APPLICATION OF FUZZY TECHNIQUE FOR SUSTAINABILITY EVALUATION OF TRANSPORTATION CORRIDORS DURING CONSTRUCTION

DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

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IN

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SUBMITTED BY:

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2K12/ENE/012

UNDER THE SUPERVISION OF:

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MASTER OF TECHNOLOGY
IN
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Dedicated to my mentor…

DELHI TECHNOLOGICAL UNIVERSITY

DELHI

Certificate

This is to certify that the thesis entitled," **Application of Fuzzy technique for Sustainability evaluation of transportation corridors during construction** " submitted by Mr. SAMEER VERMA 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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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 3.2 Kms long elevated road project under construction from Vikaspuri to Meerabagh in West Delhi by PWD and Metro rail elevated corridor (part) from Punjabi Bagh to Mayapuri as a part of phase 3, line 7 by DMRC. 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 (of PWD and DMRC), during construction under identical urban environment, was conveyed 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

Identified as a global priority in the early 1980s, the concept of sustainable development is most commonly defined as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987)". This concept has permeated many areas of engineering, including transportation systems engineering.

While there is no standard definition of sustainable transportation, sustainability is largely captured in terms of transportation system effectiveness and system impact on economic productivity, environmental integrity, and the social quality of life (Jeon and Amekudzi 2005). In fact, the three factors are commonly considered the essential dimensions of a sustainable transportation system (See Figure 1).

Figure 1 Three essential factors of transportation system sustainability

This Research work starts out by characterizing the emergent thinking on what constitutes sustainability of transportation infrastructure during construction and how to attain it. Then, the study identifies some of the major transportation system sustainability issues during construction in Metropolitician cities like Delhi. 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 3.2 Kms long elevated road project under construction from **Vikaspuri to Meerabagh in West Delhi by PWD** and **Metro rail elevated corridor (part) from Punjabi Bagh to Mayapuri as a part of phase 3, line 7 by DMRC**. 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*. Finally, the study focuses on demonstrating a comparison between the above mentioned two sites under construction, by two government organizations, i.e. PWD and DMRC, under identical urban environment, using the Fuzzy logic methodology for evaluating sustainability based on identified sustainability indicators using data furnished by conducting surveys (questionnaire pro forma) from the experts and public (residents/commuters).

This chapter provides background information about the research, including the motivation for this research and its significance, as well as the problem statement. The objectives, approach, and scope of the research are then defined. An outline of the thesis follows, providing a synopsis of the research.

1.1 MOTIVATION

New Delhi, the Capital city of India has been facing a phenomenal growth of vehicular traffic without the proportionate growth of infrastructure. It resulted in all sorts of traffic congestions, increase in pollution level, exponential rise in travelling time, the increase in stress level, etc. etc. The traffic flow system of Delhi is a Ring-Radial pattern with two concentric Roads popularly known as Ring Road and Outer Ring Road which are the lifelines for citizens of Delhi.

Delhi has the most extensive road network in India - 21% of its geographical area are just motorways. Yet, there is not enough space for the traffic. Delhi had just five flyovers at the end of Asian Games it hosted in 1982. Today, the number has increased to 94. In the last three decades, Delhi's vehicle stock has increased 51 times. 10% of the country's vehicles are registered in Delhi. 17% of country's all private vehicles run on Delhi's roads. The number of vehicles is growing at 10% every year. According to a Centre for Science and Environment projection, the day trips are expected to explode from 15 million today to 25 million in 2020. The road spaces have been increased to decongest the existing traffic. But new roads end up attracting more traffic, which is explained as the "induced traffic" phenomenon. The studies on traffic concluded that half of the increased roadway capacity is consumed by adding traffic in about five years, 80 % of increased capacity is eventually consumed by induced traffic. In fact in many cities in the West and also in the US, dismantling of flyovers and expressways is taking place. Delhi may not need to take such extreme steps yet, but soon it will be impossible to keep adding to infrastructure beyond its physical limits. A more sustainable solution to Delhi's infrastructure problems must be assessed. Highways have a large negative impact on surrounding ecosystems and overall environmental quality. **The next step in transportation infrastructure's advancement needs to include practices that reduce the effect on the natural environment, increase capacity, and benefit society which can be achieved by instituting a system of Sustainable transportation infrastructure**.

In order to accommodate the number of vehicles on the road, corridor development, which includes the design, construction, maintenance, and operation of a road, must not only satisfy the needs of the public, but also adapt to the needs of the environment. Sustainable principles serve as a mechanism to accommodate mobility while recognizing the challenges of the environment. A defined methodology for applying Sustainable principles to transportation investments, particularly corridor development, is needed in order to reduce environmental impacts and promote sustainability.

Sustainable transportation development standards are lagging significantly 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 (Michelle Renee Oswald, 2008).**

This statement very well describes that the sustainability plays a vital role in a fast developing urban environment with lots of infrastructure projects going on. These projects don't only have to cater to the needs of the public, but methodologies adopted for fulfilling those needs have to be green in nature. Considering the need of green development various standards such as LEED , GRIHA etc. have been developed for green building certification but there is no accepted method for evaluating sustainable transportation projects. In this fast growing economy and the world facing severe environmental issues a defined sustainable transportation evaluation method is needed in order to meet the much required green standard for transportation corridor development.

1.2 PROBLEM STATEMENT

Today, the worldwide need for sustainable development is ensured and accordingly it is essential that every activity we perform for the development of society should be sustainable. On reviewing, the sustainability parameters widely accepted are environmental issues, social factors and economics. But these 3 factors are limited to developing countries where the need for sustainable development has been forecast. When we see the current development scenario in New Delhi or any other urban city in India, we observe that the world wide acceptance of these three parameters cannot fulfil the requirement in India.

It is observed that construction of transportation corridors in urban areas like Delhi is executed by Construction Agencies in a very shabby manner. Agencies are least sensitive towards the pollutants being discharged to the environment, maintenance of amenities in the project area and comforts of residents as well as the traffic passing through the project area. Even the concerned authorities are not making their necessary efforts in implementation of various measures envisaged in the agreement. As a result of indifferent attitude, the comfort of local people as well as people moving through the corridors is badly affected.

Considering the need of green development various standards such as LEED , GRIHA etc. have been developed for green building certification but there is no accepted method for evaluating sustainable transportation projects.

A greater part of environmental problems originate from the internal operating mechanism of cities, and have their local impact, as air pollution, congestionand noise pollution. However, many efects also exist that have a transborder nature, for example waste water flow, waste disposal, or even a global one, through contribution of trafic and heating emissions to greenhouse efect and global warming.

In order to address the issues a study has been decided to be carried out to appreciate the issues apart from the construction activities and the impact of such activities on the environment and society at this stage.

1.3 OBJECTIVES OF STUDY

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 (Jeon, Amekudzi et al. 2006).The criterion for evaluating Sustainability of transportation infrastructure has nowhere been defined and requires lots of research work. Sustainability indicators have to be identified by visiting on-going project sites and interaction with all major stakeholders in this field and with required standards incorporated into the materials and technologies to be deployed during the construction of the transportation corridor. Also, it is necessary to develop a dynamic system which is flexible to incorporate future technologies. Considering the need of the day for a sustainable future without compromising to the ability of the younger generation to fulfil their own needs, research work will be carried out with following broad objectives.

1. Identification of Sustainability Indicators as applicable to the transportation infrastructure projects during construction in a Metropolitan city like Delhi
2. To develop a methodology for Sustainability Evaluation
3. Application of a model based on fuzzy for evaluating sustainability of construction sites under consideration as a case study

4. To implement suitable Sustainability indicators during construction of a transportation infrastructure.

1.4 OVERVIEW OF APPROACH

This research is based on identifying sustainability indicators of transportation corridor during construction and indicators are then applied to existing model to evaluate sustainability of the two sites under study. In order to identify sustainability indicators, it was necessary to understand basic sustainability concepts, the purpose of sustainable transportation, and to determine sustainability programs and frameworks already established. Therefore, the methodology for evaluating sustainability draws on sustainability concepts illustrated in the literature review (Chapter 2). These concepts are then applied to the established model for evaluating sustainability in the Results and Discussion section (Chapter 6), based on what constitutes a sustainable transportation corridor. An evaluation was done through a case study application in order to determine its suitability and applicability to corridor projects under construction.

The sustainability indicators are identified and sustainability evaluation of the sites is conducted using the following approach:

• Review information on sustainability concepts and issues, transportation impacts, and sustainable transportation applications during construction

• Review existing sustainable implementation frameworks and sustainability evaluation models

• Identification of Sustainability Indicators as applicable to the transportation infrastructure projects during construction in a Metropolitan city like Delhi

-Select the sites under identical urban environment

- Visit the sites and take photographs of the various noticeable sustainability issues

- Study the phographs and note the issues which will serve as indicators

- Identify indicators by observation or expert comments

- Develop sustainable indicator categories

- Develop sustainable indicators

- Develop a proforma with sustainability indicators along with columns for quantitative and qualitative rating
- Assign quantatitative and qualitative rating to each identified indicators on proforma by experts reviews and opinion

• Define a methodology for evaluating the sustainability and apply to the existing model

- Define methodology and determine the existing model for sustainability evaluation
- Understanding Fuzzy logic and Fuzzy set theories and its application
- Determine indicator scale in order to transform indicators into weightage
- Assign membership functions to the qualitative ratings using fuzzy logic
- Develop a triangular fuzzy of qualitative ratings using MATLAB.
- Weightage assigned to the indicators by furnishing data via proforma from experts
- Rate identified sustainability indicators of the alternatives (PWD and DMRC) by furnishing data via surveys from the commuters/ residents at the sites and its neighbourhood

• Evaluate the sustainability of the sites based on identified sustainability indicators using chosen model.

1.5 SCOPE OF WORK

With the growing demand for infrastructure development of society, the time has gone when construction on the urban environment were taken up without consideration of its adverse impact on society. Today, the worldwide need for sustainable development is ensured and accordingly it is essential that every activity we perform for the development of society should be sustainable. On reviewing, the sustainability parameters widely accepted are environmental issues, social factors and economics. But these 3 factors are limited to developing countries where the need for sustainable development has been forecast. When we see the current development scenario in New Delhi or any other urban city in India, we observe that the world wide acceptance of these three parameters cannot fulfil the requirement in India. Three more parameters and its sub categorization have been defined for sustainable development to be ensured. It has already been mentioned in the problem Statement that the provision for comforts of residents, traffic, users as well as environment protection is there in the agreement but not implemented in true spirit. Hence governance has been ensured for sustainability.

It is observed that Delhi is growing fast with Hi-tech projects and implementation of technologies well tested in developed countries. Still big gap is observed while implementing the technology and making it implementable under the circumstances dominated in an urban environment. For e.g. in the corridor from Vikas Puri to Meera Bagh, it is observed that the shift of centeral verge to the center line at right of way caused the uprooting of the additional 450 trees and width of slip roads is getting reduced because of issues taken up by National Green Tribunal at later stage. There is a need of a strong technological base while taking a final decision on technological issues. Accordingly, 5^{th} parameter titled as "Technologies Issues" has been included for sustainable transportation during construction as an important parameter. Further, it was observed that during construction when the site was already much occupied, there was an unauthorized parking which further adds to the congestion. Lot of honking, ingress of vehicles in an unruly manner takes place and no traffic marshals were present to handle the situation. Accordingly, the fourth parameter, i.e. Governance was included and its importance for sustainable development is to be considered seriously. Further, the rude and annoyed behaviour was stated on the corridor when drivers have to negotiate in limited when under a time frame so as to reach the destination at a targeted time. Lot of honking, ingress of vehicles in an unruly manner takes place, resulting in congestion and lots of patience in order to maintain a cool temperament, it is essential that all stakeholders like construction agencies, workers, owners and residents to attain a sense of spirituality so as to maintain a cool behaviour and to reduce negative impacts of miss happenings in such a situation. May be this factor does not pay big role, but this cannot be ignored to maintain the temperament in such a situation. Accordingly, this parameter, i.e. spirituality is included which is very well required to be maintained.

1.6 OUTLINE OF THE THESIS

This thesis documents the research behind identifying sustainability indicators and evaluating sustainability of transportation corridor during construction in an urban environment in the following chapters:

• Chapter 2 focuses on a literature review and work that had been done by different authors in the context of sustainability and sustainable development of transportation corridors.

• Chapter 3 defines sustainability and its relationship to transportation systems based on a literature review. The impacts of transportation sustainability and the use of indicators to quantify sustainability are described.

• Chapter 4 describes fuzzy logic, explains the concepts of fuzzy logic and fuzzy sets and its application for sustainability evaluation of the transportation corridor project.

• Chapter 5 explains the methodology and numerical application of the Fuzzy VIKOR method for evaluating sustainability of the two transportation corridors under construction and its results are discussed.

• Chapter 6 provides recommendations and conclusions about Sustainability of transportation corridors in an urban environment as well as future work to be completed.

CHAPTER 2

LITERATURE REVIEW

Various approaches have been proposed to evaluate sustainable transport systems. Following the classification recently proposed, they are divided in eight categories (Awasthi A et al., 2011):

1. **Life-cycle analysis (LCA)** combines pollution emissions and resources used during the life course of a product in order to calculate some criteria. Originally developed for industrial processes, LCA has limited application in the context of transport systems, since it does not take social aspects into account.
2. **Cost-Benefit Analysis (CBA)** examines the monetary equivalent of all the positive and negative effects of a project alternative, with the aim of minimizing the costs related to that alternative. When it is not possible to calculate the monetary value of the advantages or when the realization degree of the result to reach is given, cost effectiveness analysis (CEA) is used. The main difficulty of CBA or CEA concerns the monetary quantification of external and social costs.
3. **Deeper analysis of project alternatives** can involve Environmental Impact Assessment (EIA).
4. **Optimisation models**, applied in the context of sustainable transport, aim at optimal solutions under the specified constraints of social, economic and environmental objectives.
5. In the case of complex systems, **System Dynamics Models** are useful to describe the relationships between the elements of the system by examining time-varying flows and feedback mechanisms.
6. **Assessment indicator models** define indicators which evaluate the sustainability of a practice or a project. Tao and Hung identified three types of models: composite index, multi-level index and multi-dimension matrix models. Composite index models generate a single index, such as the ecological footprint or the green gross national product. However, evaluation is generally so complex that it requires examination of a series of indicators

representing various goals organised in hierarchies (multi-level index models) or related through complex interactions (multi-dimensional matrix models).

7. **The Data Analysis approach** uses statistical techniques, such as hypothesis testing or structural equation modeling, to evaluate sustainability.
8. **Multi-Criteria Decision Analysis (MCDA) methods** represent an ample set of methods, including the well-known Multi-Attribute Utility Function Theory (MAUT), Analytic Hierarchy Process (AHP) and ELECTRE methods. Multi-Criteria Decision Analysis evaluates the alternatives to each criterion and collects criterion outcomes in a decision table (or decision matrix). Alternatives are ranked and the "best" solution on the criteria set is found. As there is generally no alternative which optimizes all the criteria at the same time, the methods find a compromise solution. MCDA methods are probably the most common approach used for sustainability evaluation in the transport field.

Further, in the paper by Anjali Awasthi et al., (2013) four multi-criteria decision making (MCDM) techniques, namely TOPSIS, VIKOR, SAW and GRA have been investigated for sustainability evaluation of urban mobility projects under qualitative data and demonstrated their application through a numerical example. Fuzzy sets and systems theory can be an effective tool to deal with conditions and assess the sustainability of a given action plan, since it can formalize situations characterised by: – non-homogeneous variables or quantities;

– Uncertain and imprecise information on the system (present and future), in particular when judgments expressed by experts are included in the evaluation;

– Interrelations among the dimensions of sustainability, which tend to induce ”overlaps” (”fuzzy” boundaries).

In this paper a Fuzzy-Based Evaluation Method (F-BEM which formalizes the three-dimensional concept of sustainability, is tested on a case study to evaluate its usefulness as a tool to interpret the preferences expressed by the decision makers, to identify the most important characteristics of alternative transportation policies and to support the design of hypothetical transportation services (”What to” analysis).

Riccardo Rossi et al., (2012) in their paper supported Fuzzy-Based Evaluation Method (F-BEM) as a useful tool for evaluating the sustainability of alternative transport policies. The structure of the method formalizes the concept of the "three pillars of sustainability" by means of a set of indicators as input variables. The method determines an overall fuzzy index of the sustainability of each alternative policy analysed and provides information about the combined dimensions of sustainability (equity, viability and bearableness).

Stuart Samberg et al.,(2011) in the paper mentioned that a crucial element of sustainability is the optimization of system efficiency by the maximization of existing resources and the limitation of the necessity of infrastructure expansion. This paper reviews the literature on operational and proposed evaluation strategies for transportation projects and proposes a sustainable transportation evaluation method. The sustainable transportation evaluation method builds on the observed beneficial qualities of the existing evaluation systems and attempts to address their shortcomings. Implementation of the sustainable transportation evaluation method relies on established multi-criterion techniques that allow for quantitative and qualitative evaluation of the sustainability of transportation projects during the planning, design, and construction phases

In a dissertation presented to the academic faculty by Christy Mihyeon Jeon for the Ph.D. Degree in the School of Civil and Environmental Engineering, Georgia Institute of Technology, December 2007, definitions, performance measures, and evaluation methodologies for transportation system sustainability have been reviewed and a framework for incorporating sustainability considerations in transportation planning and decision making has been demonstrated. The study starts out by characterizing the emergent thinking on what constitutes transportation sustainability and how to measure it. Then, the study identifies some of the major transportation system sustainability issues in different countries depending on prevailing socioeconomic conditions. Finally, the study focuses on demonstrating a feasible methodology for incorporating sustainability considerations into the planning process using data from the metropolitan Atlanta region.

Todd Litman **(2009) In a recommended research program for developing sustainable transportation indicators and data** , mentioned that the Planning activities rely on indicators (standardized information suitable for analysis) for guidance, just as people rely on senses such as sight, hearing and touch. Indicators let us analyse trends and model impacts. Which indicators are selected and how data are collected and analysed is important. An option may seem to be appropriate and desirable if evaluated by one set of indicators, but unsustainable if evaluated by others. Indicators are important tools for making decisions and measuring progress. Decision-making increasingly incorporates sustainability concepts, such as consideration of long-term economic, social and environmental impacts. As a result, there is growing demand for suitable planning tools, such as sustainable transportation indicators. Such indicators help determine how individual, short-term decisions affect long-term, strategic goals. Such indicators must be carefully selected to reflect diverse impacts and perspectives, while being feasible to collect and analyse.

According to Steg Linda, (2005) et al in their paper**,** it is generally accepted that sustainable transport implies balancing current and future economic, social and environmental qualities. *A key set of sustainable transport indicators has not yet been identified.* The negative environmental, social and economic externalities outweigh the social and economic values of transport. In this paper, the positive and negative values and the externalities of current transport systems are examined, such as energy and land use, waste, traffic safety, traffic noise, health consequences, accident costs, accessibility and economic wealth. Sustainability indicators are defined and operationalized as sustainable transport policy goals, and whether the transport system is moving towards sustainability is monitored. This implies a need to consider a broader range of sustainability indicators, because changes in current transport systems may affect other sectors that also contribute to unsustainable development. Various methods and models have been developed to assess economic, social and environmental consequences of transportation plans. However, only a few social indicators are considered because of the lack of knowledge and valid methods, tools and techniques for assessing relevant social impacts. Adequate transport systems can only be obtained by use of a new sustainable transportation paradigm and accompanying analytical framework. Therefore, this thesis has presented a theoretical framework, together with a methodology to better incorporate the requirements of sustainable development into models for transport policy and planning, in particular travel demand models. With the knowledge and outcomes presented in this thesis, it should become possible to make more effective and efficient use of available and affordable scarce resources for enhancing transport system performance.

In the years since the National Environmental Policy Act was signed into law in 1970, the range of concerns about the relationship between the highway and its associated effects on the surrounding environment has expanded. The document entitled Illinois Livable and Sustainable Transportation (I-LAST) Rating System and Guide and is a sustainability performance metric system developed by the Joint Sustainability Group of the Illinois Department of Transportation (IDOT), the American Council of Engineering Companies–Illinois (ACEC-Illinois) and the Illinois Road and Transportation Builders Association (IRTBA). The approach of sustainability and I-LAST is to incorporate a broader range of issues into the development and completion of state highway projects.

The purpose of this guide is threefold:

- Provide a comprehensive list of practices that have the potential to bring sustainable results to highway projects.
- Establish a simple and efficient method of evaluating transportation projects with respect to livability, sustainability, and effect on the natural environment.
- Record and recognize the use of sustainable practices in the transportation industry.

According to the document titled “Multi-criteria Sustainability Evaluation of Transport Networks for Selected European Countries”, transportation has complex interactions with the environment and society as an essential economic activity. Since the concept of sustainable development has become one of the top priorities for nations, there has been a growing interest in evaluating the performance of transport systems with respect to sustainability issues. The main purpose of this study is to introduce a decision making framework to assess the sustainability of the transport networks in a multidimensional setting and a technique to identify non-compromise alternatives. We also propose an elucidation technique to identify according to which criteria a system needs to be improved and how much improvement is required to attain a certain level of sustainability. The proposed methods are applied to a set of selected European countries within a case study.

CHAPTER 3

SUSTAINABILITY CONCEPTS

This chapter defines sustainability and its relationship to transportation systems based on a literature review. The impacts of transportation investments and the use of indicators to quantify sustainability are described.

3.1 What is Sustainability?

3.1.1 Definition of Sustainability

The most widely accepted definition of sustainability comes from the United Nations, Bruntland Commission in 1987. The commission defines sustainability as **"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 highway projects are to:

- Minimize impacts to environmental resources
- Minimize consumption of material resources
- Minimize energy consumption
- Preserve or enhance the historic, scenic and aesthetic context of a highway project
- Integrate highway projects 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 into a highway project
- Find a balance between what is important:
  - ✓ to the transportation function of the facility
  - ✓ to the community
  - ✓ to the natural environment, and
  - ✓ is economically sound

- Encourage the use of new and innovative approaches in achieving these goals.

3.1.2 Triple Bottom Line

The concept of sustainability many times is narrowly viewed from an ecological perspective, focusing on issues such as pollution and resource depletion (Litman and Burwell, 2006). A more useful approach is to look at sustainability in the context of the triple bottom line approach, also referred to as the three pillar approach, which requires an integrated view of environmental, social, and economic issues (Belka, 2005). The easiest way to visualize the triple bottom line approach to sustainability is through a Venn-diagram format where each circle represents the environment, economic, and social perspectives. Figure represents sustainability in terms of the triple bottom line showing the context for specific sustainability issues.

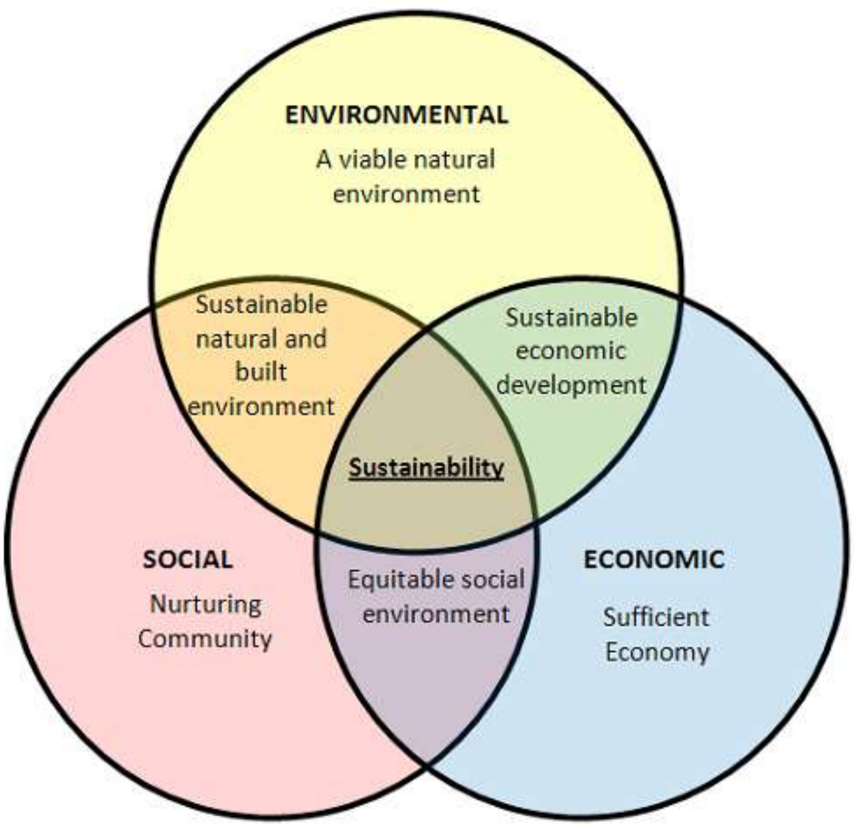

Figure 2 -Triple Bottom Line Approach (source data from CIRIA, 2008)

This multidimensional view illustrates that sustainability issues are interrelated and are each fundamental to achieving sustainability that addresses “people, planet, and prosperity” (Doughty and Hammond, 2004).

Within the triple bottom line perspective, each issue is associated with individual criteria that help to define the economic, social, and environmental implications. For instance, the economic issue relates to employment, trade, and business activity. The social issue relates to human health, public involvement, and community livability. The environmental issue refers to climate change, biodiversity, and emissions.

3.1.3 Sustainability issues at corridors under study

As per the triple Bottom line approach sustainability comprises all 3 elements, social, environmental and economical. While visiting the site and observing the sustainability issues, it was observed that the current situation demands beyond these 3 parameters to make up a sustainable corridor in real sense. So 3 more parameters were included, i.e. technical, governance and spirituality considering the demand of sustainable transportation corridor in an urban environment. The various issues identified are listed below:

1. Control of Air Pollution at site
2. Control on drainage system due to construction activities
3. Control of water logging during Monsoon/rains
4. Control of noise pollution due to construction activity during day
5. Control of noise pollution during night
6. Removal of trees/ depletion of Green Belt
7. Plantation scheme
8. Any other technique that is being used in site to make the project more green.
9. Increase in the stress level of commuters
10. Health of workers
11. Welfare activities for family of workers
12. Sanitation conditions
13. First Aid facility on site
14. Safety measures

15. Impact on Health of residents
16. Impact on safety of residents
17. Public conveniences in the project area
18. Increase in Travel time
19. Increase in travel cost
30. Disturbance to the business/Employment of nearby residents
31. Display of Project Details
32. Display of Mandatory, Informatory and Cautionary Signage
33. Traffic Diversions
34. Visibility and sight distance to moving traffic
35. Lighting of Construction site
36. Barricading the site
37. Aesthetics of Project
38. Handling of C & D Waste
39. Ensuring the mobility of Traffic in the project area
30. Effective Functioning of Traffic Marshalls
31. Unauthorized/Improper parking in Project area
32. Maintenance of existing drainage system
33. Maintenance of Barricades
34. Ensuring the SHE (safety, Health and Environment) at the site
35. Maintenance of existing utilities
36. Maintenance of existing greenery during construction
37. Facilities of Yoga/meditation
38. Performance of Rituals at site like Vishvakarma Puja, May Day
39. Celebration during Festivals at site

While classifying these issues it was observed that it will be unfair to limit to the 3 parameters, i.e. Social, Environmental and Economical for classification of parameters. One of the major setback observed was increase in an abnormal delay in travel time because of the impatient behaviour of travellers, mixing and messing of different categories of traffic vehicles, i.e. Buses, Cars, 3 wheelers, 2 wheelers, E-Rickshaws, Manual Rickshaws etc. but this issue cannot be classified in any of the above 3 parameters, i.e., Social, environmental and Economical. Hence the 4th parameter which is covered such issue is Governance. On talking to the office of Delhi Traffic Police on all the concerned areas, it was found that all such regularity parameters are there in their books but implementation is not there.

Further, in the corridor from Vikas Puri to Meera Bagh, it is observed that the width of slip roads is getting reduced because of issues taken up by National Green Tribunal. There is a need of a strong technological base while taking a final decision on technological issues. Accordingly, 5th parameter titled as “Technologies Issues” has been included for sustainable transportation during construction as an important parameter.

Lot of honking, ingress of vehicles in a unruly manner takes place, resulting in congestion and lots of patience in order to maintain a cool temperament, it is essential that all stakeholders like construction agencies, workers, owners and residents, etc. to attain a sense of spirituality so as to maintain a cool behaviour and to reduce negative impacts of miss happenings in such a situation. May be this factor does not pay big role, but this cannot be ignored to maintain the temperament in such a situation. Accordingly, this parameter, i.e. spirituality is included which is very well required to be maintained.

Figure 3: Improper, merging and porous barricades causing traffic congestion, Jam, more fuel consumption, CO_2 emission.

Figure 4: Damaged existing road , no proper drainage system

Figure 5: Misleading signboard, No informatory or Warning signboards

3.2 Measuring Sustainability

3.2.1 Sustainability Indicators

Due to the vast amount of information available regarding social, environmental, and economic issues in sustainable development, indicators are used to facilitate ordering this information. Indicators are described as an index or a "means devised to reduce a large quantity of data down to its simplest form, retaining the essential meaning for the questions that are being asked of the data" (Ott, 1978). The indicators provide orientation, or direction, for measuring sustainability amongst its many complexities (Bossel, 1999). In terms of sustainability, indicators simplify the process of answering the question of how to reduce human impact and protect future generations. Sustainable development indicators are a useful tool that can be used to promote sustainable techniques within the public and policy sectors (Mitchell, 1996). Therefore, sustainable transportation indicators are used as a way to quantify sustainability related to corridor development/redevelopment. When related to the transportation systems, sustainable development indicators must hold two distinct requirements (Bossel, 1999):

1. Provide information that paints a picture of the current state and the corresponding viability of the transportation system
2. Provide sufficient information about the transportation system's contribution to the performance of other systems that depend on them In addition to these requirements, "good" indicators separate out the policy aspects from their outcomes (Litman, 3008).

3.2.2 Methodology for Developing Indicators

Proper selection of effective indicators is fundamental to the success of an index or rating system. A general procedure must be followed when finding appropriate indicators. Bossel (1999) has developed four main steps for going from a total system to individual indicators and implementing them into the participatory process. The four main steps are (Bossel, 1999):

1. Understand, conceptually, the entire system
2. Identify representative indicators

3. Quantify basic orientor satisfaction

4. Conduct a participative process

The first step, understanding the total system, is fundamental to the viability of the orientors and indicators that will later be developed. The second step, identify the representative indicators, has its own sub-steps, which are discussed below. Within these sub-steps, representative indicators must be chosen from the vast number of potential candidates (Bossel, 1999). The third step requires a prioritization of the indicators in order to translate indicator information into orientor satisfaction. The final step requires input through external opinions in order to counterbalance the choices and decisions made by the person who developed the indicators. By having appropriate outside reviewers, a wide rangeof knowledge, experience, mental models, and social/environmental concerns can be brought forward (Bossel, 1999).

Mitchell (1996) has developed a methodology, specific to sustainable development, for finding appropriate indicators for the total system. The methodology is as follows:

1. Define the system objectives, specifying the purpose of the indicators and their user group

2. State what is known in terms of sustainable development by specifying sustainable development definitions and principles that can be applied

3. Define issues that are important on a local and global level

4. Match indicator properties to the types of users and objectives of the rating system

5. Evaluate indicators against desirable characteristics and rating system objectives

3.2.3 Sustainable Transportation Indicators

Sustainable transportation indicators are a combination of the aspects of a transportation system with the economic, environmental, and social issues of sustainability. Examples of potential indicators for sustainable transportation have been developed by Litman (2008) and organized based on the economic, social, environmental categories of sustainability. Economic indicators refer to a community's progress toward economic objectives including wealth, employment, productivity, social welfare, and increased income (Litman, 2008). Social indicators relate to human health, equity, community livability, community cohesion, cultural resources, and aesthetics (Litman, 2008).

Environmental indicators encompass impacts such as noise, air, water pollution, and depletion of nonrenewable resources, habitat fragmentation, hydrologic disruptions, heat island effects, wildlife deaths due to collision, and other land use effects (Litman, 2008). These example indicators refer to the entire transportation system and are simply representative of the types of indicators that can be measured within the transportation system.

CHAPTER 4

SUSTAINABILITY ASSESSMENT BASED ON FUZZY LOGIC

4.1 Fuzzy logic overview

Zadeh introduced Fuzzy logic as an expansion of the classical two-valued logic, in which a hypothesis is either true or false and an matter either belongs or does not belong to a set. He studied the concept of inexactness/vagueness by assuming that hypothesis and set memberships are true with degrees ranging from 0 (100% false) to 1 (100% true). This method can handle incomplete knowledge and inexact or vague data in an organised way. Fuzzy logic is often referred to as a way of "reasoning with uncertainty." It gives an explicit mechanism to deal with uncertain and incompletely defined data, so that precise deductions can be made from imprecise data. Fuzzy theory provides a system for depicting linguistic constructs such as "many," "low," "medium,""often," "few." In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities.

Fuzzy sets are commonly used to express the way humans extract qualitative information from numerical, categorical or linguistic data, and the way they rate, summarize, and process this information to make decisions and assessments. To this end, a fundamental concept of fuzzy logic is the notion of a linguistic variable introduced by Zadeh. Loosely speaking, a linguistic variable is a variable "whose values are words or sentences in a natural or artificial language," as Zadeh has put it. More precisely, a linguistic variable is a fuzzy partition of some physical domain X into possibly overlapping regions. Each region is represented by a fuzzy set in X called linguistic value.

Fuzzy logic is a scientific tool that permits modelling a system without detailed mathematical descriptions using qualitative as well as quantitative data. Computations are done with words, and the knowledge is represented by IFTHEN linguistic rules. A system based on fuzzy logic can be considered an expert system which emulates the decision-making ability of human experts. The user supplies facts or other information to the expert system and receives expert advice for his queries. The internal organization of an expert system consists of a knowledge-base and an inference engine. The knowledge – base contains the knowledge with which the inference engine draws conclusions. The inference engine is a control structure which helps in generating various hypotheses leading to conclusions that form the basis of answers to user queries. Fuzzy logic introduced by Zadeh permits the notion of nuance. It presumes that this condition could be anything from almost true/false to hardly true/false.

4.2 Need to assess sustainability via fuzzy logic

Sustainability is a multifaceted concept for which there is no widely accepted definition or measurement method. The dynamics of any socio-environmental system cannot be described by the rules of traditional mathematics. Sustainability is difficult to define or measure because it is inherently vague and complex concept. Policy makers often prefer natural language expressions rather than equation or numerical values in assessing sustainability.

Statistics and system identification are used to build models for a system whose structure is not known. These methods require a number of input-output measurements, a collection of candidate models, and a criterion to select the best model based on these measurements. The main problem with assessing sustainability using these methods is the lack of output data. Although many of the inputs are measurable, it is impossible to estimate the output.

Fuzzy logic, on the other hand, is suitable for assessing sustainability because it can model complex systems about which we have only partial knowledge as to their dynamics, the parameters or inputs that affect them, and the values of these inputs. Fuzzy logic can handle knowledge and data represented in various ways, such as mathematical models, linguistic rules, numerical values or linguistic expressions.

4.3 Preliminaries of fuzzy set theory

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

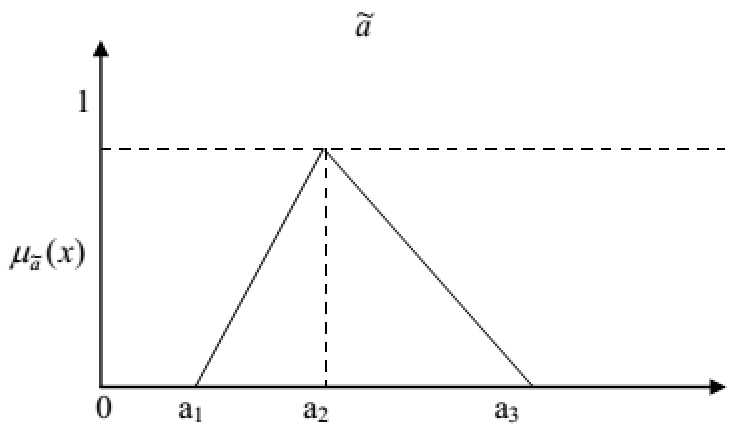

Figure 6: Triangular fuzzy number a

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:

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

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.

4.4 Linguistic variables and fuzzy set theory

In fuzzy set theory, conversion scales are applied to transform the qualitative terms into fuzzy numbers. A scale of 0–9 is used to rate the criteria and the alternatives. Table 2 and 3 present 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

4.5 Fuzzy number

A fuzzy number is a quantity whose value is imprecise, rather than exact as is the case with "ordinary" (single-valued) numbers. Any fuzzy number can be thought of as a function whose domain is a specified set (usually the set of real numbers, and whose range is the span of non-negative real numbers between, and including, 0 and 1000. Each numerical value in the domain is assigned a specific "grade of membership" where 0 represents the smallest possible grade, and 1000 is the largest possible grade.

4.6 Triangular fuzzy number

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

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

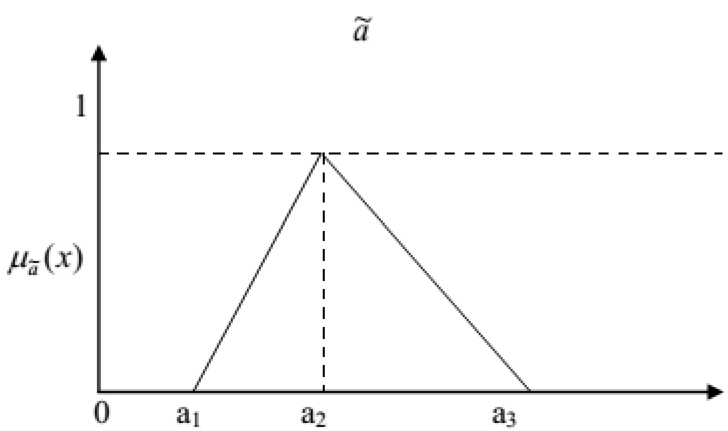

Figure 6: Triangular fuzzy number a

Now if you get crisp interval by α-cut operation, interval 'a' shall be obtained as follows $\forall \alpha \in [0, 1]$.

From

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

We get

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

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

Thus

$$A\alpha = [a1(\alpha), a3(\alpha)]$$

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

4.7 VIKOR method

Vlsekriterijumska Optimizacija I Kompromisno Resenje (i.e. VIKOR) method was developed by Opricovic in 1998 for multi-criteria optimization of complex systems (Opricovic, 1998 and Opricovic and Tzeng, 2002). VIKOR focuses on ranking and sorting a set of alternatives against various, or possibly conflicting and non-commensurable, decision criteria assuming that compromising is acceptable to resolve conflicts. Similar to some other MCDM methods like TOPSIS, VIKOR relies on an aggregating function that represents closeness to the ideal, but the unlike TOPSIS, introduces the ranking index based on the particular measure of closeness to the ideal solution and this method uses linear normalization to eliminate units of criterion functions (Opricovic & Tzeng, 2004).

The VIKOR method was introduced as one applicable technique to be implemented within MCDM problem and it was developed as a multi criteria decision making method to solve a discrete decision making problem with non-commensurable (different units) and conflicting criteria[1,5]. This method focuses on ranking and selecting from a set of alternatives, and determines the compromise solution for a problem with conflicting criteria, which can help the decision makers to reach a final solution. The multi-criteria measure for compromise ranking is developed from the L_P–metric used as an aggregating function in a compromise programming method[31,32].

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 A1,A2,……Am. For alternative Ai, the rating of the jth aspect is denoted by fij (i= 1,2,…. m; j=1,2,… n), i.e., fij is the value of jth criterion function for the alternative Ai, n is the number of criteria. Development of the VIKOR method is started withthe 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∞;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 fj* and the worst fj- 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 Qi; i = 1;2;……m, by the following relation:

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

Where,

$S^* = \min_i S_i$;

$S^- = \max_i S_i$;

$R^* = \min_i R_i$;

$R^* = \min_i R_i$;

Wherever introduced as the weight of the strategy of ‘‘the majority of criteria’’ (or ‘‘the maximum group utility’’), 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

Methodology and application of the Fuzzy VIKOR method are illustrated in next chapters.

CHAPTER 5

MATERIALS AND METHODS

5.1 Selection of Case Study Corridor

The corridors selected for the case study application are a 3.2 Kms long elevated road project under construction from Vikaspuri to Meerabagh in West Delhi by PWD and Metro rail elevated corridor (part) from Punjabi Bagh to Mayapuri as a part of phase 3, line 7 by DMRC.

The traffic flow system of Delhi is a Ring-Radial pattern with two concentric Roads popularly known as Ring Road and Outer Ring Road which are the lifelines for citizens of Delhi. These corridors were selected based on their location on the Ring Road under the same urban environment. The ongoing construction of transportation corridors on the ring road in West Delhi area:

By PWD

1. Vikaspuri to Meerabagh
2. Mangolpuri to Deepali chowk
3. Madhuban chawk to Mukarba chawk
4. Prembari to Azadpur
5. Barapulla phase 2 from JLN to INA

By DMRC

1. Punjabi Bagh to Mayapuri as a part of phase 3, line 7 by DMRC (south west Delhi)

As the thesis is based on the sustainability of transportation corridors during construction so these sites undergoing construction were selected. Among the sites mentioned above Vikaspuri to Meerabagh site by PWD and Punjabi Bagh to Mayapuri site as a part of Metro rail elevated corridor phase 3, line 7 by DMRC were selected. These two corridors were selected because they were constructed by two different Delhi government organizations IE. PWD and DMRC. Further, these corridors were located on the ring road, under the identical traffic flow, environmental and social conditions. The comparative study of these two corridors was possible because of the similar characteristics they possess and these characteristics are:

1. Both the corridors are located in the western part of Delhi
2. Both the corridors are under construction elevated road and rail projects

3. Located at Ring road and Outer Ring road
4. Both corridors are in the stretch of 4 Kms to 6 Kms long
5. Both corridors are Single pier, Two carriageways
6. Both corridors have their casting yards away from the site. Identical Transportation conditions and elevation by launchers is carried out.

The research also exhibits the comparative study for sustainability evaluation of the two sites so the selection was done on the basis of these sites being constructed by two different government agencies i.e. PWD and DMRC. This way the working methodology of the two agencies can be known on the basis of identified sustainability indicators under identical urban environment. These sites were selected after visiting and observing the sustainability issues prevailing during the construction of corridors. In fact, the Vikaspuri to Meera Bagh corridor was selected after a resident wrote a letter to the Chief Minister of Delhi complaining about the problems and environmental issues due to the construction of the corridor, which caught our attention and so the site was selected after observation. Further, the other corridors site by DMRC were an underground construction so Metro rail elevated corridor (part) from Punjabi Bagh to Mayapuri as a part of phase 3, line 7 by DMRC was selected for case study.

5.2 Steps followed for the Identification of sustainability indicators

The five step methodological processes defined in this research can be applied to develop sustainability indicators. The five steps are:

1. Select a corridor under construction and define infrastructure criteria for the corridor

2. Develop sustainability indicator categories

3. Identify sustainability indicators

4. Compile a proforma which include sustainability indicators and columns for rating

5. Assign quantitative and qualitative ratings to the identified indicators by furnishing ratings from the expert’s opinion

Each of the steps can be applied for a sustainable transportation corridor development during construction in an urban environment.

5.3 Data Sources and Collection

Once the segments along the two corridors were selected as the location for the case study application, data were collected. The first step was to identify the data needs as well as the sources from which the data could be retrieved. Therefore, a table was developed listing the data sources and the individual data required for each credit application. Sources include site visit results, experts in the transportation corridor field and the public (residents/ commuters) using existing roads along these corridors.

For identifying sustainability indicators and assigning them qualitative and quantitative ratings, were done with furnishing data from the proforma dully filled by experts in this field and their reviews on it. This data were furnished to us via Emails.

For sustainability evaluation of the study corridors, the data were collected by conducting a survey of public (commuters/ residents) availing facilities on those sites. The proforma which includes indicators and a column for quantitative ratings for each site was distributed in the neighbouring colonies and shops near the construction sites. The proformas were collected personally and few with the help of other known people using the corridor or residing in nearby colonies.

Information that was not received by any of the specified sources was considered an assumption and documented as such. For example, Spirituality indicators were considered an assumption due to the lack of public access to information regarding these facilities at the locations. Therefore, spirituality indicators were documented as such and applied to evaluation techniques using data as received from the sources.

The samples of the data collection are shown in Appendix.

Figure 7: Map of elevated road project Vikaspuri to Meerabagh by PWD (Source: Google Maps)

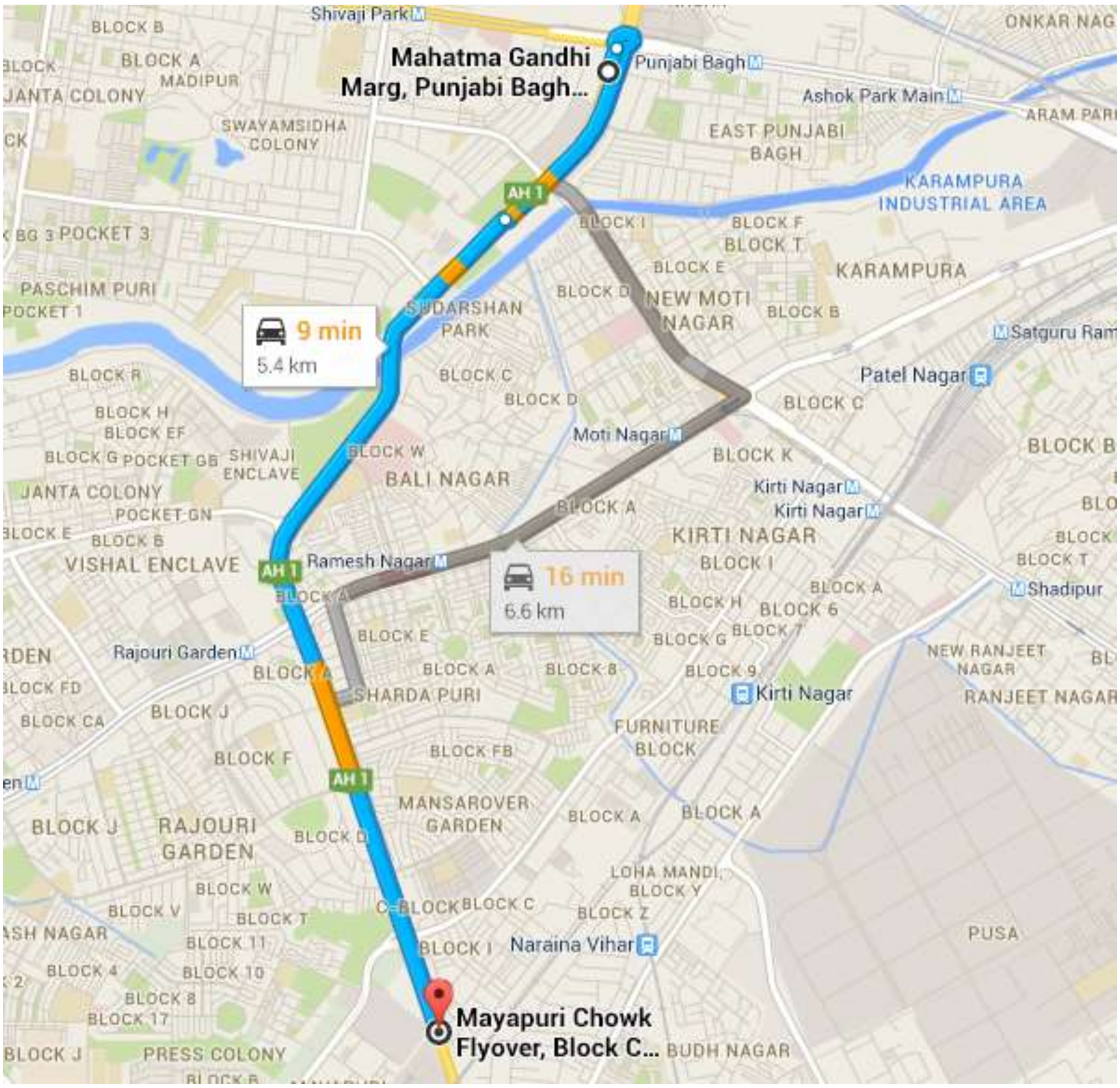

Figure 8: Map of Metro rail elevated corridor from Punjabi Bagh to Mayapuri as a part of phase 3, line 7 by DMRC (Source: Google Maps)

5.4 Fuzzy VIKOR Application

5.4.1 Selection of evaluation criteria

The first step involves the selection of criteria for evaluating sustainability of urban transportation corridor through a comprehensive literature review (Jeon, Amekudzi and Guensler 2008, Litman 2009, Zietsman 2000), and our site visit experience, observations and expert opinion. The final list contains 39 criteria (Table 1).

Table 1 : Identified Sustainability Indicators

Criteria	Sustainability Indicators
A.	**ENVIRONMENTAL**
1.	Control on Air Pollution
2.	Control on drainage system due to construction activities
3.	Control on water logging during Monsoon/rains
4.	Control on noise pollution due to construction activity during day
5.	Control on noise pollution during night
6.	Removal of trees/ depletion of Green Belt
7.	Plantation scheme
8.	Any other technique that is being used in site to make the project more green or Eco-friendly
B.	**SOCIAL**
9.	Increase in stress level of commuters
10.	Health of workers
11.	Welfare activities for family of workers
12.	Sanitation conditions
13.	First Aid facility at site
14.	Safety measures
15.	Impact on Health of residents
16.	Impact on safety of residents
17.	Public conveniences in project area

C.	**ECONOMICS**
18.	Increase in Travel time
19.	Increase in travel cost
20.	Disturbance to the business/Employment of nearby residents
D.	**TECHNICAL**
21.	Display of Project Details
22.	Display of Mandatory, Informatory and Cautionary Signage
23.	Traffic Diversions
24.	Visibility and sight distance to moving traffic
25.	Lighting of Construction site
26.	Barricading the site
27.	Aesthetics of Project
28.	Handling of C & D Waste
E.	**GOVERNANCE**
29.	Ensuring the mobility of Traffic in the project area
30.	Effective Functioning of Traffic Marshalls
31.	Unauthorized/Improper parking in Project area
32.	Maintenance of existing drainage system
33.	Maintenance of Barricades
34.	Ensuring the SHE (safety, Health and Environment) at site
35.	Maintenance of existing utilities
36.	Maintenance of existing greenery during construction
F.	**SPIRITUALITY**
37.	Facilities of Yoga/meditation
38.	Performance of Rituals at site like Vishvakarma Puja, May Day
39.	Celebration during Festivals at site

5.4.2 Generating qualitative criteria and alternative ratings

For sustainability evaluation of urban transportation corridor, we need data on social-economic-environmental-technical-governance-spirituality indicators. However, it has been observed in general practice, that often there have been almost none or very limited data available on this subject, thereby making the evaluation process difficult. To address this situation, we made use of qualitative ratings such as Good, Very Good, Fair, Poor, Very Poor for assessing the alternatives from the public and Very Low, Low, Medium, High, Very High for the criteria by expert opinion. Later, they were transformed into fuzzy numbers using conversion schemes provided in Table 2 and Table 3 for further processing through Fuzzy VIKOR technique.

Table 2: Fuzzy transformation for qualitative alternative site 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)

Table 3: Fuzzy transformation for qualitative criteria 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)

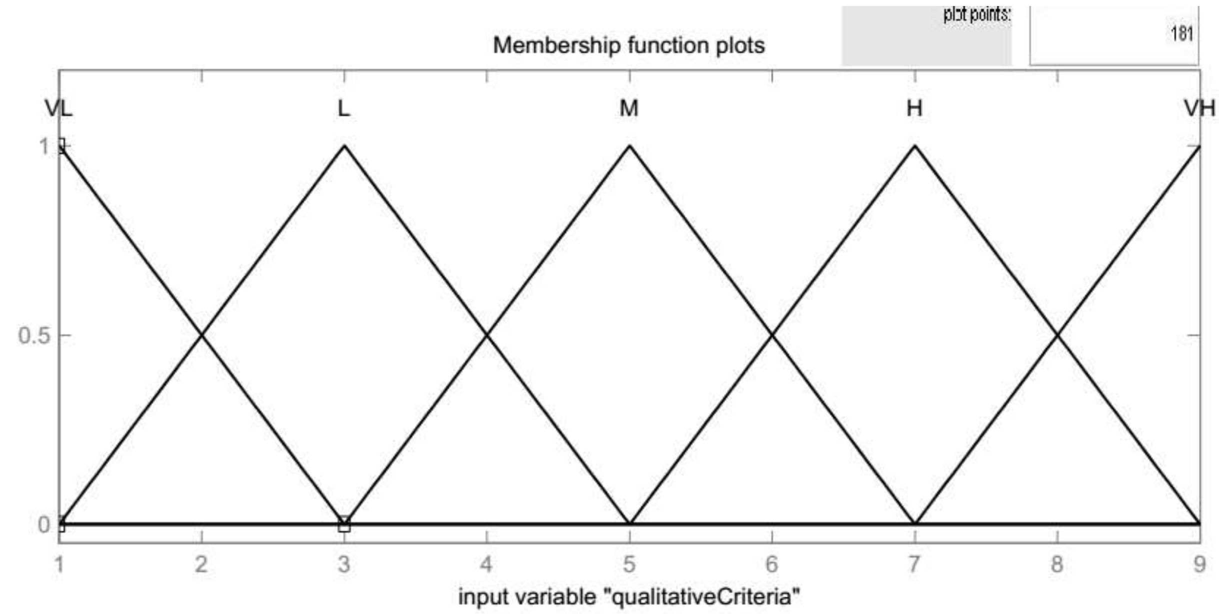

Figure 9: Triangular Fuzzy from Membership function for qualitative Criteria (using MATLAB)

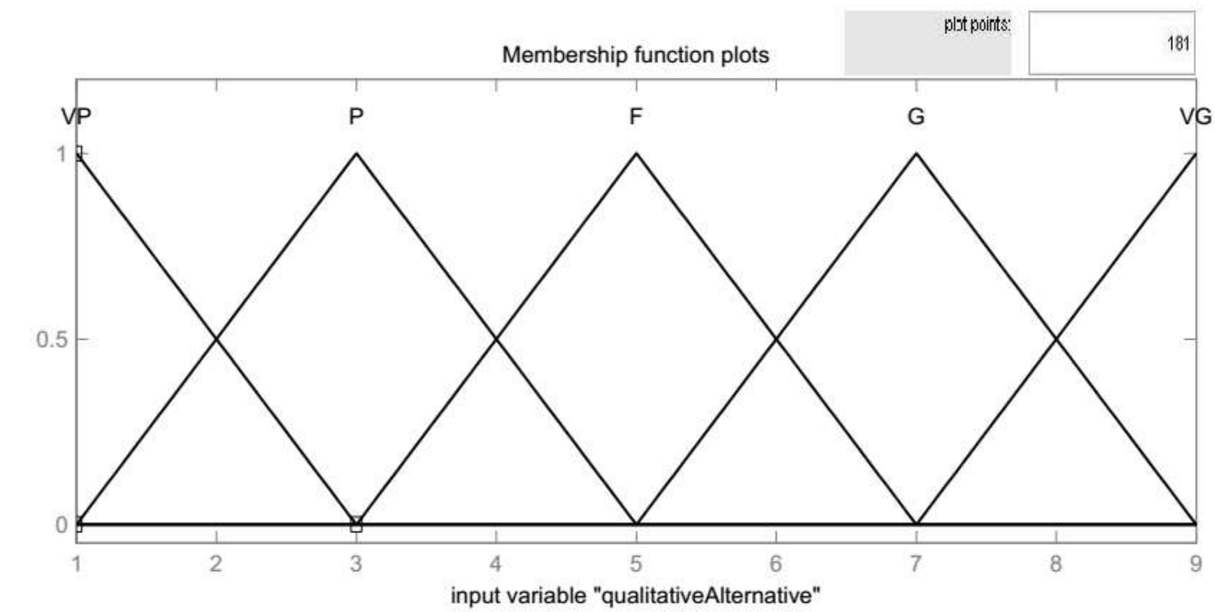

Figure 10: Triangular Fuzzy from Membership function for the qualitative alternative site (using MATLAB)

5.4.3 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: Assignment of ratings to the criteria and the alternatives.

Let us consider a set of *m* alternatives called A = {A1, A2,., A_m }which are to be evaluated against a set of *n* criteria, C = {C1 ,C2 ,., Cn }. The criteria weights are denoted by wj (j=1,2,..,n). The performance ratings of decision maker D_k (*k* = 1,2,…, K) for each alternative A_i (i=1,2,..,m) with respect to criteria C_j (*j*= 1,2,..,n) are denoted by :

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

Step 2: Compute aggregate fuzzy ratings for the criteria and the alternatives.

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

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

If the fuzzy rating and importance weight of the k^{th} decision maker are x_{ijk} = (a_{ijk}, $b_{ijk,}$ c_{ijk}) and w_{ijk} = (w_{jk1}, w_{jk2} , w_{jk3}), i = 1,2,…,m, j = 1,2,….n respectively, then the aggregated fuzzy ratings (x_{ij}) of alternatives with respect to each criteria are given by x_{ij} = (a_{ij} , b_{ij} , c_{ij}) where

$$a_{ij} = \min\{a_{ijk}\},\ w_{j2} = \frac{1}{K}\sum_{k=1}^{k} w_{jk2},\ c_{ij} = \max\{c_{ijk}\} \qquad (2)$$

The aggregated fuzzy weights (w_{ij}) of each criterion are calculated as w_j = (w_{j1}; wj2; wj3) where

$$w_{j1} = \min\ \{w_{jk1}\},\ wj2 = \frac{1}{K}\sum_{k=1}^{k} wjk2,\ w_{j3} = \max\{c_{jk3}\} \qquad (3)$$

Step 3: Compute the fuzzy decision matrix

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

$$D = \begin{array}{c} \\ A1 \\ A2 \\ A3 \\ A4 \end{array} \begin{array}{c} \begin{array}{cccc} C1 & C2 & \ldots.. & Cn \end{array} \\ \begin{bmatrix} X11 & X12 & \ldots.. & X1n \\ X21 & X22 & \ldots.. & X2n \\ \ldots & \ldots & \ldots.. & \ldots \\ Xm1 & Xm2 & \ldots.. & Xmn \end{bmatrix} \end{array}, \text{ i= 1, 2,....m ; j= 1,2,.n} \quad (4)$$

$$W = (w_1, w_2 \ldots w_n) \quad (5)$$

Step 4: Defuzzify the elements of fuzzy decision matrix for the criteria weights and the alternatives into crisp values. A fuzzy number a~= (a1, a2, a3) can be transformed into a crisp number a by employing the below equation:

(6)

$$a = \frac{a1 + 4a2 + a3}{6}$$

Step 5: Determine the best f_j* and the worst values f_j^- of all criteria ratings

j=1, 2,..., n

$$f_j* = \max_i \{x_{ij}\} \quad (7)$$

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

Step 6: Compute the values Si and Ri using the following equations

$$Si = \sum_{j=1}^{n} w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-}$$

(8)

$$Ri = max_j \; w_j \; \frac{f_j^* - x_{ij}}{f_j^* - f_j^-}$$

Step 7: Compute the values Qi as follows

(9)

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

Where:

$S^* = \min_i S_i$;

$S^- = \max_i S_i$;

$R^* = \min_i R_i$;

$R^* = \min_i R_i$; (10)

And v is the weight for the strategy of maximum group utility and 1-v is the weight of the individual regret.

Step 8: Rank the alternatives, sorting by the values S, R and Q in ascending order. The results are three ranking lists.

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

C1: Acceptable advantage

$Q(A^{(2)}) - Q(A^{(1)}) \geq DQ$ (11)

Where $A^{(2)}$ is the alternative with second position in the ranking list by Q and

DQ = 1/J-1

C2: Acceptable stability in decision making (12)

The alternative $A^{(1)}$ must also be the best ranked by S or/and R. The compromise solution is stable within a decision making process, which could be the strategy of maximum group utility (when v>0.5 is needed), or ―by consensus v = 0.5 , or ―with veto (v<0.5). Please note that v is the weight of the decision making strategy of maximum group utility.

If one of the conditions is not satisfied, then a set of compromise 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).

Application of Fuzzy VIKOR technique for sustainability evaluation of the case study corridors, as mentioned above step wise is executed and its Result is compiled in chapter 6.

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Numerical Application

This section presents the application of a chosen technique, namely Fuzzy VIKOR for sustainability evaluation of two transportation project sites under construction (A1, A2) in the context of the city of Delhi. Examples of these projects are sustainability evaluation of 3.2 Kms long elevated road project under construction from Vikaspuri to Meerabagh in West Delhi by PWD (A1), and Metro rail elevated corridor (part) from Punjabi Bagh to Mayapuri as a part of phase 3, line 7 by DMRC (A2).

A committee of ten experts (E1, E2… E10) is formed to obtain qualitative ratings (Tables 2 and 3) for the criteria and the alternatives. These ratings are presented in Table 4.

Table 4: Qualitative Assessments and Aggregate fuzzy criteria ratings

Criteria	Qualitative rating										Aggregate Fuzzy Rating	Crisp rating
	E1 LP	E2 ops	E3 Pk	E4 SKR	E5 vsk	E6 hks	E7 vks	E8 ss	E9 S sri	E10 pks		
C1	VH	VH	VH	H	H	VH	VH		VH	VH	(5,8.55,9)	8.03
C2	H	VH	M	VH	M	M	H	VH	VH	H	(3,8.2,9)	7.47
C3	VH	VH	M	VH	M	M	H	VH	VH	VH	(3,7.6,9)	7.07
C4	M	H	H	H	L	H	M	M	M	M	(1,5.6,9)	5.40
C5	H	VH	VH	VH	VH	H	H	H	H	VH	(5,8,9)	7.67
C6	VH	VH	M	H	H	VH	VH	H	H	H	(3,7.6,9)	7.07
C7	VH	VH	VH	H	H	M	H	M	H	H	(3,7.2,9)	6.80
C8		H	M		VH	H			VH	H	(3,7.33,9)	6.89
C9	H	VH	VL	VH	M	VH	VH	H	M	VH	(1,7,9)	6.33
C10	VH	VH	H	VH	H	VH	H	H	H	VH	(5,8,9)	7.67
C11	VH	H	L	VH	H	H	H	M	H	H	(1,6.8,9)	6.20
C12	VH	VH	H	VH	H	VH	H	H	H	H	(5,7.8,9)	7.53

C13	VH	VH	VH	VH	H	VH	VH	VH	H	VH	(5,8.6,9)	8.07
C14	VH	VH	VH	VH	VH	VH	VH	VH	VH	VH	(7,9,9)	8.67
C15	VH	VH	VH	VH	M	VH	VH	H	H	H	(3,8,9)	7.33
C16	VH	VH	VH	VH	H	VH	VH	VH	VH	H	(5,8.6,9)	8.07
C17	VH	VH	M	H	M	H	VH	VH	H	VH	(3,7.6,9)	7.07
C18	VH	VH	VH	VH	M	VH	H	H	VH	H	(3,8,9)	7.33
C19	VH	VH	VH	VH	M	M	H	H	VH	H	(3,7.6,9)	7.07
C20	H	H	VH	VH	L	M	H	H	H	M	(1,6.6,9)	6.07
C21	H	H	M	H	L	L	H		VH	L	(1,5.66,9)	5.44
C22	VH	VH	VH	VH	VH	VH	VH	H	VH	H	(5,8.6,9)	8.07
C23	VH	VH	VH	VH	VH	VH	VH	VH	VH	H	(7,8.8,9)	8.20
C24	VH	VH	H	VH	M	VH	VH	VH	H	H	(3,8,9)	7.33
C25	VH	VH	H	VH	VH	VH	VH	VH	VH	H	(5,8.60,9)	8.07
C26	VH	VH	H	VH	H	VH	VH	H	VH	VH	(5,8.40,9)	7.93
C27	M	H	L	H	H	VH	M	M	H	M	(3,6.00,9)	6.00
C28	H	H	M	VH	H	VH	VH	H	H	H	(3,7.40,9)	6.93
C29	VH	VH	VH	VH	VL	VH	H	VH	VH	VH	(5,8.00,9)	7.67
C30	VH	VH	H	VH	VH	VH	H	H	H	VH	(5,8.20,9)	7.80
C31	H	M	M	VH	VL	VH	H	H	H	M	(3,6.20,9)	6.13
C32	VH	VH	H	VH	H	VH	H	VH	VH	VH	(5,8.40,9)	7.93
C33	H	M	H	VH	H	VH	H	VH	H	M	(3,7.20,9)	6.80
C34	VH	H	VH	VH	VH	VH	VH	VH	H	H	(5,8.40,9)	7.93
C35	VH	H	VH	VH	VH	VH	H	VH	H	H	(5,8.20,9)	7.80
C36	VH	VH	M	VH	H	H	H	H	H	VH	(5,7.60,9)	7.40
C37	M	M	M	H	VL	M	VL	L	VL	L	(1,3.60,7)	3.73
C38	VL	L	H	VH	VH	M	VL	M	H	L	(1,5.00,9)	5.00
C39	M	VL	VH	H	VL	M	VL	M	M	VL	(1,4.00,9)	4.33

The aggregated fuzzy weights (w_{ij}) of criteria are obtained using Eq. (3). For example, for criteria C1 (Qualitative Rating = (VH, VH, VH, H, H, VH, VH, , VH, VH)), the aggregated fuzzy weight is given by wj =(wji, wj2, wj3) where:

wj1 = min(7,7,7,5,5,7,7, ,7,7),

wj2= 1/9(9+9+9+7+7+9+9+ +9+9),

wj3= max(9,9,9,9,9,9,9, ,9,9)

wj= (5,8.55,9)

The aggregated fuzzy weights wj is transformed into crisp number wc using eqn (6). For example, for criteria C1, wj= (5, 8.55, 9), we have $\mathrm{wc} = \frac{1*5 + (4*8.55) + 9}{6} = 8.03$. Likewise, we compute the aggregate weights for the remaining criteria. The results for aggregate weights of the 39 criteria, are presented in the last column of Table 4. Table 5 and 6 presents the qualitative ratings for the two alternative sites, i.e. PWD and DMRC provided by the commuters/residents.

The qualitative ratings are converted into fuzzy triangular numbers and then aggregate ratings are generated using the equation (2). Table 7 presents the aggregate fuzzy decision matrix for the two alternative sites.

Table 7. Aggregate fuzzy decision matrix for the two alternative sites

Criteria	**A1 (PWD)**	**A2 (DMRC)**	**Min**	**Max**
C1	(1,3.28,9)	(1,5.12,9)	1	9
C2	(1,4.08,9)	(1,4.92,9)	1	9
C3	(1,3.85,9)	(1,4.52,9)	1	9
C4	(1,4.72,9)	(1,4.80,9)	1	9
C5	(1,4.16,9)	(1,5.12,9)	1	9
C6	(1,3.40,9)	(1,4.68,9)	1	9
C7	(1,4.11,9)	(1,4.28,9)	1	9
C8	(1,3.86,9)	(1,4.80,9)	1	9
C9	(1,4.14,9)	(1,4.32,9)	1	9
C10	(1,4.86,9)	(1,4.48,9)	1	9
C11	(1,5.12,9)	(1,4.67,9)	1	9
C12	(1,4.56,9)	(1,4.20,9)	1	9
C13	(1,4.63,9)	(1,4.92,9)	1	9
C14	(1,5.72,9)	(1,5.80,9)	1	9
C15	(1,4.20,9)	(1,5.08,9)	1	9
C16	(1,4.80,9)	(1,4.13,9)	1	9
C17	(1,5.36,9)	(1,4.68,9)	1	9
C18	(1,2.44,7)	(1,3.73,9)	1	9
C19	(1,4.80,9)	(1,4.44,9)	1	9
C20	(1,4.32,9)	(1,3.92,9)	1	9
C21	(1,3.80,9)	(1,4.80,9)	1	9
C22	(1,4.68,9)	(1,4.91,9)	1	9
C23	(1,5.24,9)	(1,4.72,9)	1	9
C24	(1,4.96,9)	(1,4.42,9)	1	9
C25	(1,6.08,9)	(1,5.45,9)	1	9

C26	(1,3.40,9)	(1,4.52,9)	1	9
C27	(1,4.24,9)	(1,4.36,9)	1	9
C28	(1,3.81,7)	(1,3.76,7)	1	9
C29	(1,2.64,7)	(1,4.68,9)	1	9
C30	(1,3.24,9)	(1,5.68,9)	1	9
C31	(1,2.84,7)	(1,5.08,9)	1	9
C32	(1,2.48,7)	(1,4.96,9)	1	9
C33	(1,4.68,9)	(1,5.56,9)	1	9
C34	(1,4.24,9)	(1,4.88,9)	1	9
C35	(1,3.56,7)	(1,4.56,9)	1	9
C36	(1,2.60,7)	(1,4.32,9)	1	9
C37	(1,2.50,7)	(1,2.33,7)	1	7
C38	(1,2.16,5)	(1,2.00,5)	1	9
C39	(1,2.66,7)	(1,2.85,7)	1	9

After obtaining the fuzzy decision matrix and fuzzy/crisp criteria weights, the Fuzzy VIKOR technique for sustainability evaluation is applied. The results are presented as follows

First of all, generate aggregate crisp ratings for the two alternative sites using equation (6). Based on these values, we will compute the best f_j* and the worst values f_j- of the 39 criteria using equation (7). Table 8 presents the results for the aggregated crisp ratings, f_j* and f_j- of the 39 criteria.

Table 8. The best values f_j* and the worst values f_j- of the 39 criteria

Criteria	**Crisp Ratings**		**f_j***	**f_j-**
	A1 (PWD)	**A2 (DMRC)**		
C1	3.85	5.08	5.08	3.85
C2	4.39	4.95	4.95	4.39
C3	4.23	4.68	4.68	4.23
C4	4.81	4.87	4.87	4.81

C5	4.44	5.08	5.08	4.44
C6	3.93	4.79	4.79	3.93
C7	4.41	4.52	4.52	4.41
C8	4.24	4.87	4.87	4.24
C9	4.43	4.55	4.55	4.43
C10	4.91	4.65	4.91	4.65
C11	5.08	4.78	5.08	4.78
C12	4.71	4.47	4.71	4.47
C13	4.75	4.95	4.95	4.75
C14	5.48	5.53	5.53	5.48
C15	4.47	5.05	5.05	4.47
C16	4.87	4.42	4.87	4.42
C17	5.24	4.79	5.24	4.79
C18	2.96	4.15	4.15	2.96
C19	4.87	4.63	4.87	4.63
C20	4.55	4.28	4.55	4.28
C21	4.20	4.87	4.87	4.20
C22	4.79	4.94	4.94	4.79
C23	5.16	4.81	5.16	4.81
C24	4.97	4.61	4.97	4.61
C25	5.72	5.30	5.72	5.30
C26	3.93	4.68	4.68	3.93
C27	4.49	4.57	4.57	4.49
C28	3.87	3.84	3.87	3.84
C29	3.09	4.79	4.79	3.09
C30	3.83	5.45	5.45	3.83
C31	3.23	5.05	5.05	3.23
C32	2.99	4.97	4.97	2.99
C33	4.79	5.37	5.37	4.79
C34	4.49	4.92	4.92	4.49
C35	3.71	4.71	4.71	3.71

C36	3.07	4.55	4.55	3.07
C37	3.00	2.89	3.00	2.89
C38	2.44	2.33	2.44	2.33
C39	3.11	3.23	3.23	3.11

Table 9 presents the Si, Ri and Qi values for the three alternatives computed using equation (7-9).

The values of S*= 0.324, S-= 0.675, R*= 0.029, R-=0.0315 are obtained using equation (10).

Table 9. Si, Ri and Qi values for the two alternative sites

	A1 (PWD)	**A2 (DMRC)**
Si	0.674600575	0.323688903
Ri	0.031553663	0.029843142
Qi	1	0

Table 10 ranks the three alternatives, sorting by the values of Si, Ri and Qi obtained from Table 9 in ascending order.

Table 10: Alternative rankings

Si	A2	A1
Ri	A2	A1
Qi	A2	A1

It can be seen from the results of Table 10 that site A2 is the best ranked by the measure Qi(minimum). We now check it for the following two conditions (step 9).

1). C1: acceptable advantage (eqn(11)).

Using eqn (11), DQ = 1/39-1 = 1/38 = 0.0263. Applying eqn (10),

we find Q(A1) - Q(A2) = 1 - 0= 1 > 0.0263, hence the condition $QA^{(1)} – QA^{(2)} \geq DQ$ is satisfied.

2). C2: Acceptable stability in decision making (eqn (12))

Since site A2 is also best ranked by Si and Ri (considering the ―"by consensus rule v =0.5"), therefore it is ranked as a more sustainable corridor.

6.2 Results

Results of the study has been shown in Table 10, which indicates that alternative A2 i.e. Metro rail elevated corridor (part) from Punjabi Bagh to Mayapuri as a part of phase 3, line 7 by DMRC is a more sustainable corridor, considering the identified sustainability indicators, among the two corridors selected for case study.

6.3 Discussion

6.3.1 Identifying sustainability indicators

The five step methodological processes defined in this research can be applied to develop sustainability indicators. The five steps defined were:

1. Select a corridor under construction and define infrastructure criteria for the corridor

2. Develop sustainability indicator categories

3. Identify sustainability indicators

4. Compile a proforma which include sustainability indicators and columns for rating

5. Assign quantitative and qualitative ratings to the identified indicators by furnishing ratings from the expert opinion

Each of the steps can be applied for a sustainable transportation corridor development during construction in an urban environment. **This process started with the need for categorization of sustainability from its existing three pillars i.e. Environmental, Economic and Social aspects to developing of three more vital aspects such as Technical, Governance and Spirituality.** Then the individual indicators under these six sustainability categorizations were identified by visiting and observing corridor under construction and consultation with experts. Finally, the process ends with the creation of a proforma that furnishes Qualitative and Quantitative rating to each identified sustainability indicator from experts in this field.

6.3.2 Sustainability evaluation

The application of a chosen technique, namely Fuzzy VIKOR for sustainability evaluation of two transportation project sites under construction (A1, A2) in the context of the city of Delhi was executed. These projects were sustainability evaluation of 3.2 Kms long elevated road project under construction from Vikaspuri to Meerabagh in West Delhi by PWD (A1), and Metro rail elevated corridor (part) from Punjabi Bagh to Mayapuri as a part of phase 3, line 7 by DMRC (A2).

Methodology for sustainability evaluation was defined and its application via Fuzzy VIKOR technique using the identified sustainability indicators was executed. The quantitative ratings for sustainability indicators and opinions were furnished from a survey of public (commuters/ residents) at each site A1 & A2. This data was then used in the Fuzzy VIKOR technique to evaluate sustainability of the two sites under study and further to know which site is more sustainable on the basis of the identified sustainability indicators. **The results after the numerical application exhibit that the site A2, i.e. Metro rail elevated corridor (part) from Punjabi Bagh to Mayapuri as a part of phase 3, line 7 by DMRC was more sustainable considering the identified sustainability indicators.**.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the purpose of identifying sustainability indicators for transportation corridors and its applicability to corridor development and sustainability evaluation. The implications of these identified sustainability indicators for sustainability evaluation of transportation corridors are stated and future work is suggested in order to further refine sustainability in transportation corridors.

7.1 Conclusions

Following conclusions are drawn from the above study:

1. 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.

2. 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.

3. As per the triple Bottom line approach sustainability comprises all 3 elements, social, environmental and economical. While visiting the site and observing the sustainability issues, it was observed that the current situation demands beyond these 3 parameters to make up a sustainable corridor in real sense. So 3 more parameters were included, i.e. technical, governance and spirituality considering the demand of sustainable transportation corridor in an urban environment.

4. The comparative study of two transportation corridors under construction, elevated road project from Vikaspuri to Meerabagh in West Delhi by PWD (A1), and Metro rail elevated corridor (part) from Punjabi Bagh to Mayapuri as a part

of phase 3, line 7 by DMRC (A2) has yielded an overview of the approach towards the implementation of sustainability in projects.

5. A defined MCMD technique, Fuzzy VIKOR was accordingly modified and implemented for sustainability evaluation of the corridors under study.

6. The results after the numerical application of Fuzzy VIKOR technique exhibit that the site A2, i.e. Metro rail elevated corridor (part) from Punjabi Bagh to Mayapuri as a part of phase 3, line 7 by DMRC is more sustainable in the context of identified sustainability indicators.

7. The study exhibits that the implementation of suitable Sustainability indicators during construction is required for a sustainable transportation infrastructure development.

7.2 Recommendations

1. List of Identified sustainability indicators is recommended to be made more concise.

2. Once the identification of sustainability indicators is complete, a case study application, similar to the one completed in this research, is recommended to evaluate sustainability of transportation corridors in whole Delhi.

3. Proforma for public survey is recommended to be clear and simple, as it is difficult for public to understand technical terms.

4. For sustainability evaluation data from public survey is recommended to be acknowledged from the set of people, who are well aware of the problems related to the corridor under study.

5. Sustainability evaluation by techniques other than fuzzy technique is also recommended for more convenient application and accurate results.

6. The implementation of indicators and sustainability evaluation for developing a rating system for transportation corridors is recommended since it is not within the scope of this research.

7.3 Scope of future work

In this research, we have limited our study to identification of sustainability indicators and demonstrating the application of Fuzzy VIKOR technique for sustainability evaluation of the urban transportation corridor. In our future works, we intend to develop a green rating system for transportation corridors in an urban environment. This research will serve as a reference for the implementation of the most suitable Sustainability indicators during construction of a transportation infrastructure. A green rating system will encourage the development of technologies based on the criteria used for evaluating transportation infrastructures /corridors as well as developing sustainable technologies.

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APPRENDIX A

SUBJECT : SURVEY TO ASSIGN THE WEIGHTAGE TO THE VARIOUS SUSTAINABILITY INDICATORS IDENTIFIED FOR AN INFRASTRUCTURE PROJECT UNDER CONSTRUCTION IN AN URBAN ENVIRONMENT

A survey has been undertaken by a Project/Research Team of Environmental Engineering Department of Delhi Technological University (DTU) to assign the weightage to the various sustainability indicators identified for an infrastructure project under construction in an urban environment .

A Performa with Various sustainability indicators is enclosed herewith and it is requested to submit your opinion regarding its importance on following two scales.

SCALE 1 : Quantitative Analysis on a scale **0 to 9**. The sustainability indicator with no importance may be assigned **'0'** value and most important indicator may be assigned **'9'** value. Accordingly values may be assigned from **0** to **9** on the basis of its importance.

SCALE 2 : Qualitative Analysis among **VL** (Very Low), **L** (Low), **M** (Medium), **H** (High) and **VH** (Very High). The sustainability indicator with least importance may be assigned **'VL'** value and most important indicator may be assigned **'VH'** value. Accordingly values may be assigned from **VL** to **VH** on the basis of its importance.

Please furnish your fair comments/ opinion in so that indicators identified may be used for grading a project from sustainability point of view and we can make more sustainable projects in future.

Opinion can be furnished to **Sameer Verma,** Room no. 407, JCB Hostel, DTU campus, Shahbad Daultpur, Bawana Road, Delhi – 110042. Email- sameerverma.ce@gmail.com

Your details :
Name :Dr. Lakshmy Parameswaran
Organisation :CSIR-CRRI

Mobile No.(optional) :09810274002 Email (optional): lakshmy.crri@nic.in

PROFORMA (for Experts)

S. No.	Sustainability Indicators	Rating	
		Quantitative	**Qualitative**
A.	**ENVIRONMENTAL**		
1.	Control on Air Pollution	9	VH
2.	Control on drainage system due to construction activities	7	H
3.	Control on water logging during Monsoon/rains	9	VH

4.	Control on noise pollution due to construction activity during day	5	M
5.	Control on noise pollution during night	7	H
6.	Removal of trees/ depletion of Green Belt	9	VH
7.	Plantation scheme	9	VH
8.	Any other technique that is being used in site to make the project more green or Eco-friendly		
B. SOCIAL			
9.	Increase in stress level of commuters	7	H
10.	Health of workers	9	VH
11.	Welfare activities for family of workers	9	VH
12.	Sanitation conditions	9	VH
13.	First Aid facility at site	9	VH
14.	Safety measures	9	VH
15.	Impact on Health of residents	9	VH
16.	Impact on safety of residents	9	VH
17.	Public conveniences in project area	9	VH
C. ECONOMICS			
18.	Increase in Travel time	9	VH
19.	Increase in travel cost	9	VH
20.	Disturbance to the business/Employment of nearby residents	7	H
D. TECHNICAL			
21.	Display of Project Details	7	H
22.	Display of Mandatory, Informatory and Cautionary Signage	9	VH
23.	Traffic Diversions	9	VH
24.	Visibility and sight distance to moving traffic	9	VH
25.	Lighting of Construction site	9	VH
26.	Barricading the site	9	VH
27.	Aesthetics of Project	5	M
28.	Handling of C & D Waste	7	H
E. GOVERNANCE			
29.	Ensuring the mobility of Traffic in the project area	9	VH
30.	Effective Functioning of Traffic Marshalls	9	VH
31.	Unauthorized/Improper parking in Project area	7	H
32.	Maintenance of existing drainage system	9	VH
33.	Maintenance of Barricades	7	H
34.	Ensuring the SHE (safety, Health and Environment) at site	9	VH
35.	Maintenance of existing utilities	9	VH
36.	Maintenance of existing greenery during construction	9	VH
F. SPIRITUALITY			
37.	Facilities of Yoga/meditation	5	M
38.	Performance of Rituals at site like Vishvakarma Puja, May Day	3	VL
39.	Celebration during Festivals at site	5	M

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Your details :
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Organisation : MoRT&H, Transport Bhawan, New Delhi

Mobile No.(optional) :…………………….. Email opshri@yahoo.com

PROFORMA (for Experts)

S. No.	Sustainability Indicators	Rating	
		Quantitative	Qualitative
A.	**ENVIRONMENTAL**		
1.	Control on Air Pollution	9	VH
2.	Control on drainage system due to construction activities	8	VH
3.	Control on water logging during Monsoon/rains	8	VH
4.	Control on noise pollution due to construction activity	7	H

	during day		
5.	Control on noise pollution during night	9	VH
6.	Removal of trees/ depletion of Green Belt	9	VH
7.	Plantation scheme	8	VH
8.	Any other technique that is being used in site to make the project more green or Eco-friendly (Use of solar energy instead of generators)	7	H
B. SOCIAL			
9.	Increase in stress level of commuters	9	VH
10.	Health of workers	8	VH
11.	Welfare activities for family of workers	7	H
12.	Sanitation conditions	9	VH
13.	First Aid facility at site	9	VH
14.	Safety measures	9	VH
15.	Impact on Health of residents	8	VH
16.	Impact on safety of residents	9	VH
17.	Public conveniences in project area	8	VH
C. ECONOMICS			
18.	Increase in Travel time	9	VH
19.	Increase in travel cost	9	VH
20.	Disturbance to the business/Employment of nearby residents	7	H
D. TECHNICAL			
21.	Display of Project Details	6	H
22.	Display of Mandatory, Informatory and Cautionary Signage	9	VH
23.	Traffic Diversions	8	VH
24.	Visibility and sight distance to moving traffic	9	VH
25.	Lighting of Construction site	9	VH
26.	Barricading the site	9	VH
27.	Aesthetics of Project	7	H
28.	Handling of C & D Waste	7	H
E. GOVERNANCE			
29.	Ensuring the mobility of Traffic in the project area	9	VH
30.	Effective Functioning of Traffic Marshalls	8	VH
31.	Unauthorized/Improper parking in Project area	5	M
32.	Maintenance of existing drainage system	9	VH
33.	Maintenance of Barricades	6	M
34.	Ensuring the SHE (safety, Health and Environment) at site	7	H
35.	Maintenance of existing utilities	7	H
36.	Maintenance of existing greenery during construction	8	VH
F. SPIRITUALITY			
37.	Facilities of Yoga/meditation	5	M
38.	Performance of Rituals at site like Vishvakarma Puja, May Day	4	L
39.	Celebration during Festivals at site	2	VL

SUBJECT: SURVEY TO ASSIGN THE WEIGHTAGE TO THE VARIOUS SUSTAINABILITY INDICATORS IDENTIFIED FOR AN INFRASTRUCTURE PROJECT UNDER CONSTRUCTION IN AN URBAN ENVIRONMENT

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SCALE 2 : Qualitative Analysis among **VL** (Very Low), **L** (Low), **M** (Medium), **H** (High) and **VH** (Very High). The sustainability indicator with least importance may be assigned **'VL'** value and most important indicator may be assigned **'VH'** value. Accordingly values may be assigned from **VL** to **VH** on the basis of its importance.

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Opinion can be furnished to **Sameer Verma,** Room no. 407, JCB Hostel, DTU campus, Shahbad Daultpur, Bawana Road, Delhi – 110042. Email- sameerverma.ce@gmail.com

Your details:
Name : PIYUSH KANSAL
Organisation :RITES LTD.

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PROFORMA (for Experts)

S. No.	Sustainability Indicators	Rating	
		Quantitative	**Qualitative**
A. ENVIRONMENTAL			
1.	Control on Air Pollution	9	VH
2.	Control on drainage system due to construction activities	5	M
3.	Control on water logging during Monsoon/rains	6	M

4.	Control on noise pollution due to construction activity during day	7	H
5.	Control on noise pollution during night	8	VH
6.	Removal of trees/ depletion of Green Belt	6	M
7.	Plantation scheme	9	VH
8.	Any other technique that is being used in site to make the project more green or Eco-friendly	6	M
B. SOCIAL			
9.	Increase in stress level of commuters	0	GVL
10.	Health of workers	7	H
11.	Welfare activities for family of workers	5	L
12.	Sanitation conditions	7	H
13.	First Aid facility at site	8	VH
14.	Safety measures	9	VH
15.	Impact on Health of residents	8	VH
16.	Impact on safety of residents	8	VH
17.	Public conveniences in project area	6	M
C. ECONOMICS			
18.	Increase in Travel time	0	VL
19.	Increase in travel cost	0	VL
20.	Disturbance to the business/Employment of nearby residents	0	VL
D. TECHNICAL			
21.	Display of Project Details	6	M
22.	Display of Mandatory, Informatory and Cautionary Signage	8	VH
23.	Traffic Diversions	9	VH
24.	Visibility and sight distance to moving traffic	7	H
25.	Lighting of Construction site	7	H
26.	Barricading the site	7	H
27.	Aesthetics of Project	4	L
28.	Handling of C & D Waste	5	M
E. GOVERNANCE			
29.	Ensuring the mobility of Traffic in the project area	8	VH
30.	Effective Functioning of Traffic Marshalls	7	H
31.	Unauthorized/Improper parking in Project area	6	M
32.	Maintenance of existing drainage system	7	H
33.	Maintenance of Barricades	7	H
34.	Ensuring the SHE (safety, Health and Environment) at site	9	VH
35.	Maintenance of existing utilities	8	VH
36.	Maintenance of existing greenery during construction	5	M
F. SPIRITUALITY			
37.	Facilities of Yoga/meditation	6	M
38.	Performance of Rituals at site like Vishvakarma Puja, May Day	7	H
39.	Celebration during Festivals at site	8	VH

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Opinion can be furnished to **Sameer Verma,** Room no. 407, JCB Hostel, DTU campus, Shahbad Daultpur, Bawana Road, Delhi – 110042. Email-sameerverma.ce@gmail.com

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Civil Construction Unit,
Min. of Enviroment &Forest,Delhi
Mobile No.(optional) :……………………. Email(optional)…………………..:

PROFORMA (for Experts)

S. No.	Sustainability Indicators	Rating	
		Quantitative	**Qualitative**
A.	**ENVIRONMENTAL**		
1.	Control on Air Pollution	5	H
2.	Control on drainage system due to construction activities	7	VH
3.	Control on water logging during Monsoon/rains	7	VH

4.	Control on noise pollution due to construction activity during day	5	H
5.	Control on noise pollution during night	7	VH
6.	Removal of trees/ depletion of Green Belt	5	H
7.	Plantation scheme	6	H
8.	Any other technique that is being used in site to make the project more green or Eco-friendly		
B. SOCIAL			
9.	Increase in stress level of commuters	7	VH
10.	Health of workers	7	VH
11.	Welfare activities for family of workers	7	VH
12.	Sanitation conditions	7	VH
13.	First Aid facility at site	7	VH
14.	Safety measures	8	VH
15.	Impact on Health of residents	8	VH
16.	Impact on safety of residents	8	VH
17.	Public conveniences in project area	6	H
C. ECONOMICS			
18.	Increase in Travel time	8	VH
19.	Increase in travel cost	8	VH
20.	Disturbance to the business/Employment of nearby residents	7	VH
D. TECHNICAL			
21.	Display of Project Details	5	H
22.	Display of Mandatory, Informatory and Cautionary Signage	8	VH
23.	Traffic Diversions	7	VH
24.	Visibility and sight distance to moving traffic	7	VH
25.	Lighting of Construction site	8	VH
26.	Barricading the site	7	VH
27.	Aesthetics of Project	6	H
28.	Handling of C & D Waste	7	VH
E. GOVERNANCE			
29.	Ensuring the mobility of Traffic in the project area	7	VH
30.	Effective Functioning of Traffic Marshalls	7	VH
31.	Unauthorized/Improper parking in Project area	7	VH
32.	Maintenance of existing drainage system	8	VH
33.	Maintenance of Barricades	7	VH
34.	Ensuring the SHE (safety, Health and Environment) at site	8	VH
35.	Maintenance of existing utilities	8	VH
36.	Maintenance of existing greenery during construction	7	VH
F. SPIRITUALITY			
37.	Facilities of Yoga/meditation	5	H
38.	Performance of Rituals at site like Vishvakarma Puja, May Day	7	VH
39.	Celebration during Festivals at site	5	H

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Opinion can be furnished to **Sameer Verma,** Room no. 407, JCB Hostel, DTU campus, Shahbad Daultpur, Bawana Road, Delhi – 110042. Email-sameerverma.ce@gmail.com

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PROFORMA (for Experts)

S. No.	Sustainability Indicators	Rating	
		Quantitative	**Qualitative**
A.	**ENVIRONMENTAL**		
1.	Control on Air Pollution	7	H
2.	Control on drainage system due to construction activities	5	M
3.	Control on water logging during Monsoon/rains	5	M
4.	Control on noise pollution due to construction activity	4	L

	during day		
5.	Control on noise pollution during night	8	VH
6.	Removal of trees/ depletion of Green Belt	7	H
7.	Plantation scheme	7	H
8.	Any other technique that is being used in site to make the project more green or Eco-friendly	8	VH
B. SOCIAL			
9.	Increase in stress level of commuters	5	M
10.	Health of workers	6	H
11.	Welfare activities for family of workers	6	H
12.	Sanitation conditions	7	H
13.	First Aid facility at site	7	H
14.	Safety measures	9	VH
15.	Impact on Health of residents	5	M
16.	Impact on safety of residents	6	H
17.	Public conveniences in project area	5	M
C. ECONOMICS			
18.	Increase in Travel time	5	M
19.	Increase in travel cost	5	M
20.	Disturbance to the business/Employment of nearby residents	4	L
D. TECHNICAL			
21.	Display of Project Details	4	L
22.	Display of Mandatory, Informatory and Cautionary Signage	8	VH
23.	Traffic Diversions	8	VH
24.	Visibility and sight distance to moving traffic	6	M
25.	Lighting of Construction site	8	VH
26.	Barricading the site	7	H
27.	Aesthetics of Project	7	H
28.	Handling of C & D Waste	7	H
E. GOVERNANCE			
29.	Ensuring the mobility of Traffic in the project area	2	VL
30.	Effective Functioning of Traffic Marshalls	8	VH
31.	Unauthorized/Improper parking in Project area	1	VL
32.	Maintenance of existing drainage system	7	H
33.	Maintenance of Barricades	7	H
34.	Ensuring the SHE (safety, Health and Environment) at site	8	VH
35.	Maintenance of existing utilities	8	VH
36.	Maintenance of existing greenery during construction	7	H
F. SPIRITUALITY			
37.	Facilities of Yoga/meditation	1	VL
38.	Performance of Rituals at site like Vishvakarma Puja, May Day	8	VH
39.	Celebration during Festivals at site	1	VL

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Your details :
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Organisation : Executive engineer ,F-123, PWD, Delhi

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PROFORMA (for Experts)

S. No.	Sustainability Indicators	Rating	
		Quantitative	Qualitative
A.	**ENVIRONMENTAL**		
1.	Control on Air Pollution	8	VH
2.	Control on drainage system due to construction activities	7	H
3.	Control on water logging during Monsoon/rains	9	VH
4.	Control on noise pollution due to construction activity	5	M

	during day		
5.	Control on noise pollution during night	8	VH
6.	Removal of trees/ depletion of Green Belt	7	H
7.	Plantation scheme	6	H
8.	Any other technique that is being used in site to make the project more green or Eco-friendly	6	H
B. SOCIAL			
9.	Increase in stress level of commuters	8	VH
10.	Health of workers	9	VH
11.	Welfare activities for family of workers	7	H
12.	Sanitation conditions	7	H
13.	First Aid facility at site	9	VH
14.	Safety measures	9	VH
15.	Impact on Health of residents	7	H
16.	Impact on safety of residents	7	H
17.	Public conveniences in project area	8	VH
C. ECONOMICS			
18.	Increase in Travel time	7	H
19.	Increase in travel cost	7	H
20.	Disturbance to the business/Employment of nearby residents	5	M
D. TECHNICAL			
21.	Display of Project Details	4	L
22.	Display of Mandatory, Informatory and Cautionary Signage	7	H
23.	Traffic Diversions	7	H
24.	Visibility and sight distance to moving traffic	7	H
25.	Lighting of Construction site	7	H
26.	Barricading the site	9	VH
27.	Aesthetics of Project	5	M
28.	Handling of C & D Waste	7	H
E. GOVERNANCE			
29.	Ensuring the mobility of Traffic in the project area	8	VH
30.	Effective Functioning of Traffic Marshalls	9	VH
31.	Unauthorized/Improper parking in Project area	5	M
32.	Maintenance of existing drainage system	9	VH
33.	Maintenance of Barricades	5	M
34.	Ensuring the SHE (safety, Health and Environment) at site	7	H
35.	Maintenance of existing utilities	7	H
36.	Maintenance of existing greenery during construction	9	VH
F. SPIRITUALITY			
37.	Facilities of Yoga/meditation	4	L
38.	Performance of Rituals at site like Vishvakarma Puja, May Day	4	L
39.	Celebration during Festivals at site	2	VL

SUBJECT : SURVEY TO ASSIGN THE WEIGHTAGE TO THE VARIOUS SUSTAINABILITY INDICATORS IDENTIFIED FOR AN INFRASTRUCTURE PROJECT UNDER CONSTRUCTION IN AN URBAN ENVIRONMENT

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SCALE 1 : Quantitative Analysis on a scale **0 to 9**. The sustainability indicator with no importance may be assigned **'0'** value and most important indicator may be assigned **'9'** value. Accordingly values may be assigned from **0** to **9** on the basis of its importance.

SCALE 2 : Qualitative Analysis among **VL** (Very Low), **L** (Low), **M** (Medium), **H** (High) and **VH** (Very High). The sustainability indicator with least importance may be assigned **'VL'** value and most important indicator may be assigned **'VH'** value. Accordingly values may be assigned from **VL** to **VH** on the basis of its importance.

Please furnish your fair comments/ opinion in so that indicators identified may be used for grading a project from sustainability point of view and we can make more sustainable projects in future.

Opinion can be furnished to **Sameer Verma,** Room no. 407, JCB Hostel, DTU campus, Shahbad Daultpur, Bawana Road, Delhi – 110042. Email-sameerverma.ce@gmail.com

Your details :
Name : H K Srivastava
Organisation : Additional D G (Works), CPWD, Retd

Mobile No.(optional) :……………………. Email (optional)…………………..:

PROFORMA (for Experts)

S. No.	Sustainability Indicators	Rating	
		Quantitative	Qualitative
A.	**ENVIRONMENTAL**		
1.	Control on Air Pollution	9	VH
2.	Control on drainage system due to construction activities	5	M
3.	Control on water logging during Monsoon/rains	6	M
4.	Control on noise pollution due to construction activity	7	H

	during day		
5.	Control on noise pollution during night	7	H
6.	Removal of trees/ depletion of Green Belt	8	VH
7.	Plantation scheme	5	M
8.	Any other technique that is being used in site to make the project more green or Eco-friendly	7	H
	B. SOCIAL		
9.	Increase in stress level of commuters	8	VH
10.	Health of workers	9	VH
11.	Welfare activities for family of workers	7	H
12.	Sanitation conditions	9	VH
13.	First Aid facility at site	8	VH
14.	Safety measures	9	VH
15.	Impact on Health of residents	8	VH
16.	Impact on safety of residents	9	VH
17.	Public conveniences in project area	7	H
	C. ECONOMICS		
18.	Increase in Travel time	8	VH
19.	Increase in travel cost	5	M
20.	Disturbance to the business/Employment of nearby residents	5	M
	D. TECHNICAL		
21.	Display of Project Details	4	L
22.	Display of Mandatory, Informatory and Cautionary Signage	8	VH
23.	Traffic Diversions	8	VH
24.	Visibility and sight distance to moving traffic	9	VH
25.	Lighting of Construction site	8	VH
26.	Barricading the site	8	VH
27.	Aesthetics of Project	8	VH
28.	Handling of C & D Waste	8	VH
	E. GOVERNANCE		
29.	Ensuring the mobility of Traffic in the project area	8	VH
30.	Effective Functioning of Traffic Marshalls	8	VH
31.	Unauthorized/Improper parking in Project area	8	VH
32.	Maintenance of existing drainage system	8	VH
33.	Maintenance of Barricades	8	VH
34.	Ensuring the SHE (safety, Health and Environment) at site	9	VH
35.	Maintenance of existing utilities	9	VH
36.	Maintenance of existing greenery during construction	7	H
	F. SPIRITUALITY		
37.	Facilities of Yoga/meditation	5	M
38.	Performance of Rituals at site like Vishvakarma Puja, May Day	6	M
39.	Celebration during Festivals at site	5	M

SUBJECT : SURVEY TO ASSIGN THE WEIGHTAGE TO THE VARIOUS SUSTAINABILITY INDICATORS IDENTIFIED FOR AN INFRASTRUCTURE PROJECT UNDER CONSTRUCTION IN AN URBAN ENVIRONMENT

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Your details :
Sarvagya Srivastava
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Flyover Project Zone, PWD (GNCTD), New Delhi
Phone No.: (01123317926) Email: cepwddelhifzf1@gmail.com

PROFORMA (for Experts)

S. No.	Sustainability Indicators	Rating	
		Quantitative	Qualitative
A.	ENVIRONMENTAL		
1.	Control on Air Pollution	9	VH
2.	Control on drainage system due to construction activities	9	VH
3.	Control on water logging during Monsoon/rains	9	VH

4.	Control on noise pollution due to construction activity during day	6	M
5.	Control on noise pollution during night	7	H
6.	Removal of trees/ depletion of Green Belt	8	H
7.	Plantation scheme	8	H
8.	Any other technique that is being used in site to make the project more green or Eco-friendly	9	VH
B. SOCIAL			
9.	Increase in stress level of commuters	6	M
10.	Health of workers	8	H
11.	Welfare activities for family of workers	7	H
12.	Sanitation conditions	8	H
13.	First Aid facility at site	7	H
14.	Safety measures	9	VH
15.	Impact on Health of residents	7	H
16.	Impact on safety of residents	8	VH
17.	Public conveniences in project area	7	H
C. ECONOMICS			
18.	Increase in Travel time	8	VH
19.	Increase in travel cost	8	VH
20.	Disturbance to the business/Employment of nearby residents	7	H
D. TECHNICAL			
21.	Display of Project Details	9	VH
22.	Display of Mandatory, Informatory and Cautionary Signage	9	VH
23.	Traffic Diversions	9	VH
24.	Visibility and sight distance to moving traffic	8	H
25.	Lighting of Construction site	9	VH
26.	Barricading the site	9	VH
27.	Aesthetics of Project	8	H
28.	Handling of C & D Waste	7	H
E. GOVERNANCE			
29.	Ensuring the mobility of Traffic in the project area	9	VH
30.	Effective Functioning of Traffic Marshalls	8	H
31.	Unauthorized/Improper parking in Project area	7	H
32.	Maintenance of existing drainage system	9	VH
33.	Maintenance of Barricades	8	H
34.	Ensuring the SHE (safety, Health and Environment) at site	8	H
35.	Maintenance of existing utilities	8	H
36.	Maintenance of existing greenery during construction	8	H
F. SPIRITUALITY			
37.	Facilities of Yoga/meditation	2	VL
38.	Performance of Rituals at site like Vishvakarma Puja, May Day	8	H
39.	Celebration during Festivals at site	5	M

SUBJECT : SURVEY TO ASSIGN THE WEIGHTAGE TO THE VARIOUS SUSTAINABILITY INDICATORS IDENTIFIED FOR AN INFRASTRUCTURE PROJECT UNDER CONSTRUCTION IN AN URBAN ENVIRONMENT

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Please furnish your fair comments/ opinion in so that indicators identified may be used for grading a project from sustainability point of view and we can make more sustainable projects in future.

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Your details :
Name :Vijay Kumar Shrivastava
Organisation :VKS Infratech Management Pvt. Ltd.

Mobile No.(optional) :09810210383 Email (optional): vijay@vksinfra.com

PROFORMA (for Experts)

S. No.	Sustainability Indicators	Rating	
		Quantitative	Qualitative
A.	**ENVIRONMENTAL**		
1.	Control on Air Pollution	9	VH
2.	Control on drainage system due to construction activities	8	H
3.	Control on water logging during Monsoon/rains	8	H
4.	Control on noise pollution due to construction activity	5	M

	during day		
5.	Control on noise pollution during night	8	H
6.	Removal of trees/ depletion of Green Belt	9	VH
7.	Plantation scheme	8	H
8.	Any other technique that is being used in site to make the project more green or Eco-friendly		
B. SOCIAL			
9.	Increase in stress level of commuters	9	VH
10.	Health of workers	8	H
11.	Welfare activities for family of workers	8	H
12.	Sanitation conditions	8	H
13.	First Aid facility at site	9	VH
14.	Safety measures	9	VH
15.	Impact on Health of residents	9	VH
16.	Impact on safety of residents	9	VH
17.	Public conveniences in project area	9	VH
C. ECONOMICS			
18.	Increase in Travel time	8	H
19.	Increase in travel cost	7	H
20.	Disturbance to the business/Employment of nearby residents	7	H
D. TECHNICAL			
21.	Display of Project Details	7	H
22.	Display of Mandatory, Informatory and Cautionary Signage	9	VH
23.	Traffic Diversions	9	VH
24.	Visibility and sight distance to moving traffic	9	VH
25.	Lighting of Construction site	9	VH
26.	Barricading the site	9	VH
27.	Aesthetics of Project	8	M
28.	Handling of C & D Waste	9	VH
E. GOVERNANCE			
29.	Ensuring the mobility of Traffic in the project area	8	H
30.	Effective Functioning of Traffic Marshalls	8	H
31.	Unauthorized/Improper parking in Project area	7	H
32.	Maintenance of existing drainage system	8	H
33.	Maintenance of Barricades	7	H
34.	Ensuring the SHE (safety, Health and Environment) at site	9	VH
35.	Maintenance of existing utilities	8	H
36.	Maintenance of existing greenery during construction	7	H
F. SPIRITUALITY			
37.	Facilities of Yoga/meditation	3	VL
38.	Performance of Rituals at site like Vishvakarma Puja, May Day	3	VL
39.	Celebration during Festivals at site	3	VL

APPRENDIX B

SUBJECT: SURVEY TO ASSESS THE CONSTRUCTION OF INFRASTRUCTURE PROJECTS IN DELHI FROM SUSTAINABILITY POINT OF VIEW

A survey of the Residents /Commuters residing/passing through the construction site of Infrastructure projects in Delhi has been undertaken by a Project/Research Team of Environmental Engineering Department of Delhi Technological University (DTU) to assess the construction of few infrastructure projects in New Delhi from the sustainability point of view.

The indicators identified have been listed on left hand side. Construction agency is expected to make suitable arrangements so that there is least impact or in-convenience to the public residing nearly or passing through the corridor. The rating from 0 to 9 can be given depending upon the inconvenience caused to the public. Best arrangements can be assigned higher marks and least ararngments causing maximium inconvenience can be assigned minimum marks

Following two Projects have been selected for study and making a comparison between them

1. PWD Elevated road Project from Vikaspuri to Meerabag
2. DMRC Metro Rail Elevated Corroidor (Part) from Punjabi Bagh to Mayapuri as a part of Phase 3, Line 7

A common Performa with various sustainability indicators is enclosed herewith and it is requested that the resident/commuter rate the indicators of either Site A or Site B or both sites depending on the knowledge of the sites under consideration. Please submit your rating regarding the indicators mentioned on the following scale.

NOTE: It is requested to rate only those indicators which a resident/commuter is aware of at the site under construction otherwise leave the space blank.

Please furnish your fair comments/ opinion in so that indicators identified may be used for grading a project from sustainability point of view and we can make more sustainable projects in future.

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