

EMGT 835 FIELD PROJECT

Sustainable Transportation Design In the United States: Background, Current Initiatives and Optimization

By


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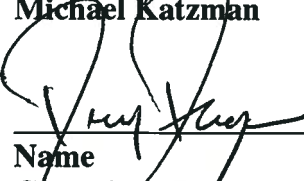

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Executive Summary

Decades of increased highway maintenance and construction, the constant use of finite resources, the severity of highway accidents, increased congestion, harmful emissions, and other negative environmental impacts have created an unsustainable highway system in the United States. While the modern environmental movement began in the 1960's, American's have only recently realized that something must be done regarding the environmental impacts due to the development of transportation systems.

To date, there isn't a single most commonly used definition of sustainable transportation, however; sustainable transportation can be linked to sustainable development which is most commonly defined as, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Thus far, much of the focus on sustainable transportation has been on green-house gases (GHG's) and other harmful emissions of the automobiles which use U.S. highways.

While this is indeed a significant factor negatively affecting the environment, economy and social well-being of American's, it is not the only issue with transportation systems in the United States.

Since the development of the modern federal highway system began in the 1950's, highway design, construction, operations and maintenance efforts have enjoyed nearly infinite use of America's valuable resources. Unfortunately the use of these valuable resources is now outpacing the rate at which they can be renewed, which could soon result in the elimination or unavailability of certain resources if the development of America's roadways doesn't change.

In response to this new dilemma, several initiatives have recently been introduced across America to address the unsustainable nature of transportation projects. Some of these include sustainable rating systems similar to the LEED (Leadership in Energy and Environmental Design) rating system for buildings developed by the United States Green Building Council (USGBC). Most of these systems are in the infant stages of development and implementation and the actual environmental benefits that result from using these systems is yet to be seen.

There are several pros and cons for sustainable transportation rating systems. The pros are the environmental and sustainable benefits that result in using a system directed toward sustainability. The cons are a little more complex. They include the unknowns like the time, cost and effort for certification, the integrity of the system, and the question of whom, in the end, is responsible for certification. Even so, with the success of the LEED rating system, it would be surprising if these systems were unsuccessful.

However, just because these systems are expected to succeed, does not infer that other avenues toward sustainable transportation should not be explored.

Sustainable transportation optimization is a new concept presented in this paper which combines rating systems with linear programming models by using cost and public input as well as site specific environmental concerns as part of the decision-making process for inclusion of sustainable measures in a given project. Like sustainable transportation rating systems, further research is needed to determine if it is worth the extra effort that may be required for implementing a sustainable transportation optimization system.

1 Introduction

1.1 The Modern Environmental Movement

Although environmentalism can be traced back to the 19th century, the modern environmental movement essentially began in the United States in the 1960's and early 1970's in response to the publication of Rachel Carson's, *Silent Spring*, in 1962. While Carson's *Silent Spring*, focused mainly on the dangers of the "indiscriminate use of pesticides," especially DDT (dichloro-diphenyl-trichloroethane), "the influence of her book brought together over 14,000 scientists, lawyers, managers, and other employees across the country to fight" for environmental protection. Although there was significant skepticism among certain parties regarding the science behind Carson's claims, her "literary genius" brought about widespread concern for the environment that went well beyond the dangers of pesticides and DDT (Lewis, 1985). Her book "called into question the paradigm of scientific progress and defined postwar American culture" (Lytle, 2007, 166).

Since the 1960's, the modern environmental movement has evolved from what was then seen as something of a localized, grassroots effort of alarmists to now federally legislated policies, with environmental proponents ranging from large organizations and political powers to local communities and small independent organizations.

Significant environmental legislation began with the National Environmental Policy Act (NEPA) in 1969, followed by the Clean Air Act (CAA) of 1970. Both NEPA and the CAA had considerable impact on the United States highway systems. NEPA required that

an environmental impact statement (EIS) be prepared for all federally funded projects over a specific dollar amount and the CAA introduced emissions standards for new automobiles (Cox et al., 2005).

1.2 The Interstate Highway System

Following World War II, congestion caused by dramatic increases in vehicle ownership, annual vehicle miles traveled and suburban housing construction led to legislation which would begin construction of the modern interstate highway system. While the federal government actually created the interstate system in 1944, most historians credit the Federal-Aid Highway Act of 1956 and the Highway Revenue Act of 1956, with the beginning of the modern federal highway system. From this legislation, the current interstate highway system was constructed and funded under the highway trust fund (Cox et al., 2005).

From 1956 to the present, the Federal-Aid Highway Act has evolved into a federal program which has gone beyond the interstate to support transit systems, safety, research and the environment, and incorporates nearly unlimited stakeholders in the decision making process. While many people believe that the current federal-aid highway program is in serious need of drastic changes in order to secure the funding required to meet America's transportation infrastructure needs, it has provided American's with "unparalleled mobility that remains the envy of much of the world." (Cox et al., 2005)

However, this mobility has not come without consequence. Decades of increased highway maintenance and construction, the constant use of finite resources, the severity of highway accidents, increased congestion, harmful emissions, and other negative

environmental impacts have created an unsustainable highway system in the United States. Unfortunately the need for sustainable transportation systems has just recently been realized as an off-shoot of sustainable development, a concept that was popularized by what is commonly known as the Brundtland Report, which was the name given to a report from the United Nations World Commission on Environment and Development (WCED) in 1987.

1.3 Sustainable Development

The Brundtland Report was an important document for change. It called attention to the global environmental crisis facing the world with the expected future population growth and infrastructure development. Currently, population growth and human consumption is outpacing the rate at which resources can be renewed or replaced at an alarming rate, so much so, that the needs of future generations are at risk of not being met.

While the idea of sustainability was not new, the Brundtland Report gave it further meaning by attempting to define the concept of sustainable development. The Report defined it as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. This is currently the most commonly used definition of sustainable development. The Report further defined the concept, concluding that “sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development; and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations” (Brundtland Report, WCED, 1987). Unfortunately the concept is still somewhat confusing and open to interpretation because it does not explicitly state what the *needs* are or for how many *future generations*

should be accounted (Black, 2010). This has led to disagreements among experts as to what the conditions are for sustainable development but it is generally agreed that sustainable development requires a delicate balance of environmental, social and economic needs, also known as the triple bottom line.

While sustainable development seems like a natural segue to sustainable transportation, it would be nearly 20 years before the concept of sustainable transportation, also known as sustainable transport, would finally begin to take root in the United States.

1.4 Sustainable Transportation

To date, there isn't a single most commonly used definition of sustainable transportation but much like sustainable development, sustainable transportation is a concept that requires a balance of "economic development, environmental preservation and social development" (Jeon and Amekudzi, 2005). Further, sustainable transportation can be viewed as a subsection of sustainable development, so one could easily derive a definition based on a combination of the definition of transportation and the definition of sustainable development (Black, 2010). Therefore, an appropriate definition might be *the safe and efficient movement of people and goods from one location to another while meeting the needs of the present without compromising the ability of future generations to meet their own needs*. One author, William R. Black (2010), defines sustainable transport as *"a system that provides transport and mobility with renewable fuels while minimizing emissions detrimental to the local and global environment and preventing needless fatalities, injuries and congestion."* However, when discussing the design, development, or maintenance of transportation systems, specifically U.S. highways, neither of these definitions quite fit the bill. The first definition is too broad, leaving the

needs and *future generations* to interpretation and the second definition doesn't take into account other non-renewable resources (besides fuels) that are consumed or the waste that can be created during the construction of highway projects.

Much of the focus on sustainable transportation thus far has been on green-house gases (GHG's) and other harmful emissions of the automobiles which use U.S. highways.

While this is indeed a significant factor negatively affecting the environment, economy and social well-being of Americans, it is not the only issue with transportation systems in the U.S. Like sustainable development, the development of transportation systems themselves needs to change.

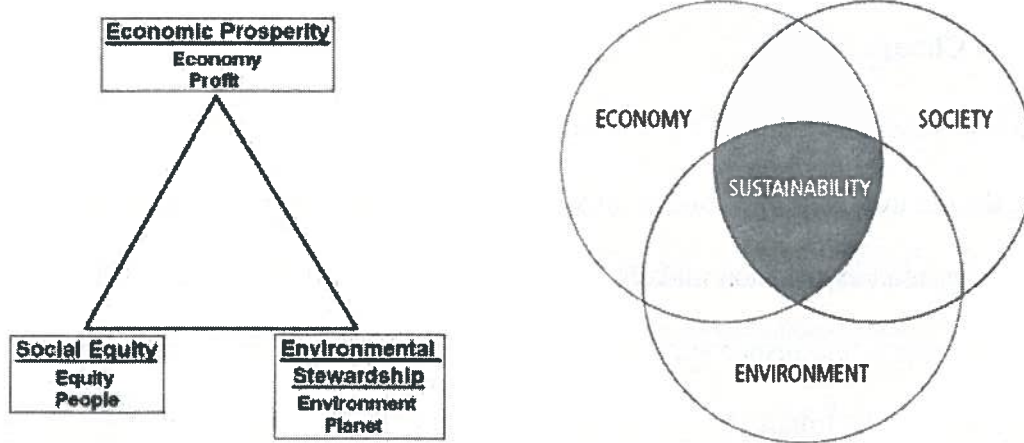
Through research and development of sustainable highway design criteria and objectives, this paper will attempt to provide highway engineers, designers and planners with a tool which can be easily understood and implemented, to begin developing sustainable highways in the United States. For this paper, sustainable highway design should limit the use of non-renewable resources and waste while preserving the natural environment and maintaining social equity and economic opportunity for all stakeholders to all extents possible.

2 Literature Review

2.1 Climate Change

Given the unsustainable nature of transportation and the recent public surge of interest in protecting the environment, the concept of sustainable transportation is gaining strength in communities and key decision makers in both the public and private sector. Much of the focus with regard to transportation has been on climate change and the concept of global warming. With climate change and transportation there are two distinct, opposing schools of thought: anti-automobile and pro-automobile; although they may not actually identify themselves as one or the other. The anti-automobile side believes that personal vehicle use should be limited in order to reduce GHG emissions, which are known to be harmful to human health and the environment (depletion of the ozone layer). The pro-automobile side believes that mobility is essential for economic vitality and that a reduction in GHG emissions should come through innovative design rather than limiting automobile use. They consider legislation and decision-making that favors transit over automobiles as a limitation on mobility which would negatively affect the economy and the quality of life of individuals who desire to travel autonomously. Both schools of thought are concerned with climate change, the economy and quality of life, centered on the ever-building congestion in America's cities. This is in line with the triple bottom line approach (balancing environmental, economic and social impacts) that the American Association of State Highway and Transportation Officials (AASHTO) has adopted for evaluating sustainability for transportation system policies and performance (Greenberg, 2008).

Figure 2.1- 1 Illustrations of the Triple Bottom Line Concept



Sources: <http://www.centerforsustainability.org/resources.php>
www.azpbs.org/sustainability/essaysdetail.php

2.2 The Transit Solution

There is no shortage of literature on transportation and climate change with an emphasis on changes in human travel behavior. “Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions”, is a study written by Cambridge Systematics, Inc. (Urban Land Institute, 2009) which falls in this category. The study focuses on reducing GHG emissions by modifying “travel activity” and improving “vehicle system operations.” In other words, by shifting vehicle travel to “more efficient modes of transportation” such as mass-transit or ride-sharing and improving the transportation network efficiency “so that a larger share of vehicle operations occurs in favorable conditions” (Urban Land Institute, 2009, 1). Cambridge Systematics suggests that this can be done through pricing and taxes for driving under specific conditions, by using operational and intelligent transportation system strategies or by expanding current highway capacities.

William R. Black (2010), author of “Sustainable Transportation Problems and Solutions”, also believes that single-occupancy vehicles are one of the chief reasons that American transportation systems are so unsustainable. He identifies climate change, substandard urban air quality, diminishing petroleum reserves, congestion, and motor vehicle fatalities and injuries as some of the main contributors. He suggests several solutions which include both policy amendments and changes in basic human behavior that seem to either lean toward promoting transit and other shared-ridership or not driving at all, over single-occupancy motor vehicle use. Some specific solutions Black suggests include pricing and tax solutions, land-use planning, indicator-based planning (performance measures), travel demand management, education, information and communication technology, alternative fuels, alternative vehicle technologies and intelligent transportation systems (ITS) (Black, 2010).

2.3 The Mobility Solution

Traffic congestion is harmful to the environment through increased GHG emissions over GHG emissions resulting from free-flow traffic operations. However, congestion has negative impacts that go beyond the environment and include thwarting the economy and denying people a certain desired quality of life. Congestion negatively impacts all three pillars of sustainability which makes finding a solution a must, in order for a transportation system to reach a state of sustainability.

Typically one thinks of transit or shared travel as one of the forefront solutions for congestion. However, Sam Staley and Adrian Moore (2009), authors of “Mobility First: A New Vision for Transportation in a Globally Competitive Twenty-First Century”, believe that “discouraging one mode of transportation, such as personal automobile use”

will have a negligible impact on climate change, due to new technology, rapid growth in countries such as China and Indonesia (increased GHG emissions) and the way that GHG emissions are currently calculated (Staley and Moore, 2009, 200). Although their book is not actually about sustainability, it's about eliminating congestion, which in itself is sustainable. For example, they point out that vehicles stuck in traffic in 2006, wasted 2.9 billion gallons of fuel, which caused 25 million tons of CO₂ to be released into the atmosphere. They consider trade-offs to be the real conundrum. For instance, increasing mobility increases travel which increases emissions, but it also eliminates waste, benefits the economy and allows people the freedom to go where they want, when they want. Further, they do not believe that the personal and economic benefits of mobility should be sacrificed in order to lessen GHG emissions. In short, they believe that there's a better more significant way to address the climate change issue than to limit mobility.

Cox et al. (2005), the authors of "21st Century Highways: Innovative Solutions to America's Transportation Needs" also consider mobility vital to the economy. They believe the automobile provides people more access to jobs, housing, and leisure opportunities and that they actually "help people become wealthier" (Cox et al., 2005, 39). Like Staley and Moore they also believe that personal automobile travel fulfills a basic human need, providing social opportunities and fast, flexible travel to wherever people want to go. They state that the automobile critics are wrong, however they too acknowledge that "automobile travel involves a set of unavoidable trade-offs" (Cox, et al., 2005, 39). While people enjoy the autonomy, privacy and mobility that personal vehicles provide, the noise, congestion, accidents, and pollution that also occur are nearly

inevitable. Fortunately new technologies have significantly decreased nearly all of these unwanted side-effects and continue to do so.

2.4 Beyond Climate Change

Climate change gets a lot of attention when addressing sustainability. However sustainable development goes beyond climate change and involves a balance among economic, social and environmental impacts. Over the past several years there has been a number of sustainable transportation rating systems developed, or in development, which attempt to address these aspects of transportation projects. Among them are the “GreenLITES Project Design Certification Program” developed by the New York State Department of Transportation (NYSDOT), the “Illinois- Livable and Sustainable Transportation Rating System and Guide (I-LAST)” developed by the Illinois Department of Transportation (IDOT), and the “Greenroads” rating system, a sustainability performance metric for roadways, based on Martina Soderlund’s master’s thesis at the University of Washington and developed by the University of Washington, CH2MHILL and a consortium of engineers and researchers. While GreenLITES and I-LAST were specifically developed for projects in their respective states, the Greenroads system was designed to be applicable for any roadway design and construction project in the United States and includes third-party certification. It is currently out for review, public comment and case studies.

Each of these systems has similarities to the U.S. Green Building Council’s (USGBC) highly successful and nationally accepted LEED (Leadership in Energy and Environmental Design) rating system for buildings. They each award points for the possible sustainable measures that can be implemented in a roadway project, based on the

sustainable measure's potential environmental impact, which are then added together to certify the project. There are different levels of certification depending on the number of points achieved; the more sustainable the project, the higher the certification level. To date, there are no nationally *accepted* sustainable transportation rating systems. This is likely due to the natural uniqueness of roadway and transportation projects.

So how does one compare one project to another through a national rating system when no two projects are the same? This is precisely the problem that engineers and planners are facing when it comes to creating sustainable roadways. Greenroads tries to address this issue by developing what they call "Voluntary Credits," of which there are a possible 108 points. For the lowest certification level a project only needs to qualify for 32 of these credits, making it seem like almost any roadway project could get certified with little additional effort. Further addressing the individuality of each roadway project, they have also allowed for 10 custom credits, which are design or construction solutions unique to a specific project, not included in Greenroads, but more sustainable than current practice. Documentation and supporting research is required for the custom credits to be applied toward project certification, making these credits a little more difficult to achieve.

Greenroads and other metric (rating) systems can be used as a way to assess a roadway project's sustainability, quantitatively, or simply as a tool for decision-making. This approach to sustainable transportation has benefits and drawbacks, as well as supporters and opponents. The benefits can be as simple as getting roadway engineers and planners to think about sustainability while a major drawback includes the apparent complexity of the system due to the unique and complex nature of roadway projects.

3 Current State of Sustainable Transportation

3.1 Technological Advances

Since the recent consciousness in America regarding the unsustainable nature of transportation systems, technology has played the most visible role in working toward sustainability for America's highways. Technological advances resulting in more sustainable highways include advances in vehicle design, alternative fuel sources, increased energy efficiency, modified construction techniques, improved pavement technologies, implementation of intelligent transportation systems (ITS) and enhancements in information and communication technologies.

3.1.1 Vehicle Design, Alternative Fuels & Energy Efficiency

Advances in vehicle design have been going on since the vehicle was invented in the 1800's. Battery powered electric vehicles (EV's), which have no tail pipe and zero emissions have been considered several times since then but continue to be replaced by other vehicles due to limitations for recharging and range, safety concerns, and high prices. In the 2000's Americas have seen an increase of hybrid vehicle usage due to soaring gas prices and widespread environmental awareness. These vehicles utilize a battery powered electric motor paired with a small internal combustion engine to extend range. However, the use of the internal combustion engine means these vehicles produce emissions making them less sustainable than the pure electric vehicle. Other vehicle advancements include the development of fuel cell vehicles but due to the shear weight of the fuel cells scientists believe that this technology may be limited to larger vehicles such as busses, trucks and tractors. Nevertheless, this is a relatively untapped technology still

in the developmental stages and has significant potential for environmental benefits over other types of vehicles (Black, 2010).

Advances in vehicle design also incorporate alternative fuels. These vehicles are sometimes referred to as alternative fuel vehicles (AFV). Some alternative fuels currently being researched and developed for possible use in AFV's include ethanol, compressed natural gas (CNG), liquefied petroleum gas (LPG), hydrogen, and electricity (FHWA, 2006). One of the most common AFV's are known as flexible fuel vehicles (FFV). They have the ability to operate on an 85% ethanol, 15% gasoline mixture, called E85, or straight gasoline. While the use of E85 helps preserve oil reserves, researchers have found that people who buy FFV's typically buy them because of their lower cost from government subsidies and often do not use E85 in them due to the lack of gas stations that supply E85, the additional cost of the fuel, and fewer miles per gallon (MPG) achieved when compared to gasoline (Black, 2010). Another popular AFV is the LPG-fueled vehicle which uses a primarily propane based mix, often referred to as autogas. Even though LPG-fueled vehicles produce fewer toxic air pollutants than gasoline-fueled vehicles they have not been commercially produced since 2004, likely due to issues with efficiency and safety. LPG is a highly flammable pressurized gas which gets fewer MPG's than petroleum based gasoline.

FFV and LPG-fueled vehicles are the most commonly seen AFV's on the road today, although LPG-fueled vehicles are becoming rarer. While other AFV's have been developed with promising results, drawbacks in production, utilization and distribution, among other things, have thus far made them impractical for widespread development

(Black, 2010). Figure 3.1.3-1 illustrates this trend of alternative fueled vehicle use in the U.S. from 2004-2008.

Figure 3.1.1-1

Alternatives to Traditional Transportation Fuels, 2008
 Release Date: April 2010
 Next Release Date: April 2011

Estimated Number of Alternative Fueled Vehicles in Use in the United States, by Fuel Type, 2004 - 2008

Fuel Type	2004	2005	2006	2007	2008
Compressed Natural Gas (CNG)	118,532	117,699	116,131	114,391	113,973
Electric ^a	49,536	51,398	53,526	55,730	56,901
Ethanol, 85 percent (E85) ^{b,c}	211,800	246,363	297,099	364,384	450,327
Hydrogen	43	119	159	223	313
Liquefied Natural Gas (LNG)	2,717	2,748	2,798	2,781	3,101
Liquefied Petroleum Gas (LPG)	182,864	173,795	164,846	158,254	151,049
Other Fuels ^d	0	3	3	3	3
Total	565,492	592,125	634,562	695,766	775,667

^aExcludes gasoline-electric and diesel-electric hybrids because the input fuel is gasoline or diesel rather than an alternative transportation fuel. The Department of Energy, which has Energy Policy Act implementation authority, ruled that gasoline-electric and diesel-electric hybrids are not "alternative fuel vehicles."

^bThe remaining portion of 85-percent ethanol is gasoline.

^cIn 1997, some vehicle manufacturers began including E85 fueling capability in certain model lines of vehicles. For 2008, the EIA estimates that the number of E85 vehicles that are capable of operating on E85, gasoline, or both, is about 7.1 million. Many of these alternative fueled vehicles (AFVs) are sold and used as traditional gasoline-powered vehicles. In this table, AFVs in use include only those E85 vehicles believed to be used as AFVs. These are primarily fleet-operated vehicles.

^dMay include P-Series fuel or any other fuel designated by the Secretary of Energy as an alternative fuel in accordance with the Energy Policy Act of 1995.

Notes: Vehicles in Use do not include concept and demonstration vehicles that are not ready for delivery to end users. Vehicles in Use represent accumulated acquisitions, less retirements, as of the end of each calendar year. The estimated number of neat methanol (M100), 85-percent methanol (M85), and 95-percent ethanol (E95) vehicles in use is zero for all years included in this table. Therefore, those fuels are not shown.

Source: U. S. Energy Information Administration, Office of Coal, Nuclear, Electric, and Alternate Fuels and the DOE/GSA Federal Automotive Statistical Tool (FAST).

Transportation networks depend on many sources of energy for construction, operation and maintenance. Energy consumption most often associated with transportation involves the consumption of fossil fuels, specifically petroleum (Rodrigue et al., 2006). Efforts in developing AFV's and advancements in vehicle design focus mainly on limiting energy consumption related to fossil fuels.

The consumption of electric energy is sometimes overlooked on construction projects, however, lighting and signal systems consume a significant amount of energy over the lifetime of a roadway. In recent years light emitting diodes (LED) have been replacing sodium and mercury lighting previously used on roadway projects. LED lighting provides energy savings, longer service life and lower lifecycle costs (Muench et al., 2010).

However, a major drawback of LED lighting is that they do not get hot enough to melt snow, which has caused deadly accidents when used at signalized intersections (Saulny, 2010).

3.1.2 Construction Techniques & Pavement Technologies

Modern construction techniques utilized in roadway projects typically incorporate recycling and re-use of highway construction materials and industrial bi-products such as rubblized pavements, fly-ash, rubber, slag, glass, asphalt shingles, etc. (Sustainable Transportation Panel, 2007). The use of these elements which would otherwise end up in landfills or polluting virgin soils is fundamental in developing sustainable transportation systems. Failure to incorporate industrial bi-products and manage the enormous waste which could be incurred on roadway projects is potentially devastating to local ecosystems.

As with roadway construction, there are many negative impacts to the environment due to pavements. Some of these include the urban heat island (UHI) effect, resource consumption (fuel, energy and materials), stormwater quantity and quality, air pollution and negative human health impacts (Calkins, 2008). Advancements in pavement technologies include the development of long-life pavements, permeable concrete pavements, porous asphalt pavements, cool pavements, colored pavements and quiet pavements. These innovative technologies have helped to curb some of the harmful effects of pavement by reducing life-cycle costs, decreasing stormwater run-off, increasing stormwater quality, reducing the UHI effect and reducing noise pollution (Muench et al., 2010).

3.1.3 Intelligent Transportation Systems

Intelligent transportation systems (ITS), formerly Intelligent Vehicle Highway Systems (IVHS) were developed to increase the safety, efficiency, and mobility of transportation networks while decreasing the negative impacts on the environment. Six major types of ITS systems have emerged: Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Advanced Vehicle Control Systems (AVCS), Advanced Public Transportation Systems (APTS), Commercial Vehicle Operations (CVO), and Advanced Rural Transportation Systems (ARTS). Those systems that decrease fatal and injury accidents, limit congestion, and increase the efficiency and operation of transportation networks have the greatest positive impact on the network's sustainability. However, these improvements may actually be counter-productive in that they could actually promote additional travel due to the increased safety and efficiency of the system (Black, 2010).

3.1.4 Information & Communication Technology

Information and communication technologies, like teleconferencing and video conferencing, involves the conveyance of information from one place to another, and enables people to remain at home or remote locations for meetings or other matters which would otherwise require travel. While transportation is defined as a means of conveyance or travel from one place to another by Merriam-Webster (Merriam-Webster Online, 2010), in the context of this paper, transportation refers to the movement of people or goods from one place to another. While worth noting, advancements in information and communication technologies are not being considered as a sustainable element of transportation, because these technologies actually replace transportation with technology.

3.2 Sustainable Transportation Rating Systems

While all of the aforementioned technological advances are important and play a significant role in reaching a state of sustainability for America's highways, they still do not address the development of transportation systems. A highway constructed with modified construction techniques and cold-mix asphalt, driven on by hybrid cars with E85 and operating with ITS and LED lighting sources is certainly not sustainable if it is constructed through a wetland, a forest, a community or farmland with no regard for ecological habitats, social equity, physical surroundings, or the consumption of non-renewable resources. Further, transportation planners and consulting roadway engineers have little control over the use of many of these technologies; especially what type of vehicle is driven or what construction techniques the contractor employs.

Recognizing that more can be done in regard to sustainable transportation initiatives, several different entities have developed or begun developing rating systems and performance measures for the purpose of creating more sustainable roadways in the United States. Sustainable transportation rating systems can be extremely beneficial to planners, engineers, contractors, owners and other stakeholders because they provide a platform for minimizing negative environmental impacts (NYSDOT, 2008), recognizing the benefits of sustainable design (Bryce, 2008), evaluating roadway projects with respect to sustainability (IDOT, 2009) and managing and improving sustainability on roadway projects (Muench et al., 2010).

3.2.1 National Rating Systems

Greenroads is a national rating system (performance metric) that awards points and certifies projects for implementing sustainable best practices in roadway projects. It was developed by the University of Washington, CH2MHILL and a consortium of engineers and researchers, and is currently still in the developmental stages. Version 1.0 was issued for print on the Greenroads website (<http://www.greenroads.us/>) in January of 2010 and revisions are expected based on industry review comments and case study results.

According to Steve Muench associate professor at the University of Washington and advisor for the thesis project by Martina Sodurlund, which resulted in the Greenroads Rating System, the goal is for Greenroads to be *the* nationally accepted sustainable transportation rating system in the U.S (Muench, Personal Communication, 2010).

While it is generally agreed that change is necessary for roadway projects in the U.S., the path to change is not. There are both proponents and opponents of creating a rating system for roadway projects. The potential benefits of implementing a national rating

system for roadways such as Greenroads are enormous. It would ensure a nationwide baseline or standard for sustainable roadway design and construction which, in turn, would presumably have a nationwide positive social, economic and environmental impact. Specific benefits include increased access and mobility, improved safety, additional lifecycle savings, longer lifecycle service, stricter habitat protection, and greater conservation of natural resources, to name a few (Muench, 2010).

However, even with all these potential benefits, there are also drawbacks to a nationwide system, although they may not be quite so obvious. Many of the shortcomings are related to the many unknowns in regard to a nationwide roadway rating system, due to the newness of this concept. For instance, the time, effort and cost inputs for implementation are virtually unknown right now, making it unclear if the benefits are actually worth the cost (Stein and Reiss, 2004). According to Kathy Harvey, State Design Engineer for the Missouri Department of Transportation (MoDOT), MoDOT is currently not interested in using a rating system like Greenroads due to the complexity of the system. The leaders at MoDOT feel that it would take too much time, effort and expense to invest in learning, training and implementing the system at this time (Harvey, Personal Communication, 2010).

There are also other unexpected issues that can arise when using a nationwide sustainable transportation rating system. Luckily, the USGBC introduced LEED, a highly successful and nationally accepted rating system for buildings, over ten years ago, so there are some things that can be learned from LEED. For example, there is a great deal of high-level engineering judgment that goes into making decisions on roadway projects; placing too much emphasis on certification may actually interfere with professional judgment

resulting in inferior design. There is also the potential for designers to develop a “most points for the least money” mentality, resulting in inclusion of sustainability elements that may not actually provide any significant sustainable benefits to the project (Stein and Reiss, 2004). Knowing these potential drawbacks in advance provides opportunity for provisions.

One of the main advantages of the Greenroads Rating System (besides the obvious sustainable benefits) cited by Steve Muench is that it is third-party certified (Muench, Personal Communication, 2010). He believes this gives the sustainability certification credibility by taking out any bias that may occur with a self-certified system. It also ensures that the certification is standardized and doesn't vary by project. However, on the other hand, third-party certification may introduce an issue regarding who is responsible for ensuring that the project gets certification. As previously mentioned, a lot of time, money and effort can be invested in project certification. When project certification involves design, construction, operation and maintenance, the question that arises is who is responsible for the project certification. Typically an engineering firm or state highway department is responsible for the design, a contractor is responsible for the construction, and the owner is responsible for the operation and maintenance. So the question is which of these people are responsible for ensuring that the project gets certified? The LEED rating system for buildings has only experienced a few issues regarding responsibility which have resulted in lawsuits but as LEED becomes more and more prevalent and as LEED buildings age, more such legal and liability problems may arise.

Another significant disadvantage of a nationwide sustainable transportation rating system is the fact that environmental, social and economic issues are not the same across the

nation, making it difficult to assign points based on potential environmental impacts of sustainable measures. For example, the desert states have very different ecological systems, endangered species and climate concerns than the Midwestern states, and the coastal states have oceanic concerns while inland states do not. One solution to this issue is development of sustainable transportation rating systems issued by state DOT's to be used statewide rather than nationwide.

3.2.2 State Rating Systems

Some forward-thinking DOT's have already created, or are in the process of creating rating systems specific for their state. The New York State Department of Transportation (NYSDOT) and Illinois Department of Transportation (IDOT) issued rating systems for use in their corresponding state in 2008 and 2010, respectively. While NYSDOT has established its system, GreenLITES, as an internal management program for use on specific projects (NYSDOT, 2008), IDOT's system, I-LAST, which is still very new in comparison to GreenLITES, is not an official policy and is only intended to be used as a guide to assess and document sustainable practices (IDOT, 2010). Still, both systems strive to minimize consumption of natural resources and materials, conserve energy, encourage stakeholder involvement, and promote innovation in order to make roadway projects more sustainable (NYSDOT, 2008; IDOT, 2010).

Like a nationwide rating system, there are both benefits and weaknesses with statewide systems. One benefit of a state system is that it would be developed to better focus on the state's specific social, economic and environmental needs than a nationwide system would. Also, with a state system, the DOT would be able to specify limits and procedures for recycled material use in pavements and fills, whereas those limits and procedures

would not be listed with a nationwide system, which could lead to designing for recycled content in a state where it is not allowed. This could in turn result in less sustainability points awarded for the project than were previously thought which could then lead to possible denial of certification. Along those same lines, each state having its own certification system could also make it difficult for small to mid-size consulting engineering firms who already work with multiple states standard plans and specifications, to become experts of each state's system.

Additionally, state rating systems would likely be self-certified by the respective state department of transportation (DOT). Because of this, the issue regarding who is responsible for making sure the project gets certified goes away; the responsibility would be with the DOT since they would have oversight over the certification, but now the potential for bias is introduced.

Further, while state rating systems can focus on that state's specific social, economic and environmental needs, it can not address the uniqueness of each roadway project or the differences in environmental concerns between the urban and rural areas of the state, such as wildlife crossings and pesticide run-off from farmland in rural areas, or provisions for multiple modes of transportation and smog build-up in urban areas.

Although a potential for drawbacks exist with both national and state specific sustainable transportation rating systems, they are still extremely beneficial in that they provide an avenue for developing more sustainable roadway projects; however, further research needs to be done to create a system that will work for all roadway projects, regardless of where the project is or how unique it may be.

4 Recommendation Regarding Rating Systems

There are two main issues that were previously introduced with both statewide and nationwide sustainable transportation rating systems that need to be addressed further.

The first issue is who is responsible for certification. This is a significant issue because of the time, money and effort that goes into certification not to mention the time, money and effort that would potentially be consumed by lawsuits. This liability could be enormous, possibly in the millions of dollars range.

While moving from a nationwide system to a statewide system shifts the responsibility to the owner, the credibility of the system suffers due to the possibility of introducing bias. This could result in much time, effort and money invested in a project that is certified sustainable but in reality is not actually as sustainable as it appears on paper. This approach also has the potential for a lot of wasted time, effort and money.

The other main issue is the fact that environmental, social and economic issues are not the same across the country, across the state or from project to project, making it difficult to standardize the assignment of points based on potential environmental impacts of specific sustainable measures. In other words a sustainable measure that has a significant environmental impact on one project may not have as much or any environmental impact on another. Therefore the number of points awarded for a sustainable element on one project should not be equal to the amount of points awarded for the same element on the other. A prime example would be the use of wildlife crossings in a rural setting versus an urban setting. Another example is specifying the use of bicycle racks along a route where bicyclists are not allowed versus specifying the use of bicycle racks along a route with provisions for bicyclists.

Fortunately the rating systems reviewed for this project all attempt to address the uniqueness of roadway projects by including sustainable measures for every possible situation and allow the decision makers to pick from a list of what is applicable to their specific project. These systems also incorporate possible credits for innovation; that is, they allow for credits for sustainable measures that are not already included as an option in the rating system, however, significant documentation may be required. The systems also list a maximum number of credits for each measure, allowing the certifier the option to award anywhere from zero to the maximum available points for each sustainable measure. Again, however, giving the certifier power to decide the number of points awarded, raises potential for bias which takes credibility from the certification process or if the project is not certified, possible liability and litigation, which could be incredibly costly to everyone involved.

4.1 A New Concept: Sustainable Transportation Optimization

A solution to these issues (bias, liability, responsibility, etc.) which could have potentially dramatic positive impacts involves optimization of decision making for sustainable transportation projects. This would entail pairing a rating system with a linear programming model, called sustainable transportation optimization, which includes stakeholder input combined with environmental impact and cost as part of the decision making process regarding the implementation of sustainable elements on a specific project. This approach would provide a better balance among the social, economic and environmental impacts (the triple bottom line) required for sustainability.

The rating systems previously reviewed are based mainly on the weight of the environmental impacts of sustainable measures which are decided by the project certifier.

The social inputs in these rating systems are sustainable measures that benefit society such as provisions for aesthetics or multiple modes of transportation, while the economic inputs focus mainly on improved lifecycle service and lifecycle cost. Rating systems typically don't include what society or stakeholders actually view as important, or upfront costs like a sustainable transportation optimization system potentially could. The application of sustainable transportation optimization would likely be fairly complex. A standardized linear programming model could be developed as a starting point but would need to be modified based on the unique aspects of the project. The foundation essentially would be a sustainable transportation rating system such as Greenroads but without the associated possible points. It basically would consist of a list of possible sustainable elements that could be used on any transportation project. The project engineers and planners would evaluate the specific project and determine which sustainable elements could and should reasonably be applied to the project. This is similar to the process that probably would be employed for rating a project with one of the sustainable transportation rating systems previously reviewed.

Once the list of possible sustainable elements is identified for a project, engineers and designers can start estimating the cost for each element and also present the sustainable possibilities to the appropriate stakeholders. The engineers and designers must be careful to communicate to the stakeholders that not all of the options are possible and the decision will be based on stakeholder input, environmental impact and cost to implement. Stakeholders would then be given the opportunity to rank each sustainable measure by which measures are most important to them. Another important factor to consider, however, is that most of the stakeholders are probably not planners, engineers or

contractors. Therefore their input should not include measures related to specifying pavement types, construction techniques and other technical aspects of the project. The next step is for the planners and engineers to determine the environmental impact of each possible sustainable measure. Several factors will need to go into determining the environmental impact depending on the sustainable measure being evaluated. Such factors could include, haul distance, recycled content, local materials, natural resource conservation, life-cycle analysis (LCA), recyclability, waste reduction, and economic and social benefits. Many of the possible sustainable transportation measures have already been extensively studied so much of the information regarding the environmental benefits of each measure is already available. The focus will need to be on the environmental impact as it relates to the specific project and the surrounding areas of the project that could be impacted.

All the information needed is now available to create a linear programming model (LPM) for optimization of sustainable transportation decision-making. The following figure, in section 4.2, can be used to illustrate how a simplified sustainable transportation optimization system might work by using the LPM software, "Management Scientist." An actual sustainable optimization system would likely be far more complex than the following example.

4.2 Sustainable Transportation Optimization Example

For the purpose of this theoretical example, arbitrary values will be used for all "known" variables. The stakeholder ranking, environmental weight and cost are all known variables. The sustainable score is the average stakeholder ranking multiplied by the environmental weight of each sustainable measure. Also, since money is not an infinite

resource, the dollar amount available for sustainable measures, which is typically known up-front, is a significant limitation or constraint for the model. The unknown variable, D_n , is whether or not to include the sustainable element in the project. The following figures show the generic variables and specific values used for each variable in this example.

Figure 4.2-1: Generic LPM Variables

Sustainable Design Element	Design Yes/No	Average Stakeholder Ranking	Project Environmental Weight	Calculated Sustainable Score	Estimated Up-Front Cost
Pedestrian Access	D_1	R_1	W_1	S_1	C_1
Combined Ped/Bicycle Access	D_2	R_2	W_2	S_2	C_2
Transit/HOV Access	D_3	R_3	W_3	S_3	C_3
Runoff Quality & Flow Control	D_4	R_4	W_4	S_4	C_4
Site Vegetation/Trees	D_5	R_5	W_5	S_5	C_5
Habitat Restoration/Protection	D_6	R_6	W_6	S_6	C_6
Ecological Connectivity	D_7	R_7	W_7	S_7	C_7
Energy Efficiency	D_8	R_8	W_8	S_8	C_8

Total Dollars Available for Sustainability = T_1

Figure 4.2-2: Specific LPM Values

Sustainable Design Element	Average Stakeholder Ranking	Project Environmental Weight	Calculated Sustainable Score	Estimated Up-Front Cost
1. Pedestrian Access	6	3	18	\$211,200
2. Combined Ped/Bicycle Access	8	3	24	\$264,000
3. Transit/HOV Access	1	5	5	\$528,000
4. Runoff Quality & Flow Control	2	2	4	\$26,400
5. Site Vegetation/Trees	7	3	21	\$105,600
6. Habitat Restoration/Protection	4	4	16	\$105,600
7. Ecological Connectivity	3	4	12	\$158,400
8. Energy Efficiency	5	1	5	\$79,200

Total Dollars Available for Sustainable Measures: \$800,000

Ranking: 8= most important, 1= least important

Environmental Weight: 5= Most Benefit, 1= Least Benefit

Figure 4.2-3: LPM Objective Function & Constraints

The following objective function and constraints will be entered into the LPM software, substituting the known values shown in Figure 4.2-2 for the variables, S_n , C_n and T_1 shown in Figure 4.2-1.

Objective Function:

$$S_1D_1 + S_2D_2 + S_3D_3 + S_4D_4 + S_5D_5 + S_6D_6 + S_7D_7 + S_8D_8 \quad \text{Maximize Sustainable Score}$$

Constraints:

1. $C_1D_1 + C_2D_2 + C_3D_3 + C_4D_4 + C_5D_5 + C_6D_6 + C_7D_7 + C_8D_8 \leq T_1$ Funding Limit
2. $D_1 + D_2 \leq 1$ Include either Ped. or Combined Ped./Bike, Not both
3. $D_1 \leq 1$ Constraint 3-10: Include element, 1; Do not include element, 0
4. $D_2 \leq 1$
5. $D_3 \leq 1$
6. $D_4 \leq 1$
7. $D_5 \leq 1$
8. $D_6 \leq 1$
9. $D_7 \leq 1$
10. $D_8 \leq 1$

Note: The objective is to get an answer of 0 or 1 for each D_n . This indicates whether or not the sustainable element should be included in the project, therefore integer linear programming is necessary for this example. A decision of 1 indicates that the element should be included; a decision of 0 indicates the element should not be included in the project in order to maximize the sustainable score and also meet all the constraints.

Figure 4.2-4: Integer LPM Results

Solving for the objective function using the Management Scientist software yields the following results.

Objective Function Value = 46.000

Variable	Value	Variable	Value
D1	0.000	D5	1.000
D2	0.000	D6	1.000
D3	1.000	D7	0.000
D4	1.000	D8	0.000

Constraint	Slack/Surplus	Constraint	Slack/Surplus
1	34400.000	6	0.000
2	1.000	7	0.000
3	1.000	8	0.000
4	1.000	9	1.000
5	0.000	10	1.000

Figure 4.2-5: Tabulated LPM Example Results

Sustainable Design Element To be Implemented	Average Stakeholder Ranking	Project Environmental Weight	Calculated Sustainable Score	Estimated Up-Front Cost
3. Transit/HOV Access	1	5	5	\$528,000
4. Runoff Quality & Flow Control	2	2	4	\$26,400
5. Site Vegetation/Trees	7	3	21	\$105,600
6. Habitat Restoration/Protection	4	4	16	\$105,600
Total			46	\$765,600

4.3 Explanation of LPM Example Results

According to this LPM, the sustainable elements that should be implemented in order to optimize the sustainable score for the example project are D3, D4, D5, and D6 as shown in the Management Scientist software results by a value of 1 (and a value of 0 for D1, D2, D7 and D8 which indicates these elements should not be implemented) and in the above tabulated results.

Implementing these sustainable elements would cost \$765,600, resulting in a surplus of \$34,400 (See Slack/Surplus for Constraint 1). This is not ideal for a roadway project.

Additional constraints should be included to ensure that the surplus is minimized. The Slack/Surplus equal to 1 for constraints 2, 3, 4, 9 and 10 correspond to the decision variables, D1 + D2, D1, D2, D7 & D8, respectively. These are the sustainable elements that were not recommended for implementation by this optimization example and therefore there is a surplus of 1 for each of these (since they were not recommended for implementation).

4.4 Sustainable Transportation Optimization Summary

One of the previously noted drawbacks to rating systems was the complexity of the systems. Although, the application of the concept of sustainable transportation optimization would be fairly complex, the programming model could likely be standardized so that the decision-makers could simply input the values determined from public input, cost analysis and environmental review. Further, incorporating public input and cost along with environmental impacts gives a more accurate sustainable result (balance of the social, economic and environmental impacts) than simply scoring sustainable measures. Also, to further enhance the system, a model could be created for each phase of the project. This would eliminate the question of who is responsible for certification which was the other main concern with rating systems.

4.5 Sustainable Transportation Certification and Optimization by Phase

There are generally three phases to transportation projects. Phase 1 is the planning and design stage, phase 2 is the construction stage, and phase 3 is the operation and maintenance stage. Sustainable transportation rating systems and future sustainable transportation optimization systems should be considered at each of the three phases of the project. There should be one system for the planning and design phase, a separate system for the construction phase and a third rating system for the operation and maintenance phase, resulting in each phase of the project having a separate certification. While this may seem like a lot of different systems, it essentially simplifies the systems by narrowing down the list of sustainable measures to those that are applicable to each phase. As with any project though, it's still important to consider construction while the

project is being planned and designed. Designing something that can't be constructed would be counter-productive.

Further, by splitting the system up by phases, the question of responsibility goes away.

While the owner typically oversees the project and makes the ultimate decisions regarding what is and isn't included, splitting the certification system up by phase identifies who is responsible for certification. In this case, the engineer would be responsible for the design certification, the contractor would be responsible for the construction certification and the owner would be responsible for any certification relating to the operation and maintenance of the project.

5 Conclusion

Sustainability is a broadly defined subject. Unfortunately there is no accepted standard definition of sustainability, sustainable development or sustainable transportation.

Because of this, these concepts are difficult to understand, making interpreting data, goals and results extremely complicated.

Even though it's commonly agreed that sustainability entails a balance of social, economic and environmental impacts, many sustainable elements or issues overlap.

Further complicating the matter, a sustainable measure that has a positive impact in one area may actually have a negative impact in another; known as the law of unintended consequences. An example of this in transportation projects is the use of plastic geogrid for base stabilization. Geogrid reinforces the pavement subgrade thus allowing the application of thinner base and pavement layers which saves time, money and valuable resources. However, geogrid is typically made from virgin materials and creates waste both in the manufacturing process as well as at the end of the pavement life. A "real-world" example that most people can probably relate to is recycling used drink containers. While recycling conserves natural resources, the recycling company usually requires the containers to be rinsed out which wastes water. Additionally, sorting, hauling and processing of the containers further consumes natural resources.

Until the concept of sustainability is better understood and defined, significant progress in sustainable transportation initiatives like sustainable transportation optimization and rating systems will be difficult to measure. However, this does not suggest that research and development of such initiatives should halt. In fact, continued research is absolutely

necessary in order to come to a better understanding of sustainability and develop truly sustainable transportation projects.

6 Suggestions for Additional Research

While sustainable transportation optimization is an idea whose time has come, there is much more research required to determine for which projects it is feasible, if it results in more sustainable projects and if it is worth the time, effort and cost that would go into developing and implementing such a system.

Further research should also be done on sustainable rating systems. Are they really making transportation projects more sustainable? Are they worth the time, effort and cost that go into developing and implementing them? Additional case studies need to be published on rating system projects that are in each of the three different phases: planning and design, construction, and the operation and maintenance phases.

The “unavoidable” trade-offs that occur with sustainability should also be further investigated. Is there a way to predict and evaluate the potential trade-offs or a way to determine the more sustainable option?

Further, since pavements make up the bulk of transportation projects, studies on the sustainable attributes of different types of pavements needs to continue. Pavement materials and design are continuously evolving with experimentation with different pavement types, mix designs, and construction applications. Additional investigations should be conducted to determine which of these pavements types, mixes or applications are more sustainable than the others and still offer the strength and durability required for safe and efficient travel.

Transportation funding is another hot-button topic across the U.S. The next Transportation Bill is yet to be seen and states are lacking the funding required to maintain the current infrastructure, let alone expand existing roadways or construct new

projects. Further research is needed regarding the pros and cons of linking sustainability to transportation policy.

Finally, there is currently an abundance of information appearing regarding transportation sustainability. Compiling all of this information into one database and grouping it into specific study areas would go a long way to furthering progress for such a broad subject matter like sustainable transportation.

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8 Appendix A: Links to Current Sustainable Transportation

Initiatives at State DOT's in the U.S.

Illinois	http://www.dot.state.il.us/Green/index.html
Maryland	http://www.green.maryland.gov/
Minnesota	http://www.dot.state.mn.us/sustainability/
Missouri	http://www.modot.mo.gov/beinggreen/index.htm
New Jersey	http://www.state.nj.us/transportation/works/njfit/links/faq.shtm
New York	https://www.nysdot.gov/programs/greenlites
North Carolina	http://www.ncdot.gov/programs/drivegreen/default.html
Ohio	http://www.dot.state.oh.us/policy/Initiatives/Pages/StrategicInitiativeSix-10-11.aspx
Oregon	http://www.oregon.gov/ODOT/SUS/index.shtml
Tennessee	http://www.tdot.state.tn.us/smartcommute/
Vermont	http://www.connectingcommuters.org/
Virginia	http://www.governor.virginia.gov/news/viewRelease.cfm?id=452
Washington	http://www.wsdot.wa.gov/SustainableTransportation/
Wisconsin	http://www.dot.wisconsin.gov/projects/env/index.htm

Note: This is not a comprehensive list. Other sustainable transportation initiatives at state DOT's are likely in existence or in development which may not currently be available online.

9 Appendix B: Acronyms and Abbreviations

Term/Phrase	Definition
AASHTO	American Association of State Highway and Transportation Officials
AFV	Alternate Fuel Vehicle
APTS	Advanced Public Transportation System
ARTS	Advanced Rural Transportation System
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System
AVCS	Advanced Vehicle Control System
CAA	Clean Air Act
CNG	Compressed Natural Gas
CVO	Commercial Vehicle Operations
DDT	Dichloro-Diphenyl-Trichloroethane
DOT	Department of Transportation

Term/Phrase	Definition
E85	Ethanol, 85%
EIS	Environmental Impact Statement
EV	Electric Vehicle
FFV	Flexible Fuel Vehicle
FHWA	Federal Highway Association
GHG	Green-House Gas
IDOT	Illinois Department of Transportation
I-LAST	Illinois-Livable and Sustainable Transportation Rating System
ITS	Intelligent Transportation System
IVHS	Intelligent Vehicle Highway System
LCA	Life-Cycle Analysis
LED	Light Emitting Diode
LEED	Leadership in Energy and Environmental Design

Term/Phrase	Definition
LPG	Liquefied Petroleum Gas
LPM	Linear Programming Model
MoDOT	Missouri Department of Transportation
MPG	Miles Per Gallon
NEPA	National Environmental Policy Act
NYSDOT	New York State Department of Transportation
UHI	Urban Heat Island
USGBC	U.S. Green Building Council
WCED	World Commission on Environment and Development
WCED	World Commission on Environment and Development

