Assessing Sustainability Effect of Infrastructure Transportation Projects Using Systems-Based Analytic Framework

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NCITEC Project No. DTRT12-G-UTC14

Conducted for

NCITEC

July 1, 2015

Technical Report Documentation Page

1. Report No.

2. Government Accesion No.

3. Recipient Catalog No.

4. Title and Subtitle: Assessing Sustainability Effect of Infrastructure Transportation Projects Using Systems-Based Analytic Framework

5. Report Date:
July 1st, 2015

6. Performing Orgainization Code:

7. Authors: Dr. Islam El-adaway and Dr. Dennis Truax

8. Performing Organization Report:

9. Performing Organization Name and Address:
Mississippi State University
501 Hardy Road, 235C Walker Engineering Building,
P.O. Box 9546, Mississippi State, MS 39762

10. Work Unit No.:

11. Contract or Grant No.:

12. Sponsoring Agency Name and Addrees:
NCITEC
260 McCain
Mississippi State, MS 39762

13. Type of Report or Period Covered: Final

14. Sponsoring Agency Code:
#XXXX

15. Supplementary Notes:

16. Abstract:
Sustainability means providing for the necessities of today without endangering the necessities of tomorrow within the technical, environmental, economic, social/cultural, and individual contexts. The assessment tools available to study the sustainability of the built environment are limited in their approach and lacking in their content due to several reasons: (1) differences amongst the actors within the industry; (2) fragmentation as represented by lack of communication and understanding between the industry and those whom it serves; and (3) regionalism as represented by the disconnection between the construction projects and their host community systems. The narrow focus of the currently available assessment methods does not collectively address the technical, environmental, economic, social/cultural, and individual sustainability indicators as well various aspects of sustainability. To this end, this research develops three innovative system-based concepts to assess sustainability of civil infrastructure projects: (1) work, (2) nature, and (3) flow. The “work benchmark” defines the socio-behavioral relationships amongst the products and the actors of the built environment. It also attempts to delineate how the end-product is affected by how well the producers are connected to the product. The “nature benchmark” focuses on the effects of the built process on the environment through studying the interaction between the construction actors, their associated processes, and the end-products within their host systems. The “flow benchmark” identifies the overall system changes within the host systems and the effects of these changes on the natural environment and the socio-economic setting. For testing and evaluation of “nature” and “work” on five different types of civil infrastructure projects, the author utilized a three-step methodology comprising: (1) structured survey; (2) data collection; and (3) analysis. In order to avoid being unrepresentative of the industry, the author chose projects with different scopes representing a wide spectrum of construction projects. This process provided an improved understanding of the environmental, social, and economic effects of these projects from a systems perspective. For future work, the concept of “flow” will be further explored using macro-level system dynamics modeling, micro-level agent-based simulation, and multi-objective optimization to

17. Key Words:
Sustainability Management

18. Distribution Statement:

19. Security Classification (of this report): Unclassified

20. Security Classification (of this page): Unclassified

21. Number of Pages:

22. Price

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ABSTRACT

Sustainability means providing for the necessities of today without endangering the necessities of tomorrow within the technical, environmental, economic, social/cultural, and individual contexts. However, the assessment tools available to study the sustainability of the transportation infrastructure are limited in their approach and lacking in their content due to several reasons: (1) differences amongst the actors within the industry; (2) fragmentation as represented by lack of communication and understanding between the industry and those whom it serves; and (3) regionalism as represented by the disconnection between the transportation construction projects and their host community systems. The narrow focus of the currently available assessment methods does not collectively address the technical, environmental, economic, social/cultural, and individual sustainability indicators as well various aspects of sustainability.

To this end, this research develops three innovative system-based concepts to assess sustainability of the transportation infrastructure projects: (1) work, (2) nature, and (3) flow. The "work benchmark" defines the socio-behavioral relationships amongst the products and the actors of the built environment. It also attempts to delineate how the end-product is affected by how well the producers are connected to the product. The "nature benchmark" focuses on the effects of the infrastructure system on the environment through studying the interaction between the transportation projects actors, their associated processes, and the end-products within their host systems. The "flow benchmark" identifies the overall system changes within the host systems and the effects of these changes on the natural environment and the socio-economic setting.

For testing and evaluation of "nature" and "work" on five different transportation and civil infrastructure projects, which are in a relation to a transportation project, the authors utilized a three-step methodology comprising: (1) structured survey; (2) data collection; and (3) analysis. This process provided an improved understanding of the environmental, social, and economic effects of these projects from a systems perspective. For future work, the concept of "flow" will be further explored using macro-level system dynamics modeling, micro-level agent-based simulation, and multi-objective optimization to measure the overall system change.

ACKNOWLEDGMENTS

This work would have never been possible without NCITEC's funding as well as the support of various agencies that provided needed traffic data.

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INTRODUCTION

The environmental and other primary concerns are addressed in an approach called sustainable development, a balance between the available technologies, strategies of innovation, and the policies of governments. This approach takes into account the will to live in a healthy environment and provide future generations with improved social, economic, and environmental conditions while providing the current generation with new or improved built facilities. Since the early to mid-1980s, transportation infrastructure sustainable development has gained much attention, generating considerable interest and a considerable amount of discussion within the transportation sector, and amongst communities and nations. The culmination point of this interest was a report calling for a strategy that united development and environment, following the World Commission on Environment and Development entitled Our Common Future in 1987 (Ortiz et al., 2009).

Over the years, the desire and need for transportation infrastructure sustainable development pushed communities, as well as organizations across the various industry sectors, to come up with or adopt ways, means, and methods to study and analyze the development process and its effects. Especially since the early 1990s, the transportation infrastructure development sector has been active in developing assessment tools, which have gained considerable success and amassed new knowledge databases through the contributions of actors and experiences from across the construction spectrum (Haapio and Viitaniemi, 2008). While this awareness has brought forth a series of positive consequences, most of the sustainable built process assessment methods are narrowly focused and fail to place the object of the analysis within a broad holistic context that reaches beyond the simple parameters that surround that particular object. These methods often focus on individual aspects of the project such as the effects on the natural environment, storm water discharge, indoor air quality, pedestrian mobility, and used materials. A great number of the existing methods are not designed for evaluating different types of activities and fail to provide a standard to assess work performance and establish a performance benchmark. This shortcoming makes it difficult for professionals to keep records of their goals and achievements (Tam et al., 2004).

There are several reasons for implementing a method and a metric that addresses a wider spectrum of issues instead of a single topic. The transportation industry and the associated infrastructure building process are very much multi-faceted: Several industries are involved in the design, manufacturing and transportation of construction materials; the type of building professionals involved in the process range from engineers, architects, and planners, to general contractors and their workers, to purchasers, owners, and financiers of projects; and a built facility can have a wide variety of use-purpose, such as a school, a grocery store, a highway, an oil refinery, a business complex, or a solar energy field. Rapid urbanization during recent decades has revealed the need for considering the built environment, transportation planning, residential neighborhoods, and public services as a whole body, instead of handling them as separate civic development topics. The suburban population in the United States has increased from nearly one third of the overall population in 1960s to nearly half in 1990s. The hurry to urbanize left the infrastructure behind and suffering, and the environment in an even worse condition. The rapid increase in suburban populations continues to be major concern due to its unintended but nonetheless detrimental effect on the environment (Haapio, 2011).

Another shortcoming of the extensive spectrum of evaluation tools is that the effectiveness of some of these tools is questionable, as the intended use of each tool, how and when it should be utilized, is not clear (Haapio and Viitaniemi, 2008). Questionable or not, these methods are widely implemented throughout the industry, who are in intense competition against one another to gain recognition and market share. There is a clear lack of coordination among industry players on the use of these methods and metrics to analyze various aspects of construction (Foley et al., 2003). The lack of coordination and communication is apparent in identifying the most important design concepts, material or phase of the infrastructure construction process to evaluate.

The lack of communication is often exasperated by the fact that each community has its own self-developed planning, construction, and maintenance guidelines and standards, as well as adopted means to evaluate various aspects of the transportation development process. The disconnection amongst communities often shifts the decision making power from local level representation to policy makers of larger governing bodies. As a result, differing interests and competing economic demands make it difficult to reach a consensus on issues such as zoning and development planning.

The sustainable built environment assessment methods available to the industry and its customers place their focus mainly on materials, construction techniques, and environmental impact. The disconnections amongst the actors within the building industry, disagreements within the industry on what method to implement, lack of communication between the industry and its customers, and the disharmony amongst communities and governments highlight the need for an integrated, holistic assessment approach that is based on the interdependencies of the transportation industry and the people whom it serves.

This is why it is necessary to derive and define an assessment method that relies on an analytical method that involves and links together the environmental, economic, social, cultural, and individual sustainability concepts together and provides a means to oversee the progression in which variables change throughout the process which we call the built environment.

OBJECTIVE

The main goal of this research is to develop an innovative-systems methodology based upon a set of three benchmarks that are intended to bring transportation industry and its customers together to recognize the broad sustainability indicators (i.e. technical, environmental, economic, social/cultural, and individual) of the development processes. This is attained through:

1. <u>Define a sustainability systems approach to study the built environment</u>. It is important to develop a set of tools that take into account the natural environment as well the socio-economic environment. By doing so, an all-inclusive approach that is environmentally conscious can be developed and implemented.
2. <u>Assess the degree of communication between the industry and its community host systems</u>. The degree of communication can be observed through the type of projects that communities are committing to build, and the level of interest and commitment that the transportation industry displays towards these projects.
3. <u>Evaluate the relationship between the construction industry and its customers</u>. By evaluating this relationship, the need for the industry to consider the effects of their products and processes on their customers can be underlined.

SCOPE

The assessment tools available to study the transportation development process are limited in their approach and lacking in their content, and the communities and professionals that utilize them are disorganized in their approaches to assessment. This can be attributed to a collective set of reasons including: (1) differences amongst the actors within the transportation industry; (2) fragmentation as represented by lack of communication and understanding between the development and those whom it serves; and (3) regionalism as represented by the disconnection between the development projects and their host community systems (i.e. federal, state, and local governments). To this end, Daniell et al. (2005) suggests that:

1. Governments and planning authorities worldwide require more holistic methods for sustainability assessment in order to develop future planning strategies;
2. Decision makers find it difficult to make judgments which are consistent with sustainability goals for development due to the narrow focus of current assessment tools;
3. Current sustainability assessment tools do not adequately represent the temporal, spatial, and behavioral aspects of sustainability;
4. There is no common methodology which relates measures of resource use and other variables indicators to assess sustainability; and
5. There is a specific need for a methodology that can be used to assess the sustainability of complex systems.

Sustainability

In an ideal world, the industries would build products that have a positive impact to their surroundings, and take into account the ecological, economic, and social well-being of the ecosystem in which the industry operates (Tessema et al., 2009). The Marrakech Task Force SBC workshops in 2007 defined the goal of sustainable infrastructure as fulfilling performance requirements while having minimum negative impacts to the environment, and improving social, cultural and economic conditions. This can be accomplished through utilizing responsible material sources, as well as having well thought-out design, operation and maintenance practices (Tessema et al., 2009).

The environment only approach is still very prevalent amongst the customers and the professionals of the various industries, which presents a barrier to further understanding concept and putting it in practice. One of the reasons for this incomplete representation of the idea, that is sustainable development, is that some industries are slow to respond and adapt to new concepts. Though the response is slow, the need is acknowledged by many.

The need for sustainable development is apparent when the dramatic effects of rapid urbanization are studied. According to Ndubisi (2008), the most noticeable effect of urban development, or urbanization, is the fragmentation of land into smaller parcels. The negative consequences of urbanization are also seen in land use conversions, and changes in land use type and intensity. Many metropolitan cities experience urban development in the form of urban sprawl. Ndubisi (2008) defines urban sprawl as a result of inconsistent and irregular planning and distribution of land use, as well as infrastructure required to serve the new land use. This form of rapid urban development has leads to suburbanization, political fragmentation, and declining quality of life in urban areas, increases the cost and financial burden of public services, and disrupts local ecology (Ndubisi, 2008). Economic and population growth provides the policy makers and the residents of a city with employment, larger public spending budgets, and increased status, all of which are positive improvements that promote further growth while overlooking the effects of these developments on the socio-economic and environmental fronts. Therefore, it is essential to have the support of the general public as well as the policy makers when establishing a sustainable built environment.

Amongst the many factors that are important in the formation of a sustainable built environment is active government involvement at all levels. According to Gomes and Silva (2005), actions that governments at the local and national levels have taken to ensure the fostering of sustainable development practices are:

1. Leading by example. This is effectively done by improving public facilities and incorporating sustainable development concepts in public bidding and procurement;
2. Integration of sustainability concepts into development codes, ordinances, laws and regulations;
3. Implementation of subsidies and financial incentives;
4. Public financing of sustainable development projects;
5. Assistance in importing and financing of non-available or high-cost materials and technologies until local supply capacity is improved.

Converting short term actions to long term behaviors is vital in order to ensure the continuity of policies, regulations and practices that promote a sustainable environment. Yitmen (2007) suggests that long term strategies that consider the manufacture and use of appropriate technologies and materials must be implemented to ensure sustainable development at all levels and to create sustainable livelihoods.

The sustainable development process has an end goal of enabling designers, builders and customers of the transportation development process to create an infrastructures that do not negatively affect the society and the environment, at the present time or in the future. In recent years, discussions on sustainability in the development process have gained momentum internationally (Haapio and Viitaniemi, 2008). In their discussions, Haaipo and Viitaniemi (2008) show the Green Building Challenge (GBC) as an example; GBC is an organization which has vastly contributed to the success and worldwide reach of sustainable concepts by organizing major international conferences.

In addition to defining sustainability in the development process, it is also important to define the standardized requirements for various aspects that make up this concept. One of the challenges the sustainable built environment often faces is the non-conformed understating of the concept by industry professionals, customers of the industry, and the policy makers.

Challenges within the Industry

Gomes and Silva (2005) list various general challenges within the developement industry with regards to the sustainable built environment:

- The integration of sustainable development practices in local and national policies and regulations has led to a greater level of sustainable awareness amongst architects, engineers, and contractors; however, a clear gap still remains.
- There is a shortage of appropriate, low-risk, and geographically and financially non-prohibitive materials and services that promote the understanding of and provide the means to the sustainable built process.
- There is a lack of performance data of sustainable products and services, which makes cultural and technological assimilation at all levels of development challenging. Combating such challenges requires additional effort from product vendors and service providers, pushing the transportation infrastructure market to a service oriented process instead of the conventional approach that emphasizes the product. Sustainable development often requires ongoing product support, maintenance, and disposal services, in place of the one-time sale and exchange of materials and services.

Compared to other industries, the infrastructure construction industry provides services and products in an entirely different manner. Unlike in other sectors, the customer purchases or commits to purchase a product based on a concept that is immobile, custom-made, and not-yet-made. In other industries, generally speaking, the product is often mass-produced and presented to the customer after it is designed and manufactured (Dulaimi, 2005). The entire transportation infrastructure construction and development process is driven by the needs, wishes and wants of the customer, and the final product should be expected to meet or exceed these needs. However, Yitmen (2007) claims that the disconnection between the industry professionals and the customers leave often either party disappointed in the level of participation they see from each other. Yitmen (2007) continues by stating that today's construction industry infrastructure customers demand innovative solutions. For this reason, the importance the industry places on innovation, including innovative sustainable solutions is rapidly increasing.

Fragmentation

Gonzalez et al. (1998) argue that variations in regulations, institutional restrictions, and labor and tax regulations imposed on the construction industry are the main culprits of the fragmentation of the infrastructure construction industry. Fragmentation is an increase in the number of entities and a decrease of the average size of these entities. According to Gonzales et al. (1998), the fragmentation process is a qualitative change that de-emphasizes employment relationships and emphasizes market relationships. If firms are defined as teams, entrepreneurship transfers from the team to the team members through the process of fragmentation.

Fragmentation can be within a team or a firm, in a group of firms or partnerships, or within the industry or different subgroups within the industry. With fragmentation, the activities of each individual entity reduce to focus on more sophisticated roles within the industry. Gonzales et al. (1998) argue that labor regulation affects the costs of employment and external contracting, which causes fragmentation as an adaptive reaction. To this end, Gonzales et al. (1998) lists several specific social and private costs and inadequacies fragmentation causes:

1. The impact of reduced assets on financing of projects, bonding of agreements;
2. Increased cost monitoring;
3. In efficient risk allocation due to the smaller size of contracting parties that are naturally risk averse;

4. Excessive allocation of resources to low-tax and high-regulation activities;
5. Legal inequality and disrespect for law.
6. Fragmentation of the industries complicates the industries dealings with the governing bodies, which are already in a state of disharmony due to the effects of regionalism.

Regionalism

The concept of regionalism was originated in the early twentieth century by three individuals, Scottish botanist and planner Patrick Geddes, urban historian and critic Lewis Mumford, and forester and planner Benton MacKaye. In the 1960s and 1970s, the regionalist ideas were redefined to emphasize the community-ecology relationship, the main focus being metropolitan growth and urban sprawl. Regionalism provided a platform to discuss and propose changes in the existing social, economic, and political order to contain the urban sprawl (Ndubisi, 2008). According to Haughton and Counsell (2004), planning at the regional level has been considered essential in providing a discussion platform and a path for deciding the nature of future settlement patterns. Many regional government bodies are now either tasked with or desire to pursue sustainable development as a part of their regional development policies.

Regionalism is a multi-faceted concept that involves many interconnected and multi-level economic, social, political and cultural factors. According to Dent and Richter (2011), by definition, regionalism refers to the processes and arrangements that aim to manage and improve unity within a region in terms of economic, political, security, socio-cultural and other associations. Dent and Richter (2011) list the processes that create these associations under three categories:

1. *Micro-level processes:* Regional concentrations of interrelated private and civil sector activities. These activities and the relationships between the actors delineate the concept of regionalization;
2. *Macro-level public policy:* Intergovernmental agreements and policy cooperation that govern the relationships amongst countries, such as a free trade agreements or other economic cooperation, economic initiative and economic integration projects;
3. *Meso-level initiatives:* Initiatives, agreements and ventures that exist between the micro and macro levels, which is also called sub-regionalism.

Though approaches to sustainable development have differed over time, as mentioned previously, the major point of concern for planning purposes has usually been the environment. Nonetheless, Haughton and Counsell (2004) state that, in more recent times, socio-economic concerns have started to emerge as another focus area within sustainable development, and fragmentation amongst regional government bodies with regards to visions of economic development have become more apparent.

While regionalism provides a framework and guideline for development, the number of players involved in the transportation infrastructure decision making process of regional policies and strategies may cause sustainable development to be interpreted differently by the different stakeholders. This can then lead to differences between the policy areas of economic development and planning, due to the assumptions about the importance of employment and wealth creation (Haughton and Counsell, 2004).

Regionalism and fragmentation, coupled with the other challenges within the transportation infrastructure industry create discord and make it difficult to introduce new trends, concepts and technologies to the sector. In the case of the sustainable built environment, the problem is compounded by the fact that the sustainable development assessment methods adopted and implemented by the owners of infrastructure construction projects and the regulatory organizations vary greatly. This impediment demonstrates the need for a standardized method of assessing the sustainability of the built environment.

Sustainable Development

The concept of sustainable development finds itself in a place between the tools and technologies available to the industry, and the needs and policies of governments. The intent of this finely balanced state of equilibrium is to provide future populations with improved levels of environmental conditions and strong socio-economic stability. In essence, this approach aims to ensure that the meets of the present are met without compromising the needs of the future. While the common definitions of sustainable development oftentimes place too much attention on the effects on environment, it is of the utmost importance to highlight the need to improve social structure, strengthen economic development and define an achievable higher standard of living for all people. This much broader understanding of sustainable development includes five key terms:

1. Technical Sustainability: A number of factors affect the processes that contribute to the manufacturing of goods and development of communities. The product design must be supported by appropriate research, and function of the product must match the intended use of

that product. The product must be easy to use, efficient, and of durable quality. Operational safety and maintenance characteristics must be taken into account.

2. Environmental Sustainability: As a result of the processes and products used in manufacturing and development, the environment is affected to a certain degree. The materials used in the production process must fit be compatible within the triangle of reduce, reuse, and recycle.
3. Economic Sustainability: The policies and processes that lead to profit making affect persons at the individual and community levels. Standards of living, business climate and policies, economic health of communities, and employment rates.
4. Social and Cultural Responsibility: Individuals, communities, and societies all have roles in the built process and the sustainable environment. Various factors such as race, ethnicity, social class, income level affect the roles of these entities.
5. Individual Sustainability: This is sustainability at the individual level, and refers to the lifestyle choices that affect the positive emotional, social, and spiritual development of persons. At the individual level, one must understand that sustainability is not limited to one's own actions in life, but the interaction within a greater community and actions that affect the environment, society, and economy.

In the built environment, the use of sustainability indicators ensure that we can provide for the needs of today without compromising the needs of the future. Much like other natural ecosystems, the transportation infrastructure development ecosystem is very much real and not lab-confined. Thus, the discussion surrounding the sustainability of the built environment and sustainability indicators must reach beyond theory and into actual performance of products, processes, development professionals and users (Walsh, 1999-2002).

Segnestam (2002) states that sustainability indicators can be used in a participatory or non-participatory manner, and lists four (4) steps to describe the most common indicator initiatives:

1. Development of a framework to organize the information provided for a particular case or project. The framework must be able to address the parameters considered, the behaviors and interactions between various aspects of data, and the identification of essential data and behavior;

2. Definition of a set of sustainability indicators that is agreed upon by all involved parties and stakeholders;
3. Formation of a network to provide consultative or participatory support;
4. Conducting a data search and developing databases for the set of indicators.

As indicated above, it is important to develop a set of indicators that are accepted by the stakeholders involved in the process. By doing so, the set of indicators will not only categorize the transportation project data but also become useful in the education of these stakeholders on the sustainable aspects of their project. Following the development of quantifiable indicators that garner input and interest from all actors, an analysis of project data can be conducted, and a data set that is simple yet effective can be produced.

KNOWLEDGE GAP

When assessing the sustainability of the transportation infrastructure, it is necessary to conduct an analysis that addresses individual, local, and regional/global perspectives. The individual perspective focuses on the overall quality of life and the health of the product user. At the local level, the emphasis is the surrounding communities, neighborhoods and the socio-economic and natural environments. The regional/global perspective is concerned with the extraction, manufacture and transport of materials and their associated energy use; the energy use of the final product; and the impact of this final product to the socio-economic and natural environments at a larger scale (Tessema et al., 2009).

While the need for assessing the sustainability of the transportation infrastructure is widely recognized, there is little agreement on what methods and tools are the most effective. Daniell et al. (2005) points to previous research and literature that concludes that governments and planners require more holistic sustainability assessment methods; however, the narrow focus of the assessment methods available today do not adequately address the sustainability goals of future developments and the temporal, spatial and behavioral aspects of sustainability. In addition, there is lack of common methodology to collectively address resource usage together with various sustainability indicators (i.e. technical, environmental, economic, social/cultural, and individual). These shortcomings make it necessary to develop a new assessment method to measure the sustainability of the transportation infrastructure built environment (Daniell et al., 2005). Moreover, there are a variety of other reasons that make it necessary to develop a holistic and comprehensive assessment method to study, analyze and evaluate the sustainable development process including:

1. There is little consensus on the meaning of Sustainability Assessment (Heijungs et al., 2010).
2. Existing research has contradicting findings on the environmental effects of the transportation infrastructure construction process (Bilec et al., 2010-b).
3. Existing sustainable development assessment methods are ecology-driven and narrowly focus on construction materials, energy use during operation, and waste management during decommissioning, and there is little no focus on the socio-economic effects of development and the on-site construction process (Bilec et al., 2010-b; El-adaway and Knapp, 2012).
4. Widely used tools such as LCA, GREENLITES and GreenRoads have many shortcomings, are not reliable, and do not produce objective conclusions (Krozer and Vis, 1998).
5. Fragmentation amongst regional government bodies with regards to visions of economic development are apparent (Haughton and Counsell, 2004). There is also a lack of coordination within the industry with regards to sustainable development methods and assessment tools. Thus, the assessment methods required by governments, non-governmental organizations, corporations or private individuals may vary greatly.

METHODOLOGY

In order to analyze the transportation infrastructure built environment within a holistic framework that brings the transportation infrastructure development industry and its customers together to recognize the socio-economic impact of the development process, this study examines the various relationships that exist within the industry, and uses a combination of quantitative and qualitative methodologies to develop an all-inclusive and multi-disciplinary framework that can be utilized to evaluate the actors, products, and the dynamics within the industry.

Developing a Framework

In order to understand the dynamic nature and the effects of the transportation products and the infrastructure construction ecosystem, a number of meaningful benchmarks must be defined to identify the points at which the relationship between the two concepts affect one another. The framework must include the process, producers, products, the natural and socio-economic environments and the relationships of each one of these concepts with one another, and utilize the five key terms previously described: technical sustainability, environmental sustainability, economic sustainability, social and cultural responsibility, and individual sustainability. The innovative and transformative benchmarks used to develop this framework can be grouped in three categories: (1) Work, (2) Nature, and (3) Flow. The relationship between these three benchmarks and the resource dynamics within a system are depicted in Figure 1:

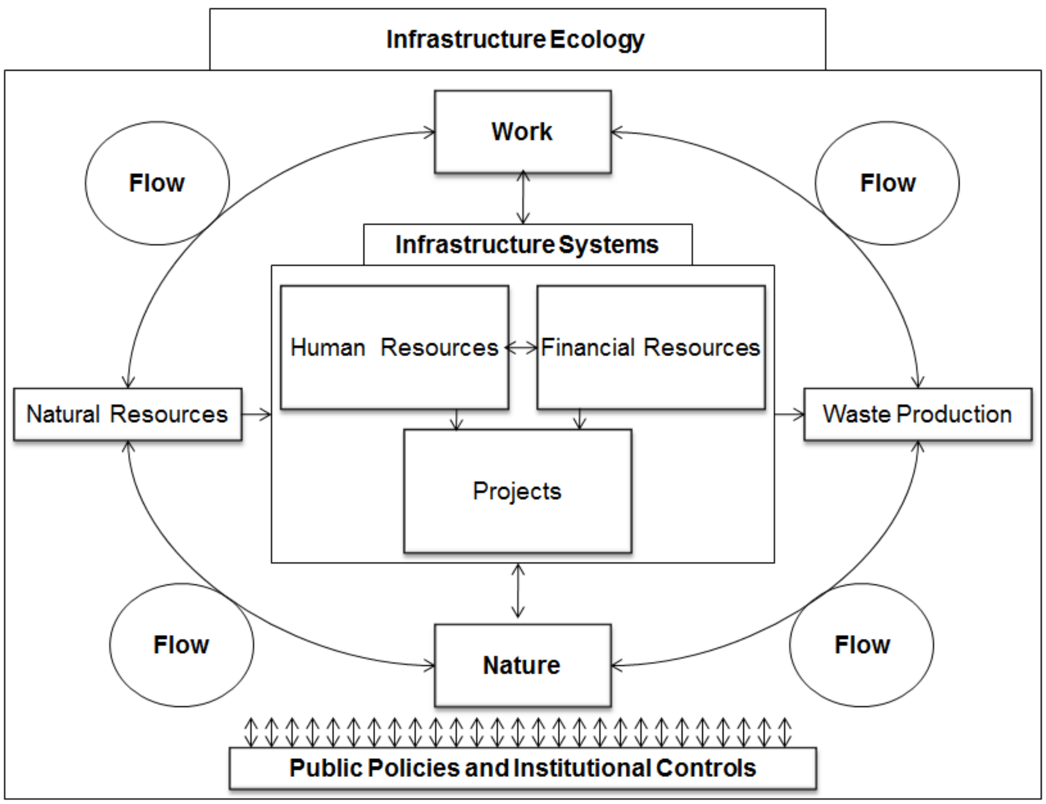

Figure 1: Transportation Infrastructure Resource Dynamics: Work, Nature and Flow

Work

The "work" benchmark defines the socio-behavioral relationships amongst the transportation products, and the actors and stakeholders of the infrastructure built environment. The work benchmark brings clarity the interactions between what is made, by whom it is made and why it is made. In any given project, the involvement of the actors is not due to the desirability of the development process or the relationships with other actors, but the usefulness and the need for the end-product. Thus, while the interactions amongst the actors are important, the relationship between the product and the actors is more important.

The relationship between the product and the user in the built environment has traditionally been explained by either a rigid understanding that defines each entity separately and as distinct from each other, which increases the negative socio-economic outcomes of the built process, or one that attempts to define a relationship between the products and the user but fails to do so, because it only considers the extreme positives and negatives of the individual and community behaviors. By considering only the extreme negatives, only the extreme negatives are addressed and not the issues that rest in the intermediate level. The rigid definition is called a disposable framework, and the latter is a shallow framework (Imbroscio, 2010).

The common definitions and perceptions toward the product and end-user relationship in the infrastructure built environment, as described above, constitute the framework for the current set of tools and methods used to evaluate the sustainability of the built environment. As the definitions and perceptions lack depth, so do the assessment tools that are built on them. These tools focus on a limited range of issues that focus on the extreme negative and extreme positive environmental and mechanical impacts of the process and fail to address the entire the full spectrum of issues; transportation infrastructure construction ecology, as well as the socio-economic impact of transportation development is not addressed.

The relationship of the producer with the end-product can be classified as either temporary, or permanent but weak. When the relationship is temporary, the connection between the producers and the settings in which the end-products will be located, communities and natural environment, is often incapacitated. In this classification, the manufacturers and designers follow a set of standards designed to maximize efficiency and reduce risk, and are not led to follow a project specific approach. As a result, the end-product that is low-risk to design and produce form the manufacturers' and designers' perspectives, is a high-risk product from an environmental and socio-economic setting standpoint.

The permanent but weak relationship is an improvement to the temporary relationship; though, similarities exist. In this framework, the producers are more connected with the communities and the natural environment where the project is located. However, the current applications of this approach focus almost solely on the transportation development products and their effects on the environment, and assume that the environmentally conscious means will lead to socially conscious ends. The approach takes into account transportation products, environmental impact of the development, public access, waste management, and occupant health. While an argument to define the connection between improvements in environmental conditions and social progress can be made, the relevance, strength, and duration of that bond is debatable. Besides, these approaches attempt to address and fit environmental consciousness, without addressing the vital need for understanding and implementing sustainable development practices in our communities.

In light of the above, the components that make up the work benchmark will be analyzed to understand if and how the end-product is affected by how well the producers are connected to the product. This understanding will provide an insight into how the dynamics within the transportation development industry as well as between the industry and its products relate to the socio-economic and environmental effects of the process that makes up the built environment. The effects of the work benchmark are felt in the areas of transportation infrastructure development, government policies and regulations as it provides a connection between the who's and what's of the built environment.

Nature

The "nature" benchmark focuses on the effects of the transportation infrastructure development process on the environment by studying the interactions of the actors, the process and the end-products with the environment. Ndubisi (2008) points out the negative effects of rapid urbanization on the environment, and Bilec et al. (2010-b) describe in detail the significant regional, national, and global environmental impacts of the development process, in addition to its socio-economic effects. The timeline that makes up any given development project, from design to completion, includes many sub-processes that may have significant impacts on the environment.

The case of the aforementioned rapid urbanization and its negative effects presents how the shift in societal focus from a higher quality of living space to commuter developments has a deep impact on the natural environment. Rapid urbanization is the result of having a business and income focus in urban planning, placing workers and consumers in places that are efficient, socially agreeable and economically acceptable, though the end results are usually inefficient and unacceptable. As a part of the greater transportation infrastructure and construction ecosystem, the products of rapid urbanization are the points of congestion and lowered quality of life for the users, and also the sources of negative environmental impact.

The nature benchmark will study how transportation products can be designed and built in ways that improve the human experience, from birth to end of life, and for future generations. Components of the nature benchmark include spatial considerations, including project location, public access, project layout, and land use.

Through these components, the sustainable built environment follows an infrastructure ecosystem that imitates those systems found in the nature. A healthy infrastructure ecosystem builds facilities; thus, building professionals that have the ability to direct healthy growth of communities through carefully planned infrastructure developments.

Flow

The focus of the "flow" benchmark recognizes the dynamic nature of the industry. It focuses on the means and methods used to analyze the changes that the actors, stakeholders, and the products experience over time. Understanding the ever-changing nature of those who are involved in the process can explain the changes seen in the transportation products over time. Identifying the positive changes, and finding associations with these improvements and the changes in the attitudes of and the methods used by the professionals indicates that there is a clear pathway between positive changes in the process and the positive changes in the products, which in turn identifies the level of lessened impact to nature.

This benchmark can identify the changes in the producers and their products, and the effects of these changes on the environment and the socio-economic setting that encompasses the project. The changes that are identified can then be studied within the work and nature benchmarks to produce an understanding that emphasizes the dynamic nature of the relationships within the transportation development industry, connections between producers and their products, and interactions with the natural and socio-economic environments.

In order to address the dynamic nature of change over time, the analysis must include a combination of macro-level system dynamics modeling, micro-level agent-based simulation, and multi-objective optimization. However, this more developed modeling approach is out of the scope of this research and will be subject of another future work effort.

The Framework

Two of the three aforementioned benchmarks that will be a part of this study, work and nature, bring together the transportation development process, producers, products and the natural and socio-economic environments, by placing each variable in the infrastructure ecosystem and studying them in a way similar to other nature sciences where observation is the method of data collection used to identify relationships, associations, causes and effects. The depth and extent of producers-products relationship is studied and the effects on environment are analyzed in light of the dynamic nature of the producers, their products, and the process in which they operate. The outcome of this research is an improved understanding of environmental, social and economic effects of the built environment and its transportation infrastructure industry products.

The five key terms of sustainability correspond to the two sustainability benchmarks to explain the interdependencies and interactions various actors and resources, and also provide a means to build a rating system under these two benchmark categories. To this end, work and nature can be addressed by evaluating the technical, economic, environmental, and individual sustainability and social and cultural responsibility.

The nature and work framework will provide a method by which civil infrastructure systems can be analyzed in a more comprehensive manner than what is offered by the means, methods, and tools available today; through its implementation, databases can be developed, which can help understand the micro-level actions of individual actors and the macro-level relationships within the system. The dataset then can be used to develop a framework that can address societal issues, economic balance, and environmental impact, all within the context of transportation infrastructure industry, its products and its customers.

In order to test and validate the aforementioned theoretical framework, a two-step approach is taken:

1. Review of the expertise and knowledge of the infrastructure professionals;
2. Review of project data from a sampling of transportation and civil infrastructure projects.

The two steps are then compared to one another in order to establish a correlation between the producer-product relationship and the impacts to natural and socio-economic environments.

RESEARCH DESIGN

For the purposes of this study, a mixed design approach was chosen, utilizing both quantitative and qualitative approaches. Quantitative methods are often considered more reliable, while qualitative research designs are often criticized for being less scientific, requiring a significant amount of preparation and planning, as well as substantial knowledge, skill, and training on the part of the researcher (Leedy & Ormrod, 2010). The application of both approaches in this study helped explain the quantitative data by utilizing qualitative means (Johnson & Christensen, 2004). As Johnstone (2004) explains, a mixed approach will improve the study with added scope and breadth, an analysis of data from multiple sources, and complementary data where various phenomena overlap. Creswell and Plane Clark (2006) further point out that mixed approaches enable the researcher to enhance the quality of a study by providing him a better understanding of the research problem.

Within the mixed methodology structure, an explanatory mixed method design is selected for this study. In this design, quantitative phase is followed by a subsequent qualitative phase that explains the quantitative data (Creswell, 2012; Creswell and Plano Clark, 2006).

Sample Projects

The five projects sampled in this study are transportation infrastructure projects, in addition to projects in proximity of a transportation project, located in the southwestern region of the United States. The researcher opted to study projects of varying scopes that represent a wide spectrum of the transportation and infrastructure construction applications. The owners, design professionals, and general contractors vary. The project timelines, from concept to completion cover an 11 year timeframe. For each project, several sources of data were obtained. These include, and are not limited to:

1. Design Proposal: Design proposals re-state the owner’s vision for the project, and outline a technical approach by which the engineer intends to complete the project. The design consultant’s experiences in similar past projects as well as the resumes of those engineering professionals that will be involved in the project are also included.
2. Preliminary Engineering Report (PER): PERs study and analyze the design concepts proposed by the owner, and provide an evaluation of various design approaches and constraints that will drive the project.
3. Environmental Impact Statement: Environmental impact statement is the findings of a study of the environmentally sensitive aspects contained within the project footprint.
4. Design Budget, Opinion of Cost, and Contractor’s Bid: The design consultant’s design budget is an estimate of the effort associated with the design of a project. Opinion of Cost is the consulting engineer’s estimate of the construction budget. Contractor’s Bid is the successful contractor’s description of the effort estimated for the completion of the construction phase.
5. Local Demographics: This dataset includes data points for population and local median income.

In addition, the researcher contacted personnel directly involved in the projects to verify and confirm information, or gather data unavailable otherwise.

The five infrastructure projects studied are:

- Highway project.
- Streets and drainage project.
- Solar energy field project.
- Wastewater treatment plant project.
- Vertical construction project.

Approach

The researcher conducted an observational study by reviewing the available project data for the five infrastructure projects listed above. An expert survey was utilized to assess a number of industry experts' attitudes towards various project attributes and their effects on the sustainable built environment. In light of the concepts of work and nature, and expert opinions, as well as other data available from existing literature, a series of sustainability indicators were developed. The researcher then analyzed the project data to measure these sustainability indicators. Sustainability indicators offer a simplified tool to compress a wide variety of otherwise incompatible information, some qualitative and some quantitative, in a more easily understood format where one can make spatial and temporal comparisons of sustainability (Copus & Crabtree, 1996).

Samplings of the projects and for the expert survey were not random. The researcher assumes that the risk of bias is reduced because the five projects listed above represent a broad spectrum of infrastructure development projects, and the experts included in the expert survey represent various professions within the industry and possess the knowledge and experience that relates to the sustainable built environment.

The expert survey was conducted between 15 April 2012 and 08 June 2012. The survey was distributed to a group of industry professionals via electronic mail, with the purpose of validating a set of questions that the five projects were analyzed against. The sampling design is non-probability sampling, and it can be defined as purposive sampling as it attempts to identify a group that the researcher believes: 1) is representative of the industry; 2) has experience in the topic at hand; and 3) can answer the set of questions posed by the researcher. The set of questions that are included in the survey and the set of questions used to analyze the projects mirror one another. According to Manly (1996), the greatest problem with observational studies is that the data used for the study may have been acquired for another purpose sometime in the past. The expert survey used by the researcher and the set of questions included in this survey are developed for this study only. Other sustainability indicator related data collected from existing literature was developed for the assessment of transportation and civil infrastructure projects.

Due to the cost and effort associated by attempting to reach the very large population that is the building professionals, the researcher identified four professions that represent the industry’s design professionals: Engineers, Architects, Landscape Architects, and Planners. Besides, according to Manly (1996), “samples may be more accurate than full censuses” and that “a relatively small but well-organized sample will often give better results than a full survey or a large sample cannot be properly administered because of the lack of adequate resources”.

The purpose of the expert survey distributed to the selected individuals in the form of a questionnaire was to validate the set of questions that will guide the general direction of the set of indicators and related questions that the five projects will be analyzed against. Thus, for the majority of the questions, the participants were not expected to provide a rating, but rather select a “yes”, “no”, or “not applicable” answer indicating the relevance of that question to the topic at hand. First, the participants were asked a series of questions for the purposes of obtaining information about participant demographics. Second part of the survey included the questions that the participants were asked to validate. The last question of this portion of the survey asked the participants to quantify a concept that the questions discussed.

Procedures

Identifying the parameters that define the work and nature benchmarks depend greatly on gathering the data required to establish the associations between the producers, the products, and the environment, which are unique to each given project and depend on the circumstances under which the project dynamics operate. Therefore, in this study, data that represent these associations are studied based on a number of scalable factors that are representative of the producer-product relationship, and the effects on natural and socio-economic environments. In order to develop a set of sustainability indicators for the purposes of this study, the researcher includes topics that are developed in parallel with the questions posed in the expert survey and the responses received, and the information from existing literature on the sustainability indicators for the assessment of transportation and civil infrastructure projects. These topics, questions and concepts are then grouped under the concepts of "work" and "nature" to develop Table 1, which is then used to analyze available project data.

Table 1: Benchmarks, Sustainability Indicators and Relevant Topics

Benchmark	Sustainability Indicator	Relevant Topic
Work		
	Vision	Owner's vision and design consultant's approaches match
	Vision	Design consultant proposes multiple approaches
	Experience	Design consultant firm's experience working on similar projects
	Experience	Design professionals' similar project experience
	Experience	Construction contractor's experience working on similar projects
	Cost	Project cost is comparable to other projects of similar scope
	Cost	Life cycle cost of the project considered
	Vicinity	Project approach addresses effects on employment of labor
	Vicinity	Project approach addresses effects on nearby businesses and residences
Nature		
	Environment	Project approach considers impact on natural environment
	Environment	Project approach considers impact on socio-economic environment
	Environment	The project considers effects on trees within project limits
	Environment	The project considers effects on natural habitat
	Environment	The project does not contribute to noise pollution (during and post construction)
	Environment	The construction effort does not produce hazardous waste
	Environment	The project considers effects on cultural heritage
	Land Use	The need for land acquisition is minimal
	Land Use	The need for re-zoning is minimal
	Reuse and Recycle	The project utilizes reuse and re-cycling of water within project limits
	Aesthetics	The project aesthetically "fits in" with the adjacent existing improvements
	Proximity	Designer's nearest permanent office to the project site (desirable proximity is considered 50 miles or less)
	Proximity	Contractor's nearest permanent office to the project site (desirable proximity is considered 50 miles or less)

Assumptions

The following were the assumptions of this research study:

1. The variables considered for the analysis have normal distributions.
2. Standard multiple regression can only estimate the relationship between dependent and independent variables if the relationships are linear in nature.
3. All variables are reliable in nature.
4. The researcher is familiar with the projects and can provide qualitative analysis.
5. Expert survey participants are clear about the content and intent of the survey questions.

This research included an expert survey to validate the relevance of the questions listed above to the topic of sustainability in the transportation infrastructure built environment. The survey, which is included in Appendix A, was distributed to twenty-four (24) experts that are licensed engineers, architects, landscape architects, and planners, and are involved in various infrastructure projects. The experts were not only asked to validate the questions, but also quantify some of the answers through their responses to other questions. These questions were then used to guide the development of a series of sustainability indicators for the purposes of this study. The researcher believes that the data provided by the expert survey is reliable, data from existing literature is applicable for the content and intents of this study and the projects discussed are representative of the transportation infrastructure projects of the infrastructure industry.

DISCUSSION OF RESULTS

In order to understand the attitudes of transportation infrastructure development professionals towards various elements of the sustainable built environment, the researcher distributed surveys to twenty-four experts that are licensed engineers, architects, landscape architects, and planners. The experts are either known to the researcher through work-related connections and activities, or are identified and recommended by the researcher's peers as persons of desired level of expertise. The survey communicated to the participants that their identities are confidential and their answers will be kept anonymous. Of the twenty-four surveys distributed, fifteen were returned to the researcher, which corresponds to a response rate of 62.5%.

Table 2 summarizes the demographic information of the expert survey group. The demographic data includes occupation, years of experience in the development industry, number of design projects that the professional has been a part of, number of transportation construction projects that the individual has participated in, number of projects that included sustainability elements in the scope of work, and average client project budget that the individual works on, including design and construction budgets.

Table 2: Demographics of Expert Survey Participants (n=15)

Occupation and Years of Experience

Occupation	*n*	*Percentage*	*Years of Experience*	*N*	*Percentage*
Engineer	7	46.7 %	0 – 10 years	1	6.7 %
Architect	3	20.0 %	11 – 20 years	4	26.7 %
Landscape Architect	3	20.0 %	21 years or more	10	66.7 %
Planner	2	13.3 %			
Total	*15*	*100.0 %*	*Total*	*15*	*100.0 %*

Project Experience

	Design		*Construction*		*With Sustainability Elements*	
Number of Projects	*n*	*Percentage*	*n*	*Percentage*	*N*	*Percentage*
0 – 10	0	0.0 %	3	20.0 %	9	60.0 %
11 – 20	5	33.3 %	8	53.3 %	6	40.0 %
21 or more	10	66.7 %	4	26.7 %	0	0.0 %
Total	*15*	*100.0 %*	*15*	*100.0 %*	*15*	*100.0 %*

Average Budget of Projects

Project Budget	*n*	*Percentage*
$100,000 or less	1	6.7 %
$100,001 - $500,000	5	33.3 %
$500,001 - $1,000,000	7	46.7 %

Approximately one half of the respondents were engineers, with the remaining participants evenly distributed amongst architects, landscape architects, and planners. The transportation development and construction industry employs a large number of types of professionals; these four occupations represent a cross-section in the areas of planning, design and owner's representation during projects. The years of experience each participant had in their respective fields varied; two thirds of the group had 21 years of experience or more, indicating that the participants had been practicing in their fields for what most would consider a significant amount of time.

The survey revealed that the project experience of the participants focused on design projects. However, the construction experience was also noteworthy with 80% of the participants having been involved in 11 or more projects. This is likely due to the fact that all design professionals focus on design projects, while only some design professionals see their design projects through the construction and closeout phases. Lastly, the survey documented that 80% of the expert group's project budgets, including design and construction, ranged from $100,001 to $1,000,000.

Section Two of the expert survey included a series of questions intended to document the perceptions of the expert group on how important various design and development elements are to the assessment of the transportation infrastructure sustainable built environment. The questions begin with questions related to project vision, professional experience, project impact on natural and socio-economic balances, and in order to analyze the level of personal connection and commitment to the project, the geographical proximity of professionals to the projects site. The questions require a yes or no answer, with the exception of one question that requires the participants to quantify their answer and match it with a given range. Table 3 below lists the questions asked and the answers received.

According to 60% of the survey group, the design consultant's approach needs to match the owner's vision. The remaining 40% either feels that this is not necessary or that it has no effect on the assessment of that project's sustainability. If the owner's vision includes an understanding of the sustainable built environment, and it considers the various environmental and socio-economic factors relating to the project, the designer should have a clear understanding of what is required and how to design that which is desired. For this reason alone, the designer should have an approach that follows the owner's vision or improves upon it.

The next set of questions focus on the similar work experience of the design consultant, design professionals, and the contractor. The survey group generally finds these factors important to the assessment of the sustainable built environment. Experience translates to knowledge; building professionals who possess the correct expertise and experience will succeed in carrying out projects that have sustainability in mind. An experienced building professional will propose multiple approaches in the design and construction of infrastructure, which 100% percent of the expert group participants think is important.

Table 3: Survey Participants Answers to the First Portion of the Section Two Questions (n=15)

In assessing the sustainable built environment, is it important that:			
Question and Answer Options		***n***	***%***
The design consultant's approach matches the owner's vision?	Y	9	60.0%
	N	5	33.3%
	N/A	1	6.7%
The design consultant has experience working on similar projects?	Y	14	93.3%
	N	0	0.0%
	N/A	1	6.7%
The design professionals have similar project experience?	Y	14	93.3%
	N	0	0.0%
	N/A	1	6.7%
The Contractor has similar project experience?	Y	15	100.0%
	N	0	0.0%
	N/A	0	0.0%
The design consultant proposes multiple approaches?	Y	15	100.0%
	N	0	0.0%
	N/A	0	0.0%
The design approach considers impact on natural environment?	Y	15	100.0%
	N	0	0.0%
	N/A	0	0.0%
The design approach considers impact on socio-economic environment?	Y	15	100.0%
	N	0	0.0%
	N/A	0	0.0%
The design consultant's Nearest Permanent Office is in close proximity to the Project Site?	Y	13	86.7%
	N	1	6.7%
	N/A	1	6.7%
The contractor's Nearest Permanent Office is in close proximity to the Project Site?	Y	9	60.0%
	N	6	40.0%
	N/A	0	0.0%
What is the distance that you would consider "close proximity to the project site"?	0 – 10 miles	1	6.7%
	10 – 50 miles	13	86.7%
	50 – 100 miles	1	6.7%
	N/A	0	0.0%

Note: Y = Yes, N = No, N/A = Not Applicable, % = Percentage

Last three questions listed above ask whether the designer and the contractor are located in close proximity to the project site, and whether the designer considers socio-economic or environmental impacts in his approach. The designer, along with the owner, must plan and implement a design that provides the means for a sustainable transportation infrastructure development project at all levels. Thus, it is important that the designer considers the possible environmental and socio-economic impacts. In addition, the researcher assumes that, if the building professional is local or is located in close proximity to the project site, he may feel that he has a responsibility and a personal connection to the elements that make a project sustainable. In today's global business environment, for large projects, it is not uncommon to see international contracting firms involved in projects that are located at a considerable distance to their home office. In cases such as these, it is still important for the contractor to seek the guidance of local professionals or establish a local base of operations, or both, engage residents and local decision makers, and thus develop a connection to the project locality.

Work Benchmark

The "work" benchmark defines the socio-behavioral relationships amongst the development products, and the actors and stakeholders of the built environment. The work benchmark brings clarity the interactions between what is made, by whom it is made and why it is made. In any given project, the involvement of the actors is not due to the desirability of the development process or the relationships with other actors, but the usefulness and the need for the end-product.

The owner initiates and funds a project with a specific goal in mind. This goal and the vision that accompanies it are the reasons for the birth of a project. For a highway project, this goal might be reducing congestion, and for a streets and drainage project, the goal may be to provide improvements to accommodate population growth. For a transportation project to be successful, the design consultant must understand the need for the project, and provide a vision that assists the owner reach the goal of the project. Without a common understanding of the needs and the goals, the designer cannot develop a project vision that will prove to be successful.

Expert survey questions 1 through 5 were intended to highlight the "work" benchmark. Majority of the expert survey respondents agree that the work benchmark questions are valid and applicable to the assessment of the sustainable built environment. The level of the design consultant's and its design professionals' experiences working on similar projects adds to the precision of how the vision is executed. The execution includes not only design but also the development process, where ideas become physical objects. For this reason alone, the contractor must also understand the product and the need and demonstrate his building expertise. This demonstration includes not only the general capabilities required to build the product, but also the ability to provide the owner with multiple approaches to construction to effectively build what is needed. A contractor can only offer multiple appropriate approaches if he fully understands the product and the process. In order to have successful project with sustainable elements from concept to finish and into the future, it is essential that the producers, i.e. the designers and the builder, have familiarity with the project's intent and are able to propose multiple approaches and methods to achieve that vision. This will ensure that the three essential parties in the built environment, the owner, the designer, and the builder, will be able to share a common vision and understanding, ensuring the success of that project.

Nature Benchmark

The "nature" benchmark focuses on the effects of the built process on the environment by studying the interactions of the actors, the process and the end-products with the environment. The timeline that makes up any given transportation and infrastructure development project, from design to completion, includes many sub-processes that may have significant impacts on the environment.

Expert survey questions 6 through 9 are used to define the sustainable built environment surrounding a project from the perspective of the nature benchmark. "Nature" analyzes the effects of the transportation infrastructure building process on the environment, both natural and socio-economic. This is accomplished by investigating the interactions between the producers and the end-products with their surroundings. The set of questions that focus on the nature benchmark ask whether the approach presented by the designer considers impact on natural and socio-economic environments. The questions also inquire about the proximity of the designer and the contractor to the project site, attempting to establish a personal connection, responsibility and commitment from these parties to the project's surroundings and its geographical, social and economic setting.

The expert survey concluded that questions 6 and 7 are valid questions to ask when assessing a sustainable built environment. The expert survey also concluded that Questions 8 and 9 are important questions to ask, though Question 8 received a "yes" 86.7% of the time, and Question 9 received a "yes" only 60% of the time. When the experts were asked another question to quantify these two questions, 86.7% responded that "close proximity" to a project means the measured distance should not be more than 50 miles.

Sustainability Indicators

The first step in analyzing the sustainability of infrastructure development projects is to develop sustainability indicators that are easy to understand by the stakeholders and apply to the type of project data that is usually readily available (Ugwu & Haupt, 2007). With this in mind, the expert survey, existing literature and the key terms of sustainability are used as a guidance to develop sustainability indicators that correspond directly to the two benchmarks of the sustainable built environment that this study follows, work and nature. Table 4 uses the questions included in the survey, data available from the five civil infrastructure projects included in this research, and previously detailed five sustainability indicators to assess these projects.

Table 4: Sustainability Indicators Scoring Criteria

Sustainability Indicator	*Relevant Topic*	*Scoring Criteria*
	WORK	
Vision	Owner's vision and design consultant's approaches match	A score of 5 is given if the project approach described in the design consultant's proposal matches the scope of work prepared by the owner. If consultant does not agree with the owner's scope, a score of 1 is assigned.
Vision	Design consultant proposes multiple approaches	In cases where four or more different approaches are proposed, a score of 5 is given. Three approaches receive a score of 4. Two approaches receive a score of 3. In cases, where there is only one approach that is different as described in the owner's scope of work, a score of 2 is given. If there is no alternative approach described, the project is given a score of 1.
Experience	Design consultant firm's experience working on similar projects	A score of 5 is given if the design firm demonstrates past project experience that is similar to the scope of subject project. If design firm does not possess prior similar experience, a score of 1 is assigned.
Experience	Design professionals' similar project experience	A score of 5 is given if the design professionals demonstrate past project experience that is similar to the scope of subject project. If design professionals do not possess prior similar experience, a score of 1 is assigned.
Experience	Construction contractor's experience working on similar projects	A score of 5 is given if the contractor demonstrates past project experience that is similar to the scope of subject project. If contractor does not possess prior similar experience, a score of 1 is assigned.
Cost	Life cycle cost of the project considered	If the designer's approach does not include a discussion of life cycle cost, a score of 1 is given. In cases where a discussion is included, every recommendation to improve the life cycle cost receives an extra score, with four or more recommendations receiving a score of 5.

Table 4: Sustainability Indicators Scoring Criteria (continued)

Sustainability Indicator	*Relevant Topic*	*Scoring Criteria*
Cost	Project cost is comparable to other projects of similar scope	The project is compared to two other projects that are of similar scope and circumstances. A score of 5 indicates a total project cost that is within 10% of the average total cost for the other two projects, i.e. a cost agreement of 90% to 110% receives a score of 5. 80% to 90% is a score of 4. 70% to 80% is a score of 3. 60% to 70% is a score of 2. A cost agreement of less than 60% receives a score of 1.
Vicinity	Project approach addresses effects on employment of labor	A score of 5 is given if any of the project documents discuss effects on employment of labor. If there is no discussion, a score of 1 is assigned.
Vicinity	Project approach addresses effects on nearby businesses and residences	If the approach does not include a discussion of effects on nearby businesses and residence, a score of 1 is given. In cases where a discussion is included, every recommendation to lessen negative effects or to create positive effects receives an extra score, with four or more recommendations receiving a score of 5.
	NATURE	
Environment	Project approach considers impact on natural environment	If the approach does not include a discussion of effects on natural environment, a score of 1 is given. In cases where a discussion is included, every recommendation to lessen negative effects or to create positive effects receives an extra score, with four or more recommendations receiving a score of 5.
Environment	Project approach considers impact on socio-economic environment	If the approach does not include a discussion of effects on socio-economic environment, a score of 1 is given. In cases where a discussion is included, every recommendation to lessen negative effects or to create positive effects receives an extra score, with four or more recommendations receiving a score of 5.
Environment	The project considers effects on trees within project limits	If the project documents do not include a discussion of effects on trees, a score of 1 is given. A discussion with a recommended approach to reduce impact receives a score of 5. A discussion with a recommended approach to only comply with local regulations receives a score of 4.
Environment	The project considers effects on natural habitat	If the project documents do not include a discussion of effects on natural habitat, a score of 1 is given. In cases where a discussion is included, every recommendation to lessen negative effects or to create positive effects receives an extra score, with four or more recommendations receiving a score of 5.
Environment	The project does not contribute to noise pollution (during and post construction)	If the project is located in a remote area, or is intended to replace an aging infrastructure of comparable service capacity, a score of 5 is assigned. If the project offers an improvement to the capacity of an existing infrastructure, but does not change its intended use and service purpose, a score of 4 is assigned. A score of 1 is given if the project introduces a new infrastructure to an area with an already established use and purpose.

Table 4: Sustainability Indicators Scoring Criteria (continued)

Sustainability Indicator	*Relevant Topic*	*Scoring Criteria*
Environment	The construction effort does not produce hazardous waste	If construction effort produces hazardous waste, a score of 1 is given. If not, a score of 5 is assigned.
Environment	The project considers effects on cultural heritage	If the project documents do not include a discussion of effects on cultural heritage, a score of 1 is given. In cases where a discussion is included, every recommendation to lessen negative effects or to create positive effects receives an extra score, with four or more recommendations receiving a score of 5.
Land Use	The need for land acquisition is minimal	If there is no need for land acquisition, the score is 5. If 100% of the project limits is acquired for the purposes of the project, a score of 1 is given. If 1% to 5% of the project's footprint is on acquired land, the score is 4. 5% to 10% is a score of 3. 10% to 99% is a score of 2.
Land Use	The need for re-zoning is minimal	If there is a need for re-zoning, a score of 1 is given. If not, a score of 5 is assigned.
Reuse and Recycle	The project utilizes reuse and recycling of water within project limits	If the project, at any time during construction phasing or beyond completion, reuses and recycles water, a score of 5 is given. If not, a score of 1 is assigned.
Aesthetics	The project aesthetically "fits in" with the adjacent existing improvements	If the project replaces an aging infrastructure of comparable use and aesthetics, a score of 5 is assigned. If the project offers an improvement to the capacity of an existing infrastructure, enlarges the physical footprint of the infrastructure, but does not change its intended use and service purpose, a score of 4 is assigned. A score of 1 is given, if the project introduces a new infrastructure to an area.
Proximity	Designer's nearest permanent office to the project site (desirable proximity is considered 50 miles or less)	If the location is 50 miles or less, a score of 5 is given. If not, a score of 1 is assigned.
Proximity	Contractor's nearest permanent office to the project site (desirable proximity is considered 50 miles or less)	If the location is 50 miles or less, a score of 5 is given. If not, a score of 1 is assigned.

Project Data

The researcher began analysis by reviewing the available data for the five civil infrastructure projects previously mentioned. The project related data included design proposals by design professionals, preliminary engineering reports (PERs) prepared by owners and design consultants, environmental impact statements and other environmental studies conducted for the purposes of these projects, project design budgets, opinions of cost developed by the engineer or architect, contractor's bids, and local demographics of the project location.

This set of data was then used to develop scores based on the previously developed sustainability indicators. Table 5 lists the quantifiable values for each project.

Table 5: Project Data - Proximity

Proximity of Nearest Permanent Office to the Project Site (miles)	*Highway*	*Streets & Drainage*	*Solar Energy Field*	*WWTP*	*Vertical Construction*
Consultant	30	5	29	25	15
Contractor	33	7	950	31	43

Table 6 summarizes the scoring of the five projects based on previously discussed sustainability indicators. The researcher lists five projects in a single table to provide a side-by-side analysis of these projects based on sustainability indicators, as well as the relevant topics and questions asked to evaluate the projects.

Sustainability indicators listed above can be matched with the five key sustainability terms, also previously discussed. El-adaway and Knapp (2012) suggest that “work” can address social, cultural, and individual sustainability; “nature” can define environmental and economic sustainability; and “flow” can be used to oversee the overall system change. For the purposes of this study, for technical sustainability, topics that relate to technical knowledge, experience, project approach and vision are included. For economic sustainability, project cost, life-cycle cost, and other economic indicators are included. Social and cultural responsibility correlates to sustainability indicators that deal with project setting, vicinity, and proximity. Individual sustainability is addressed with topics that deal with recycled water, aesthetics, and proximity of construction professionals to the project site. Topics that cover the natural environment, cultural heritage, and land use are listed as environmental sustainability.

Table 6: Infrastructure Projects and Sustainability Indicators

Sustainability Indicator	*Relevant Topic*	*Highway*	*Streets & Drainage*	*Solar Energy Field*	*WWTP*	*Vertical Construction*
	WORK					
Vision	Owner's vision and design consultant's approaches match	5	5	5	5	5
Vision	Design consultant proposes multiple approaches	1	5	1	3	4
Experience	Design consultant firm's experience working on similar projects	5	5	1	5	5
Experience	Design professionals' similar project experience	5	5	1	5	5
Experience	Construction contractor's experience working on similar projects	5	5	5	5	5
Cost	Project cost is comparable to other projects of similar scope	4	5	5	3	5
Cost	Life cycle cost of the project considered	3	1	5	2	5
Vicinity	Project approach addresses effects on employment of labor	1	1	5	1	5
Vicinity	Project approach addresses effects on nearby businesses and residences	4	3	5	1	5
	Average	***3.7***	***3.9***	***3.7***	***3.3***	***4.9***
	NATURE					
Environment	Project approach considers impact on natural environment	2	3	2	1	5
Environment	Project approach considers impact on socio-economic environment	1	1	5	1	5
Environment	The project considers effects on trees within project limits	4	5	5	1	4
Environment	The project considers effects on natural habitat	2	2	3	1	5
Environment	The project does not contribute to noise pollution (during and post construction)	4	4	5	4	5
Environment	The construction effort does not produce hazardous waste	5	5	5	5	5
Environment	The project considers effects on cultural heritage	2	2	3	1	5
Land Use	The need for land acquisition is minimal	3	2	1	5	5
Land Use	The need for re-zoning is minimal	5	5	1	5	5
Reuse and Recycle	The project utilizes reuse and re-cycling of water within project limits	1	1	1	5	5
Aesthetics	The project aesthetically "fits in" with the adjacent existing improvements	4	5	1	4	5
Proximity	Designer's nearest permanent office to the project site (desirable proximity is considered 50 miles or less)	5	5	5	5	5
Proximity	Contractor's nearest permanent office to the project site (desirable proximity is considered 50 miles or less)	5	5	1	5	5
	Average	***3.3***	***3.5***	***2.9***	***3.3***	***4.9***

Note: A score of 5 shows the most amount of agreement with the relevant topic, and a score of 1 shows the least amount of agreement.

CONCLUSIONS

A thorough review of the dynamics within the transportation infrastructure development industry and the sustainable built environment assessment tools reveals the need for a more comprehensive method that brings the development industry and its customers together to recognize the socio-economic impact of the development process by developing a holistic and multi-disciplinary framework that can be utilized to evaluate the actors, products, and the dynamics within the industry and their evolution through time and interactions in the context of sustainable development.

In order to address the issue, this research developed three innovative system-based concepts to assess sustainability of transportation civil infrastructure projects namely: (1) work, (2) nature, and (3) flow. The "work benchmark" defined the socio-behavioral relationships amongst the transportation products and the actors of the built environment. It also attempts to delineate how the end-product is affected by how well the producers are connected to the product. The "nature benchmark" focused on the effects of the development process on the environment through studying the interaction between the development actors, their associated processes, and the end-products within their host systems. The "flow benchmark" identified the overall system changes within the community host systems and the effects of these changes on the natural environment and the socio-economic setting that encompasses the project.

Under the guidance of the "work" and "nature" benchmarks, the author discussed in detail the degree of communication between communities and the transportation and infrastructure industry, and highlighted occurrences where there was a lack of communication, or the disconnection. The relationship between the infrastructure development industry and its customers was also evaluated, and accountability of various actors was stated. In essence, the development industry is accountable to those whom it serves, which is the underlying reason why building professionals and project owners must understand that why we build the way we do and who is involved in the process of building is important.

In context of the five civil infrastructure projects studied, these two benchmarks – Work and Nature – were compared to the five key sustainability indicators (i.e. technical, environmental, economic, social/cultural, and individual) which revealed that benchmarks, indicators and other elements within a single infrastructure development project can cross boundaries and overlap with one another as shown in table 7.

Table 7: Work and Nature, and Key Terms of Sustainability

Sustainability Benchmark	*Key Term of Sustainability*
WORK	Technical Sustainability Economic Sustainability Social and Cultural Responsibility
NATURE	Environmental Sustainability Individual Sustainability Social and Cultural Responsibility

It can be concluded that this research succeeded in: (1) defining a sustainability systems approach to study of the transportation built environment; (2) assessing the degree of communication between the development industry and its community host systems; and (3) evaluating the relationship between the transportation infrastructure development industry and its customers.

RECOMMENDATIONS

Future work related this study should describe and assign relative values to the various elements of the scoring system developed in this research in order to further improve the concepts described herein. In order to utilize this system based approach in the assessment of transportation civil infrastructure projects, the simple, 5-point rating system used in this research needs to be further developed to provide a more detailed and objective weighing and ranking of the scores that are based on the sustainability indicators discussed in this study. Also, the future work of this study will further explain the three benchmarks, and focus on the development of the "flow" benchmark, and the variables that make up the ongoing and ever-changing relationships that define the producer-product-user triad. The interdependent causal interactions and relationships of the five key sustainability terms can be computationally defined and a multi-faceted performance and reliability model can be developed. This model and respective simulation efforts can lead to a new scientific approach to assessing the sustainability of the transportation built environment. Through modeling and simulation, more accurate real-time decisions will be made efficiently, and databases containing project based data as well as experience based information can be collected. Based on the results of the current research, the modeling process should follow three levels of aggregation:

1. Macro-level to model the actors' and stakeholders' use of local resources over time. The macro-level modeling should consider the continuous flow of resources such as population, industry, tourism, water-resources, water-quality pollution-control, flora and fauna, and business investment within the system. The goal of analyzing these resources as a whole would be to simulate the effects of various decisions on individual resources as well as the entire process. During a simulation run, the relationships between actors will determine the nature of resource dynamics.
2. Micro-level to model the network of decision makers and resource managers using agent-based simulation. These actors and stakeholders include residents, facility operators, government, financiers, and insurers. The relationship between any two of these agents can be described as a community relationship, where agents are led by a cognitive structure to make certain decisions based on the agents' desires, as well as engineering decisions and regulatory limitations. This will lead to some relationship being more active than others, some of which may be idle for certain periods of time. This will be a two level analysis: a) Social, where ideas, information and services

are exchanged amongst individuals; and b) Individual, which addresses the growth and development of the individual through these exchanges. In this analysis, agents' internal structure will be modeled using algorithms for learning and feedback, to accurately reflect the dynamic nature of the agent's internal structure and its ability to change over time depending on beliefs, values, and societal norms.

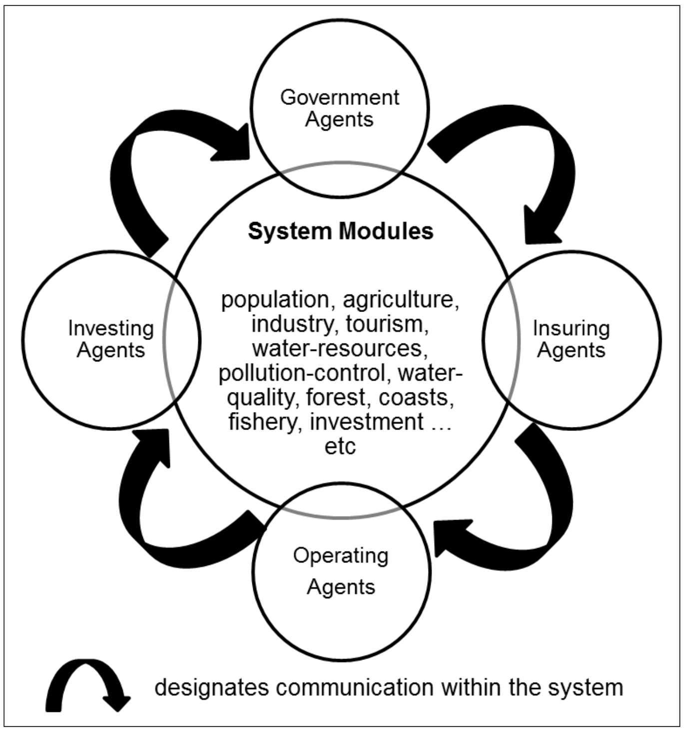

Figure 2: Architecture of the Micro-Level Agent-Based Model

3. Multi-objective optimization to allow agents to determine the Pareto optimal balance among alternative resources and strategies, as well as utilize ranked prioritization. Optimal balance will require a series of trial and errors, iterations, and coordination.

Eventually, this study and the future work that will follow will entirely re-consider the mechanics of the transportation infrastructure development process, and find contemporary answers to the questions of how we build, for whom we build, and by whose hands we build.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ASCE	American Society of Civil Engineers
CEN	European Committee for Standardization
EPD	Environmental Product Declaration
GBC	Green Building Challenge
NGOs	Non-Governmental Organizations
PER	Preliminary Engineering Report

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