccrtc.org/wp-content/uploads/2011/04/042011-STARS-Fact-Shee.pdf

Council, N. A. S. T. (2010, April 2011). Sustainable Transportation Access Rating System (STARS) Pilot Project Application Manual Retrieved December 2012 from http://sccrtc.org/wp-content/uploads/2011/04/STARS-Pilot-Project-Application-Manual.pdf

Council, N. A. S. T. (2012). STARS Safety, Health, and Equity Credits Retrieved December 2012 from http://www.transportationcouncil.org/wp-content/uploads/2011/12/STARS_SHE_Introduction.pdf

Council, N. A. S. T. (n.d.). About Us: North American Sustainable Transportation Council Retrieved November 2012 from http://www.transportationcouncil.org/about-us

Council, S. T. (2013, August 20, 2013). North American Sustainable Transportation Council - Who is using STARS? 2013, from http://www.transportationcouncil.org/about-stars/whos-using-stars

Creswell, J. W. (2003). *Research design: qualitative, quantitative, and mixed methods approaches* (2nd ed.). Thousand Oaks, Calif.: Sage Publications.

Edil, T. B. (2012). *Building Environmentally and Economically Sustainable Transportation-Infrastructure-Highways*. http://rmrc.wisc.edu/wp-content/uploads/2012/09/BEST-for-Colorado.pdf

Edil, T. B., Lee, J., Benson, C. H., & Tinjum, J. M. (2010). Use if BEST In-Highways for Green Highway Construction Rating in Wisconsin *Green Streets and Highways 2010* (pp. 480-494).

EPA (Producer). (2013, May). Climate Change. *EPA United States Environmental Protection Agency*. Retrieved from http://www.epa.gov/climatechange/science/future.html#Temperature

Faisal Awadallah, E. H. F., Mahour Mellat-Parast. (2012). *Highways and Transportation Implications on Environmental Sustainability: Urban Planning, Construction and Operation Counter Measures.* Paper presented at the ICSDEC 2012: Developing the Frontier of Sustainable Design, Engineering, and Construction, Fort Worth - Texas.

FHWA. (2012a, October 2012). INVEST- Webcast Launch Retrieved October 23, 2012, from http://mp125118.cdn.mediaplatform.com/125118/wc/mp/4000/5592/5599/18858/Archive/default.htm?ivt=%7B6d0eccff-4ff1-bba1-c102-d80de1a4a7f5%7D

FHWA. (2012b, October 2012). INVEST - Are the Criteria Weighted? Retrieved October 20, 2012, from https://www.sustainablehighways.org/885/are-the-criteria-weighted.html

FHWA. (2012c, October 2012). INVEST - How are the Criteria Organized? Retrieved October 20, 2012, from https://www.sustainablehighways.org/876/how-are-the-criteria-organized.html

FHWA. (2012d, October 2012). INVEST - How Does INVEST Measure Sustainability? Retrieved October 23, 2012, from https://www.sustainablehighways.org/875/how-does-invest-measure-sustainability.html

FHWA. (2012e, October 2012). INVEST - What Does the Operation and Maintenance Score Mean Retrieved October 20, 2012, from https://www.sustainablehighways.org/909/what-does-the-project-development-score-mean.html

Galvan, J. L. (2009). *Writing literature reviews : a guide for students of the social and behavioral sciences* (4th ed.). Glendale, CA: Pyrczak.

Gambaste, J. A. (2005). Sustainable Roadway Construction: Energy Consumption and Material Waste Generation of Roadways. *Construction Research Congress 183*.

Greenroads. (2011, February 4, 2011). Greenroads Abridged Manual v1.5 Retrieved October 3, 2012, from http://www.greenroads.org/366/download-the-manual.html

Greenroads. (2012a, August 23, 2012). About the Greenroads Rating System Retrieved October 3, 2012, from http://www.greenroads.org/347/about-the-greenroads-rating-system.html

Greenroads. (2012b, August 23, 2012). How Greenroads Works. *Voluntary Credits* Retrieved October 3, 2012, from http://www.greenroads.org/1429/browse-the-online-manual.html

Greenroads. (2012c, August 23, 2012). How Greenroads Works. *Project Requirements* Retrieved Octber 3, 2012, from http://www.greenroads.org/1429/browse-the-online-manual.html

Hirsch, A. (2011, 2011). Summary of Transportation Sustainability Rating System Programs, 2013, from http://terralogicss.com/sustainable-transportation/summary-of-transportation-sustainability-rating-system-programs

IDOT, & IJSG. (2010, January 8, 2010). I-Last - Illinois Livable and Sustainable Transportation Rating System and Guide Retrieved October 23, 2012, from http://www.dot.state.il.us/green/documents/I-LASTGuidebook.pdf

ISI. (2012a). The Envision Rating System Retrieved October 3, 2012, from http://www.sustainableinfrastructure.org/downloads/index.cfm

ISI. (2012b, August 2012). The Envision Rating System EnvisionTM and ISI Retrieved October 3, 2012, from http://www.sustainableinfrastructure.org/downloads/index.cfm

ISI. (2012c, August 2012). The Envision Rating System The Need for Envision Retrieved October 3, 2012, from http://www.sustainableinfrastructure.org/downloads/index.cfm

ISI. (2012d, 2012). Envision Workbook; An Overview of the Envision Checklist Retrieved October 3, 2012, from http://www.sustainableinfrastructure.org/portal/envision2/checklist.cfm

ISI. (2012e, 2012). Institute for Sustainable Infrastructure Education Retrieved October 3, 2012, from http://www.sustainableinfrastructure.org/education/index.cfm#application

ISI. (2012f, 2012). Institute for Sustainable Infrastructure Project Application Retrieved October 3, 2012, from http://www.sustainableinfrastructure.org/verification/index.cfm

Kibert, C. J. (2002). Policy Instruments for a Sustainable Built Environment. *Journal of Land Use and Environmental Law, 17*(2), 15.

Knuth, D., & Fortmann, J. (2011). The Development of I-LAST Illinois—Livable and Sustainable Transportation *Green Streets and Highways 2010* (pp. 495-503).

Krekeler, P., Nelson, D. A., Gritsavage, J. S., Kolb, E., & McVoy, G. R. (2010). Moving towards Sustainability: New York State Department of Transportation's GreenLITES Story *Green Streets and Highways 2010* (pp. 461-479).

Kubba, S. (2010). *LEED practices, certification, and accreditation handbook*. Burlington, MA: Butterworth-Heinemann/Elsevier.

Lane, B. (2003). MTO'S GreenPave Rating System Retrieved December 2012 from http://www.ogra.org/lib/db2file.asp?fileid=31913

Lane, B. (2010, June 2010). GreenPave: Ontario's First Pavement Sustainability Rating System. *Ontario's Transportation Technology Transfer Digest - Winter 2010 - Volume 16, Issue 1* Retrieved December 2012 from http://www.mto.gov.on.ca/english/transtek/roadtalk/rt16-1/#a6

LBC. (2013). Living Building Challenge - The Certification Process, 2013, from http://living-future.org/lbc/certification

Lee, J. C., Edil, T. B., Benson, C. H., Tinjum, J. M. . (2011). Evaluation of Variables Affecting Sustainable Highway Desgin With BE2ST-in-Highways System. *Journal of Transportation Research Board, 2233*.

Martland, C. D. (2012). *Toward more sustainable infrastructure : project evaluation for planners and engineers*. Hoboken, NJ: Wiley.

McKinsey (Producer). (2007, May). Cost and Potetial of Greenhouse Gas Abatement in Germany. *McKinsey and Company*. Retrieved from http://www.makinseyquarterly.com/article_page.aspx?ar=1911

NOAA (Producer). (2013, May). Carbon Dioxide at NOAA's Mauna Loa Observatory reaches new milestone: Tops 400 ppm. *National Oceanic And Atmospheric Administration Unted States Department of Commerce - Research*. Retrieved from http://researchmatters.noaa.gov/news/Pages/CarbonDioxideatMaunaLoareaches400ppm.aspx

NYSDOT. (2008, April 2010). GreenLITES Project Design Certification Program. *Recognizing Leadership in Transportation and Environmental Sustainability* Retrieved October 3, 2012, from https://www.dot.ny.gov/programs/greenlites/repository/Green%20LITES%20Certification%20Program%20Document%20-%20April%202010_092111.doc

NYSDOT. (2009, 2012). GreenLITES Recognizing Leadership inTransportation Environmental Sustainability. *What is GreenLITES* Retrieved October 3, 2012, from https://www.dot.ny.gov/programs/greenlites

NYSDOT. (2010, 2012). GreenLITES Recognizing Leadership in Transportation Environmental Sustainability. *GreenLITES for Sustainable Planning*

Retrieved October 3, 2012, from https://www.dot.ny.gov/programs/greenlites/repository/GreenLITES%20Project%20Solicitation%20Tool%20v1%202.doc

NYSDOT. (2012). Draft Operations Certification Program Retrieved October 3, 2012, from https://www.dot.ny.gov/programs/greenlites/repository/GreenLITES%20Operations%20Draft%20Guidance%20February%202012%20(2).doc

Oswald, M. R. M., Sue (2010). Rating Sustainability: Transportation Investments in Urban Corridors as a Case Study. *Journal of Urban Planning and Development © ASCE*, 177-185.

Reeder, L. (2010). *Guide to green building rating systems: understanding LEED, Green Globes, ENERGY STAR, the National Green Building Standard, and more*. Hoboken, N.J.: Wiley.

RMRC. (2012a). BE2ST-in-Highways™

BE2ST-in-Highways™ at RMAUPG Annual Meeting

Retrieved October 11, 2012, from http://rmrc.wisc.edu/be2st-in-highways/

RMRC. (2012b). Recycle Materials Resource Center Introduction Retrieved October 11, 2012, from http://rmrc.wisc.edu/ug-introduction/

Saaty, T. L. (1980). *The analytic hierarchy process: planning, priority setting, resource allocation*. New York: McGraw-Hill International Book Co.

Saaty, T. L., & Alexander, J. M. (1989). *Conflict resolution: the analytic hierarchy approach*. New York: Praeger.

Saaty, T. L., & Vargas, L. G. (2001). *Models, methods, concepts & applications of the analytic hierarchy process*. Boston: Kluwer Academic Publishers.

Saaty, T. L., & Vargas, L. G. (2013). *Models, Methods, Concepts and Applications of the Analytic Hierarchy Process*. London: Springer New York Heidelberg Dordrecht London.

Seely, I. H. (1997). *Quantity Surveying Practice* (Second ed.). London: PALGRAVE MACMILLAN PRESS LTD.

Staiano, M. A. (2008). *Simple Methods for Estimating Highway Noise*. Paper presented at the Transportation Research Board 88th Annual Meeting.

USGBC (Producer). (2013). U.S. Green Building Council Directory. *U.S. Green Building Council*. Retrieved from http://www.usgbc.org/projects

Yin, R. K. (2003). *Case study research : design and methods* (3rd ed.). Thousand Oaks, Calif.: Sage Publications.

Yudelson, J. (2008). The Green Building Revolution *The Green Building Revolution*. London: Island Press.

Zhang, F. L. k. K. P. X. D. M. (2013). Improved AHP Method and Its Application in Risk Identification. *Journal of Construction Engineering and Management, 139*(3), 9.

Zietsman, J. R., Tara; Potter, Joanne; Reeder, Virginia; DeFlorio, Joshua (2011). NCHRP Report 708 A guidebook for Sustainability Performance Measurement for Transportation Agencies. Washington D.C.: Transportation Research Board.

APPENDIX I. INTERVIEW QUESTIONS

This research project is funded by the Mountain-Plains Consortium (MPC) which is a university program sponsored by the U.S. Department of Transportation through its Research and Innovative Technology Administration. For this research, we will evaluate existing infrastructure sustainability rating systems in an effort to identify the one(s) that is/are best suited to be adopted by the department of transportation (DOT) of each one of the MPC states (Colorado, North Dakota, South Dakota, Utah, and Wyoming). You were specifically selected for participation in this study due to your relevant expert qualifications. Please answer all questions taking into consideration the collective view of your organization. You will be interviewed on your knowledge of sustainable infrastructure rating systems as well as on the important rating system characteristics for your organization. Based on your responses, we will provide you a second written survey asking you to compare the relative value of various characteristics using the Analytic Hierarchy Process (AHP). We thank you for your time and input in this process.

This interview will be conducted in 3 phases. The first phase will be a discussion with the objective of getting to know you and your organization. The second phase will be geared towards identifying which specific characteristics of sustainability rating systems are desired by your organization. The third phase will seek to garner information regarding any other considerations that might be important that have not been captured through the previous questions. We anticipate this initial interview will take no more than one hour.

We will send you the follow-up survey based on the characteristics you identify as important in the interview in approximately one month.

Organizational Structure at State Department of Transportation (DOT)

1. In what capacity are you employed at the Colorado State DOT?
2. What is your role at the Colorado State DOT?
3. Does your organization currently use a sustainability rating system for your projects?
4. How many projects have you used the rating system on and for what purposes was it used?
5. What types of projects are usually undertaken by the Colorado State DOT?
    a. Does the Colorado State DOT conduct planning and designing of highways?
    b. Does the Colorado State undertake the construction of highways?
    c. Does the Colorado State operate and/or maintain highways?
6. In what phases of projects do you incorporate sustainability measures?
    a. Are sustainability measures incorporated into the planning and design phases?
    b. Are sustainability measures incorporated into the construction phase of highway development?
7. Are sustainability measures incorporated into the operations and maintenance phases?
8. Now that you know more about the research project do you believe there is anyone else in your organization that we should interview for this study?

Characteristics Desired in a Sustainability Rating System

9. How do you generally incorporate sustainable strategies in the development of highway projects?
10. What are some of the main characteristics that a sustainability rating system should have?
11. Would the Colorado State DOT prefer to use a rating system that assigns a score or an award to your project?
12. Would the Colorado DOT prefer to use a sustainability rating system that requires third party verification for project sustainability assessment?
13. Would the Colorado DOT prefer to use a rating system that employs self-assessment for project sustainability assessment?
14. Would the Colorado State DOT prefer to use a rating system that evaluates projects during conceptual stages of a project?
15. Would the Colorado State DOT prefer to use a rating system that evaluates projects during the design phase of projects?
16. Would the Colorado State DOT prefer to use a rating system that evaluates projects during the construction phase of projects?
17. Would the Colorado State DOT prefer to use a rating system that evaluates projects during the operations and maintenance phase of projects?
18. Does the Colorado State DOT prefer to have the ability to allocate weights to criteria that they deem more important than others in implementing the sustainability rating system?
19. Does the Colorado State DOT prefer to have the ability to choose only those criteria from a sustainability rating system that they deem relevant for particular projects?
20. Would the Colorado State DOT prefer to use a sustainability rating system that has a rating system customized to a particular type of project (i.e.; urban, rural, custom, paving etc.)?
21. Would the Colorado State DOT prefer to use a sustainability rating system that awards points for Innovation?
22. Would the Colorado State DOT prefer the ability to have prescriptive measures towards achieving credits?
23. Would the Colorado State DOT prefer the ability to have performance measures towards achieving credits?
24. Would the Colorado State DOT prefer to use a rating system that allows a side by side comparison of different project options?
25. Would the Colorado State DOT prefer to use a rating system that facilitates the application of an award for the designer, client and contractor?
26. Would the Colorado State DOT prefer to use a rating system that aligns with that State DOT's preferred distribution of credits across the triple bottom line of sustainability (Social, Economic and Environmental concerns)?

Other Considerations

27. In general, what is the Colorado State DOTs approximate preferred distribution of credits across the triple bottom line of sustainability (Social, Economic and Environmental concerns)?

    a) Social 10%, Economic 10% and Environmental 80%

    b) Social 25%, Economic 25% and Environmental 50%

    c) Social 10%, Economic 45% and Environmental 45%

    d) Social 45%, Economic 10% and Environmental 45%

    e) Social 33%, Economic 33% and Environmental 33%

28. Does the Colorado DOT have systems in place to facilitate the implementation of a sustainability rating system?

29. How intensive a training exercise do you foresee being necessary in your organization for the use of a rating system?

30. If training in the use of sustainability rating system was mandatory, would the Colorado State DOT still consider using the rating system?

31. Would the cost component of training employees to use the sustainability rating system factor into the Colorado DOT's choice of a sustainability rating system?

32. Would your organization use a sustainability rating system if it cost money?

33. How many people in your organization will be expected to use the rating system?

34. Is it acceptable for a sustainability rating system to only evaluate project sustainability based on pavement technologies?

35. Would the Colorado State DOT prefer to use a rating system which is a standalone system?

APPENDIX II

Project Title: Evaluation of Existing Infrastructure Sustainability Rating Systems for use by the Mountain-Plains Consortium State DOTs

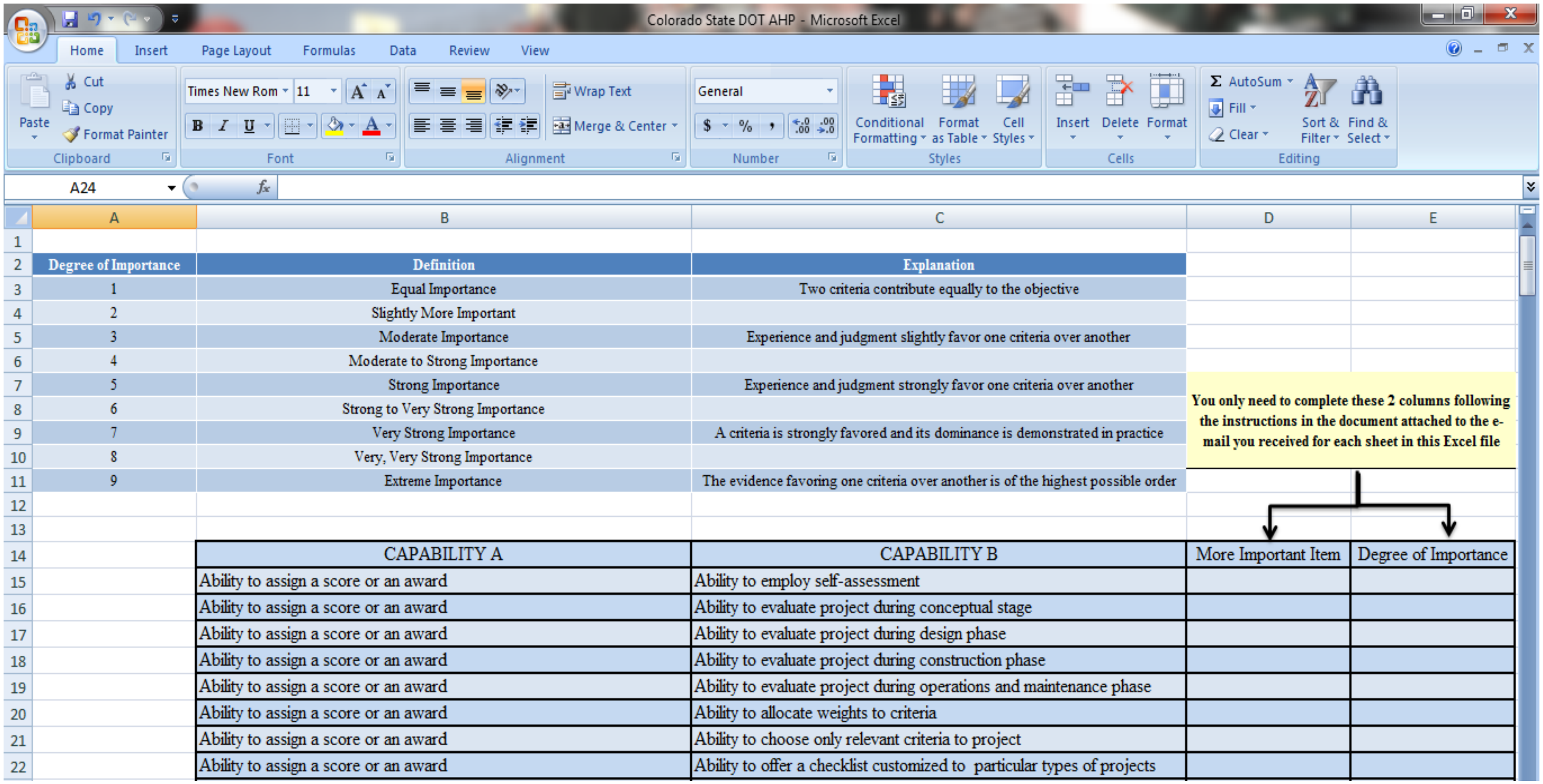
The objective of this survey is to collect information from you as a representative of CDOT. Information collected will enable the CSU research team to prioritize specific system capabilities[6] that were previously confirmed by you in your interview as important in evaluating Existing Infrastructure Sustainability Rating Systems. This information will help us determine how important one capability is compared to another according to CDOT's needs and preferences. This survey is a part of a structured technique, Analytic Hierarchy Process[7] (AHP), which will be used to assign a quantitative value (i.e., a weight) to each capability. We will use these weights to objectively assess the existing sustainability rating systems with the ultimate purpose of identifying the one that best fits CDOT's needs.

Instructions: Please perform pairwise comparisons between the capabilities shown in the Excel Spreadsheet attached in the email. You will do so by choosing whether Capability A or Capability B is more important by picking either "A" or "B" from the drop-down menu in the column labeled "More Important Item". You will then choose the number from the drop-down list which best represents the relative importance of the preferred capability in comparison to the other. Table 1 below provides the scales to be used for those comparisons. For this survey, there are 15 capabilities resulting in 105 pairwise comparisons. It is estimated that completing the survey will take no more than 30 minutes. If you have any questions with respect to this survey, please contact one of the CSU research team members.

Degree of Importance	Definition	Explanation
1	Equal Importance	Two criteria contribute equally to the objective
2	Slightly More Important	
3	Moderate Importance	Experience and judgment slightly favor one criteria over another
4	Moderate to Strong Importance	
5	Strong Importance	Experience and judgment strongly favor one criteria over another
6	Strong to Very Strong Importance	
7	Very Strong Importance	A criteria is strongly favored and its dominance is demonstrated in practice
8	Very, Very Strong Importance	
9	Extreme Importance	The evidence favoring one criteria over another is of the highest possible order

[6] For a list of capabilities in alphabetical order, please refer to page 5 of this document.
[7] For a brief overview of Analytic Hierarchy Process, please refer to page 7 of this document.

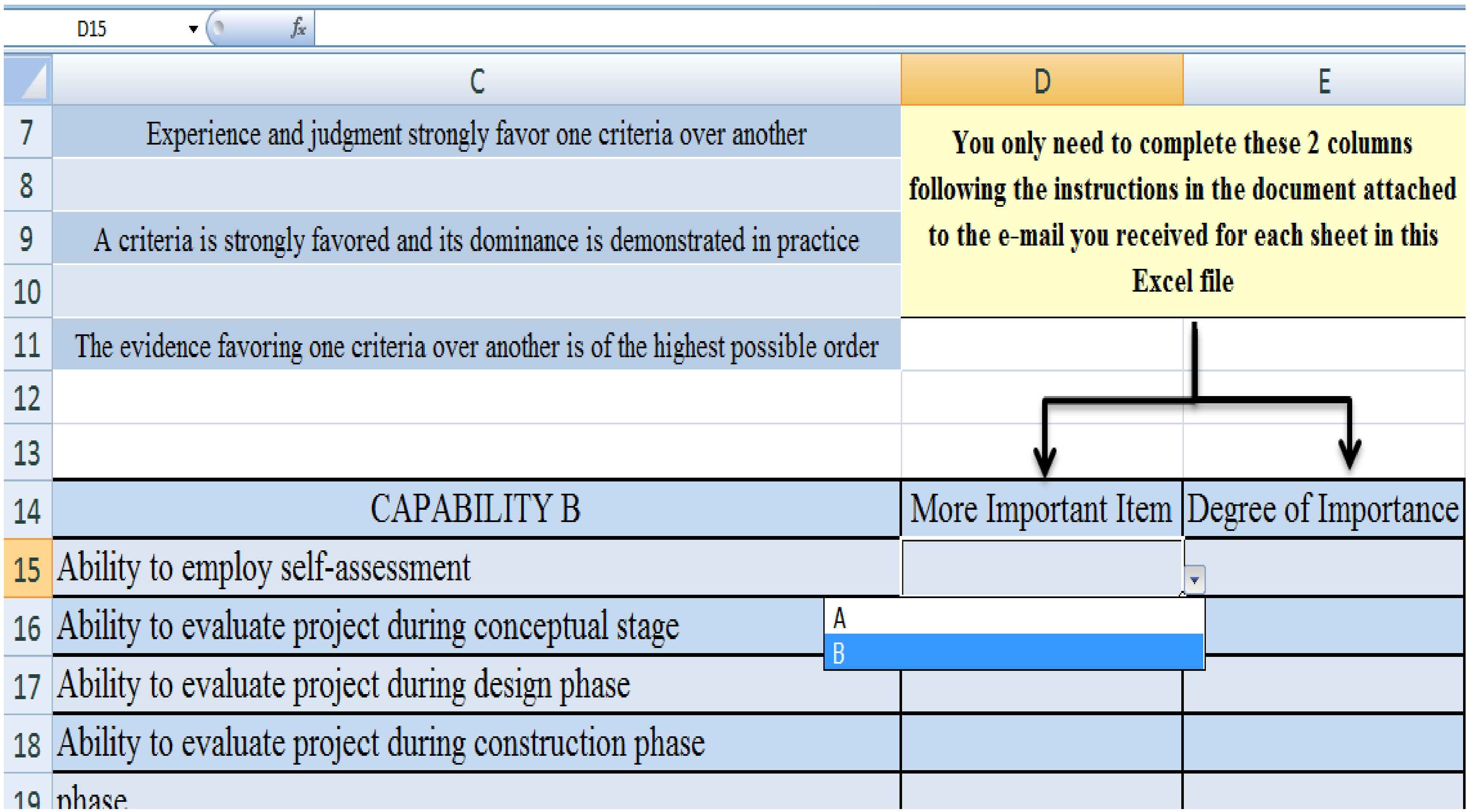
Example:
Below is an example of the Excel spreadsheet to be filled out. The only columns to be filled in are the columns to the right. The items contained in the columns labeled "Capability A" and "Capability B" should be compared to each other in order of importance. For example in the first row, "Ability to assign a score or an award" is being compared to "Ability to employ self-assessment."



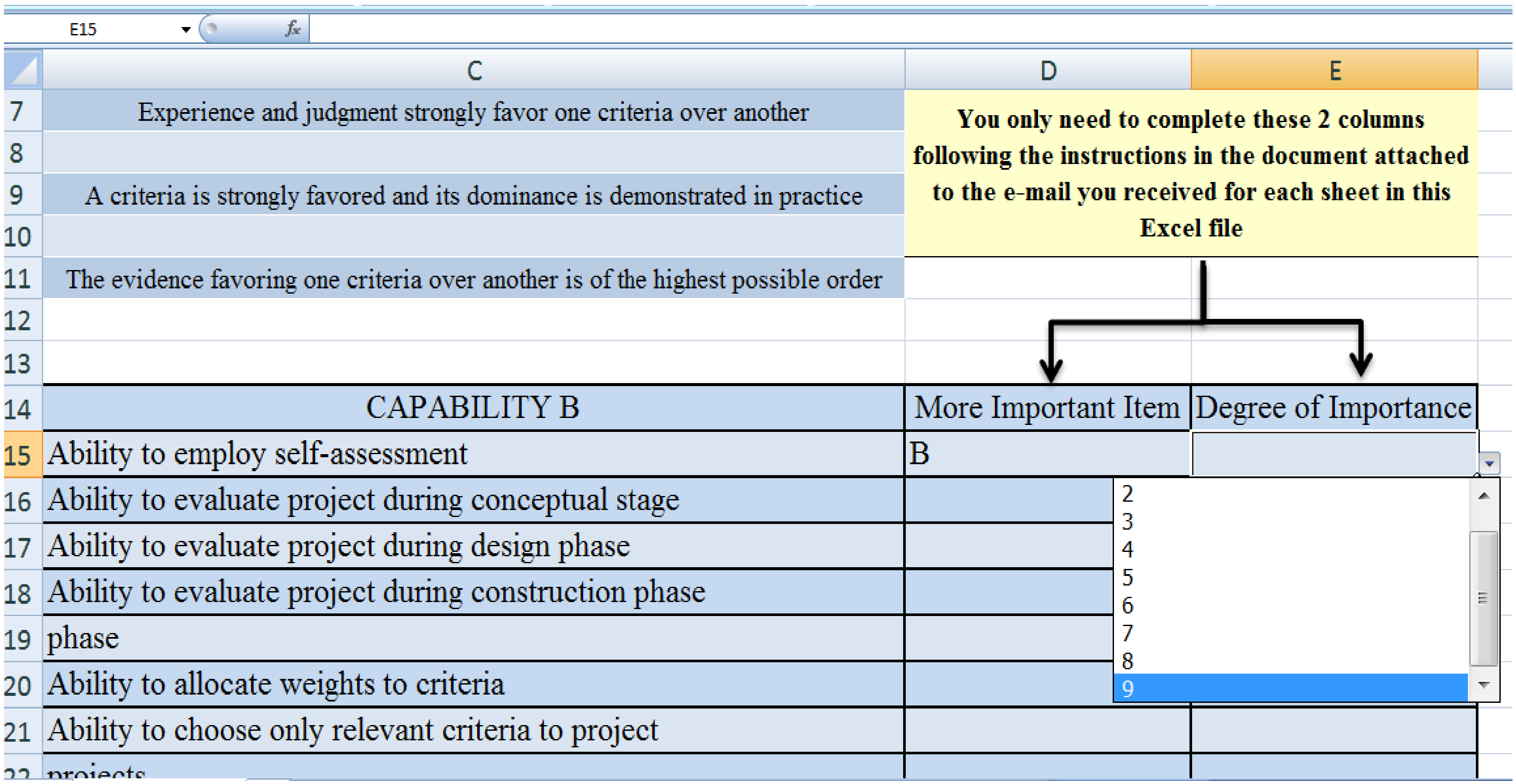
Degree of Importance	Definition	Explanation
1	Equal Importance	Two criteria contribute equally to the objective
2	Slightly More Important	
3	Moderate Importance	Experience and judgment slightly favor one criteria over another
4	Moderate to Strong Importance	
5	Strong Importance	Experience and judgment strongly favor one criteria over another
6	Strong to Very Strong Importance	
7	Very Strong Importance	A criteria is strongly favored and its dominance is demonstrated in practice
8	Very, Very Strong Importance	
9	Extreme Importance	The evidence favoring one criteria over another is of the highest possible order

CAPABILITY A	CAPABILITY B	More Important Item	Degree of Importance
Ability to assign a score or an award	Ability to employ self-assessment		
Ability to assign a score or an award	Ability to evaluate project during conceptual stage		
Ability to assign a score or an award	Ability to evaluate project during design phase		
Ability to assign a score or an award	Ability to evaluate project during construction phase		
Ability to assign a score or an award	Ability to evaluate project during operations and maintenance phase		
Ability to assign a score or an award	Ability to allocate weights to criteria		
Ability to assign a score or an award	Ability to choose only relevant criteria to project		
Ability to assign a score or an award	Ability to offer a checklist customized to particular types of projects		

In the example, “B” is chosen as being more important than A i.e. “Ability to employ self-assessment” is more important than the “Ability to assign a score or an award.”



“B” is then assigned a 9 in “order of importance,” which is translated to mean “Ability to employ self-assessment” is “Extremely Important” in comparison to “Ability to assign a score or an award.”



	C	D	E
7	Experience and judgment strongly favor one criteria over another	You only need to complete these 2 columns following the instructions in the document attached to the e-mail you received for each sheet in this Excel file	
8			
9	A criteria is strongly favored and its dominance is demonstrated in practice		
10			
11	The evidence favoring one criteria over another is of the highest possible order		
12			
13			
14	CAPABILITY B	More Important Item	Degree of Importance
15	Ability to employ self-assessment	B	
16	Ability to evaluate project during conceptual stage		2
17	Ability to evaluate project during design phase		3 4
18	Ability to evaluate project during construction phase		5 6
19	phase		7
20	Ability to allocate weights to criteria		8 9
21	Ability to choose only relevant criteria to project		
22	projects		

NOTE: The full explanations of capabilities are provided on page 5 and should be referenced while performing the pairwise comparisons.

LIST AND EXPLANATION OF CAPABILITIES IN ALPHABETICAL ORDER

Ability to assign a score or an award: Projects are assessed using a scoring system. Certain scores are awarded levels of achievement (similar to a LEED Certified, Silver, Gold, Platinum).

Ability to employ self-assessment: Project assessment (scoring or otherwise) is performed internally by a team member(s) involved in the project (i.e.; CDOT).

Ability to evaluate project during conceptual stage: The rating system facilitates consideration of decisions or activities which occur during the conceptual phase of a project when assessing the sustainability of the project.

Ability to evaluate project during design phase: The rating system facilitates consideration of decisions or activities which occur during the design phase of a project when assessing the sustainability of the project.

Ability to evaluate project during construction phase: The rating system facilitates consideration of decisions or activities which occur during the construction phase of a project when assessing the sustainability of the project.

Ability to evaluate project during operations and maintenance phase: The rating system facilitates consideration of decisions or activities which occur during the operations and maintenance phase of a project when assessing the sustainability of the project.

Ability to allocate weights to criteria: The rating system facilitates the assignment of weights to various criteria when assessing the sustainability of the project.

Ability to choose only relevant criteria to project: The rating system permits a team member(s) to determine whether or not given criteria are relevant to the project and whether they should or should not be used in the assessment.

Ability to offer a checklist customized to particular types of projects: The rating system facilitates a checklist customized to differing scenarios. For example, it may have a checklist customized to a rural setting, an urban setting, pavement only jobs, new works, etc.

Ability to award points for innovation: The rating system facilitates award of credits or points for the implementation of innovative techniques used to promote sustainability.

Ability to offer prescriptive measures towards achieving credits: The rating system prescribes and credits specific decisions or activities as certain to promote sustainability.

Ability to offer performance measures towards achieving credits: The rating system identifies and credits certain goals to promote sustainability, but does not prescribe specific decisions or activities to achieve these goals.

Ability to compare different project options side by side: The rating system facilitates side by side comparison of whole projects while assessing sustainability.

Ability to offer an award for the designer, client and contractor: The rating system facilitates award(s) for or acknowledgement of specific team members based on project sustainability.

Alignment with State DOT's preferred distribution of credits: Alignment of the rating system's distribution of credits across the triple bottom line of sustainability (i.e.; social, economic and environmental concerns) with the State's DOT preferred distribution of credits.

An overview of Analytic Hierarchy Process (AHP)

AHP is a systematic procedure that enables researcher to determine the relative importance of the capabilities developed for this study. Such a task was supported by holding interviews with experts (representing relevant State DOTs) to identify the important factors. AHP allows for the application of data, experience, insight, and intuition in a logical and thorough way. **The main purpose of AHP is the development of weights indicating the relative importance of the capabilities under investigation**. For this purpose, AHP consists of the following steps.

1. Structuring the elements under analysis (e.g., capabilities of rating systems for this study)
2. Assessment made by the decision makers through pairwise comparisons of such elements
3. Obtaining the weights (indicating the relative importance) of the elements

The critical step is the second step at which the matrices of pairwise comparison are formed. Humans are more capable of making relative rather than absolute judgments. By using the AHP pairwise comparison process, weights or priorities are derived from a set of judgments. Pairwise comparisons are basic to the AHP methodology. When comparing a pair of factors, a ratio of relative importance of the factors can be established. Usually, ratio scales (i.e. the integers 1-9 and their reciprocals) are utilized to represent the judgments of decision makers in each pairwise comparison.