

THESIS

A FRAMEWORK FOR ASSESSING TRANSPORTATION SUSTAINABILITY RATING SYSTEMS FOR IMPLEMENTATION IN U.S. STATE DEPARTMENTS OF TRANSPORTATION

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ABSTRACT

A FRAMEWORK FOR ASSESSING TRANSPORTATION SUSTAINABILITY RATING SYSTEMS FOR IMPLEMENTATION IN U.S. STATE DEPARTMENTS OF TRANSPORTATION

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 the state DOTs select a system by determining to what extent a given system suits the state DOT's preferences

This thesis presents a four step framework which 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.

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Chapter 1: Introduction

Background

Over the past decade green construction has been gaining popularity in the U.S., particularly for buildings (Yudelso, 2008) but also for transportation projects (Oswald, 2010). This growth is attributable to various causes which can be traced from 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 towards 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 (Yudelso, 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 (Yudelso, 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). It was stated in the article 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 scientist 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 percent of the energy consumed in the U.S. while contributing 6 percent of the greenhouse gas emissions in the U.S. (Gambaste, 2005). Other estimates are not so conservative and indicate that the construction industry contributes between 27 percent (Faisal Awadallah, 2012) - 30 percent of greenhouse gas emissions (Yudelso, 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.

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 percent of raw material usage, 12 percent of fresh water usage, 30 percent of greenhouse gas emissions, transportation of materials and other sundry tasks account for a further 18 percent of greenhouse gas emissions, 45-65 percent of waste to landfills, 71 percent of electricity consumption and 31 percent of mercury in solid waste (Yudelso, 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 percent energy saving, 30 – 50 percent water saving, 50 – 90 percent reduction in construction waste, and a 20 - 35 percent reduction in greenhouse gas emissions (McKinsey, 2007; Yudelso, 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 percent 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.

Sustainable Transportation Systems

Another area which 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 percent of the transportation sectors' total greenhouse gas emissions and the transport sector itself contributes 31 percent of the U.S. total greenhouse gas emissions. Considering the U.S. 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 which 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, is efficient and supports a vibrant economy while minimizing emissions and waste to a level which 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 Highways Administration, Congress and the Executive Branch, the U.S. Department of Transportation (DOT) and Federal Transit Administration; at the state level: State DOTs and independent state toll authorities; and at the regional level: Metropolitan planning organizations (MPO), public transit agencies, local-level toll authorities and local public works and transportation departments (Zietsman, 2011). Due to the fact that 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 the state DOT.

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 in use in the U.S. 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 ten prominent

systems which have been identified that are 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.

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 in fact 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 US based on the climate, population density, resource availability, core business of State DOTs, among 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 the state DOTs select a system by determining to what extent a given system suits the state DOT's preferences.

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 U.S. 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 across the U.S. to assist in the selection of “best fit” TSRS.

Scope

This framework will be developed via a case study approach involving four Mountain – Plains Consortium (MPC) State DOTs: Colorado DOT (CDOT), South Dakota DOT (SDDOT), Utah DOT (UDOT) and Wyoming DOT (WYDOT). At the conclusion of this study a recommendation will be made with regards to which existing TSRS should be adopted by each of the above named state DOTs. The methodology developed will be applicable to all state DOTs across the U.S.

This research is based solely on existing TSRS 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.

Chapter 2: Literature Review

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 TSRs 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).

Infrastructure Sustainability Rating Systems

BE²ST-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 (BE²ST-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) which 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 9 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 BE²ST-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).

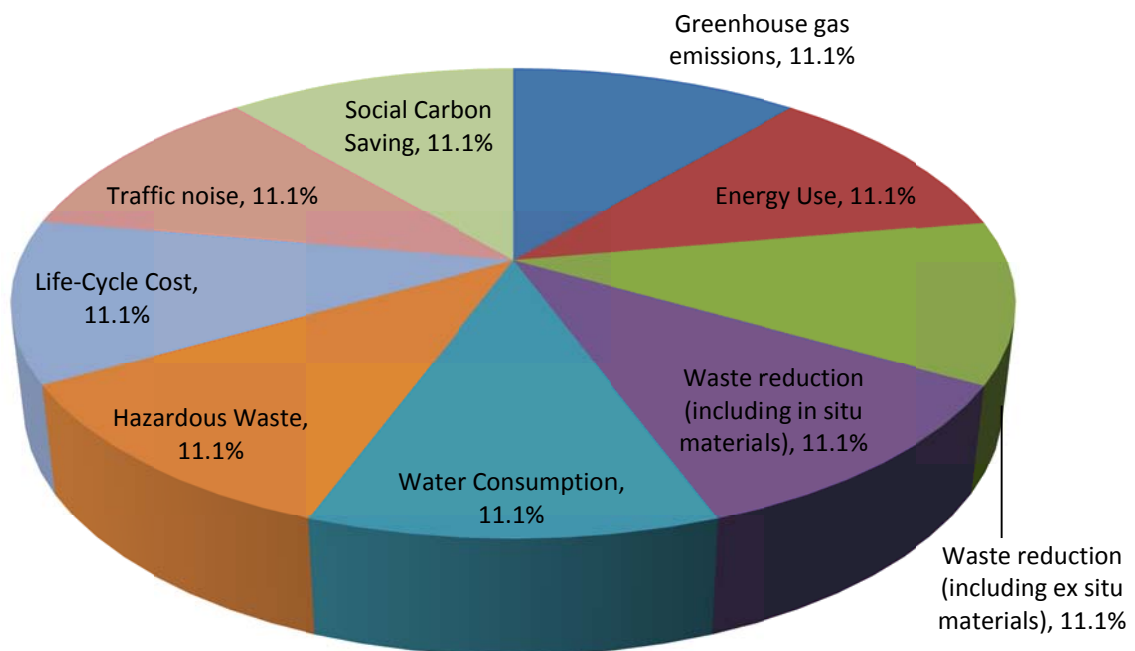


Figure 2.1: Percentage of total credit points allocated per category for BE2ST-in-Highways Sustainability Rating System

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 is calculated

of the actual score over the maximum possible score 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). BE2ST-in-Highways rating system allocates an even 11% of its credits across all nine categories contained in the rating system (see Figure 2.1).

EnvisionTM

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 (for example 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 in creating EnvisionTM (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 has to be paid before the checklist can be accessed for online 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 project as they appear (ISI, 2012f). Some questions are mandatory for any project to be certified by Envision; however there are other questions which

are optional. 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.

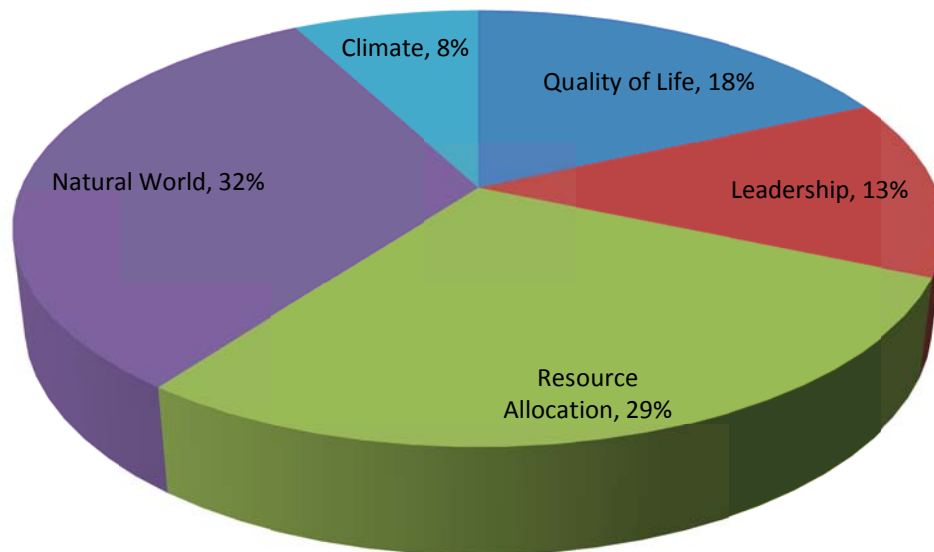


Figure 2.2: Percentage of total credit points allocated per category for Envision Sustainability Rating System

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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. It was also the hope of Stantec 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 Bachelor of Science Degree at the 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 which 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 now 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, the maximum points achievable were 82 points 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 an over 200% increase in the credits allocated for the Energy and Atmosphere category moving from 4 to 15 total points, moving from a 5% allocation to 15% (see Figure 2.3 below). There was also an increase from 6 credit points total to 18 points total being allocated for the Materials and Resource category. The following table shows the percentage point distribution across all the 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 have to be fulfilled before certification can be granted for a project seeking Green Guide for Roads certification. Criteria which offer credit points are optional and are included in a project at the discretion of the project team. Credits are comprised of 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 towards achieving a score, and a submittals section which states the documents or the evidence which needs to be presented as proof that the credit was achieved and that 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 speak to 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).

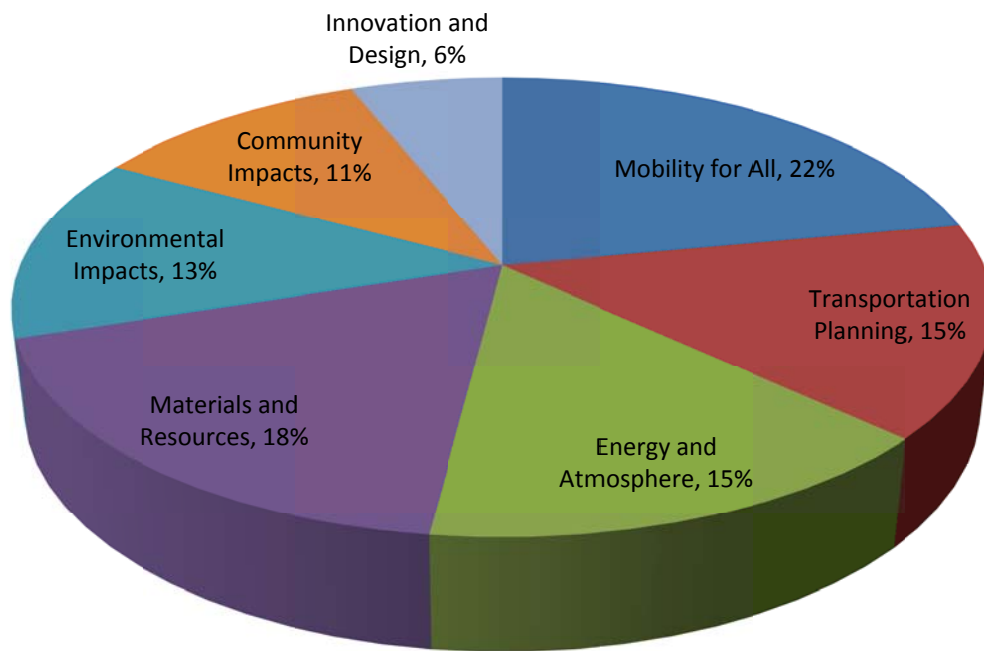


Figure 2.3: Percentage of total credit points allocated per category for the Revised Green Guide for Roads Sustainability Rating System

Mobility for All has the highest percentage of credits allocated standing at 22%. Closely following is 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 11% and Innovation and Design, 6% (see Figure 2.3).

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 whilst 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 exist across five categories (NYSDOT, 2008). The system offers transparency in the 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 the NYSDOT on all highway projects (Krekeler et al., 2010).

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 every day 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.

GreenPave

Developed by the Ontario Ministry of Transportation, GreenPave is a sustainability rating system which was modeled after the University of Washington's Greenroads and New York State Department of Transportation's (NYSDOT's) GreenLITES sustainability rating systems

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(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 Leadership in Energy and Environmental Design (LEED) rating system and Alberta's Green Guides for Roads conceptual rating system (Lane, 2003, 2010).

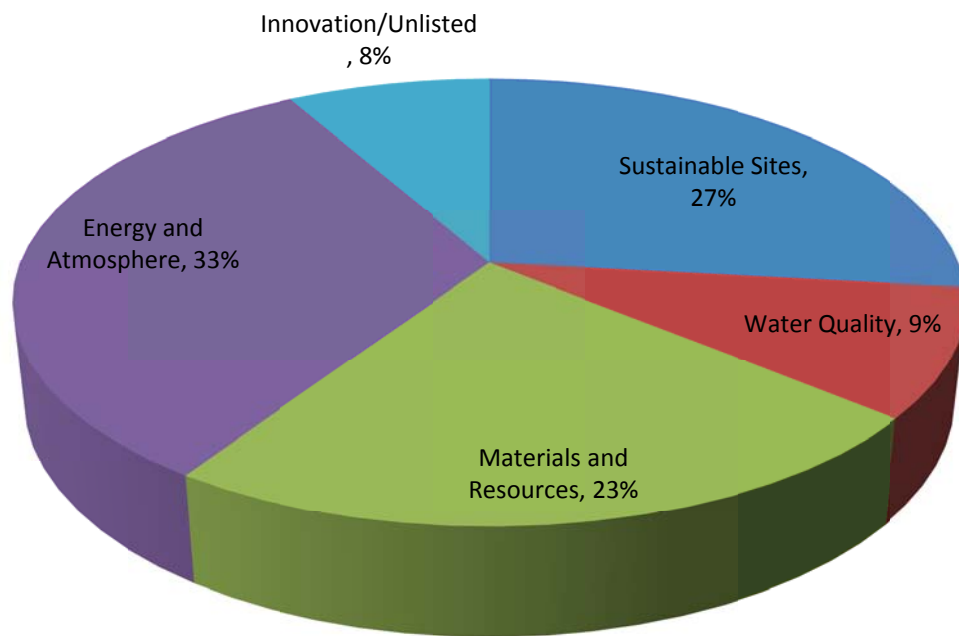


Figure 2.4: Percentage of total credit points allocated per category for GreenLITES Sustainability Rating System

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 point)
- 4) Cool Pavement (2 point)

Materials and Resources addresses project issues with regards 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: firstly, an “Objective” of the criteria is given. An example of an objective is “To encourage reusing existing pavement materials in the new pavement structure” and this is found under the Reuse of Pavement criteria. Secondly, it explains the applicability of the criteria in terms of type of project work to which the criteria is applicable. For the criteria in the example above the “Applicability” example would be “To 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 which would merit a point being awarded to the project (Lane, 2003).

A project which is 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 which 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 towards 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).

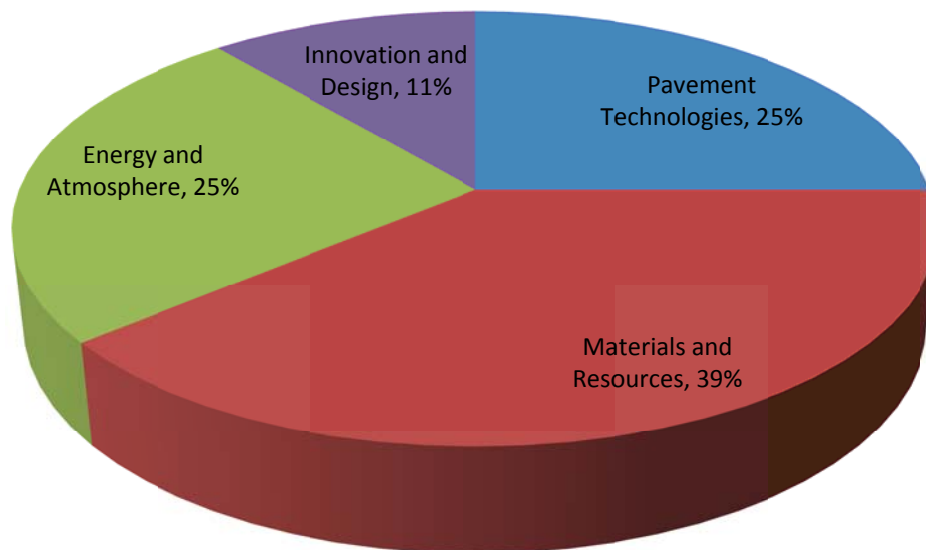


Figure 2.5: Percentage of total credit points allocated per category for the GreenPave Sustainability Rating System

GreenroadsTM

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 has to 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 6 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 towards 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 upwards 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 towards 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.

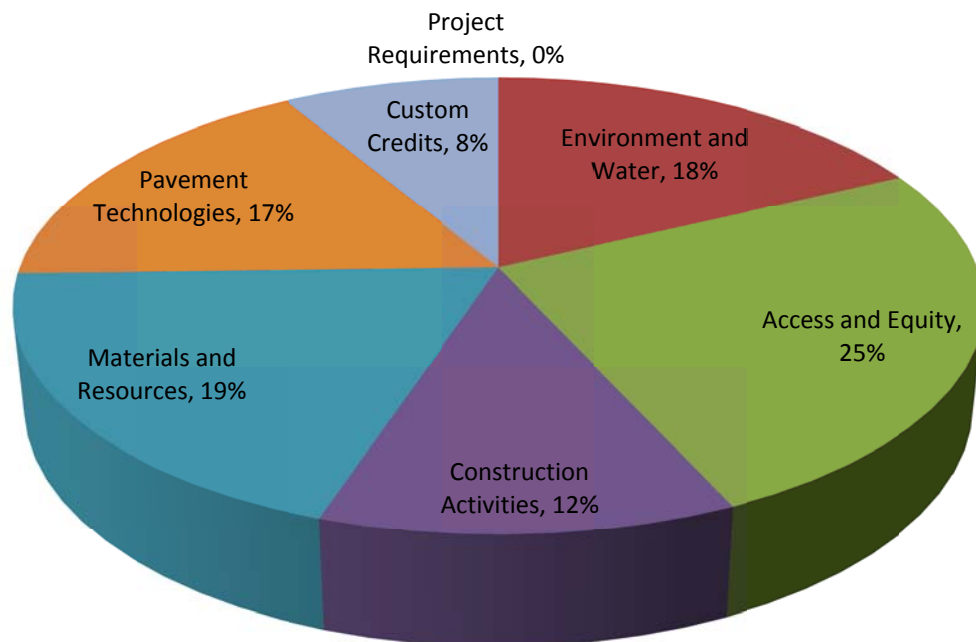


Figure 2.6: Percentage of total credit points allocated per category for Greenroads Sustainability Rating System

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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 which allows the project team to review criteria, select which ones are 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 criteria. 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 is 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).

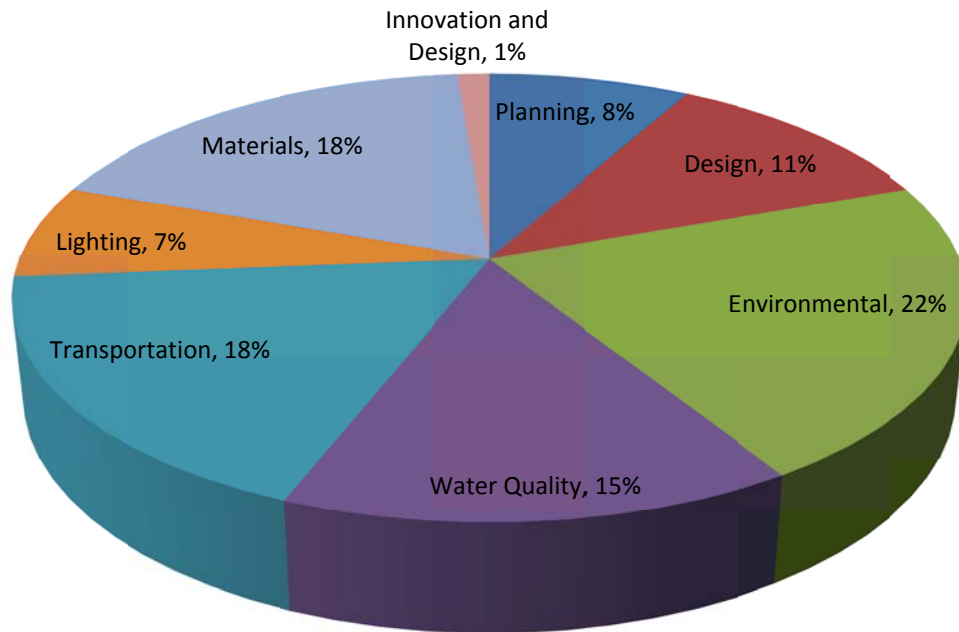


Figure 2.7: Percentage of total credit points allocated per category for I-LAST Sustainability Rating System

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 which 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 and 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 towards 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.

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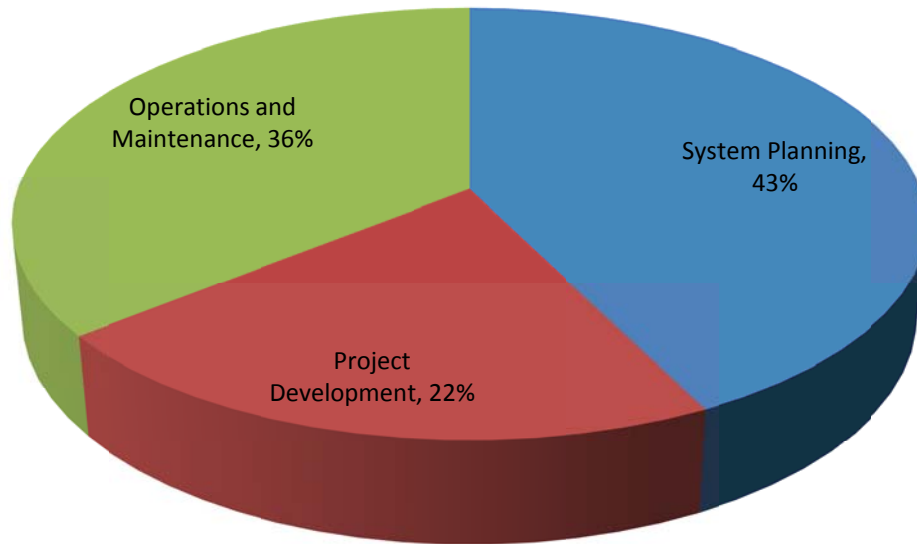


Figure 2.8: Chart Showing the Percentage of total credit points allocated per category for Invest Sustainability Rating System

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 which successfully surpass the legal minima in projects as it relates to environmental issues (CEEQUAL, 2011b). The rating system was developed by the Institution of Civil Engineers (ICE) and is supported by the Institutions 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 which 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 (CIWEM), 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, etcetera (CEEQUAL, 2011b).

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 which 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 which the questions contained therein seek to address. The questions themselves are also broken down into different sections. Firstly an explanation of the question is given followed by guidance on “scoping out”, that is, whether the question should be included or not in the assessment. It next offers the range of possible scores which are allocated for the question followed by guidance on how the assessment of the issue should be conducted. Lastly it gives examples of evidence which 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 which is 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 aim of this category is to ensure that the client and the project team not only look at their interests but the interest of the civil engineering profession as well as that of the community within which 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 which 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 which could arise from construction methodologies.

The People and Communities category evaluates the positive and negative effects of a project undertaken on the people who are affected in a community. It looks at nuisances generated as a result of the work, employment, legal requirements, and the like and how they are

addressed (CEEQUAL, 2012b, 2012c). This category is geared towards getting a project team to not only look at serving its own interest, but to make project decisions which also takes into consideration the interests of the people and the community.

The Land Use (above and below water) and Landscape category looks 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 which 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, 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 which 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 manual 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 to 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 which have successfully incorporated sustainability principles into projects. There are 6 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 begins. However, the granting of a WPA award afterwards would supersede the interim award which 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 which 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 which may fall under a terms contract are highway maintenance, railway maintenance, railway track realignments, and etcetera (Seely, 1997).

CEEQUAL is evidence based and its assessment questions/checklist is fundamentally established on the triple bottom line of sustainability; social, environmental and economic principles. The scheme has associated manuals which are to be read in conjunction with the CEEQUAL online assessment tool which is to be maneuvered by a CEEQUAL assessor that has

been trained in the CEEQUAL Version 5 Sustainability rating tool. Assessors who were trained in Version 4 can access an online training module free of charge or may attend a half day training seminar also free of charge in order to upgrade to Version 5 qualification standards (CEEQUAL, 2011b, 2012b).

All projects which are 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 which 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 regards to the applicable questions to the project. Questions which 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 has to take care to include questions which 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, that is, 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 than 75% 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 had been noted to be beneficial to project teams which seek CEEQUAL awards. Benefits which have been 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).

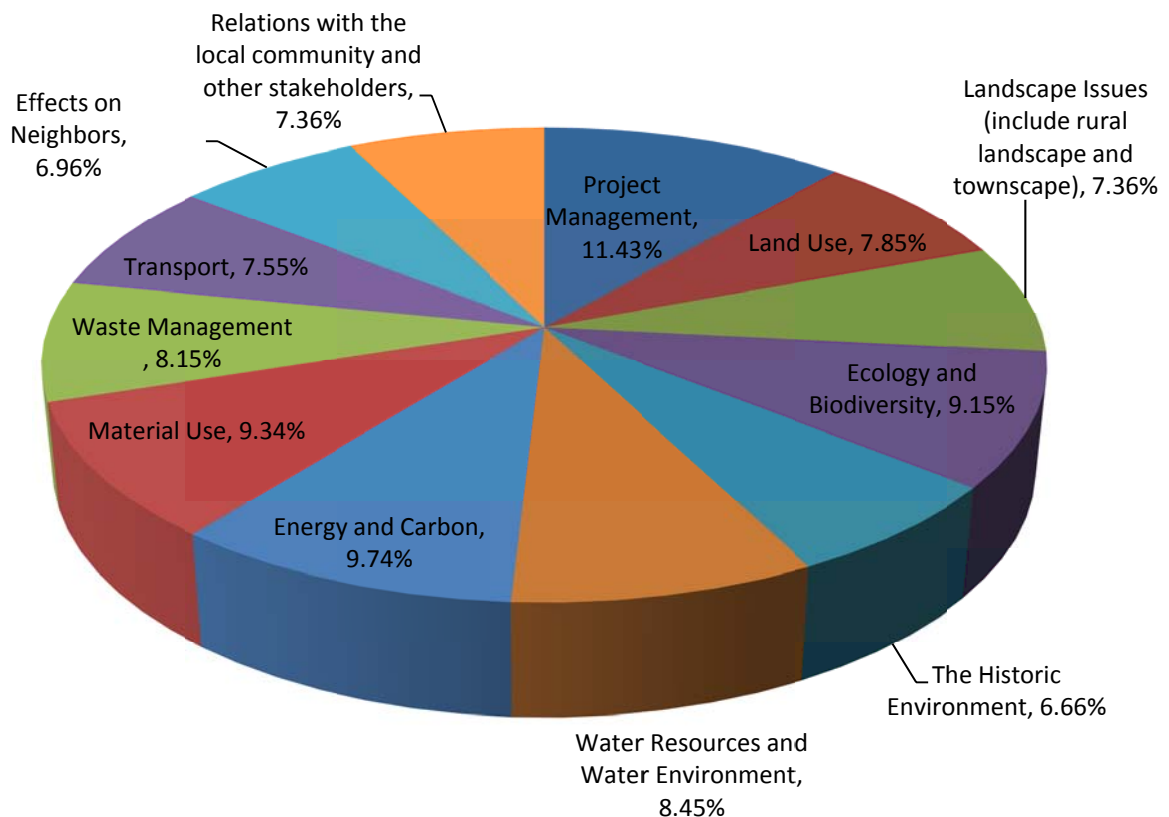


Figure 2.9: Percentage of total credit points allocated per category for CEEQUAL Sustainability Rating System

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).

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 which encourages integrated planning by the stakeholders of projects (N. A. S. T. Council, 2010).

The rating system can be used throughout the lifecycle 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 STARS Planning, 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 of 2010 is geared towards 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 they 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 which may be included under the broader category. It however does not specify

percentages or numbers and to date it 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; that is, a goal is established which is a statement of aspiration. Objectives are next established which act as a road map towards attaining the established goal. 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 towards 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 8 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 through 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 exists 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 seeing 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 at 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 which 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 standalone 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).

Comparison of the Sustainable Infrastructure Rating Systems

The ten rating systems reviewed have various similarities and differences. The following 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 ten 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 to 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.

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	✓	✓	✓	✓

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 ten 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. BE²St-in-Highways

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 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 to 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 regards to the percentage allocation for each system towards 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.

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
	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																	

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 to 1-2 points by other systems). It breaks innovation into 2 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 which award points for leadership (CEEQUAL, 2012c; ISI, 2012e).

BE²ST-in-Highways is unique because it quantifies the sustainable aspects of a project in comparison to 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). BE²ST-in-Highways is heavily weighted towards materials and resources.

GreenPave is unique in that it is the only horizontal sustainability rating system which assesses project sustainability based on the pavement only aspects of the project. Like BE²ST-in-Highways, GreenPave is heavily weighted towards 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 which was 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 teams⁵.

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.

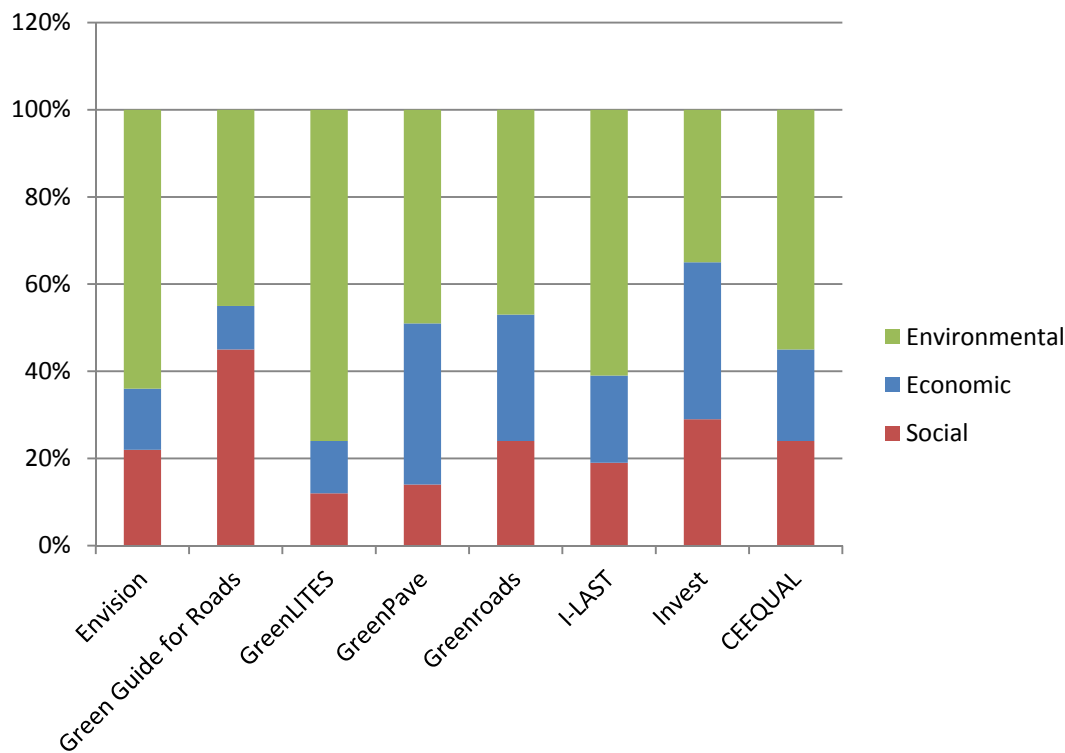


Figure 2.10: Summary of Distribution of Credits across the Triple Bottom Line of Sustainability

GreenLITES was found to have the highest distribution of credits for Environmental concerns at 76%. I-LAST and Envision both allocate over 60% of their credits to evaluating environmental concerns. GreenPave, Greenroads, CEEQUAL and Green Guide for Roads all

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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 towards social concerns standing at 45%. I-LAST, Invest, Envision, GreenPave, Greenroads, CEEQUAL and GreenLITES all allocated between 12%-29% 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 to the other rating systems evaluated throughout this literature review.

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 over 120 projects nationally and internationally (Greenroads, 2012). The majority of use has occurred in the United States. Over 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).

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 U.S. 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).

BE2ST-in-Highways has been pilot tested on the Baraboo Bypass in Wisconsin (Lee, 2011). Envision has been pilot tested on four Colorado projects; namely 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).

Over 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 their transportation plan as well as to assess the sustainability of their bicycle and pedestrian infrastructure, by Multnomah County to assess the sustainability of their bicycle and pedestrian infrastructure and by the City of Gresham to assess neighborhood's connections to a proposed bicycle path which 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 a total of 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 2 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 ten sustainable rating systems for transportation projects reveals that all of the rating systems support sharing, encouragement, and recognition of sustainable best practices. Each system differs however, in how it analyses and evaluates such practices, whether through comparison to a base design, through quantitative methods, through the use of experts in the form of third party validation or through 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 which 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.

Chapter 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 U.S. 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 and
4. an assessment of TSRSs to identify the most suitable TSRS for implementation in the State DOT using the results of the AHP survey.

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 which are geared at finding more definitive and varied explanations (Creswell, 2003). This approach is taken in this study by the researcher through interview questions which are geared at determining the

meanings ascribed by the state DOT decision makers to sustainability issues and specifically to the desires of the DOT as it relates 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 which results 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, allows each method to complement the other's weaknesses thereby strengthening the results garnered from the study (Creswell, 2003).

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; firstly it facilitates the identification of TSRSs which are available for use

in the U.S. and secondly, 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, ten (10) TSRSs available for use within the U.S. 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 ten (10) systems, sixteen (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 which 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 which 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 which 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 which 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's DOT 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 U.S. 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.

Interviews

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 which 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 be comprised of 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 which are currently a 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 which would be 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 to 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 U.S. 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 regards to desired capabilities. The following is an example of a question which was 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 which 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 which was 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 contains the interview questions which were used in the case studies.

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 which may be redundant to the research or may be 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 from would be the website of the state DOT. The state DOT website typically lists their 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 be asked to verify that they are indeed qualified to speak on the matter and in the event that 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 their 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 is 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 their 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 which are 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 the completion of the interviews, transcripts were made of the interviews and the transcripts 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.

Developing and administering secondary survey instrument – Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a decision making method which is designed to help individuals in using intuition and rational thinking in selecting the best option from a number of alternatives which 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 which can identify the subjective and personal preferences present in decision making (Saaty & Vargas, 2001). The general rationale behind the use of AHP is that it is fairly simple for individuals to look at two alternatives and decide which alternative is preferred. However this process gets

slightly more complex when there are numerous 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 will be used in the demonstration and was the tool used in developing the AHP survey instrument for this survey. It is important to note however, that there are numerous AHP software packages available for use in the event that the excel spreadsheet proves to be 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 between 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 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 presented ranges from 1 – 9 and was developed by Saaty and is illustrated in Table 3.1.

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

The spreadsheet above facilitated the choice of options by way of a drop-down menu from which the decision maker can choose either option “A” or Option “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 which 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 3.3: 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. Firstly the number derived in each row will be multiplied to get a row product. For row “Taste” the row product is derived by $1 \times 2 \times 5 \times 5 \times 8 = 400$ (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 4 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. This calculation signifies how consistent the decision maker is being with his choices. Take 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. Thirdly the consistency index (CI) is calculated using the formula:

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

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

$$CI = \frac{(\text{Lambda-Max} - n)}{(n - 1)}$$

$$CI = \frac{(5.253 - 5)}{(5 - 1)}$$

$$CI = 0.063$$

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.

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

$$R.I.$$

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

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

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

Assessing TSRSs for Implementation in State DOTs

In this framework, AHP is the proposed decision making tool which will be used to assess the suitability of TSRS for implementation in state DOTs across the U.S. The following chapter will present the findings of a case study which is 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 abovementioned 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 regards to which alternative should be chosen (Saaty & Vargas, 2001).

Chapter 4: Framework Implementation and Findings

This chapter 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 U.S. 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 DOTs 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 which may influence a DOTs 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 section geared at identifying which capabilities were desired by the state DOT, and the third section geared towards identifying any additional considerations which may influence a DOTs decision to adopt a particular TSRS.

Table 4.1 – Capabilities of Transportation Sustainability Rating Systems

CAPABILITIES OF TRANSPORTATION SUSTAINABILITY 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)

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 are additional questions which were 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).

CDOT Implementation

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 4.2 – Capabilities of Transportation Sustainability Rating Systems desired by CDOT

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

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 due to 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 which 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 which 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).

Table 4.3– Normalized Eigenvector (Weights) of the Capabilities of Transportation Sustainability Rating Systems for CDOT

CAPABILITIES OF TRANSPORTATION SUSTAINABILITY 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

Based on the weightings received by each capability, a summary was conducted to determine the scores of each TSRSs. 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 which 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 CDOTs 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%.

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 which were expressed by CDOT in the interview process which 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 which have to be gained 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 which was 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 when it presents each criteria 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 which employed 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-assessment. Otherwise the second best TSRS, STARS, as established through the AHP methodology could be adopted as it does not employ third party evaluation.

Table 4.4 – Capabilities desired by CDOT across Transportation Sustainability Rating Systems

CAPABILITIES OF TRANSPORTATION SUSTAINABILITY 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 SUSTAINABILITY 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

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.

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.

SDDOT Implementation

Framework Implementation

Based on the interview conducted with the 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 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 which is 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 TSRSs. 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 which 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).

Table 4.6 – Capabilities of Transportation Sustainability Rating Systems desired by SDDOT

<i>CHARACTERISTICS DESIRED IN A SUSTAINABILITY RATING SYSTEM</i>	<i>YES</i>	<i>NO</i>
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 4.9 the TSRSs obtained the following ranks in order of SDDOT's 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%.

Table 4.7 – Normalized Eigenvector Weights of the Capabilities of Transportation Sustainability Rating Systems for SDDOT

CAPABILITIES OF TRANSPORTATION SUSTAINABILITY 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

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 which were expressed by SDDOT in the interview process which 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 which enable the adaption of the system for rural settings. Firstly, 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 an area which is less populated, 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.

Secondly, 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 TSRSs 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 which may sway SDDOT's decision. Firstly, 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 4.8 – Capabilities desired by SDDOT across of Transportation Sustainability Rating Systems

CAPABILITIES OF TRANSPORTATION SUSTAINABILITY 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 SUSTAINABILITY RATING SYSTEMS (TSRSs)	Normalized Eigenvector	BEST- in- highways	Envision	GreenLITES	Greenroads	I-LAST	INVEST	Green Guide for Roads	GreenPave	STARS	CUEQUAL
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

Secondly, it has predesigned custom checklists which 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 which are deemed to be irrelevant, the predesigned checklist could serve as a baseline in the development of a “custom” checklist.

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.

UDOT Implementation

Framework Implementation

Based on the interview conducted with the 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 assessed to determine the results of the survey.

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 which have larger numbers of pairwise comparisons. One method which has been 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 which could be used to reduce the chances of arriving at a high consistency ratio is through the use of software which highlights the consistency ratio while the decision maker is completing the survey. This would provide a direct check and balance system which would highlight to the decision maker the decisions which are leading to a high consistency ratio and allow the correction of these errors before the survey is submitted to the researcher.

Table 4.10 – Capabilities of Transportation Sustainability Rating Systems desired by UDOT

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

Another method which has recently been 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 of 2013 (Zhang, 2013). It proposes the use of ranking and sorting methodology which seeks the selection of the highest ranked item from the list of available option; 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 which would have been 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.

Although the results of the AHP methodology for UDOT are inconclusive, they will be discussed in the following sections. For UDOT, the capability which is 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 TSRSs. 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 which 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 4.13 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.

Table 4.11 – Normalized Eigenvector Weights of the Capabilities of Transportation Sustainability Rating Systems for UDOT

CAPABILITIES OF TRANSPORTATION SUSTAINABILITY 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

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.

Table 4.12 – Capabilities desired by UDOT across Transportation Sustainability Rating Systems

CAPABILITIES OF TRANSPORTATION SUSTAINABILITY 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 SUSTAINABILITY 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

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 presented before, no conclusive recommendation can be made with regards to a specific TSRS for adoption by the UDOT based on the results of this study.

WYDOT Implementation

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 which is 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 TSRSs. 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 which had 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

<i>CHARACTERISTICS DESIRED IN A SUSTAINABILITY RATING SYSTEM</i>	<i>YES</i>	<i>NO</i>
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 of WYDOT's 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% GreenLITES at 48%.

Table 4.15 – Normalized Eigenvector Weights of the Capabilities of Transportation Sustainability Rating Systems for WYDOT.

CAPABILITIES OF TRANSPORTATION SUSTAINABILITY 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

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 which were expressed by WYDOT in the interview process which 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 due to the large distances which have to be travelled by residents. 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 areas to urban areas. The checklist is designed to address issues such as the best modes of transportation among other concerns which would arise in a rural area. There is also the option of developing a custom checklist based on the type of project which is being assessed by the state DOT. The state DOT can choose the criteria which are deemed to be relevant on a project by project basis and exclude those which 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.

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 SUSTAINABILITY 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 SUSTAINABILITY 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

Chapter 5: Conclusions

Summary of Research

The purpose of this study was to develop a framework which can be used by the state DOTs in the U.S. for assessing Transportation Sustainability Rating Systems (TSRS) for adoption. TSRS 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 TSRS 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 TSRS available for use within the U.S. 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 U.S. 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 and
4. an assessment of TSRSs to identify the most suitable TSRS for implementation in the State DOT using the results of the AHP survey.

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 summarized below briefly, for each state DOT included in the implementation case study.

Step 1 - A literature review was conducted which yielded ten TSRSs available for use in the U.S.: BEST-in-Highways, Envision, GreenLITES, Greenroads, I-LAST, Invest, CEEQUAL, Green Guide for Roads, GreenPave and STARS. A review of each of the ten 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 towards achieving credits
12. Ability to offer performance measures towards 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% 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.

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. The study was a 1 year study and information which 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 of 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 U.S.

Future Research

The results of this study have indicated that the framework herein proposed is a viable means of assessing TSRs 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 9 (Saaty & Vargas, 2001). An Improved AHP (IAHP) has been proposed for use in situations where there are more than 9 criteria on which an analysis is being made (Zhang, 2013). As such, further research should be geared towards 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 9 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 which 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 maker's confusion over terms used when comparing capabilities.

Additionally, the state DOTs included in this study could be asked to pilot test the TSRS which was 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 through looking at the performance of projects which 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 TSRSs. 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.

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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 capabilities⁶ 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 Process⁷ (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”.

Colorado State DOT AHP - Microsoft Excel

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	A	B	C	D	E
1					
2	Degree of Importance	Definition	Explanation		
3	1	Equal Importance	Two criteria contribute equally to the objective		
4	2	Slightly More Important			
5	3	Moderate Importance	Experience and judgment slightly favor one criteria over another		
6	4	Moderate to Strong Importance			
7	5	Strong Importance	Experience and judgment strongly favor one criteria over another		
8	6	Strong to Very Strong Importance			
9	7	Very Strong Importance	A criteria is strongly favored and its dominance is demonstrated in practice		
10	8	Very, Very Strong Importance			
11	9	Extreme Importance	The evidence favoring one criteria over another is of the highest possible order		
12					
13					
14		CAPABILITY A	CAPABILITY B	More Important Item	Degree of Importance
15		Ability to assign a score or an award	Ability to employ self-assessment		
16		Ability to assign a score or an award	Ability to evaluate project during conceptual stage		
17		Ability to assign a score or an award	Ability to evaluate project during design phase		
18		Ability to assign a score or an award	Ability to evaluate project during construction phase		
19		Ability to assign a score or an award	Ability to evaluate project during operations and maintenance phase		
20		Ability to assign a score or an award	Ability to allocate weights to criteria		
21		Ability to assign a score or an award	Ability to choose only relevant criteria to project		
22		Ability to assign a score or an award	Ability to offer a checklist customized to particular types of projects		

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

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”.

D15		
	C	D
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
15	Ability to employ self-assessment	
16	Ability to evaluate project during conceptual stage	A
17	Ability to evaluate project during design phase	B
18	Ability to evaluate project during construction phase	
19	nhase	

“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”.

E15			
	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	
18	Ability to evaluate project during construction phase	4	
19	phase	5	
20	Ability to allocate weights to criteria	6	
21	Ability to choose only relevant criteria to project	7	
22	projects	8	
		9	

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.