A DISSERTATION ON

SUSTAINABILITY EVALUATION OF TWO ICONIC BRIDGE CORRIDORS NAMELY, SIGNATURE BRIDGE AND BARAPULLA ELEVATION ROAD PROJECT, USING FUZZY TECHNIQUE

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Dedicated to my mentor…

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Certificate

This is to certify that the thesis entitled," **Sustainability Evaluation of two Iconic Bridge Corridors namely, Signature Bridge and Barapulla Elevation Road Project, using Fuzzy Technique "**submitted by Mr. AMANDEEP SINGH in partial requirements for the award of Master of Technology in Environmental Engineering at the Delhi Technological University, Delhi is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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This thesis is the account of six months of dedicated work in the field of Environmental Engineering at the Delhi Technological University, Delhi, India, which would not have been possible without the help of many.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The most widely accepted concept of sustainability as defined during the Bruntland Commission in 1987 is **"meeting the needs of the present generation without compromising the ability of future generations to meet their own needs".** The goals of providing sustainable features in the design and construction of transportation corridor in an Urban Environment are to minimise impacts on the environmental resources, consumption of material resources, energy consumption, encourage the use of new and innovative approaches, enhance the historic, scenic and aesthetic context and integrate into the community in a way that helps to preserve and enhance community life, encourage community involvement in the transportation planning process, encourage integration of non-motorized means of transportation and finally find a balance between what is important to the community, to the natural environment and is economically sound. **These 3 Parameters i.e. social, economic and environmental are most commonly accepted as three pillars of sustainability.**

In this research, Sustainability indicators of a transportation corridor **during construction** in an urban environment have been identified and detailed out. The research has been made on a Signature Bridge being constructed by DTTDC and Barapulla elevated corridor project undertaken by PWD. During the research study made at both sites in the midst of the construction period, *it was identified that Sustainability of these transportation corridors during the construction stage is just not limited to three Pillars, but in actually much beyond that*. Every activity or any Project is to be looked into right perspective to understand its relevance to all those it matters. Transportation Corridor is a field which, during its operational stage, can affect the life in every area varying from education sector, all kinds of commercial activities, availing of medical amenities or say movement of the public at large for any purpose they wish.

It is not only the operation stage, **but the construction stage also** makes an impact on the **residents living nearby** as well as on the **commuters passing through** the corridor on the **diverted route. Both these members of society are subjected to Air Pollution, Noise Pollution,** water pollution, and increase in travel time besides Health and Safety concerns. Environment faces

irreversible degradation besides other adverse impacts on the number of directly or indirectly related issues.

Various Sustainability Indicators during the construction stage as identified for an elevated transportation corridor and thereafter classified under various categories is covered in this research.

A comparative study on the above mentioned sites, through construction under identical urban environment, was carried out to evaluate the sustainability of these sites, using fuzzy logic, so that the site more sustainable based on identified sustainability indicators is known. Methodology and result of the study are also discussed in this research.

CHAPTER 1.
INTRODUCTION

Since 1980s the idea of sustainability has been distinguished as a worldwide need and is most ordinarily characterized as "Improvement that addresses the issues of the present without trading off the capacity of future eras to address their own particular issues. This idea has infested whole ranges of engineering, involving transportation frameworks building.

Despite the fact that there is no standard meaning of the sustainable transportation, sustainability is mostly defined in terms of transportation system efficiency and its impact on environmental integrity, economic productivity, and social quality of life (Mihyeon Jeon & Amekudzi 2005). Actually, the three variables are generally considered in the fundamental measurements of a practical transportation framework.

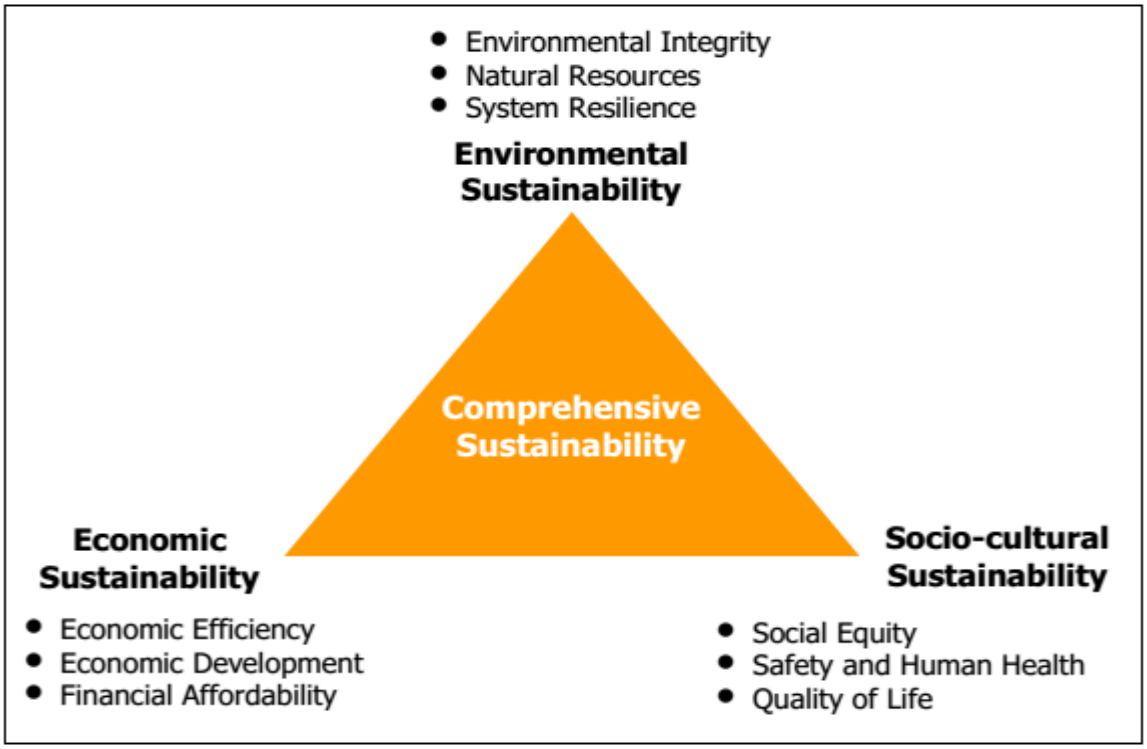

Figure 1 Essential factors of the transportation system sustainability

This Research task begins with depicting the eminent thinking on what constitutes sustainability of the transportation framework amid development and how to perform it.. Further the study identifies some of the key transportation system sustainability issues through construction in the Metro politician cities like Delhi. In this research, Sustainability indicators of the transportation corridor through development in a urban domain have been perceived and itemized out. The research has been made on **Signature Bridge being constructed on river Yamuna by DTTDC and Barapulla Elevated Corridor project being**

constructed by the PWD. Amid the research study was made at both the sites in their construction period, and *it was found that Sustainability of these transportation corridors while the development stage is just not restricted to just three Pillars, but rather in actuality much past that*. Finally, the real center of study lies on showing a correlation between the afore mentioned two construction sites by two government organizations, that is PWD and DTTDC, under the identical urban environment, by utilizing the Fuzzy rationale strategy to assess sustainability taking into account the perceived sustainability pointers utilizing information collected by directing different reviews (survey proforma) from the field specialists and the general population (occupants/suburbanites). This chapter is to provide the background information about this research project that incorporates the inspiration for this task and its significance and above all the problem statement. .In later stage the goals, methodology and scope are characterized.

1.1 MOTIVATION

In New Delhi, the Capital of India there has been a phenomenal growth in vehicular traffic lacking the proportionate growth of infrastructure. It has brought about a wide range of increment in contamination levels, traffic congestions, increment in anxiety levels, exponential rise in travelling time etc. Delhi has the traffic flow system as Ring-Radial pattern which embodies two concentric Roads prominently known as internal Ring Road and Outer Ring Road.

Delhi has one of the most extensive road networks in India that is 21% of its geographical area is covered with just roadways. Yet, there is not adequate space for the movement although five flyovers have been developed toward the end of Asian Games that were facilitated in 1982. Today, the number of flyovers has increased to 94. Delhi's vehicle stock has augmented 51 times in most recent three decades. Delhi alone has around 10% of aggregate enlisted vehicles all over India. This number of vehicles is ascending at 10% consistently. According to a CSE projections, the day trips are to increment from 15 million in 2015 to 25 million in 2020 that is an augmentation of 2 million for each year. To suit the expanding activity and to decongest existing movement, street spaces have been expanded. Though new streets wind up drawing more activity, and that is clarified as the phenomenon of “induced traffic”. The studies on traffic reveal that 50% of the increased roadway capacity is used up by increased traffic in about five years while 80 % of increased capacity is ultimately consumed by the induced traffic. Truth be told numerous urban areas in the U.S. furthermore in the West, are making amazing strides of destroying the flyovers and interstates. This might not be the required strategy in Delhi but very soon the physical limits of adding the

infrastructure might be saturated. So a more sustainable way out to Delhi's infrastructure problems need to be assessed. Expressways have a more noteworthy negative effect on the encompassing environments and on the general natural quality.

The exact next stride in the transportation framework's advancement needs comprise of practices that reduce the impacts on the natural environment, maximize the capacity, and benefit the society and this can be fulfilled just by introducing a game plan of Sustainable transportation establishment.

In order to accommodate the continually expanding number of vehicles on street, corridor improvement that incorporates the design, construction, operation and maintenance of a road, should not just pander to the needs of general society, yet ought to likewise adjust to the needs of environment. Sustainable principles serve as a tool to accommodate mobility while identifying the challenges of the environment.

Sustainable transportation development standards are lagging considerably behind those of the architectural community. **Although Leadership in Energy and Environmental Design (LEED) green building certification is an internationally recognized standard for determining the sustainability of a building's design, construction, and maintenance, there is no officially accepted method for evaluating sustainable transportation projects. Indeed, evaluation of transportation projects often ends with the assessment of construction impacts or the comparison of alternatives through benefit–cost analysis, limited by the need to determine cost impacts** (Oswald & McNeil 2010)**.**

This statement highlights the essential role played by sustainability in fast developing urban environment that has lots of infrastructure projects in construction. These projects not only cater to the needs of public, but practices adopted for accomplishing those needs have to be green in nature. Considering the need of green development, various standards such as LEED, GRIHA etc. have been established for green building certifications but there is no recognized method for evaluating the sustainable transportation projects. In this rapidly growing economy and with the world facing severe environmental issues a definite sustainable transportation evaluation method is much needed in order to meet the required green standards for the transportation corridor development.

1.2 PROBLEM STATEMENT

Nowadays, the worldwide necessity of sustainable development is confirmed and likewise it is fundamental that every single action that we perform for the improvement of the general public ought to be sustainable. The sustainability parameters that have been widely accepted are environmental issues, economics and social factors. Yet these three factors are constrained just to developing countries where the need for sustainable development has been forecasted. When we see the present development scenario in Mumbai, New Delhi or any other urban city in India we see that the overall acknowledgement of these 3 parameters can't satisfy the prerequisite in India. It is often observed that development of transportation corridors in urban ranges like Delhi are executed by the Construction Agencies in an extremely shabby way. These Agencies are slightest touchy towards the contaminants being released into nature, support of administrations in the undertaking zone and comforts of the residents as well as the traffic passing through their project area. Indeed, Even the concerned authorities are not taking the mandatory measures in implementation of various methods envisaged in the agreement. As a result of indifferent attitude, the comfort of people moving through the corridors as well as local people is badly affected.

A major part of environmental problems are originated from the internal operating mechanism of cities, and they have their local impacts, such as congestion, air pollution and noise pollution. Notwithstanding, numerous impacts likewise exist together that have a transborder nature, for instance waste disposal, waste water flow, or even a global one, such as contribution of traffic in hot emissions that leads to greenhouse effect and global warming.

To address such issues it has been chosen to do a study to appreciate the issues apart from the development activities and the effects of such activities on our surroundings and society.

1.3 BROAD OBJECTIVES OF RESEARCH

The fact that sustainability is an increasingly important issue in transportation system and service provision is evident in congested highway systems in urban areas, declining air quality and respiratory health; and the need for improved and more equitable access to basic social and economic services in several areas around the world (Mihyeon Jeon & Amekudzi 2005). The criteria for assessing the Sustainability of transportation base has no-where been characterized and it obliges a lot of research work. Sustainability indicators should be developed by going to the on-going construction destinations/sites and by interacting with all the real partners in this field, in addition to the required standards incorporated into the materials and the technologies to be deployed during the construction of transportation corridor. Likewise, it is key to build up a dynamic framework which is fit to encourage the future technologies. Bearing in mind the need of day without bargaining the capacity of the more younger generation to fulfill their own particular needs, research work has been done with taking after broad objectives.

i. Identification of different Sustainability Indicators for the transportation framework undertakings while development in a Metropolitan city such as New Delhi
ii. To build up a methodology for Sustainability Evaluation
iii. Application of a model based on fuzzy methodology to assess sustainability of the construction sites taken under consideration as a case study
iv. To practically execute suitable Sustainability indicators while development of a transportation framework.

1.4 OVERVIEW OF APPROACH

This research is based on identifying the sustainability indicators of the transportation corridor through construction and indicators are then connected to existing fuzzy model to assess and analyze the sustainability of two construction sites under study. In order to identify sustainability indicators, it was essential to comprehend essential sustainability concepts, the need of sustainable transportation, and to determine sustainability frameworks and programs already established. So, the methodology for evaluating sustainability is based on various sustainability concepts that have been explained in the literature review. These concepts are then applied to the conventional model for the assessment of sustainability in Results and Discussion section. The sustainability assessment was done through a

contextual analysis application to focus its appropriateness and applicability to the corridor projects under construction.

The various sustainability indicators are recognized and using the following approach sustainability evaluation of the sites is carried out

• Review data on transportation impacts, sustainability ideas and issues, and sustainable transportation applications through development..

• Review existing sustainability assessment models and sustainable executing frameworks.

• Identification of different Sustainability Indicators as pertinent to transportation framework extending through development in a Metropolitan city like Delhi.

i. Select the sites under same urban environment
ii. Visit the sites and snap photos of different recognizable sustainability issues
iii. Study all the photos and distinguish the issues which will serve as indicators
iv. Identify the pointers by perception and additionally by expert comments
v. Categorize sustainable indicators in different classes, for example, social,economic, environment and so forth.
vi. Develop the sustainable indicators
vii. Develop a proforma with the sustainability indicators and comparing segments for quantitative and subjective rating.
viii. Get expert and public appraisals through proforma

• Define an approach for the assessment of sustainability and apply it to the current model

i. Define an approach and focus on the traditional model for sustainability assessment.
ii. Understanding the Fuzzy logic and Fuzzy set theories and their application
iii. Develop indicator scale to transform indicators into weightage
iv. Assign the membership functions to qualitative ratings using fuzzy logic
v. Using MATLAB, develop a triangular fuzzy of qualitative ratings
vi. Assign Weightage to the indicators by outfitting information through proforma from specialists
vii. Rate the identified sustainability indicators of alternatives (PWD and DTTDC) by furnishing data through surveys from workers/inhabitants on the locales and neighborhoods

• Assess the sustainability of the sites taking into account above distinguished sustainability indicators utilizing Fuzzy triangular model.

1.5 SCOPE OF WORK

With the ever expanding demand for infrastructure development of society, it is a history when development in the urban environment was taken up without due thought of its adverse effect on society. These days, the overall need of sustainable advancement is affirmed and as needs be, it is key that every single action that we perform for the improvement of the general public ought to be sustainable. The sustainability indicators that have been generally acknowledged are natural issues, financial aspects and social variables. Be that as it may, these three components are constrained just to developing nations where the requirement for reasonable improvement has been forecasted. When we see the present advancement situation in Mumbai, New Delhi or whatever other urban city in India, we see that the overall acknowledgement of these 3 parameters can't satisfy the necessity in India. So, three extra parameters and their sub classification have been demarcated to ensure sustainable development. It has been already stated in the problem statement that the provisions for comfort of residents, traffic, users as well as environment protection are quoted in the agreement but they are not practically implemented in true spirit Henceforth administration should be guaranteed for sustainability.

It is observed that Delhi is a quickly developing metropolitan with Hi-tech undertakings and utilization of advancements that have been as of now tried in developed nations. Still big gap is observed while ideal implementation of these technologies and practical implementation under the circumstances dominated in an urban environment. There is a need of a strong technical base while making a final decision on the technical issues. Accordingly, a 5^{th} parameter titled as "Technical Issues" has been fused for sustainable transportation through development as a critical parameter. Besides, it was watched that through development when the site was at that point engrossed, there was an unapproved auto stopping which further adds to the current traffic congestion. Lots of honking, movement of vehicles in a erratic manner takes place and no traffic policemen were available to deal with the situation. Accordingly, an additional parameter, i.e. Governance was fused and its essentialness for economic advancement is considered genuinely. Additionally, the disturbing and irritated conduct was stated on the corridor at the moments when drivers are under a time frame to reach their destination at a targeted time. Excessive honking, movement of vehicles in a haphazard manner takes place, which results in congestion. So tolerance is needed keeping in mind the end goal to keep up a cool demeanor, subsequently it is fundamental that all partners like development organizations, proprietors, laborers and inhabitants need to accomplish a feeling of otherworldly existence to keep up a cool disposition and to lessen mishappenings in such a circumstance. Likewise, this last extra parameter, i.e. spirituality is also included.

CHAPTER 2.
LITERATURE REVIEW

2.1 SUSTAINABILITY EVALUATION THROUGH MATHEMATICAL MODELS

(Steg & Gifford 2005) state in their paper that it is generally accepted that sustainable transport strikes balance in current and future social, economic and environmental qualities. *Yet a basic set of sustainable transport indicators has not been defined.* The negative social, economic and environmental externalities outweigh the economic and social values of transport system. In this paper, the pros and cons and the externalities of current transport systems are diagnosed, such as waste, health consequences, energy and land use, traffic noise, traffic safety, accessibility, accident costs, and economic wealth. Sustainability indicators are defined as the sustainable transport policy goals, whether the transport system moving towards sustainability is monitored or not. This indicates a need to consider a wider range of sustainability indicators because amendments in existing transport systems might affect other sectors as well and that further contribute to unsustainable development. A variety of methods and models have been established to evaluate social, economic and environmental consequences of the transportation plans. However, only a few social indicators are taken into account because of the lack of knowledge and lack of valid methods and techniques for assessing the relevant social impacts. Adequate sustainable transport systems can only be obtained by the use of a new sustainable transportation model, accompanying analytical framework. Therefore, this research work has presented a theoretical framework, along with a methodology to better integrate the requirements of sustainable developments into the models for transport policies and planning, in a particular travel demand models. With the knowledge and results presented in this research work, it should become probable to make more efficient and effective use of available and affordable resources for enhancing the transport system performance.

In the dissertation presented to academic faculty by (Jeon Amekudzi) for the Doctorate degree (Ph.D. Degree) in the Georgia Institute of Technology, in **December 2007**, classifications, performance measures, as well as evaluation methodologies for sustainable transportation system have been reviewed and a complete framework for incorporating the sustainability considerations for the transportation planning and decision making was demonstrated. The study begins by characterizing the emergent thinking about what constitutes transportation sustainability and how it could be measured. Later, the study classifies some of the key transportation system sustainability issues in various countries depending on the prevailing socio-

economic conditions. Finally, the study emphases on demonstrating a viable methodology for incorporating the sustainability considerations into planning process using the data from the metropolitan Atlanta region.

2.2 SUSTAINABILITY EVALUATION BY DEVELOPING INDICATORS

In a research program recommended for developing sustainable transportation indicators**, Todd Litman (2009)**, mentioned that the Planning measures rely on indicators (i.e. standardized information suitable for analysis) for guidance, such as people rely on their senses i.e. sight, hearing and touch. Indicators let us analyze the trends and model their impacts. The selection of indicators and method of collection and analysis of data is important. An alternative may seem to be suitable and desirable if it is evaluated by one set of indicators, but may be found unsustainable if evaluated by others. Indicators are key tools for making decisions and evaluating progress. Decision-making increasingly include sustainability concepts, for example consideration of long-term social, economic and environmental impacts. As a matter of fact, there is increasing demand for suitable planning tools, like sustainable transportation indicators. Such indicators help to determine that how individual and short-term decisions affect long-term as well as strategic goals. Such indicators need to be carefully selected to reflect various impacts and perspectives, while being possible to collect and analyze.

2.3 SUSTAINABILITY EVALUATION THROUGH OTHER APPROACHES

A number of approaches have been proposed to assess sustainable transport systems. Ensuing the classification recently proposed, they have been broadly divided in to eight categories **(Awasthi A et al., 2011)**:

i. **Life-cycle analysis (LCA)** pools pollution emissions and the resources used during the entire life course of a product in order to estimate some criteria. Originally it was developed for industrial processes, but now LCA has limited application in the context to transport systems as it does not account for social aspects.

ii. **Cost-Benefit Analysis (CBA)** scrutinizes the monetary equivalent of all the negative as well as positive effects of a project alternative with the aim of curtailing the costs related to that alternative. Cost effectiveness analysis (CEA) is used when it is impossible to calculate the monetary value of

the alternatives or when the realization degree of the result to reach is given. The main toil of CBA or CEA concerns the monetary quantification of external and social costs.

iii. **Thorough analysis of project alternatives** involves Environmental Impact Assessment (EIA).

iv. **Optimization models**, applied to the sustainable transport, aim towards finest solutions under the specified constrictions of social, economic and environmental objectives.

v. **System Dynamics Models** are applied the case of complex systems and are found quite useful to furnish the relationships between the elements of system by examining feedback mechanisms and time-varying flows.

vi. **Assessment indicator models** are indicators which ascertain the sustainability of a particular practice or a project. **Tao and Hung** identified three types of such models ie: composite index models, multi-level index models and multi-dimension matrix models. Composite index models create a single index, such as the green gross national product or ecological footprint. Yet, evaluation is generally so tedious that it requires scrutiny of a series of indicators signifying various goals organized in the hierarchies (multi-level index models) or are related through the complex interactions (multi-dimensional matrix models).

vii. **The Data Analysis approach** uses the statistical techniques such as structural equation modeling or hypothesis testing or, to evaluate the sustainability.

viii. **Multi-Criteria Decision Analysis (MCDA) methods** consist of an ample set of methods, including the renowned Multi-Attribute Utility Function Theory (MAUT), ELECTRE methods and Analytic Hierarchy Process (AHP). MCDA evaluates the alternatives for each criterion and collects significant criterion outcomes in the decision table (or decision matrix).Proposed Alternatives are ranked and the "best" outcome on the criteria set is identified. Since there is generally no alternative which can optimizes all the criteria at the simultaneously, the methods find a most probable solution. MCDA methods are the most commonly used approach for sustainability evaluation in the transport field.

Stuart Samberg et al.,(2011) in their paper mentioned that a key element of sustainability is the optimization of the system efficiency by the intensification of existing resources and the restriction of the need of infrastructure expansion. This paper analyses the literature present on the operational and proposed evaluation strategies for the transportation projects and further proposes a sustainable transportation evaluation method. This sustainable transportation evaluation method is built on the existing evaluation systems and tries to address their shortcomings. Application of this sustainable transportation evaluation method depend on established multi-criterion methodologies that are for qualitative and quantitative

evaluation of sustainability of transportation projects through the planning, design, and construction phases.

Riccardo Rossi et al., (2012) in their paper supported the Fuzzy-Based Evaluation Method (F-BEM) and defined it as a suitable tool for evaluating the sustainability of the transport policies. In this method the concept of the "three pillars of sustainability" i.e. social, economic and environmental are formulized by means of a set of indicators as input variables. This method determines an overall fuzzy index for the sustainability of each and every alternative policy analyzed and provides the information about the composite dimensions of sustainability i.e. equity, viability and bearableness.

2.4 SUSTAINABILITY EVALUATION THROUGH MCDM TECHNIQUES

Moreover, in a paper by **Anjali Awasthi et al., (2013),** four of the major multi-criteria decision making (MCDM) techniques i.e. TOPSIS, VIKOR, SAW and GRA have been thoroughly investigated for the sustainability evaluation of the urban mobility projects under variety of qualitative data and their application have been demonstrated through a numerical example. Fuzzy sets and the systems theory can be a very effective tool to deal with prevailing conditions and evaluate sustainability of a given action plan, as it can formalize the situations characterized by:

- Non-homogeneous quantities or variables;
- Uncertain and vague information on the system (both present and future), in a particular when verdicts expressed by the experts are included in the evaluation;
- Interrelations among the various dimensions of sustainability, which be likely to induce "overlaps" ("fuzzy" boundaries).

In this aforementioned paper a Fuzzy-Based Evaluation Method (F-BEM) that formalizes the three-dimensional concept of the sustainability, is verified on a case study to evaluate its effectiveness as a tool to deduce the preferences expressed by decision makers, to classify the most vital characteristics of the alternative transportation policies and further, to support the design of the hypothetical transportation services ("What to" analysis).

According to a document titled "**Multi-criteria Sustainability Evaluation of Transport Networks for Selected European Countries**", the transportation has a complex interactions with the society, environment and as a key economic activity. As the concept of the sustainable development has become one of the foremost priorities for nations, there has been an increasing interest in the evaluation of the performance of transport systems in terms of sustainability issues. The key purpose of this study is to present a decision making framework for assessing the sustainability of transport networks in a multi-dimensional setting and develop a methodology to identify non-compromising alternatives. They also propose an elucidation technique to identify required improvisation of various system needs and quantify them to attain a certain level of sustainability. The proposed methods have been applied to a set of selective European countries within a case study.

Since the National Environmental Policy Act (NEPA) was signed as a law in 1970, the range of concerns about the relationship between the transport corridors and their associated effects on the surrounding environment has expanded. The research document entitled **(I-LAST) Illinois Livable and Sustainable Transportation, Rating System and Guide** is a sustainability performance evaluation metric system developed by the Joint Sustainability Group of the IDOT (Illinois Department of Transportation), the ACEC-Illinois (American Council of Engineering Companies–Illinois) and the IRTBA (Illinois Road and Transportation Builders Association). The approach of I-LAST is to incorporate a wider range of issues into the various development projects such as state highway projects. The purpose of this guide is as given below:

- Provide a complete list of practices or methods that have the potential to produce sustainable results in highway projects.
- Establish an efficient and simple method to evaluate transportation projects with respect to sustainability, livability, and effects on the natural environment.
- Record and identify the use of sustainable practices in the transportation industry.

CHAPTER 3.
SUSTAINABILITY CONCEPTS

This section characterizes the sustainability and its relationship with transportation frameworks taking into account the literature survey. The different effects of transportation speculations and the utilization of indicators to evaluate the sustainability are depicted as underneath..

3.1 DEFINITION OF SUSTAINABILITY

The most frequently utilized meaning of sustainability is derived from the United Nations, Brundtland Commission in 1987. This commission defines sustainability as ***"meeting the needs of the present generation without compromising the ability of future generations to meet their own needs"***. The point of presenting sustainable elements in design and construction of various development tasks is to

- To minimize impacts on environmental assets
- To minimize the utilization of material resources.
- To minimize the energy utilization.
- To safeguard or improve the historic and aesthetic context of the highway project.
- To fuse highway ventures into the community in such a way that it helps to preserve and enhance the community life.
- To empower the community association in the planning procedure.
- To encourage the incorporation of non-motorized means of transportation into the highway project.
- To encourage the utilization of creative methodologies in accomplishing these objectives.
- To find a harmony between what is essential
    1) for the transportation function of the facility
    2) for the community
    3) for the natural environment

3.1.1 TRIPLE BOTTOM LINE

The concept of sustainability is generally viewed from an ecological perspective, which focuses on issues like pollution and resource depletion (Litman 2008). A more suitable approach is to study sustainability in the perspective of triple bottom line approach, also known as the three pillar approach, and it requires an integrated view of social, economic and environmental issues **(Belka, 2005)**. The most effortless approach to imagine the triple bottom line approach for sustainability is through a Venn-diagram where every circle denotes the social, financial, and environmental points of view. Following figure represents the sustainability in the terms of triple bottom line.

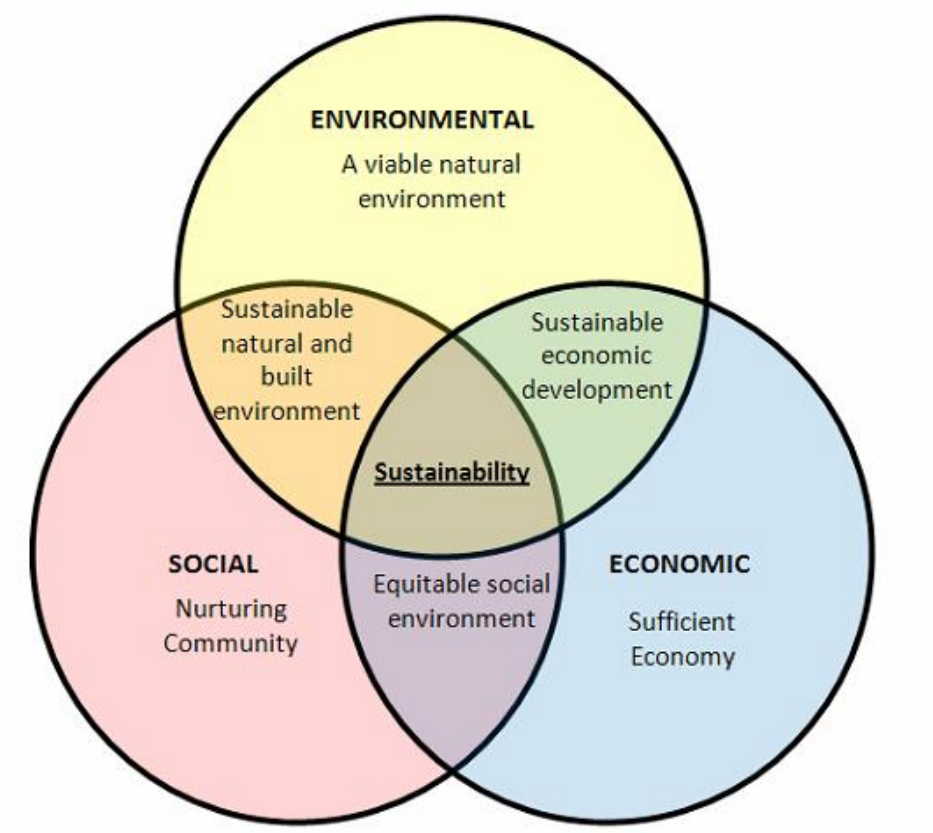

Figure 2 Triple Bottom Line Approach (source: CIRIA, 2008)

This multidimensional view demonstrates that sustainability issues are correlated and each of them are fundamental for achieving sustainability that addresses "planet, people, and prosperity"

In the triple bottom line perspective every last issue is connected with individual criteria that aides in characterizing the social, financial, and environmental ramifications .For example, the economic issues identify with exchange, business and work exercises. The social issues identify with human wellbeing,

community livability and public involvement. The environmental issues allude to emissions, biodiversity and environmental change.

3.1.2 SUSTAINABILITY ISSUES IN TRANSPORT CORRIDORS UNDER STUDY

As per the triple Bottom line approach, the sustainability contains every one of the 3 components, social, financial and environmental. At the time of visiting the sites and observing the sustainability issues, it was deduced that the prevailing situation demands beyond these 3 parameters in order to make up a sustainable corridor a reality. So 3 more additional parameters were introduced,namely Governance, Technical and Spirituality in lieu of demands of sustainable transportation corridor in an urban environment. The recognized issues are recorded as beneath:

i. Control on Air Pollution
ii. Control on Existing Drainage system
iii. Control on Noise pollution during day
iv. Control on Noise pollution during night
v. Depletion of Green Belt
vi. Effective Plantation scheme
vii. Any other Alternate schemes for make the project more sustainable
viii. Condition of Health of workers
ix. Any Welfare activity for family of workers
x. Sanitation conditions
xi. Availability of First Aid facilities
xii. Safety measures adopted at site
xiii. Increase in stress level of residents/commuters
xiv. Impact on Health of residents/commuters
xv. Impact on safety of residents/ commuters
xvi. Preserving the social spaces like cremation ground, Sur Ghat
xvii. Public attraction with the aesthetics of the Project
xviii. Utility of the Project to Public
xix. Preserving the heritage structures
xx. Increase in Travel time
xxi. Increase in travel cost
xxii. Disturbance to the business/Employment of nearby residents
xxiii. Increase in cost of Construction due to lack of funds

xxiv. Increase in cost of Construction due to time overrun
xxv. Display of Project Details
xxvi. Effective Traffic Diversions
xxvii. Visibility and sight distance to moving traffic
xxviii. Lighting of Construction site
xxix. Barricading the site
xxx. Effectiveness of Technology used
xxxi. Handling of C & D Waste
xxxii. Quality Assurance on the Project
xxxiii. Ensuring the mobility of Traffic within the project area
xxxiv. Maintenance of existing drainage system
xxxv. Maintenance of Barricades
xxxvi. Maintenance of existing utilities
xxxvii. Maintenance of existing greenery
xxxviii. Time over run due to delay in Govt. decisions
xxxix. Time over run due to mismanagement at site
xl. Facilities of Yoga/meditation
xli. Performance of Rituals at site like Vishvakarma Puja, May Day
xlii. Celebration during Festivals at site
xliii. Motivation to workers by reward policy or otherwise

While distinguishing these issues it was observed that it would be unjustifiable to stick to the three parameters, i.e. Social, Economic and Environmental for the arrangement of parameters. One of the real setback that was observed was increment in delay in travel time because of the restless conduct of the voyagers, erratic blending and development of distinctive classifications of vehicles, i.e. Autos, Buses, 3 wheelers, E-Rickshaws, 2 wheelers, Manual Rickshaws and so forth., yet this issue can't be arranged in any of the previously stated three parameters, i.e., Social, environmental and Economical. Thus the fourth parameter was presented which secured such issues and is termed as Governance. On identifying with the officers of Delhi Traffic Police in all the concerned territories, it was found that all such consistency parameters are specified there in their guideline books however functional execution needs.

Excessive honking, movement of vehicles in an unruly and haphazard manner takes place, which brings about movement blockages. A lot of tolerance is needed to keep up a cool disposition, and thus it is vital that all partners, for example, development offices, specialists, proprietors and occupants, and so on need

to accomplish a feeling of deep sense of being to keep up a cool demeanor and to diminish the setbacks emerging, for example, street fierceness. May be this component is not as vital as others but rather it can't be disregarded too. Appropriately, this last parameter, i.e. spirituality is also included.

Figure 3 Malba lying on roadside

Figure 4 Unauthorized parking

Figure 5 Movement not hindered. Pipes laid to maintain flow of water body

Figure 6 preserving aesthetics of Silver Oaks Park and choosing alignment with least no of trees to be cut

Figure 7 No disturbances to existing utilities

Figure 8 Proper signage and motivational quotes

3.2 MEASURING SUSTAINABILITY

3.2.1 SUSTAINABILITY INDICATORS

Sustainability Indicators are described as *an index or* "*a means developed to reduce a large volume of data to its simplest form, while retaining the vital meaning for the questions that are being asked about the data*" (Ott 1978)**.** The indicators provide direction, for measuring sustainability despite of its many complexities **(Bossel, 1999)**. With respect to sustainability indicators are used to simplify the process of answering the questions about how to reduce the human impacts and protect the future generations. Sustainable development indicators are very useful tools that can be used to endorse sustainable techniques within the policy and public sectors **(Mitchell, 1996)**. In relation to the transportation systems, sustainable development indicators need to hold two distinct requirements **(Bossel, 1999)**:

1. To provide information that paints a perfect picture of the prevailing or existing state and its viability.
2. To provide sufficient data about the transportation system's influence on the performance of any other systems that might depend on them. Along with these requirements, "good" indicators isolate the policy aspects from its outcomes **(Litman, 2008)**.

3.2.2 METHODOLOGY FOR DEVELOPING INDICATORS

Proper determination of successful indicators is a principal key to the accomplishment of a record or a rating framework. A typical system must be taken after while building up appropriate indicators. **Bossel** (1999) built up four key strides for going from an entire framework to individual indicators and later implementing them into the participating procedures

The four main steps are as follow (Bossel, 1999):

1. Understand, conceptually, the entire system
2. Identify the representative indicators
3. Quantify the basic orienteer satisfaction
4. Conduct a participative process

The first step, understanding the entire framework, is vital to the practicality of the orienteers and the indicators that will later be produced. The second step, recognizing the representing indicators, further contains sub-steps. In these sub-steps, representing indicators are chosen from the colossal number of

potential indicators (Bossel, 1999). The third step requires the prioritization of the indicators keeping in mind the end goal to change over indicator information into orienteer satisfaction. The final step involves input through external opinions in order to compensate the decisions made by the person who has established the indicators. By having proper outer analysts, a wide range of learning, mental models, experience, and social/ecological concerns can be highlighted (Bossel, 1999).

Mitchell (1996) has developed a practice, specific to the sustainable development, for identifying appropriate indicators for the entire system. The method is as follows:

i. Defining the system objectives, stating the purpose of indicators along with their user group
ii. Stating what is known in the terms of sustainable development by specifying the sustainable development principles and definitions that can be applied.
iii. Defining the issues that are important on a local and global scale.
iv. Comparing indicator properties against the types of users and the objectives of rating system
v. Evaluating the indicators against desirable characteristics and objectives of rating system.

3.2.3 SUSTAINABLE TRANSPORTATION INDICATORS

Sustainable transportation indicators are the blend of wide variety of aspects of a transportation system comprising of social, economic and environmental issues of sustainability. Various samples of the potential indicators of practical transportation have been produced by Litman (2008) and have been organized based on the social, economic and environmental categories of sustainability. Economic indicators discuss group's progression toward financial destinations including expanded wage, riches, profitability, occupation and social welfare (Litman, 2008). Social indicators identify with value, human wellbeing, social assets, group decency, group attachment, and style (Litman, 2008).Environment indicators incorporate effects, for example, air, water, commotion contamination, and exhaustion of non-renewable assets, hydrologic interruptions, warmth island impacts, living space fracture, untamed life passings, and other area use delayed consequences((Litman, 2008). These specimen indicators allude to the whole transportation framework and are merely representative of the types of indicators which can be used in the transportation system.

CHAPTER 4.
FUZZY LOGIC

4.1 OVERVIEW

Fuzzy Logic was started in 1965 by Lotfi A. Zadeh , teacher for software engineering at the University of California in Berkeley. Essentially, Fuzzy Logic (FL) is a multivalued rationale that permits moderate qualities to be characterized between routine assessments like true/false, yes/no, high/low, and so forth. This system can be utilized to handle fragmented information and dubious information in an exceptionally orderly manner.

Fuzzy logic is referred to as a way of "reasoning with uncertainty." It gives an all-around characterized system to manage dubious and not completely characterized information, so one can make exact findings from uncertain information The fuzzy theory provides a mechanism for representing linguistic constructs such as "many," "low," "medium," "often," "few." Notions like rather tall or quick can be figured numerically and prepared by PCs, with a specific end goal to apply a more human-like mindset in the programming of PCs. As a rule, the fuzzy rationale gives a surmising structure that empowers suitable human thinking capacities.

Fuzzy logic provides an inference morphology which empowers surmised human thinking capacities to be connected to learning based frameworks. The fuzzy rationale hypothesis gives a numerical quality to catch the vulnerabilities connected with human subjective procedures, for example thinking and reasoning. The conventional approaches to knowledge representation lack the means for representing the meaning of fuzzy concepts. As a consequence, the approaches based on first order logic and classical probability theory do not provide an appropriate conceptual framework for dealing with the representation of commonsense knowledge, since such knowledge is by its nature both lexically imprecise and non-categorical.Some of the crucial qualities of of fuzzy logic are :-

- In fuzzy logic, exact reasoning is viewed as a limiting case of approximate reasoning.
- In fuzzy logic, everything is a matter of degree.
- In fuzzy logic, information is deciphered as collection of elastic or, equivalently, fuzzy constraint on a collection of variables.
- Inference is viewed as a process of propagation of elastic constraints.
- Any consistent framework can be fuzzified

There are two primary attributes of fuzzy frameworks that give them better execution for particular applications. They are:

- Fuzzy framework are suitable for uncertain or inexact thinking, particularly for the framework with a numerical model that is hard to infer.
- Fuzzy rationale permits choice making with assessed values under deficient or uncertain Information.

4.2 NEED TO ASSESS SUSTAINABILITY VIA FUZZY LOGIC

Sustainability is a multifaceted idea for which we have no extensively acknowledged definition or estimation system. The guidelines of customary mathematics can't depict the flow of any socio environmental system. As Sustainability is inherently vague and complex idea so it is extremely hard to characterize or measure it. Normal dialect expressions are frequently favored by Policy creators as opposed to comparison or numerical values in evaluating the sustainability.

We use statistics and system identification to manufacture models for framework whose structure is not known. A large number of input-output measurements, a collection of candidate models, and a criterion for selection of the best model based on these measurements are required. The primary issue while evaluating sustainability using these methods is lack of output data. Despite the fact that a considerable lot of the inputs can be measured yet it is difficult to gauge the yield.

Whereas on the other hand, Fuzzy logic is quite suitable for evaluating sustainability on the grounds that it can show complex frameworks for which we have just a little or inadequate information about their dynamics, the parameters that affect them, and the values of those parameters. Fuzzy logic is capable of handling knowledge and data represented in different ways such as mathematical models, linguistic rules or expressions, numerical values.

4.2.1 CHARACTERISTICS AND USABILITY OF FUZZY LOGIC

(Sustainability: an ill-defined concept and its assessment using fuzzy logic Yannis A. Phillis *, Luc A. Andriantiatsaholiniaina)

It is universally accepted that a reliable measure of sustainability should be the outcome of integrating

economic as well as natural resources accounts. However, this is not easily achievable due to the lack of unsolved methodological problems (Kaufmann and Cleveland, 1995) and sufficient data availability. The following basic features justify the use of the fuzzy logic reasoning for assessing sustainability:

(a) Fuzzy logic has the ability to deal with complex and polymorphous concepts, which are not pliable to a straightforward quantification and contain uncertainties. In addition, reasoning with such vague concepts may not be clear and evident, but rather fuzzy.

(b) Fuzzy logic offers the mathematical tools to handle vague concepts and reasoning, and finally gives tangible answers ('crisp' as they are known) to problems fraught with subjectivity. Sustainability is, indeed, quite subjective. What seems unsustainable to an environmentalist may be sustainable for an economist and the elements signifying sustainability may vary for these specialists.

Another important characteristic of fuzzy logic is that it utilizes linguistic variables, thus executing computation with words. If we adopt a traditional mathematical approach for sustainability assessment, such as cost-benefit analysis or algebraic formulas, then specific factors, which are difficult to quantify, would be left out. However, there are certain aspects of sustainability, which cannot be quantified and yet are very significant such as, values and opinions. In this certain area of human thought, fuzzy logic delivers successfully (Zadeh, 1973; Zimmermann, 1991).

The final crisp value is achieved by defuzzification, which does the reverse of fuzzification. A straightforward delineation of IF –THEN fluffy estimated thinking is the appraisal of human joy in light of the mainstream feeling about the centrality of wellbeing. Selecting cash and wellbeing as the key variables of enjoyment, the fuzzy tenets may be.

- IF one has "much" cash AND "great" wellbeing, THEN he is "exceptionally" upbeat.
- IF one has "much" cash AND "terrible" wellbeing, THEN he is "inadequately" cheerful.
- IF one has "little" cash AND "great" wellbeing, THEN he is "attractively" upbeat.
- IF one has "little" cash AND "terrible" wellbeing THEN At that point he is "inadequately" cheerful.

"Much" and "little" are semantic estimations of the linguistic variable cash; they compare to the fuzzification of a certain measure of cash. (Great, terrible), and (inadequately, acceptably, exceptionally) are semantic estimations of the condition of wellbeing and satisfaction. Defuzzification of the semantic qualities 'inadequately', "agreeably" and "exceptionally" gives a fresh estimation of happiness.

4.3 PRELIMINARIES OF FUZZY SET THEORY

Some of the definitions related to fuzzy set theory adapted from (Zadeh, 1965; Buckley, 1985; Kaufmann & Gupta, 1991; Dubois & Prade, 1982; Pedrycz, 1994; Klir & Yuan, 1995; Zimmermann, 2001) are represented as follows.

Definition 1. A fuzzy set ~ a in a universe of discourse X is characterized by a membership function $\mu_a(x)$ that maps each element x in X to a real number in the interval [0, 1]. The function value $\mu_a(x)$ is termed the grade of membership of x in~ a (Kaufmann and Gupta). The nearer the value of $\mu_a(x)$ to unity, the higher the grade of membership of x in ~ a.

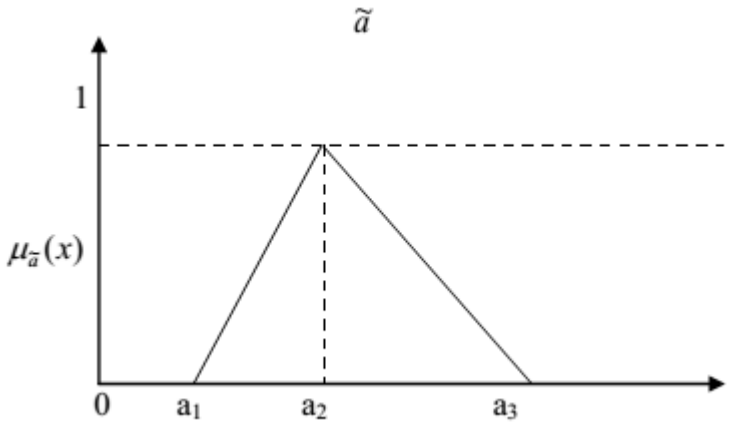

Figure 9 Triangular fuzzy number 'a'

Definition 2. A triangular fuzzy number (Fig. 1) is represented as a triplet ~ a= (a1; a2; a3). Due to their conceptual and computation simplicity, triangular fuzzy numbers are very commonly used in practical applications (Klir & Yuan, 1995; Pedrycz, 1994). The membership function of $\mu_a(x)$ triangular fuzzy number is given by:

$$\mu_a(x) = \left\{ \begin{array}{c} 0,\ x \le a1 \\ \frac{x-a1}{a2-a1},\ a1<x\le a2 \\ \frac{a3-x}{a3-a2}, a2 < x \le a3 \\ 0, x > a3 \end{array} \right\}$$

Where a1, a2, a3 are real numbers and a1<a2<a3. The value of x at a2 gives the maximal grade of $\mu_a(x)$ i.e., $\mu_a(x) = 1$; it is the most probable value of the evaluation data. The value of x at a1 gives the minimal grade of $\mu_a(x)$ i.e., $\mu_a(x) = 0$; it is the least probable value of the evaluation data. The narrower the interval [a1, a3], the lower is the fuzziness of the evaluation data.

4.3.1 LINGUISTIC VARIABLES AND FUZZY SET THEORY

In fuzzy set theory, conversion scales are used to transform the qualitative terms into fuzzy numbers. A scale of 0–9 is used to rate the criteria and the alternatives. Following Tables represent the conversion schemes for the qualitative, alternative and criteria ratings.

Qualitative Rating	Membership Function
Very poor (VP)	(1,1,3)
Poor (P)	(1,3,5)
Fair (F)	(3,5,7)
Good (G)	(5,7,9)
Very good (VG)	(7,9,9)

Fuzzy transformation for qualitative alternative site ratings

Qualitative Rating	Membership Function
Very Low (VL)	(1,1,3)
Low (L)	(1,3,5)
Medium(M)	(3,5,7)
High (H)	(5,7,9)
Very High (VH)	(7,9,9)

Fuzzy transformation for qualitative criteria ratings

4.3.2 FUZZY NUMBER

A fuzzy number is a quantity whose value is ambiguous, rather than exact as is the case with "conventional" (single-valued) numbers. Any fuzzy number can be assumed as a function whose domain is a specified set (usually set of the real numbers) and whose range lies within the span of non-negative real numbers 0 and 1000(both included). Each numerical value in the domain is allotted a specific "grade of membership" where 0 represents the minimum possible grade, and 1000 is the maximum possible grade.

4.3.3 TRIANGULAR FUZZY NUMBER

Among the various shapes of fuzzy number, triangular fuzzy number (TFN) is the most prevalent one.

Definition(Triangular fuzzy number): It is a fuzzy number represented with three points as follows :

A= (a1, a2, a3)

This representation is interpreted as membership functions.

$$\mu_a(x) = \begin{Bmatrix} 0, \ x \leq a1 \\ \frac{x-a1}{a2-a1}, \ a1<x\leq a2 \\ \frac{a3-x}{a3-a2}, a2 < x \leq a3 \\ 0, x > a3 \end{Bmatrix}$$

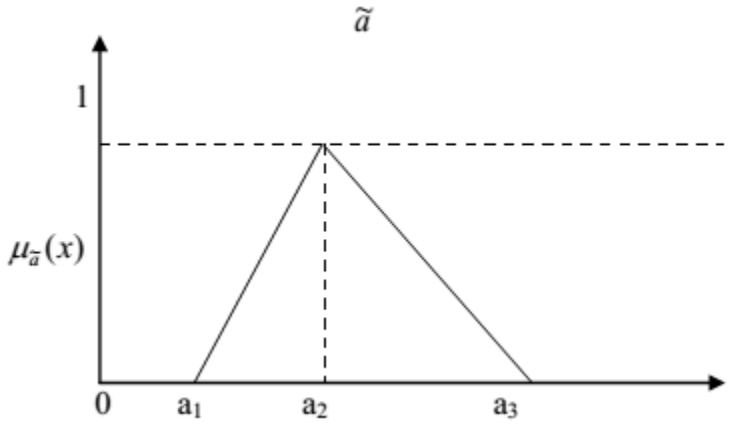

Figure 6: Triangular fuzzy number a

Now if you get crisp interval by α-cut operation, interval 'a' shall be obtained as follows ∀α ∈ [0, 1].

From

$$\frac{a1(\alpha)-a1}{a2-a1} = \alpha, \quad \frac{a3(\alpha)-a3}{a3-a2} = \alpha$$

We get

$a1(\alpha) = (a2-a1)\alpha + a1$

$a3(\alpha) = -(a3-a2)\alpha + a3$

Thus $A\alpha = [a1(\alpha), a3(\alpha)]$
$= [(a2-a1)\alpha + a1, -(a3-a2)\alpha + a3]$

4.4 VIKOR METHOD

In 1998 VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje) method was developed by the Opricovic for the multi-criteria optimization of the complex systems. VIKOR method focuses on ranking and sorting a set of alternatives against various decision criteria assuming that compromising is only adequate to resolve conflicts. Alike some other MCDM methods like TOPSIS, VIKOR depends on an aggregating function that signifies closeness to the ideal, but unlike the TOPSIS, introduces the ranking index based on the particular measures of closeness to the ideal solutions and hence this method uses linear normalization for eliminating units of the criterion functions (Opricovic & Tzeng, 2004). The VIKOR strategy was introduced as one appropriate method for actualizing within MCDM issue and was produced as a multi criteria choice for making a procedure to tackle a discrete decision making problem with non-commensurable and clashing criteria. This method focuses on the ranking and selection from a set of alternatives, and evaluates the compromise solution for a problem within conflicting criteria, which can aid the decision makers to reach a final solution. The multi-criteria measure for bargain positioning is produced from the LP–metric utilized as a totaling capacity as a part of a tradeoff programming method.

Assuming that each alternative is evaluated according to each criterion function, the compromise ranking could be performed by comparing the measure of closeness to the ideal alternative. The various m alternatives are denoted as $A_1, A_2, \ldots\ldots A_m$. For alternative A_i, the rating of the j^{th} aspect is denoted by f_{ij} (i= 1,2,…. m; j=1,2,… n), i.e., f_{ij} is the value of j^{th} criterion function for the alternative A_i, n is the number of criteria. Development of the VIKOR method starts with the following form of L_P-metric:

$$Lp,i = \left\{ \sum_{j=1}^{n} \left[wj(f_j^* - f_{ij})/(f_j^* - f_j^-) \right]^p \right\}^{1/p}, \qquad 1 \le p \le \infty$$

In the VIKOR method $L_{1,i}$ (as Si) and $L\infty;i$ (as Ri) are used to formulate ranking measure. The solution obtained by min Si is with a maximum group utility (''majority'' rule), and the solution obtained by min Ri is with a minimum individual regret of the opponent.

The compromise ranking algorithm of the VIKOR method has the following steps:

(a) Determine the best f_j* and the worst f_j- values of all criterion functions j=1,2,…..n. If the jth function represents a benefit then:

$f_j^* = \max_i \{f_{ij}\}$

$f_j^- = \min_i \{f_{ij}\}$

(b) Compute the values Si and Ri; i = 1;2;……m, by these relations:

$$Si = \sum_{j=1}^{n} wj \frac{\text{fj} * - \text{xij}}{\text{fj} * - \text{fj} -}$$

$$Ri = maxj\ wj \frac{\text{fj} * - \text{xij}}{\text{fj} * - \text{fj} -}$$

Where wj are the weights of criteria, expressing their relative importance.

(c) Compute the values Q_i; i = 1;2;……m, by the following relation:

$$Qi = v\frac{Si - S*}{S - -S*} + (1 - v)\frac{Ri - R*}{R - -R*}$$

Where,

$S^* = \min_i S_i$; $S^- = \max_i S_i$; $R^* = \min_i R_i$; $R^* = \min_i R_i$;

here suppose v = 0:5.

(d) Rank the alternatives, sorting by the values S, Rand Q in decreasing order. The results are three ranking lists.

(e) Propose as a compromise solution the alternative A, which is ranked the best by the measure Q(Minimum) if the following two conditions are satisfied:

C1. Acceptable advantage: $Q(A) - Q(A) \geq DQ$

Where A is the alternative with second position in the ranking list by Q. $DQ = 1/(m - 1)$, m is the number of alternatives.

C2. Acceptable stability in decision making: Alternative A must also be the best ranked by S or/and R. This compromise solution is stable within a decision making process, which could be ‘‘voting by majority rule’’ (when v>0:5is needed), or ‘‘by consensus’’v=0:5, or ‘‘with veto’’(v<0:5). Here, v is the weight of the decision making strategy ‘‘the majority of criteria’’ (or ‘‘the maximum group utility’’).If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

Alternatives A1 and A2 if only condition C2 is not satisfied, or

Alternatives A1,A2,….Am if condition Cl is not satisfied; Amis determined by the relation $Q(Am) - Q(A1) < DQ$ for maximum M(the positions of these alternatives are ‘‘in closeness’’).

The best alternative, ranked by Q, is the one with the minimum value of Q. The main ranking result is the compromise ranking list of alternatives, and the compromise solution with the ‘‘advantage rate’’. VIKOR is an effective tool in multi-criteria decision making, particularly in a situation where the decision maker is not able, or does not know to express his/her preference at the beginning of system design. The obtained compromise solution could be accepted by the decision makers because it provides a maximum ‘‘group utility’’ (represented by min S) of the ‘‘majority’’, and a minimum of the ‘‘individual regret’’ (represented by min R) of the ‘‘opponent’’. The compromise solutions could be the basis for negotiations, involving the decision maker’s preference by criteria weights.

CHAPTER 5
SITE SELECTION

Two iconic bridges of Delhi that are Signature Bridge and Barapulla elevated Corridor have been taken into consideration for sustainability review.

SIGNATUE BRIDGE AT WAZIRABAD: Signature bridge project or Wazirabad bridge project is an upcoming project which is of national as well as international significance. Wazirabad Bridge Project over River Yamuna consists of a main bridge with eastern and western approaches and creation of tourist destination along the east and west banks. Later on it was decided to implement these in two phase's viz. construction of Bridge in Phase-I and creation of a Tourist Destination in Phase-II

BARAPULLA ELEVATED ROAD CORRIDOR: Elevated Road Project over Barapulla Nallah is a corridor connecting East and South Delhi. The Project has been conceived in three phases with nodal locations as Mayur Vihar in East Delhi and Aurobindo Marg in South Delhi with intermediate locations as Sarai Kale Khan and Jawahar Lal Nehru Stadium.

It was found out that both the projects have striking similarities which led to formation of common ground for unbiased comparison of sustainability. The aforementioned similarities are as follows:-

i. **Both of the projects are on water bodies:** The Wazirabad bridge is on river Yamuna, 600m downstream of existing barrage at Wazirabad and also covers Najafgarh drain. The Barapulla project is built over Barapulla Nallah (Phase I and II)) as well as over River Yamuna(Phase III) which collects the discharges of other internal, peripheral and trunk drains to further discharge its contents-1,25,000 Kld of domestic sewage into the Yamuna. The areas along the Barapulla Nallah include INA, Sewa Nagar, JLN Stadium, CGO complex, Jangpura, Nizammuddin, Siddhartha Extension and Sarai Kale Khan Village.

ii. **Both of the projects are iconic bridges and one of their kind: Signature Bridge is an asymmetric cable stayed bridge with main span of 251 m, while the Bridge over River Yamuna in Barapulla Phase III is Extra Dose bridge with multi spans of 120 m. In both the cases the deck is supported on Cables.**

iii. **Both projects are conceived on new alignments that is they are neither the up gradation nor the expansion of existing corridors.**

iv. **Both the projects are carried out in phases where partially completed sites have been opened for public use:** In Wazirabad bridge eastern and western approaches have been completed and hence have been opened for public use. The main bridge part is under construction. In Barapulla elevated project Phase 1 has been open to public and phase 2 has been partially completed and shortly will be opened to traffic. Phase 3 is under construction.

v. **Both the projects were constructed in same period i.e. their construction works begin prior to commonwealth games of 2010:** Signature Bridge is estimated to be completed by 2016 and Barapulla would be completed by 2017.

vi. **Both the projects boast about usage of new and highly improvised technologies. Segmental constructions have been adopted in both the projects.**

vii. **Both the projects have their major portions constructed away from the urban parts of city and there has been least disturbance to the public. The normal life has not been hindered in any manner.**

viii. **The wazirabad project connects the North East Delhi to North Delhi whereas Barapulla connects East Delhi to South Delhi.**

CHAPTER 6.
BARAPULLA ELEVATED ROAD PROJECT

6.1 DESCRIPTION

Elevated Road Project over Barapulla Nallah is corridor connecting East and South Delhi. The Project has been apprehended in three phases with the nodal locations as Mayur Vihar in East Delhi and Aurobindo Marg in the South Delhi with intermediate locations such as Sarai Kale Khan and Jawahar Lal Nehru Stadium. An Elevated road that is 4 Kms long connecting Sarai Kale Khan and Jawahar Lal Nehru Stadium has been completed in 1st Phase. Work from Nehru Stadium to Aurobindo Marg is under construction in 2nd Phase, while the 3rd Phase that is link between Sarai Kale Khan and Mayur Vihar to complete the South-East link, has recently been awarded to L&T. The Precast Segmental Construction Technique with span by span construction and having deck continuity up to four spans was adopted in order to speed up the project and complete in given time frame.

6.2 LOCATION

The Proposed Barapulla Nala Corridor was considered as an East-south connecting corridor ,an optional course to the congested area of Ring Roads between Sarai Kale Khan and AIIMS, that fulfilled the quick need of Commonwealth Games and in long run for the development of payload, merchandise, individuals, and utilities.

Figure 10 Barapulla Elevated Corridor and Nalla

Figure 11 Loop structure At Sarai−Kale Khan

The arrangement along the Barapulla Nallah (channel) gathers the discharges from internal, peripheral and trunk drains and further release its substance i.e. 1,25,000 Kld of household sewage into the stream Yamuna. Barapulla Nallah in its east west arrangement begins from Ring Road to INA, crosses significant area i.e. Mathura railroad track, a few Arterial Roads specifically Nizamuddin Railway Station Road, Mathura Road close Jangpura, Lala Lajpat Rai close CGO Complex, Bhishm Pitamaha Marg close Sewa Nagar Flyover, and meeting Aurobindo Marg before being secured under Dilli Haat. The Nallah with a width of 70 m. and it covers a region of 9.60 Ha. The territories along the Barapulla Nallah incorporate INA, Sewa Nagar, JLN Stadium, CGO complex, Jangpura, Nizammuddin, Siddhartha Extension and Sarai Kale Khan Village.

6.3 DESIGN ASPECTS

For spans other than those at significant intersection, the precast segmental development strategy was effectively utilized. Here, a span is developed by fitting together a few precast units of length more or less equivalent to 3.0 m & then pre-stressing them. For facilitating the standardization of segments, the cables were profiled such that they draped up/down only in the segments near to the end but followed horizontal profile in the middle segments. By considering some of segments from the central zone, various span lengths were probable. Such arrangements offered flexibility in planning of the substructure location depending on the site conditions. The construction was carried out span-by-span starting at one end of continuous stretch and last at other end. Due to adoption of segmental technique It was conceivable to erect a typical 34 m span in time frame of just 2.5 days.

Figure 12 Lala Lajpat Rai Crossing

With the end goal of minimizing the expansion joints and to upgrade the wonderful riding quality, it was chosen to have a procurement of deck continuity. Expansion joints were given after every three progressive compasses.

At all the significant intersections, three/ five span continuous units have been given. The central piers were made integral to superstructure. Twin leaf slender piers were provided in the structure instead of one thick pier in order to counterbalance the impact of temperature change, shrinkage and creep, as twin leaf slender piers could absorb most of the deformation without developing excessive moments. These fundamental crossings are in precast segmental construction.

There was an additional requirement of crash barrier dowels as the depth of girders varied from 4.584 m to 2.45 m .Transportation of these heavy segments to site from casting yard was planned carefully. For the purpose of transportation of these segments special low bedded trailers were employed.

Special lifter were acquired from the NRS for lifting of the portions, adjusting them and keeping them in position till they were stuck to already casted structure through temporary/ permanent pre-stressing.

Segment on the main side was raised, adjusted, epoxy paste was spread at visible surface and was fixed to structure through temporary pre-stressing. After this the complementary portion on other side was raised, adjusted, epoxy paste spread at first glance and provisional pre-stressing was done. Later on, the perpetual cantilever cables were threaded in and were stressed to finalize the erection of a pair of the cantilevering segment.

For this project 5 lifters were employed with each lifter weighing around 90 tons. Each lifter served the purpose of lifting the segment from ground, rotating it, aligning it and finally transferring the segments on the precast structure. At some locations where the lifting of segments directly under the bridge was impossible, the segments were first raised from the other side (lateral span) and later transferred on the precast structure. At certain locations where the lifting of segments directly under the bridge from either sides was impossible, the segments were lifted with help of cranes. Ground supported trestles were used to erect the end portion of the end span. Central stitch was completed cast-in-situ.

6.4 SUSTAINABILITY CONSIDERATIONS

1. The study of alignment connecting the INA near Dilli Haat and Ring Road at Barapulla Nallah was most economical, direct, aesthetic, and was based on swift constructability. The project enhanced the aesthetics of the urban space. Intrusions next to the historic monuments were very sensitive. The work was executed without disrupting the flow of traffic

2. At all the sensitive receivers noise barriers were provided. A suitable mix of indigenous species including deciduous species and broad-leaved evergreen have been planted along the roadside. The deciduous species were planted on slopes.

3. While driving from Sarai kale khan to INA on the new Elevated Corridor, the Barapulla Bridge is aesthetically visible.

4. The alignment of the road with reference to Khan-e-Khana's Tomb was proposed to be as far as possible, even more than 100 meters away from the notified monuments that are designated as Prohibited Areas within which no construction is permitted. Archeological Survey of India (ASI) recommended engaging a heritage consultant for Khan-e-Khana's Tomb and Barapulla Bridge. It was found that the earlier preferred alignment option was contrary to the specifications of the Ancient Monuments and Archeological Sites and Remains Act 1958. Alignment was moved

towards east to provide 107 meter distance between the Monument and structure. Structure soffit level was raised from 5.5 mts to 12 mts above Mathura Road Level.

5. The Archaeological Beauty of the entire area has been restored by landscaping the area. Edge Alignment is proposed to be 107m away from Khan-e-Khana Mirza Abdur Rahims khan Tomb (Protected Monument) with vertical Clearance of 12 m from Mathura road to guarantee visibility of Khan-e-khana Tomb. Elevated Roads provide unhindered visibility to Old Barapulla Bridge complying with ASI observations.

6. For minimizing the disturbance to road and rail traffic, segmental construction was planned. The sequence of operation were planned and executed in such a manner that the road as well as rail traffic moved uninterrupted throughout the construction period.

7. As per the recommended practice for treatment of the embankment slopes, turfing was done on the embankment. Trees were planted on the both sides of the road and inside the rotary.

8. No disturbance has been caused to the prevailing drainage patterns. Side drains have been provided connecting to the main outfall drain. The Sections of the corridors have been modified suitably along with the cross drainage structures.

9. Safety of workers during construction was ensured by providing helmets, masks, safety goggles, etc. Adequate barriers, signage and persons with flags to control traffic were provided during the entire period of construction. Proper drainage was ensured around the sites in order to avoid water logging leading to diseases.

10. The asthetics of Silver Oaks park were preserved by providing an alignment which led to cutting of least number of trees. Moreover, park was saved from getting divided into two parts by providing structure on stilts in park.

11. Near INA, Tailor made structures were provided to accommodate DMRC tunnels. First piling was done by PWD and then tunneling was done by DMRC and later on pile caps were constructed.

CHAPTER 7.
SIGNATURE BRIDGE

7.1 BACKGROUND OF THE PROJECT:

Wazirabad Bridge Project over River Yamuna, was entrusted to DTTDC as a Deposit Work by Govt. of Delhi on the basis of a MOU was signed on August 27, 2004. As directed by the Govt., DTTDC prepared a Detailed Project Report (DPR) for creating a "Tourist Destination" in which there were provision for having a large water body, various water based sports, development of East and West banks with a number of tourist facilities. An iconic cable stayed bridge at the centre was the main attraction. However, in later discussions with Delhi Government, it was decided to implement the project in two phases viz. construction of Bridge in Phase-I and creation of a Tourist Destination in Phase-II.

Figure 13 the Signature Bridge at Wazirabad, Delhi

7.2 DESIGN OF BRIDGE:

Keeping in mind the ensuing Common Wealth Games, Government modified the normal symmetrical cable stayed bridge to an iconic structure, which would become the Signature for Delhi. Accordingly, the design was modified to have bow shaped unsymmetrical inclined 154m high pylon and clear waterway of 251m. With the provision of lifts, it will be possible to reach at the top of the pylon and have a panoramic view of Delhi through the Glass Façade.

7.3 ENVIRONMENTAL CLEARANCE

i) It is pertinent to mention that while the Project was planned and mandatory clearances from various local bodies were obtained, matter was referred to M/O Environment and Forest for their clearance, but it was returned with remarks that "Bridges are not covered under EIA notification 2006 and as such Environmental clearance is it required".

ii) Subsequently, a case was filed before the National Green Tribunal Court against the construction of this Bridge on the same grounds that the requisite Environment Clearance has not been obtained.

iii) The case was defended before the Hon'ble NGT Court and finally as per the judgment pronounced on 12.02.2015, the case has recently been referred to Ministry of Environment, Forest & Climate Change for providing Environmental Clearance to the Project.

7.4 SANCTION OF THE PROJECT:

An A/A & E/S (modified after the receipt of tenders) amounting to Rs. 1131.00 Crores was accorded by Government of Delhi on 26.02.2010. This included the Eastern & Western Approaches and the Main Cable Stayed Bridge over River Yamuna.

7.4 BRIEF DESCRIPTION OF THE PROJECT:

7.4.1 APPROACHES:

The work of approaches was awarded to M/s Gammon India Ltd. in June 2008 for a sum of Rs 348.90 Crores with stipulated date of start as June 2008 and stipulated completion in December 2011.

Other details are given below

a. Cost of Approaches Rs. 348.90 Crores
b. Present Progress 98%
c. Likely date of completion August 2015

Few Highlights:

- **Main Flyovers and other independent loop on the Eastern Approach and Western Approaches have since been completed and opened to traffic**.
- **Recently DTTDC completed the launching of 49 m span with Pre-cast segments using overhead launcher. <u>It is the longest span and heaviest segments launched in India so far.</u>**

7.4.2 BRIDGE:

The work of Main Bridge over river Yamuna was awarded to a Joint venture of M/s Gammon (India)-Construtora Cidade (Brazil)-Tensacciai (Italy) for a sum of Rs. 631.81 Crores in March 2010, with stipulated date of completion in December 2013. Due to delay in handing over site and redesign of foundation P-23, the work is delayed and now the target of completion is June 2016. Other details are given below

a. Cost of Bridge Rs. 631.81 Crores
b. Present Progress 64%
c. Likely date of completion June 2016

7.5 PRESENT STATUS OF WORK

The present status of the work is furnished in the following paras

(i) At present all the foundations except integrated pile of P-23 wells have been completed. Integrated Piling in P23 is in progress.

(ii) The erection work for the pylon and steel girders for the Bridge is in progress.

(iii) All the girders have been received from China.

(iv) The fabrication of temporary structures is nearing completion and the erection work is in progress.

(v) The two pylon bases, the heaviest part and L_0 elements have been placed and welded on the Piers P19. The erection of cross tie is also completed.

(vi) The structural steel fabrication (14000 MT) for the main pylon is in progress with M/s ZTSS in China. Four consignments totaling 8000 MT of the fabricated material have been received at site and the trial assembly work is in progress for the last consignment. The 5^{th} consignment will be dispatched in two parts. First part of 5^{th} consignment is expected for dispatch by June 2015 and balance by October 2015

(vii) All bearings have been fabricated and assembled in Germany and have arrived at site.

(viii) Methodology for the Stay cables has been received and the material will be dispatched to the site in September 2015.

(ix) A Revised Preliminary Estimate amounting to Rs. 1594 crores has been framed and has been sent to Govt. of Delhi for scrutiny, processing and approval.

7.6 QUALITY CONTROL

Q-4 (Extra High Quality Assurance) as described in IRC : SP: 47 and 57 is followed for this project. Besides this, ISO 9000 Standards have been followed in Project. **Further, in this project 4 Tier Quality Assurance System is being followed**

- QC by ZTSS
- QC by JV
- QC by LRA (3rd Party)
- QC by sbp gmbh (Design Consultant)

7.7 SAFETY ASPECTS

The project is being executed in River, in depth as deep as 50 m below the ground, as height as high as 154 m. All kinds of precautions for safety of workmen working at site, for the movement of Engineers and Protection of Environment have been adopted and till date not a single mis-happening has been reported.

CHPAPTER 8.
MATERIALS AND METHODS

8.1 SELECTION OF CORRIDOR

Two major corridors of Delhi namely Barapulla Elevated Corridor and Signature Bridge at wazirabad have been taken into account for study. The criteria for site selection has been justified in Chapter 5.

8.2 METHODOLOGY FOLLOWED FOR THE IDENTIFICATION OF SUSTAINABILITY INDICATORS

Following procedure has been followed in this research to identify the sustainability indicators.

1. Selection of a corridor under construction and defining the infrastructure criteria for the corridor.

2. Developing sustainability indicator categories

3. Identifying sustainability indicators

4. Compiling a proforma that includes sustainability indicators and columns for rating

5. Assigning quantitative as well as qualitative ratings to the recognized indicators by furnishing ratings from the expert's opinions

8.3 DATA SOURCES AND COLLECTION

As soon as the segments along the two corridors were settled as the area for the contextual analysis, information was gathered. The introductory step was to distinguish the information necessities and the sources from where the information could be gathered. Henceforth, a table was produced posting all the information sources and the individual information necessity from every credit application. Sources incorporate observations from site visit, specialists in the transportation field and the general population (workers/occupants).

With the end goal of recognizing sustainability indicators and confirming their weightage ,a proforma with subjective and quantitative appraisals for these indicators was produced and sent to different specialists of transportation field. They sent back the rightfully filled proforma through email..

For assessment of the corridors under investigation, the information was gathered by leading a study out in the open (workers/occupants) including offices on those destinations. The proforma which included indicators and a section for the quantitative appraisals for every site was

disseminated in the neighboring settlements and the shops close to the development s. The proforma were gathered actually and wherever obliged the genuine object was additionally disclosed to individuals with a specific end goal to get one-sided audits.

Data that was not outfitted by any of the predetermined sources was considered as a supposition and was archived accordingly. Case in point, Spirituality indicators were considered as a suspicion because of the absence of community access to inner environment at site .Hence, spirituality indicators were recorded accordingly and were connected to the assessment systems.

8.4 FUZZY VIKOR APPLICATION

8.4.1 SELECTION OF EVALUATION CRITERIA

The chief step involves the selection of the criteria for evaluating sustainability of an urban transportation corridor through a comprehensive literature review (Jeon, Amekudzi and Guensler 2008, Litman 2009, Zietsman 2000), through our site visit experience, observations and expert opinion. The finalised list contains 43 criteria.

S.No.	SUSTAINABILITY INDICATORS
A. ENVIRONMENTAL	
1.	Air Pollution
2.	Existing Drainage system
3.	Noise pollution during day
4.	Noise pollution during night
5.	Depletion of Green Belt
6.	Plantation scheme
7.	Alternate schemes for make the project more sustainable
B. SOCIAL	
8.	Health of workers
9.	Welfare activities for family of workers
10.	Sanitation conditions
11.	First Aid facilities
12.	Safety measures
13.	Increase in stress level of residents/commuters
14.	Impact on Health of residents/commuters
15.	Impact on safety of residents/ commuters
16.	Preserving the social spaces like cremation ground, Sur Ghat
17.	Public attraction with the aesthetics of the Project
18.	Utility of the Project to Public
19.	Preserving the heritage structures
C. ECONOMICS	

20.	Increase in Travel time
21.	Increase in travel cost
22.	Disturbance to the business/Employment of nearby residents
23.	Increase in cost of Construction due to lack of funds
24.	Increase in cost of Construction due to time overrun
D. TECHNICAL	
25.	Display of Project Details
26.	Traffic Diversions
27.	Visibility and sight distance to moving traffic
28.	Lighting of Construction site
29.	Barricading the site
30.	Effectiveness of Technology used
31.	Handling of C & D Waste
32.	Quality Assurance on the Project
E. GOVERNANCE	
33.	Ensuring the mobility of Traffic within the project area by traffic Marshalls
34.	Maintenance of existing drainage system
35.	Maintenance of Barricades
36.	Maintenance of existing utilities
37.	Maintenance of existing greenery
38.	Time over run due to delay in Govt. decisions
39.	Time over run due to mismanagement at site
F. INNER ENGINEERING	
40.	Facilities of Yoga/meditation
41.	Performance of Rituals at site like Vishvakarma Puja, May Day
42.	Celebration during Festivals at site
43.	Motivation to workers by reward policy or otherwise

8.4.2 GENERATING QUALITATIVE CRITERIA AND ALTERNATIVE RATINGS

For the purpose of sustainability evaluation of an urban transportation corridor, assessment of a urban transportation corridor, we require the information on social-economic-environmental-technical-governance-spirituality indicators. However, in general practice it has been observed, that there is none or restricted information accessibility on this subject, consequently making this assessment process troublesome.To experience this circumstance, we made utilization of different subjective appraisals, for example, Good, Very Good, Fair, Poor, Very Poor for evaluating the options from people in general and Very Low, Low, Medium, High, Very High for the criteria by

expert opinion. Later, they were changed into fuzzy numbers using the conversion schemes provided in following Tables for further processing through Fuzzy VIKOR technique.

Qualitative Rating	Membership Function
Very poor (VP)	(1,1,3)
Poor (P)	(1,3,5)
Fair (F)	(3,5,7)
Good (G)	(5,7,9)
Very good (VG)	(7,9,9)

Figure 14 Fuzzy transformation for qualitative alternative site ratings

Qualitative Rating	Membership Function
Very Low (VL)	(1,1,3)
Low (L)	(1,3,5)
Medium(M)	(3,5,7)
High (H)	(5,7,9)
Very High (VH)	(7,9,9)

Figure 15 Fuzzy transformation for qualitative criteria ratings

8.4.3 FUZZY VIKOR TECHNIQUE FOR EVALUATION

The fuzzy VIKOR technique involves fuzzy assessments of criteria and alternatives in VIKOR (in Serbian: VlseKriterijumska Optimizacija IKompromisno Resenje). It measures the closeness of the alternative with respect to the positive ideal solution for evaluation (Anjali Awasthi et al. 2013).

Step 1: To Assign ratings to various alternatives and criteria

Let us take a set of ***m*** alternatives called **A** = {A1, A2,., A_m }which we need to evaluate against a set of ***n*** criteria, that is **C** = {C1 ,C2 ,., Cn }. The criteria weights are represented by $\mathbf{w_j}$ where (j=1,2,..,n). The performance ratings of the decision maker $\mathbf{D_k}$ (*k* = 1,2,…, K) for each alternative $\mathbf{A_i}$ (i=1,2,..,m) according to criteria $\mathbf{C_j}$ (*j*= 1,2,..,n) are denoted by :

$\mathbf{R_k = x_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})}$, where j = 1, 2,…, n; i= 1,…., m; k =1, 2 ,.., K with membership function $\mu_{Rk}(x)$.

Step 2: To compute the aggregate fuzzy ratings corresponding to alternatives and criteria.

When fuzzy ratings for all the decision makers are described as the triangular fuzzy number $R_k=(a_k, b_k, c_k)$, where k=1,2,...,K, then the aggregated fuzzy rating is defined by R=(a, b, c), k=1,2,...,K where;

$$\mathbf{a = min\{a_k\},}\ \boldsymbol{b = \frac{1}{K}\sum_{k=1}^{k} bk,}\ \mathbf{c = max\{c_k\}} \qquad \mathbf{(1)}$$

The aggregated fuzzy weights ($\mathbf{w_{ij}}$) corresponding to each criterion are calculated as $w_j = (w_{j1}; wj2; wj3)$ where

$$\mathbf{w_{j1} = min\{w_{jk1}\},}\ \boldsymbol{wj2 = \frac{1}{K}\sum_{k=1}^{k} wjk2,}\ \mathbf{w_{j3} = max\{c_{jk3}\}} \qquad \mathbf{(2)}$$

Step 3: To compute the fuzzy decision matrix

The fuzzy decision matrix for the criteria (W) and the alternatives (D) is constructed as follows:

$$D = \begin{array}{c} \\ A1 \\ A2 \\ A3 \\ A4 \end{array} \begin{array}{c} \begin{array}{cccc} C1 & C2 & \ldots.. & Cn \end{array} \\ \begin{bmatrix} X11 & X12 & \ldots.. & X1n \\ X21 & X22 & \ldots.. & X2n \\ \ldots & \ldots & \ldots.. & \ldots \\ Xm1 & Xm2 & \ldots.. & Xmn \end{bmatrix} \end{array}, \ i= 1, 2,….m ; j= 1,2,.n \qquad \mathbf{(3)}$$

W = (w_1, w_2… w_n)

Step 4: To defuzzify the elements of the fuzzy decision matrix corresponding to the alternatives and the criteria weights into crisp values.

For example a fuzzy number a~= (a1, a2, a3) can be converted into a crisp number a by employing the below equation:

$$\boldsymbol{a = (a1 + 4a2 + a3)/6} \qquad \mathbf{(4)}$$

Step 5: To Determine the best and worst values of critera rating where f_j^* is best and values f_j^- is worst value

$f_j^* = \max_i \{x_{ij}\}$ **(5)**

$f_j^- = \min_i \{x_{ij}\}$

Step 6: To compute the values of S_i and R_i using the equations given below

$$Si = \sum_{j=1}^{n} w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \quad \textbf{(6)}$$

$$Ri = max_j\, w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \quad \textbf{(7)}$$

Step 7: To compute the values of Q_i using

$$Qi = v\frac{s_i - s^*}{s^- - s^*} + (1 - v)\frac{R_i - R^-}{R^- - R^*} \quad \textbf{(8)}$$

Where:

S^* = minimum S_i

S^- = maximum S_i

R^* = minimum R_i

R^- = maximum R_i

And v is the weight for the strategy of maximum group utility and here it is taken to be 0.5

Step 8: To rank the alternatives by sorting the values Q, R and S in ascending order.

Step 9: To propose a compromise solution for the alternative ($A^{(1)}$) which is the best ranked by the measure Q(minimum) if the following two conditions are satisfied

C1: Acceptable advantage

If $Q(A^{(2)}) - Q(A^{(1)}) \geq DQ$ **(9)**

Where $A^{(2)}$ is the alternative that holds second position in the ranking list according to Q and

DQ = 1/J-1 where j is number of criteria

C2: Acceptable stability in decision making **(10)**

The alternative $A^{(1)}$ should also be the best ranked by R or/and RS. The settlement solution is stable only within a specific decision making process, and that could be the strategy of maximum group utility (when v>0.5 is needed), or ―by consensus when v = 0.5 , or ―with veto ie (v<0.5). If one of the above conditions is not satisfied, then a set of settlement solutions is proposed, which consists of:

- **Alternatives $A^{(1)}$ and $A^{(2)}$ if only the condition C2 is not satisfied Or**
- **Alternatives $A^{(1)}$, $A^{(2)}$,…. A(M)if the condition C1 is not satisfied; $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum M (the position of these alternatives are in closeness).**

CHAPTER 9.
RESULTS AND DISCUSSION

9.1 NUMERICAL APPLICATION

In this section sustainability evaluation of the two transportation corridors namely A1 and A2,in Delhi, under construction have been carried out using the Fuzzy VIKOR technique and is presented in this. These project sites are Barapulla Elevated Corridor (A1) constructed by PWD and Signature Bridge (A2) constructed by DTTDC.

A committee of 10 experts (E1, E2… E10) was formed to obtain the qualitative ratings for the criteria and the alternatives.

- Calculation of Fuzzy membership functions for the expert views. The Crisp values of have been calculated as per equation no 4

Table 1: Qualitative Assessments and Aggregate fuzzy criteria ratings

Criteria	Qualitative rating										Aggregate Fuzzy Rating	Crisp Value
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10		
	OPS	LP	SKR	PK	HKS	VKS	VSK	PKS	SSRI	SS		
C1	VH	VH	VH	H	H	VH	VH		VH	VH	(3,8.2,9)	7.466667
C2	H	VH	M	VH	M	M	H	VH	VH	H	(3,7.2,9)	6.8
C3	M	H	H	H	L	H	M	M	M	M	(1,5.6,9)	5.4
C4	H	VH	VH	VH	VH	H	H	H	H	VH	(5,8,9)	7.666667
C5	VH	VH	M	H	H	VH	VH	H	H	H	(3,7.6,9)	7.066667
C6	VH	VH	VH	H	H	M	H	M	H	H	(3,7.2,9)	6.8
C7	H	M		VH	H			VH	H	H	(3,6.6,9)	6.4
C8	VH	VH	H	VH	H	VH	H	H	H	VH	(5,8,9)	7.666667
C9	VH	H	L	VH	H	H	H	M	H	H	(1,6.8,9)	6.2
C10	VH	VH	H	VH	H	VH	H	H	H	H	(5,7.8,9)	7.533333
C11	VH	VH	VH	VH	H	VH	VH	VH	H	VH	(5,8.6,9)	8.066667
C12	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	(7,9,9)	8.666667
C13	H	VH	VL	VH	M	VH	VH	H	M	VH	(1,7,9)	6.333333
C14	VH	VH	VH	VH	M	VH	VH	H	H	H	(3,8,9)	7.333333

C15	VH	VH	VH	VH	H	VH	VH	VH	VH	H	(5,8.6,9)	8.066667
C16	H	VH		M		VH		H	VH	H	(3,6.8,9)	6.533333
C17	M	H	L	H	H	VH	M	M	H	M	(1,6,9)	5.666667
C18	VH	VH	M	H	M	H	VH	VH	H	VH	(3,7.6,9)	7.066667
C19	VH	M	M		M		VH		VH	H	(3,6.4,9)	6.266667
C20	VH	VH	VH	VH	M	VH	H	H	VH	H	(3,8,9)	7.333333
C21	VH	VH	VH	VH	M	M	H	H	VH	H	(3,7.6,9)	7.066667
C22	H	H	VH	VH	L	M	H	H	H	M	(1,6.6,9)	6.066667
C23	H	H	H	VH	VH	VH	H	H	VH	VH	(5,8,9)	7.666667
C24	H	H	H	VH	VH	VH	H	H	VH	VH	(5,8,9)	7.666667
C25	H	H	M	H	L	L	H		VH	L	(1,5.6,9)	5.4
C26	VH	VH	VH	VH	VH	VH	VH	VH	VH	H	(5,8.8,9)	8.2
C27	VH	VH	H	VH	M	VH	VH	VH	H	H	(3,8,9)	7.333333
C28	VH	VH	H	VH	VH	VH	VH	VH	VH	H	(5,8.6,9)	8.066667
C29	VH	VH	H	VH	H	VH	VH	H	VH	VH	(5,8.4,9)	7.933333
C30	VH	H	H	H	M	M	M	H	VH	H	(3,6.8,9)	6.533333
C31	H	H	M	VH	H	VH	VH	H	H	H	(3,7.4,9)	6.933333
C32	VH	H	VH	VH	VH	VH	VH	VH	H	H	(5,8.4,9)	7.933333
C33	VH	VH	VH	VH	VL	VH	H	VH	VH	VH	(1,8,9)	7
C34	VH	VH	H	VH	H	VH	H	VH	VH	VH	(5,8.4,9)	7.933333
C35	H	M	H	VH	H	VH	H	VH	H	M	(3,7.2,9)	6.8
C36	VH	H	VH	VH	VH	VH	H	VH	H	H	(5,8.2,9)	7.8
C37	VH	VH	M	VH	H	H	H	H	H	VH	(3,7.6,9)	7.066667
C38	H	H	VH	VH	VH	H	H	M	VH	VH	(3,7.8,9)	7.2
C39	H	H	VH	VH	M	M	VH	VH	VH	H	(3,7.6,9)	7.066667
C40	M	M	M	H	VL	M	VL	L	VL	L	(1,3.6,9)	4.066667
C41	VL	L	H	VH	VH	M	VL	M	H	L	(1,5,9)	5
C42	M	VL	VH	H	VL	M	VL	M	M	VL	(1,4,9)	4.333333
C43	VH	VH	H	H	VH	VH	H	H	VH	VH	(5,8.2,9)	7.8

- We convert the qualitative ratings into fuzzy triangular numbers and then we generate aggregate ratings using the equation (2).The following Table presents the aggregate fuzzy decision matrix for the both the alternative sites.

Table 2. Aggregate fuzzy decision matrix for the two alternative sites

CRITERIA	A1 (PWD)	A2 (DTTDC)	MINIMUM	MAXIMUM
C1	(1,6.72,9)	(1,6.52,9)	1	9
C2	(1,6.76,9)	(1,6.72,9)	1	9
C3	(1,6.92,9)	(1,6.76,9)	1	9
C4	(3,6.48,9)	(3,6.28,9)	3	9
C5	(3,7.24,9)	(3,6.8,9)	3	9
C6	(1,4.16,9)	(1,4.36,9)	1	9
C7	(3,7.12,9)	(3,6.88,9)	3	9
C8	(1,6.72,9)	(1,6.52,9)	1	9
C9	(1,4,9)	(1,4.28,9)	1	9
C10	(1,4.04,9)	(1,4.36,9)	1	9
C11	(3,7.28,9)	(3,6.8,9)	3	9
C12	(1,6.72,9)	(1,6.52,9)	1	9
C13	(1,6.64,9)	(1,6.68,9)	1	9
C14	(3,6.96,9)	(3,6.88,9)	3	9
C15	(3,7.2,9)	(3,6.76,9)	3	9
C16	(3,6.96,9)	(3,6.8,9)	3	9
C17	(1,6.72,9)	(1,6.52,9)	1	9
C18	(3,7.28,9)	(3,6.76,9)	3	9
C19	(3,7.28,9)	(3,6.8,9)	3	9
C20	(3,7.4,9)	(3,6.92,9)	3	9
C21	(3,7.28,9)	(3,6.8,9)	3	9
C22	(3,7.24,9)	(3,6.8,9)	3	9

C23	(3,7.28,9)	(3,6.84,9)	3	9
C24	(3,7.12,9)	(3,6.76,9)	3	9
C25	(3,7.24,9)	(3,6.8,9)	3	9
C26	(3,7.24,9)	(3,6.88,9)	3	9
C27	(3,7.24,9)	(3,6.76,9)	3	9
C28	(3,7.28,9)	(3,6.88,9)	3	9
C29	(3,7.24,9)	(3,6.8,9)	3	9
C30	(3,7.32,9)	(3,6.84,9)	3	9
C31	(3,7.28,9)	(3,6.8,9)	3	9
C32	(3,6.96,9)	(3,6.8,9)	3	9
C33	(3,6.96,9)	(3,6.84,9)	3	9
C34	(3,6.88,9)	(3,6.8,9)	3	9
C35	(3,7.24,9)	(3,6.84,9)	3	9
C36	(3,6.92,9)	(3,6.84,9)	3	9
C37	(1,5,9)	(1,6.08,9)	1	7
C38	(3,7.28,9)	(3,6.8,9)	3	9
C39	(3,6.88,9)	(3,6.8,9)	3	9
C40	(3,6.96,9)	(3,6.84,9)	3	9
C41	(3,6.96,9)	(3,6.84,9)	3	9
C42	(1,7.16,9)	(1,6.72,9)	1	9
C43	(3,6.96,9)	(3,6.76,9)	3	9

- Generate aggregate crisp ratings for both the alternative sites using equation (4). Based on these values, we will calculate the best f_j^* and the worst f_j^- values of all 43 criteria using equation (5).

Table 3 The best values fj and the worst values fj- of the 43 criteria*

CRITERIA	CRISP RATING		WORST VALUE F_j^-	BEST VALUE F_j^*
	A1 (PWD)	A2 (DTTDC)		
C1	6.146667	6.013333	6.013333	6.146667
C2	6.173333	6.146667	6.146667	6.173333
C3	6.28	6.173333	6.173333	6.28
C4	6.32	6.186667	6.186667	6.32
C5	6.826667	6.533333	6.533333	6.826667
C6	4.44	4.573333	4.44	4.573333
C7	6.746667	6.586667	6.586667	6.746667
C8	6.146667	6.013333	6.013333	6.146667
C9	4.333333	4.52	4.333333	4.52
C10	4.36	4.573333	4.36	4.573333
C11	6.853333	6.533333	6.533333	6.853333
C12	6.146667	6.013333	6.013333	6.146667
C13	6.093333	6.12	6.093333	6.12
C14	6.64	6.586667	6.586667	6.64
C15	6.8	6.506667	6.506667	6.8
C16	6.64	6.533333	6.533333	6.64
C17	6.146667	6.013333	6.013333	6.146667
C18	6.853333	6.506667	6.506667	6.853333
C19	6.853333	6.533333	6.533333	6.853333
C20	6.933333	6.613333	6.613333	6.933333
C21	6.853333	6.533333	6.533333	6.853333
C22	6.826667	6.533333	6.533333	6.826667
C23	6.853333	6.56	6.56	6.853333

C24	6.746667	6.506667	6.506667	6.746667
C25	6.826667	6.533333	6.533333	6.826667
C26	6.826667	6.586667	6.586667	6.826667
C27	6.826667	6.506667	6.506667	6.826667
C28	6.853333	6.586667	6.586667	6.853333
C29	6.826667	6.533333	6.533333	6.826667
C30	6.88	6.56	6.56	6.88
C31	6.853333	6.533333	6.533333	6.853333
C32	6.64	6.533333	6.533333	6.64
C33	6.64	6.56	6.56	6.64
C34	6.586667	6.533333	6.533333	6.586667
C35	6.826667	6.56	6.56	6.826667
C36	6.613333	6.56	6.56	6.613333
C37	5	5.72	5	5.72
C38	6.853333	6.533333	6.533333	6.853333
C39	6.586667	6.533333	6.533333	6.586667
C40	6.64	6.56	6.56	6.64
C41	6.64	6.56	6.56	6.64
C42	6.44	6.146667	6.146667	6.44
C43	6.64	6.506667	6.506667	6.64

Following table presents the values of Si, Ri and Qi for the two alternatives calculated using equation (6, 7, 8). The values of $S^*= 0.736$, $S^- = 5.76$, $R^*= 0.163$, $R^- =0.188$ are computed using equation (9).

Table 4 Represents the values of Si, Ri and Qi for the two alternatives

	A1 (PWD)	A2 (DTTDC)
S_i	0.7359	5.7531
R_i	0.1634	0.188
Q_i	0	1

Table 5 ranks the two alternatives, by sorting the values of Si, Ri and Qi obtained from Table 4 in the ascending order.

Table 5 Ranks the two alternatives

S_i	**A1**	**A2**
R_i	A1	A2
Q_i	A1	A2

It can be seen from the above results as presented in Table 5 that site 1 that is Barapulla Elevated Corridor by the PWD is the best ranked by the measure of least value of Q_i. Therefore we now cross-examine it for the given two conditions those have been earlier discussed in step 9.

1). C1: acceptable advantage i.e. equation 9

Using equation 9 DQ = 1/43-1 = 1/42 = 0.0238.

Now to satisfy the condition $Q(A^{(2)}) - Q(A^{(1)}) \geq DQ$,where $A^{(1)}$) is the best ranked by the measure Q(minimum) and in our case it is A1.

We have

Q(A2) - Q(A1) = 1 - 0= 1 > 0.0238, hence the condition $QA^{(1)} - QA^{(2)} \geq DQ$ is satisfied.

2). C2: Acceptable stability in decision making using equation 10

Since site A1 is best ranked by S_i and R_i (considering the —"by consensus rule v =0.5"), therefore it is declared to be as a more sustainable corridor.

9.2 RESULTS

Results of this study has been illustrated in Table 5, which depicts that alternative A1 i.e. Barapulla Elevated Corridor by PWD is a more sustainable corridor, in light of the recognized sustainability indicators, among the two corridors chosen for the case study.

9.3 DISCUSSION

9.3.1 IDENTIFYING SUSTAINABILITY INDICATORS

The five step methodology defined in this research can be used for any transport corridor to develop sustainability indicators. The five steps are

1. Selection of a corridor under construction and defining the infrastructure criteria for the corridor

2. Developing the sustainability indicator categories

3. Identifying the sustainability indicators

4. Compilation of a proforma that include sustainability indicators and corresponding columns for rating

5. Assigning the quantitative as well as qualitative ratings to the recognized indicators by furnishing the ratings from the field expert's opinions

Each of these steps can be applied to evaluate a sustainable transportation corridor through construction in an urban environment. **This process began with the requisite for categorization of the sustainability from its existing three pillars i.e. Economic, Social and Environmental aspects and excelled with the development of three more vital categories namely Inner Engineering, Technical an Governance.** In later stages the individual parameters/indicators under these 6 sustainability categories were recognized by visiting the corridors through construction and consultation with the field experts. Finally, the process completed with the compilation of a proforma that furnishes Qualitative as well as Quantitative ratings to each identified sustainability indicator from the experts.

9.3.2 SUSTAINABILITY EVALUATION

The Fuzzy VIKOR technique was applied for sustainability evaluation of two major transportation corridors under construction i.e. (A1, A2) in New Delhi city. **These projects were Barapulla Elevated Corridor being constructed by PWD (A1) and Signature Bridge being constructed by DTTDC (A2).**

The Final outcomes after the numerical application of Fuzzy VIKOR method exhibit that the site A1, i.e. Barapulla Elevated Corridor being constructed by PWD is found to be more sustainable under the given conditions and the identified sustainability indicators..

CHAPTER 10.
CONCLUSIONS AND RECOMMENDATIONS

This chapter reviews the need of identifying the sustainability indicators for the transportation corridors and their applicability to sustainability evaluation as well as corridor development. The limitations and advantages of using these indicators is discussed in this chapter and also future scope for improvement and application is defined.

10.1 CONCLUSIONS

Following conclusions are drawn from the above study:

i. Through this research study it has been furnished that sustainability is not only based on three parameters but also depend on various other indicators that has been identified as per study.

ii. Various Sustainability Indicators through the construction stage has been identified for an elevated transportation corridor and hence are classified under various categories as covered in this research.

iii. The three pillars of sustainability namely social, economic and environmental are viable only for developed countries whereas in developing economies like India where various other factors such as exponential increase in population etc. come into play, the need to introduce additional parameters arises.

iv. The comparative study of 2 iconic transportation corridors through construction, **Barapulla Elevated Corridor being constructed by PWD (A1) and Signature Bridge being constructed by DTTDC (A2)** has defined a methodology for future sustainability studies

v. The results of this study yield that Barapulla Elevated corridor is more sustainable as compared to the Signature Bridge.

10.2 RECOMMENDATIONS

On the basis of above research work we would like to give some recommendations based on which the concept of sustainability could be made understood and implemented globally. Following measures also need to be taken into account while using this methodology to assess the sustainability.

i. It is recommended to concise the list of identified indicators.

ii. Awareness among masses need to be created for making them understand the concept of Sustainability and its need.

iii. Proforma for public needs to be in very simple and non-technical language.

iv. Incentives should be given to the people involved in the construction of corridors to promote the concept of sustainability

v. Ratings similar to Green buildings need to be furnished in order to achieve the concept of green flyovers or corridors.

10.3 SCOPE OF FUTURE WORK

In this research, the study has been limited to only developing the indicators and demonstrating application of FUZZY technique for sustainability evaluation of transportation corridors. In later stages we wish to develop a green rating system for transportation corridors, similar to those for the green buildings. Moreover, this research will serve as a platform or guide for the implementation of most suitable sustainability indicators through construction of a transportation infrastructure.

CHAPTER 11.
REFERENCES

1. Anjali Awasthi, Hichem Omrani, Philippe Gerber Ciise, (January 2013), "Multi-criteria decision making for sustainability evaluation of urban mobility projects", CEPS Instead, Working Paper No 2013-01
2. Jeon, C.M., 2007. Incorporating Sustainability Into Transportation Planning. October, (December).
3. Litman, T., 2008. Sustainable Transportation Indicators. Transportation, 65(November), pp.1–20. Available at: http://www.centreforsustainabletransportation.org/researchandstudies.htm.
4. Mihyeon Jeon, C. & Amekudzi, A., 2005. Addressing Sustainability in Transportation Systems: Definitions, Indicators, and Metrics. Journal of Infrastructure Systems, 11(1), pp.31–50. Available at: http://ascelibrary.org/doi/abs/10.1061/(ASCE)1076-0342(2005)11%3A1(31) [Accessed May 16, 2015].
5. Oswald, M.R. & McNeil, S., 2010. Rating Sustainability: Transportation Investments in Urban Corridors as a Case Study. Journal of Urban Planning and Development, 136(3), pp.177–185.
6. Ott, W.R., 1978. Environmental Indices: Theory and Practice, Ann Arbor Science. Available at: https://books.google.co.in/books/about/Environmental_Indices.html?id=lrYxAAAAMAAJ&pgis=1 [Accessed April 2, 2015].
7. Steg, L. & Gifford, R., 2005. Sustainable transportation and quality of life. Journal of Transport Geography, 13(1 SPEC. ISS.), pp.59–69.
8. Zietsman, J. (2000), Incorporating Sustainability Performance Measures Into the Transportation Planning Process, PhD Dissertation, Texas A&M University, College Station, December, Texas.

9. Sunita Bansal, Srijit Biswas, SK Singh, (2015), "Selection of most economical green building out of n-alternatives: approach of vague fuzzy logic", International Journal of Research in Engineering and Technology, 4(2): 164-168.

10. Sunita Bansal, FIE Srijit Biswas, SK Singh, (2015), "Approach of fuzzy logic for evaluation of green building rating system", International Journal of Innovative Research in Advanced Engineering (IJIRAE), Volume 2, Issue 3: 35-39.
11. Shishir Bansal, S.K. Singh(2015),"Sustainable handling of construction and demolition (c & d) waste", International journal of sustainable Energy and Environmental Research, 4(2): 22-48
12. Sunita Bansal, FIE Srijit Biswas, SK Singh, (2015), "Fuzzy Modelling For Selection Of Most Economical Green Building Out Of N-Alternatives", International Journal of Advanced Information Science and Technology (IJAIST), Volume 36, Issue 3: 7-11
13. Shishir Bansal, S.K. Singh, (2014), "A Sustainable Approach Towards The Construction and Demolition Waste", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 2, February, 2014.
14. Shishir Bansal, S.K. Singh, (2014), "An Elevated Road Over Barapulla Nallah In New Delhi", Proc., FIB 2014, Mumbai, India.
15. Shishir Bansal , Vinay Gupta, And S K Singh (2012) , A 3-Level Grade- Separator At Ghazipur In East Delhi And Sustainability Considerations During The Construction, , Proceeding of Conference of Indian Institute of Bridge Engineers Held In Mumbai On 24th November 2012
16. Shishir Bansal, Jose Kurian and Santosh K. Singh, Assessment of Degradation Caused to the Environment During Constructions And The Extent Of Its Replenishment, First International Conference On Concrete Sustainability, Tokyo, Japan, Being Organised By Japan Concrete Institute , May 27-29, 2013
17. Shishir Bansal ,Jose Kurian ,and Santosh K. Singh, "Application Of Environmental Friendly Systems To Protect The Environment During Construction Of Grade Separators In New Delhi" , first international conference on concrete sustainability, Tokyo, Japan, Being Organised By Japan Concrete Institute , May 27-29, 2013

18. Awasthi A, Chauhan SS, Omrani H,(2011)," Application of fuzzy TOPSIS in evaluating sustainable transportation systems", Expert Systems with Applications 38 (2011) 12270–12280

19. Bossel, H.,(1999),"Indicators for Sustainable Development: Theory, Method, Applications" Winnipeg: International Institute for Sustainable Development.

20. Belka, K.,(2005),"Multicriteria Analysis and GIS Application in the Selection of Sustainable Motorway Corridor.Master's thesis", Linkopings University.

21. CIRIA. (2008). Sustainability. Retrieved March 8, 2008, from
22. "http://www.ciria.org/complianceplus/images/sustainability2.gif."

23. Doughty, M., and Hammond, G,(2004),"Sustainability and the Built Environment at and Beyond the City Scale." Building and Environment39(10), 1223-1233,2010

24. Jeon, C. M. and Amekudzi, A. (2005) "Addressing Sustainability in Transportation Systems: Definitions, Indicators, and Metrics" Journal of Infrastructure Systems, American Society of Civil Engineers (ASCE). Volume 11, Number 1, pp 31-50.

25. Jeon Christy Mihyeon,(2007) "Incorporating Sustainability Into Transportation Planning And Decision Making: Definitions, Performance Measures, And Evaluation" Ph.D. Thesis in the School of Civil and Environmental Engineering, Georgia Institute of Technology (2007).
26. Jeon C., Amekudzi A., Guensler R.,(2008),"Sustainability Assessment at the Transportation Planning Level: Performance Measures and Indexes, in Proceedings of the 87thAnnual Meeting of the Transportation Research Board (TRB)", Washington, DC, 1-26.

27. Litman T. (2009), "A Good Example of Bad Transportation Performance Evaluation",Working paper, Victoria Transport Policy Institute.

28. Litman, T.,(2009),"Sustainable transportation indicators- A recommended research program for developing sustainable transportation indicators and data". In Proceedings of the 2009 transportation research board annual conference, CD-ROM,Washington, DC, January 11-15

29. Litman,Todd. (2003).“Sustainable Transportation Indicators.” Victoria Transport Policy Institute (VTPI), Victoria, Canada. (http://www.vtpi.org/sus-indx.pdf)

30. Litman, T., and Burwell, D. (2006).”Issues in Sustainable Transportation”, Journal of Global Environmental Issues, 6(4), 331-346.

31. Litman, T.,(2008),”Well Measured: Developing Indicators for Comprehensive and Sustainable Transport Planning”.British Columbia: Victoria Transport Policy Institute.

32. Michelle Renee Oswald (2008) a master thesis titled”Rating the sustainability of transportation investments: corridors as a case study”.

33. Mitchell, G. (1996)” Problems and Fundamentals of Sustainable Development Indicators. Sustainable Development”, 4, 1-11.

34. Ott, W,(1978), “Environmental Indices: Theory and Practice”.Ann Arbor: Ann Arbor Science.

35. Riccardo Rossi & Massimiliano Gastaldi & Gregorio Gecchele, (2012),“ Comparison of fuzzy-based and AHP methods in sustainability evaluation: a case of traffic pollution-reducing policies”, springerlink.com

36. Samberg Stuart, RK&K Engineers, Bassok Alon, (2011) Puget Sound Regional Council and Holman Shawna, Parametrix, “Method for Evaluation of Sustainable Transportation toward a Comprehensive Approach”

37. Shishir Bansal, S K Singh, Vinay Gupta, (2014), “A 3-Level Grade- Separator At Ghazipur In East Delhi And Sustainability Considerations During The Construction”, 12th International seminar on emerging trends in Transportation structures” 24-25 Nov, 2012-Mumbai, India, Seminar Documentation Vol. 1, PP 86-119

38. Shishir Bansal, S K Singh, Jose Kurian, (2014), "Application Of Environmental Friendly Systems To Protect The Environment During Construction Of Grade Separators In New Delhi", 1st First International Conference on Concrete Sustainability, 27-29 May 2013, Tokyo Japan, Program & Paper abstracts, PP 163

39. Shishir Bansal, S K Singh, Jose Kurian, (2014), "Environmental Impacts And Mitigation Measures In Infrastructure Projects In New Delhi", 1st First International Conference on Concrete Sustainability, 27-29 May 2013, Tokyo Japan, Program & Paper abstracts, PP 177

40. Shishir Bansal, S K Singh (2014), "Sustainable Construction Of Grade Separators At Mukarba Chowk And Elevated Road Corridor At Barapulla, Delhi", International conference of Advance Research and Innovations 2014, New Delhi, India, Feb 1, 2014

41. Alla M. Aenab and S. K. Singh (2012), "Critical Assessment of Environmental Quality of Baghdad, Iraq ", Journal of Environmental Engineering, ASCE, 138 (5), 601-667.

42. Shishir Bansal, S K Singh, (2014) "A Sustainable Approach Towards The Construction And Demolition Waste", International Journal of Innovative Research in Science, Engineering and Technology, (An ISO 3297: 2007 Certified Organization), Vol. 3

43. Shishir Bansal, Vinay Gupta, S K Singh, (2014) "Barapullah Elevated Road Project : Past, Present and Future", ING-IABSE SEMINAR on Elected Transport Corridors, MYSORE June 26-27, 2014 Report, PP 41-52

44. Steg Linda, (2005) Department of Psychology, University of Groningen, Grote Kruisstraat 2/I, 9712 TS Groningen, The Netherlands, Gifford Robert, Department of Psychology, University of Victoria, Victoria BC V8W 3P5, Canada, "Sustainable transportation and quality of life".

45. World Commission on Environment and Development (WCED), (1987) "Our Common Future". Oxford University Press, Oxford, England.

46. Alla M. Aenab and S.K.Singh (2012)“ Environmental Assessment of infrastructure Projects of water sector in Baghdad, Iraq, Journal of Environmental Protection, 2012 (3), 1-10.

47. Adams, J., 1999. The social implications of hypermobility. In: OECD,Project on sustainable transport (EST). The economic and social implications of sustainable transportation. Proceedings of the Ottawa Workshop, 20–21 October 1998. OECD Publications,Paris.
48. Beatley, T., 1995. The many meanings of sustainability. Journal of Planning Literature 9.
49. Berkhout, P.H.G., Muskens, J.C., Velthuijsen, J.W., 2000. Defining the rebound effect. Energy Policy 28 (6/7),
50. Shishir Bansal , Vinay Gupta, And S K Singh (2012) , A 3-Level Grade- Separator At Ghazipur In East Delhi And Sustainability Considerations During The Construction, , Proceeding of Conference of Indian Institute of Bridge Engineers Held In Mumbai On 24th November 2012
51. Shishir Bansal, Jose Kurian and Santosh K. Singh, Assessment of Degradation Caused to the Environment During Constructions And The Extent Of Its Replenishment, First International Conference On Concrete Sustainability, Tokyo, Japan, Being Organised By Japan Concrete Institute , May 27-29, 2013
52. Shishir Bansal ,Jose Kurian ,and Santosh K. Singh, “Application Of Environmental Friendly Systems To Protect The Environment During Construction Of Grade Separators In New Delhi” , first international conference on concrete sustainability, Tokyo, Japan, Being Organised By Japan Concrete Institute , May 27-29, 2013
53. Charu Sharma, sarbari Dutta, Sarah Khan and S. K. Singh, (2012), Disposal and harmful effects of plastic waste: An overview “, Seminar on Engineering for sustainable development and inclusive growth: Vision 2025, December 13-16, 2012 , New Delhi
54. Shivraj Sahai, C. Sharma, A.P. Mitra, S.K. Singh, P.K. Gupta (2011), “Assessment of trace gases, carbon and nitrogen emission from field burning of agricultural residues in India”, Nutrient Cycling in Agroecosystems, (2011)89. pp143-157
55. Singh, S.K. and Mahour, M. (2010), “Methane Estimation from Landfill Site”, Chapter-2, In: Solid Waste Management : Present and Future Challenges”, I.K. International Pvt.Ltd., Delhi, India.

56. Singh, S.K., and Mahour, M. (2010), Clean Development Mechanism : An Opportunity in Solid Waste Perspective, Chapter-18, I.K. International Pvt. Ltd., Delhi, India.
57. Vijender Kumar Malik, Ram Karan Singh and S. K. Singh (2010), "Impact of urbanization on ground water of Gurgaon District, Haryana, India", International Journal of rural Development and Management Studies, Vol 5, No 1.
58. Janhavi Inamdar and S. K. Singh,"Treatment of methylene blue dye solution with solar photo-catalytic detoxification and study of kinetic model", accepted for publication in Asian Journal of Water, Environment and Pollution.
59. Shivraj Sahai, C. Sharma, S. K. Singh and P.K. Gupta (2010), "Ambient Carbon monoxide during winter and summer agricultural burning seasons in rural northern India", Asian Journal of Water Environment and Pollution , Vol. 7 ,No. 4. pp 99-104
60. Shivraj Sahai, C. Sharma, C.K. Dixit, D.P. Singh, Meena Sahai, Nahar Singh, P. Sharma, K. Singh, S. Bhatt, Raj K. Gupta, A.P. Mitra, S. K. Singh and P.K. Gupta, "Trace gases, carbon and particulate matter emissions from in-situ open burning of rice crop residues in India", Revision submitted to Atmospheric Environment.
61. Vijender Kumar Malik, Ram Karan Singh and S. K. Singh (2010), Impact of climate change on water Resources: A review on Global Perspective", Indian Journal of Development Research and Soicial Action, Volume 6, Number 1,
62. Janhavi Inamdar and S. K. Singh, "Design and optimization of Textile effluent treatment with solar photocatalytic Detoxification", communicated to International Journal, Energy and Environment.
63. Janhavi Inamdar and S. K. Singh, "A Novel Solar Flat Plate Reactor combining both the Solar Detoxification and Solar Distillation Technologies", communicated to Environmental Pollution Control Journal.
64. Janhavi Inamdar and S. K. Singh, (2009), "Photocatalytic Degradation and Recycling of wastewater for Paper & Pulp Industry with the help of TiO2 photocatalyst", presented as oral presentation at International Conference on Changing Environmental Trends and sustainable Development 2009 at GJUST, Hisar, on February 9-11, 2009.
65. S.K. Singh and M. Mahour (2009), "Methane estimation from landfill sites", Solid waste management: present and future challenges, IK international, Delhi
66. Janhavi Inamdar and S. K. Singh, (2009), "Zero Effluent Discharge with Solar Photocatalytic Detoxification in Dairy Industry by optimizing operational parameters",

presented as oral presentation at International Conference on Energy and Environment at National Institute of Technology, Kurukshetra, on 19- 21, March 2009.

67. R. K. Singh and S. K. Singh (2009), "State of the Art and future threats- Nitrate pollution management", Solid waste management: present and future challenges, IK international, Delhi.
68. S. K. Singh and M. Mahour (2009), "Clean development mechanism- An opportunity in solid waste management", Solid waste management: present and future challenges, IK international, Delhi.
69. Janhavi Inamdar and S. K. Singh (2009), "Zero Effluent Discharge by use of Solar Detoxification at household level", International Journal 'Journal of Environmental Research and Development', Vol.3, No. 3, January-March, 744-755.
70. Bharat Jhamnani and SK Singh, (2009) "Migration of Organic Contaminants from landfills: Minimum Thickness of Liners" The Open Environmental Pollution and Toxicology Journal, Vol.2.
71. Bharat Jhamnani and SK Singh, (2009) "Evaluation of Organoclays for use in Landfill Liners" The Open Waste Management Journal, Vol.2.
72. Bharat Jhamnani and SK Singh, (2009) "Chloride Transport from Landfills", Journal of Institution of Public Health Engineers of India, Vol. 2.
73. Shivraj Sahai, S. K. Singh and P.K. Gupta (2008), Adopting a life-cycle approach in vehicular pollution, Proceeding of National Seminar on Vehicular Pollution in Delhi after the Court's Direction: An assessment, 34-47, February.
74. Janhavi Inamdar and S. K. Singh, (2008), "Zero Effluent Discharge by use of Solar Detoxification at household level", presented as oral presentation at International Conference International Congress of chemistry and Environment 2008 (ICER 2008) at BITS Goa Campus, on 18-20 Dec 2008.
75. Janhavi Inamdar and S. K. Singh, (2008), "Techno-Economic analysis of Zero Effluent Discharge by use of Solar Detoxification at household level", International Journal of Natural Sciences and Engineering, Vol. 1, No. 4. pp. 208-211.
76. Janhavi Inamdar and S. K. Singh, (2008), "Photo catalytic Detoxification method for Zero Effluent Discharge in Dairy Industry: Effect of operational parameters", International Journal of Chemical and Bimolecular Engineering, Vol. 1, No.4, pp. 160-164.

77. Janhavi Inamdar and S. K. Singh, “Performance analysis of Activated Sludge Process for waste water treatment and its comparison with Fixed Film Bioreactor”, communicated to Journal of Environmental Science and Engineering.
78. Singh S.K and Jhamnani B. (2007), “Ground water Modeling – Trends and Practices”; Journal of American Society of Civil Engineers-IS, Vol- 4, No. 1, 2007.
79. Jhamnani B & Singh S.K, (2007) “Solid Waste Management by Land filling in new Urban Growth Centres”, National Seminar on “Integrated Development of Towns as new growth Centers”, Indian Buildings Congress, 17-19 May.
80. Bharat Jhamnani & SK Singh, “Improved Landfill Liner for Metal Attenuation in Coastal Region”, International Conference on “Coastal Zone Environment and Sustainable Development Vulnerability, Adaptation and Beyond”, Ses, Jnu, 12-14 Feb.
81. Bharat Jhamnani & SK Singh, (2007) “Solid Waste Management by Land filling in New Urban Growth Centres”, Journal of Indian Buildings Congress, Journal of Indian Buildings Congress, Volume 14, No.1.
82. Bharat Jhamnani & SK Singh, (2007) ‘Landfill Liners – use of Geosynthetics’, National Conference on ‘Civil Engineering: Advancement And Challenges’, Maharishi Markandeshwar Engineering College, Ambala, Mar 9-10
83. Bharat Jhamnani & SK Singh, (2007) ‘Landfill Gas (LFG) : Composition and Reuse’, Society, Sustainability and Environment, Shivalik Prakashan, Delhi
84. Bharat Jhamnani & SK Singh, (2007) ‘Biofilters for Landfill Covers in Delhi’, National Conference on ‘Environmental Pollution and Health – Problems and Solutions’, International development centre Foundation, Delhi, 19-20 April
85. Singh R K, Singh S.K. and Nanda Satyajeet, (2006) “Water Infiltration Model for Safe Fly ash disposal in the compound of IB Thermal Power Plant, Orissa, India.”, Proceedings of the Second International Conference on Ground Water for Sustainable Development: Problems, Perspectives and Challenges (IGC-2006), New Delhi.
86. Jhamnani B & Singh S.K., (2006) ‘Sustainable Buildings – Road to Future’, Proceedings of Seminar on Green Building, Indian Buildings Congress, Raipur, 15-17 Dec.
87. Janhavi Inamdar and S.K.Singh,(2006),“Wastewater disinfection and recycling at house hold level using solardetoxification”, Proceedings of the 1st NationalConference on Advances in EnergyResearch at IIT Mumbai on 4th and 5th Dec 2006, pp. 201-204.

88. Kumar, Mukul, Singh S.K. and Mohan, S. (2004) "Analysis of noise pollution on signalised intersection in Delhi " Joun. Of Indian Association of Environmental Health, Nagpur; Journal of IAEM, Vol 31 , pp 124-131.
89. Janhavi Inamdar and S. K. Singh, (2004), "Treatment of Industrial Effluents by Solar Detoxification", Journal of Acta Ecologica, Vol. 6, No. 2, pp. 71-78.
90. Janhavi Inamdar and S. K. Singh, (2004), "Solar Energy Aided Treatment of Waste Water", Proceedings of National Conference on 'Scientific Solutions for Waste Management & Pollution Control' at Samrat Ashok Technological Institute, Vidisha (MP) on 4th October 2004, pp. 105-108.
91. Singh S.K. (2003) "Policy and investment in water supply and urban sector in India." Proc. National workshop on fresh water related issue, JNU Delhi, March 31- April 2.
92. Singh S.K., Sooch Sarabjit Singh and Grewal N.S., (2002) " Biogas: an ideal fuel for rural people" Proc. National Seminar on trends for development of regional areas of the country with Limited resources, Dwarahat (Almora), Apri 28-29.
93. Singh S.K., (2002) "Water Pollution due to disposal of Industrial Effluent in the vicinity of Copper and Fertilizer Complex", Proc. National Workshop on Water Quality, 1-2 Jan, New Delhi.
94. Singh S.K. and Gupta Arun Kumar, (2002) " Arsenic Contamination in Water and its Control", Proc. National Workshop on Water Quality, 1-2, Jan, New Delhi.
95. Rajola, V., Singh S.K. and Kanan,G.K. (2002) " Status of air quality in Delhi based on air quality index : criteria for review of existing standards " Journal. Of Environmental Protection, Vol 22, No. 12.
96. Khan Sarvar, Singh S.K. and Brar S.K., (2002) "Studies on phytoremediation of soil contaminatedwith nitro compounds". Proc. International Conference on water and waste water: Perspectives of Developing countries (WAPDEC), New Delhi, India, Dec. 11,12 &13.
97. Brehm, J.W., 1966. A Theory of Psychological Reactance. Academic Press, New York.
98. Button, K.J., 1982. Transport Economics. Heinemann, London.
99. Altinoz, C. & Winchester, S.C. (2001). A Fuzzy Approach to Supplier Selection. Journal of Textile Institute 92(2),
100. Bashiri, M. & Badri, H. (2011), A group decision making procedure for fuzzy interactive linear assignment programming, Expert Syst.

101. Chang, C.-L. (2010), A modified vikor method for multiple criteria analysis, Environmental Monitoring and Assessment,
102. Chen, C.-T. (2000), Extensions of the topsis for group decision-making under fuzzy environment, Fuzzy Sets and Systems
103. Ghodsypour, S. & OBrien, C. (1998), A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming, International Journal of Production Economics
104. Huang, J.J., Tzeng, G.H., & Liu, H.H. (2009), A Revised VIKOR Model for Multiple Criteria Decision Making - The Perspective of Regret Theory, in Y. Shi et al. (Eds.) MCDM 2009,Communications in Computer and Information Science 35(1), Springer-Verlag
105. Berlin Heidelberg. Kubat, C., & Yuce, B. (2006), Supplier Selection with Genetic Algorithm and Fuzzy AHP,
106. Proceedings of 5th International Symposium on Intelligent Manufacturing Systems, May 29–31
107. Kumar, M., Vrat, P. & Shankar, R. (2004), A fuzzy goal programming approach for vendor selection problem in a supply chain, Comput. Ind. Eng. 46(1)
108. Kuo, M.-S. & Liang, G.-S. (2011), Combining vikor with gra techniques to evaluate service quality of airports under fuzzy environment, Expert Syst. Appl. 38(3)
109. Moeinzadeh, P. & Hajfathaliha, A. (2010), A combined fuzzy decision making approach to supply chain risk assessment, International Journal of Human and Social Sciences
110. Opricovic, S. (1998), Multi-criteria optimization of civil engineering systems, Faculty of Civil Engineering, Belgrade.
111. Opricovic, S. & Tzeng, G.-H. (2004), Compromise solution by mcdm methods: A comparative analysis of vikor and topsis, European Journal of Operational Research 156(2)
112. Opricovic, S. & Tzeng, G.-H. (2007), Extended vikor method in comparison with outranking methods, European Journal of Operational Research 178(2)
113. S.K. Singh, Vishakha Kaushik, Shivani Soni, Nisha Lamba , (2014), " Waste Management in Restaurants : A Review", International Journal of Emerging Engineering Research and Technology , Volume. 2, Issue 2, May 2014, PP 14-24
114. Shishir Bansal, S.K. Singh, (2014), "Sustainable Construction of Grade Separators at Mukarba Chowk and Elevated Road corridor at Barapulla, Delhi", International journal of Advance Research and Innovation, Volume 1, Mar- 2014, PP 194-203

115. Abhas Jain, S.K. Singh, (2014), "Defluoridation of Water Using Alum Impregnated Brick Powder And Its Comparison with Brick Powder", International Journal of Engineering Science and Innovative Technology (IJESIT), Vol.3, Issue2, July, 2014.
116. Sakshi Garg, S.K. Singh, (2014), "Performance Evaluation of Common Effluent Treatment Plant of Wazirpur, New Delhi", International Conference of Advance Research and Innovation, Delhi, 2014
117. Park, J. H., Cho, H. J. & Kwun, Y. C. (2011), Extension of the vikor method for group decision making with interval-valued intuitionistic fuzzy information, Fuzzy Optimization and Decision Making 10(3).
118. Roodhooft, F. & Konings, J. (1997), Vendor selection and evaluation an activity based costing approach, European Journal of Operational Research 96(1)
119. Saghafian, S. & Hejazi, S. R. (2005), Multi-criteria group decision making using a modified fuzzy topsis procedure, in Proceedings of the International Conference on Computational Intelligence for Modelling, Control and Automation and International Conference on Intelligent Agents, Web Technologies and Internet Commerce Vol-2 (CIMCA-IAWTIC06) Volume 02, CIMCA 05, IEEE Computer Society, Washington, DC, USA, 215–221.
120. Sanayei, A., Farid Mousavi, S. & Yazdankhah, A. (2010), Group decision making process for supplier selection with vikor under fuzzy environment, Expert Systems with Applications
121. Sanayei, A., Mousavi, S. F., Abdi, M. & Mohaghar, A. (2008), An integrated group decisionmaking process for supplier selection and order allocation using multi-attribute utility theory and linear programming, Journal of the Franklin Institute.