SUSTAINABILITY STUDIES OF TRANSPORTATION CORRIDORS IN METROPOLITAN CITY DELHI

A THESIS

submitted in partial fulfillment of the requirements
for the award of the degree

DOCTOR OF PHILOSOPHY

IN

ENVIRONMENTAL ENGINEERING

by

SHISHIR BANSAL

DEPARTMENT OF ENVIRONMENTAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
DELHI, INDIA

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SHISHIR BANSAL
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JUNE, 2020

dedicated to my mother…

DELHI TECHNOLOGICAL UNIVERSITY, DELHI

DECLARATION

I hereby declare that the work presented in the thesis entitled "**Sustainability Studies of Transportation Corridors in Metropolitan City Delhi"** is based on the original work carried out by me under the supervision of Prof. (Dr.) S K Singh, Professor & Head, Department of Environmental Engineering, Delhi Technological University, Delhi, India.

I further declare that no part of this thesis has been presented or submitted for any other Degree to any other Institute or University.

Place: Delhi
Date: 27.06.2020

(Shishir Bansal)
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DELHI TECHNOLOGICAL UNIVERSITY

DELHI

CERTIFICATE

It is to certify that the thesis entitled "**Sustainability Studies of Transportation Corridors in Metropolitan City Delhi"** submitted by Mr. Shishir Bansal to the Delhi Technological University, Delhi for the award of Degree of "Doctor of Philosophy" in the Department of Environmental Engineering at is an authentic original work carried out by him under my supervision and guidance. To the best of my knowledge, Mr. Shishir Bansal has fulfilled all the requirements and requisite standards for the submission of thesis laid down by Delhi Technological University.

No part of this thesis has been presented or submitted for any other degree to any other University or Institute.

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Place: Delhi, India
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(Shishir Bansal)
2K12/PHD.ENV/04

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ABBREVIATIONS

AHP	Analytic Hierarchy Process
AIIMS	All India Institute of Medical Sciences
ASI	Archeological Survey of India
BSNL	Bharat Sanchar Nigam Limited
C & D	Construction and Demolition
CBA	Cost Benefit Analysis
CGO	Central Government Office
CIRIA	Construction Industry Research and Information Association
CLC	Cantilever construction
CO2	Carbon Dioxide
CORSIM	Microscopic Simulation Model CST
CPWD	Central Public Works Department
CRRI	Central Road Research Institute
dB(A)	Decibels in A weighted system
DDA	Delhi Development Authority
DJB	Delhi Jal Board
DMRC	Delhi Metro Rail Corporation
DPM	Diesel particulate matter
DTTDC	Delhi Tourism and Transportation Development corporation
DTU	Delhi Technological University
EIA	Environment Impact Assessment
ELECTRE	ELimination Et Choice Translating REality
ESCOT	Economic Assessment of Sustainability Policies of Transport
EU	European Union
F	Fair
FBEM	Fuzzy-Based Evaluation Method
FL	Fuzzy Logic
FOB	Foot Over Bridge
FRC	Fibre Reinforced concrete
G	Good
GDP	Gross Domestic Product
GHGs	Green-House Gases
GOOGLE	Global Organization of Oriented Group Language of Earth
GRIHA	Green Rating for Integrated Habitat Assessment
GT road	Grand Trunk Road
H	High
HDI	Human Development Index

HT cables	High Tension Cables
IG stadium	Indra Gandhi Stadium
IGL	Indraprastha Gas Limited
IIT	Indian Institute of Technology
INNOREF	INNOvation and Resource EFficiency
IP flyover	Indraprashtha Flyover
IRC:SP:47	Indian Roads Congress: Special publication 47
ISO	International Standards Organization
JCB	Joseph Cyril Bamford
JLN Stadium	Jawahar Lal Nehru Stadium
kV	Kilo Volt
L	Low
LBS	Lal Bahadur Shastri
LCA	Life Cycle Assessment
Leq	Equivalent continuous sound level
LEED	Leadership in Energy and Environment Design
M	Medium
M & O	Management & Operations
MACBETH	Measuring Attractiveness by a Categorical Based Evaluation Technique
MAUT	Multi-Attribute Utility Theory
MCDA	Multiple Criteria Decision Analysis
MCDM	Multiple Criteria Decision Making
MTNL	Mahanagar Telephone Nigam Limited
NCCBM	National Council for Cement and Building Materials
NH-24	National Highway-24
NHAI	National Highway Authority of India
NO_x	Nitrogen oxides
OECD	Organization for Economic Co-operation and Development
OFC	Optical fibre cables
OPC	Ordinary Portland Cement
P	Poor
PCs	Personal Computers
PCU	Passenger Car Unit
PhD	Doctor of Philosophy
PM	Particulate matter
PWD	Public Works Department
QA	Quality Assurance
QoL	Quality of Life
RCC	Reinforced Cement Concrete
RITES	Railway India Technical and Economic Services

RMC	Ready Mix Concrete
ROW	Right of Way
RWAs	Resident Welfare Associations
SAW	Simple Additive Weighting
SCC	Self-Compacting Concrete
SETU	Sustainability Evaluation of Transportation infrastructure in Urban areas
SPARTACUS	Systems for Planning and Research in Towns and Cities for Urban Sustainability
SWOT	Strengths, Weaknesses, Opportunities and Threats
T	Tonne
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TRB	Transportation Research Board
UNCED	United Nations Conference on Environment and Development
UNGBC	United States Green Building Council
VG	Very Good
VH	Very High
VIKOR	Vlsekriterijumska Optimizacija I Kompromisno Resenje
VL	Very Low
VOCs	Volatile Organic Compounds
VP	Very Poor
WCED	World Commission on Environment and Development
WPM	Weighted Product Model
WSM	Weighted Sum Model
r	Correlation Coefficient
μ (mu)	Mean
ρ (rho)	rank correlation
σ (sigma)	Standard Deviation

ABSTRACT

Stockholm, Sweden conducted the 1st United Nations (UN) Conference on the Human Environment in 1972. Later on, the term 'Sustainability' was coined during discussions carried out at various forums in the Brundtland Commission held in 1987. It was conceptualised as "meeting the needs of the present generation without compromising the ability of future generations to meet their own needs". The aim and ambition of making a provision of sustainable characteristics in the planning and execution of transportation corridor in an urban environment are to minimise footprints on the natural resources and their consumption for the benefit of society, encourage society in the process of planning of transportation systems and ultimately strike a balance between the demands of the community, mother nature and sound economical practices. These 3 Parameters i.e. social, economic and environmental were most commonly accepted as three pillars of sustainability.

Sustainability in transportation system has become an important issue day by day and can be observed distinctly with the traffic congestion observed in urban areas and poor quality of air we breathe-in having an impact on our health. Sustainability indicators needs to be developed by going to the on-going construction project sites and by interacting with all the stakeholders getting impacted in this field. Without conceding with the capacity of the next generation to fulfill their own needs, research work has been carried out following broad objective of Identification of different sustainability indicators for the transportation framework in urban environment, assessing the sustainability of the construction sites with application of Fuzzy-Vikor methodology and simplifying the methodology for sustainability evaluation.

The work done during the period of research is primarily carried out to notice and detail out the Sustainability indicators that governs during the execution stage of a transportation project in a predominantly urban area. The research has been made on four projects under construction and later on completed in 2016, 2017, 2018 and 2019. The methodology adopted in this research was a five step procedure in order to identify the suitable sustainability indicators, categorise them and carry out the sustainability analysis. Subsequently a simpler and more suitable technique for sustainability analysis has been developed.

As per the studies carried out on the four construction sites during the peak of their execution, it was identified that the sustainability of the transportation projects during their construction in an urban environment is just not limited to three Pillars, but is actually much beyond that. Every activity or any Project has been looked into the right perspective to understand its relevance to all those it matters. Transportation sector is an area that affects the life of every individual in all areas say education sector, commercial activities, availing of medical amenities or say movement of the public at large for any purpose they need to commute. It is not only the operation stage, but the construction stage also that makes an impact on the residents living nearby as well as on the commuters passing through the corridor on the route or through the diverted route. All such members of society are exposed to air pollution, noise pollution, water pollution, increase in travel time besides health and safety concerns. Environment faces irreversible degradation and other adverse impacts on the numerous directly or indirectly related issues.

Various Sustainability Indicators during the execution as identified during the construction of four elevated transportation corridors and thereafter their classification into various categories are a part of this research. With the comparative study on the selected construction sites during construction stage, the most sustainable site based on identified sustainability indicators was distinguished. Finally, a **SETU rating system** has been

generated for the **S**ustainability **E**valuation of the **T**ransportation infrastructure in an **U**rban Environment (**SETU**). Based on the SETU rating system, the projects during the construction stage can be assigned Silver, Gold, Diamond and Platinum ratings.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Traffic and transportation system varies largely from one country to another country and as well from one city to another city. So are the travelling patterns of the people varies largely in different countries and different cities. Even the travel characteristics are different in rural areas than in urban areas [19]. It depends upon their economic growth, population density as well as vehicular density. It also depends upon the need of the people, development that has taken place in any particular area. Depending upon the overall development in economic front or tourism potential, the city's transportation system is planned. But at large, it is observed that the all the developed countries worldwide have more popular public transportation system rather than the private mode of transport.

The day to day progress made in transportation sector in an urban environment urges the planners to plan and maintain their transportation systems in a better manner, more accurately and precisely meeting the exponentially growing demands with multiple complexities vis-à-vis numerous needs and interests like reduction in pollution levels, relief in traffic congestion, use of available resource in more efficient manner and better accessibility.

A sustainable transportation system (Figure 1) will always allow securely fulfilling the basic demands of the society and caring for the equitable transfer of existing resources from one generation to another generation without compromising with the restrictions due to additional cost whether internally or externally. It operates in a fair and efficient manner, with an overall balanced development in the region. It will limit not only the pollution

generated due to Green House Gases (GHGs) and other wastes, but also reduce the misuse of land, pollution due to noise and is designed such as to encourage the active participation of all stakeholders of the society.

Fig. 1: Essential features of a transportation system [27]

The studies during this research started with understanding the sustainability of the transportation framework, its exponential growth and efficient performance. Further the research identified the key sustainability issues related with the execution of the transportation projects in the Metropolitan cities like Delhi. In this research, Sustainability indicators of the transportation corridors during construction stage in an urban area have been identified and categorised.

A detailed study of four corridors during the construction stage in a thickly Urban Environment namely, Elevated Corridor in Western part of Delhi, Delhi Metro Rail Corridor

again in Western part of Delhi, Signature Bridge over river Yamuna in North-Eastern part of Delhi and Barapulla Elevated Corridor project in Southern Part of Delhi. In this research made at these four sites during the mid of the construction period, it was learned that sustainability of the transportation corridors during execution is not limited to just three Pillars, but rather much beyond that. It was observed that when a city is changing its fabric from the under-developed to developing and further to the developed stage, lot of social, economic, educational and general behaviour level gets modified. Priorities change for a citizen when the city changes from the under developed to developed city. Hence, the sustainability indicators identified for a developed city of US or Europe cannot be considered as such for a city like Delhi that has been facing a big challenge of existence due to human as well as vehicular population explosion. It is mainly the cultural, economic and social difference between Delhi and other developed cities worldwide.

1.2 TRAFFIC SCENARIO IN CAPITAL CITY OF INDIA

An exponential growth in vehicular traffic has been noticed in New Delhi, the metropolitan city and also the Capital of India, while the infrastructure growth has not been proportionate to it. It is observed that there is an exponential rise in the contamination levels, traffic congestions, anxiety levels, travelling time etc.. The traffic flow pattern in Delhi is nearly Ring-Radial pattern that embodies two concentric Roads prominently known as inner Ring Road and Outer Ring Road. Though Inner Ring Road is a continuous ring, but Outer Ring Road is discontinuous. Delhi has an extensive highway network in the country that covers about 21% of the city area. The number of flyovers are about to cross 100 in numbers, as on date, still there is insufficient road network for the comfortable movement of traffic. Delhi's vehicle stock has augmented 51 times in last three decades. Delhi alone has around 10% of total enlisted vehicles all over India. This number of vehicles is ascending at 10% consistently. The day trips have already crossed 20 million and there is an augmentation of 2 million for each year. To suit the expanding activity and to decongest existing movement, street spaces have been expanded. The new streets wind up drawing

more activity and induce more traffic. As per the studies carried out on traffic, it is revealed that 50% of the increased capacity is used up by increased traffic immediately, while up to 50% is consumed by the induced traffic in next five years. Numerous urban areas in the United States are making amazing strides of destroying the flyovers and interstates. This might not be the required strategy in Delhi, but very soon the physical limits of adding the infrastructure will get saturated. So, a more sustainable way out to Delhi's infrastructure problems need to be assessed.

1.3 NEED OF THE RESEARCH WORK

Nowadays, the global necessity of sustainable development is established and likewise, it is a fundamental principle that every single action we perform for the improvement of the general public has to be sustainable. The sustainability parameters that have been widely accepted are environmental issues, economics and social factors. Yet these three factors are constrained just to developing countries where the need for sustainable development has been forecast. When one observes the present development scenario in New Delhi, Mumbai, Kolkata, Chennai, Hyderabad, Bengaluru, Ahmedabad or any other urban city in India we see that the overall acknowledgement of these 3 parameters cannot satisfy the pre-requisite in India. It is often observed that development of transportation corridors in urban areas like Delhi are executed by the construction agencies in somewhat dis-organised manner. Many such agencies are not sufficiently sensitive towards the contaminants being released into nature and comforts of the residents as well as the traffic passing through their project area. Even the concerned authorities are not taking the mandatory measures in implementation of various methods envisaged in the agreement. As a result of indifferent attitude, the comfort of people moving through the corridors as well as local people is totally overlooked, compromised or say badly ignored.

The origin of majority of the environmental issues lies in the operating systems of the cities, and their impact like traffic congestion, pollution in the air, pollution due to noise

etc.. Notwithstanding, there are numerous impacts that exist together having a trans-border nature, say disposal of sanitary wastes, flow of waste water, or even global issues such as hot emissions due to traffic leading to greenhouse effect and in turn results in global warming. With an objective of addressing such issues, it has been chosen to do a study to appreciate the issues apart from the development activities and the effects of such activities on our surroundings and society.

As far as Sustainable transportation development is concerned, it lags considerably behind the building infrastructure. Leadership in Energy and Environmental Design (LEED) is an internationally accepted certification to qualify buildings as green as far as their design, execution and post-execution maintenance is concerned. There is still a need to develop such a system for transport infrastructure projects to qualify them as green or say, sustainable transport systems. Indeed, transportation infrastructure projects are in general evaluated with an objective of achieving a good cost–benefit ratio with the limitation on the budget provisions. Considering the need of green development, a definite sustainable transportation evaluation method is required for setting up the green standards for the transportation corridor development. One major difference between buildings infrastructure and transport infrastructure is that building construction takes place in confined boundary walls whereas transportation infrastructure are executed in public places directly impacting the public passing through and others living nearby the construction site. Transport infrastructure has different phases in its life that starts from designing and planning followed by execution, then maintenance, major repairs and finally replacement after its service life is over. Hence, while the standard rating system of transportation infrastructure is to be developed, it is to be created separately for all these stages. The stage which has been covered up in this research work is the construction stage taking place in an urban environment that has a direct impact on public residing nearby as well as that makes the traffic passing through the corridor under construction.

1.4 OBJECTIVES OF STUDY

Sustainability in transportation system is becoming an important issue day by day and can be observed distinctly with the traffic congestion observed in Urban area and poor quality of air we breathe-in having an impact on our health. There is an urgent need for an improved and justified access to the services, be it social services or economic services in all areas across the globe [28]. The criteria for assessing the Sustainability of transportation base has nowhere been characterised and it encourages a lot of research work. Sustainability indicators needed to be developed by studying the on-going construction sites and by interacting with all the stakeholders making an impact and also those who gets impacted in this field. Bearing in mind, the need of day without dealing with the capacity of the next generation to fulfill their own particular needs, research work has been carried out with following broad objectives.

i. Identification of Sustainability Indicators for the transportation framework while undertaking development in Metropolitan city Delhi
ii. Application of a Fuzzy-Vikor methodology to assess sustainability of the construction sites chosen for the research work
iii. To simplify the methodology for Sustainability Evaluation
iv. To make the execution sustainable while creating a transportation network.

1.5 SCOPE OF WORK

With the ever-expanding demand for infrastructure development of society, it is a history when development in the urban environment was taken up without due thought of its adverse effect on society. These days, the overall need of sustainable advancement is affirmed and as needs be, it is key that every single action for the improvement of the general public is performed ought to be sustainable. The sustainability indicators that have been generally acknowledged are environmental issues, financial aspects and social variables. Factually, these three components are suitable just to developing nations. When

we see the developing country like India and further progressing situation in Mumbai, New Delhi or other urban city in India, we see that the overall acknowledgement of these 3 parameters cannot fulfill its necessity. So, the list has been extended with three additional parameters and their sub classification have been evolved to ensure sustainable development.

It has already been stated that the provisions for comfort of residents, traffic, users as well as environment protection are quoted in the agreement of various construction works, but they are not practically implemented in true spirit. Hence, Governance is another issue that requires attention for achieving the sustainability. Further, It was observed that Delhi is a fast developing metropolitan city with deployment of latest state of the art technologies and utilisation of advancements tried in many developed nations. Still, a big gap is observed while implementation of these technologies and practical implementation under the circumstances dominated in an urban environment. There is a need of a strong technical base while making a final decision on the technical issues. Besides this, it was observed that there is kiosk at site during the construction and as well as off the site where heavy traffic is negotiating the corridor. The labour working on the site during the hot sunny day or chilly cold nights during winters compromise with their health as well as self-dignity. Off the site, it is observed that excessive honking, haphazard movement of vehicles adding to the traffic congestion creates turbulence in the mind of commuters passing through. Lots of tolerance is needed to maintain the cool temperament that can be achieved by enhancing the spirituality quotient in each of the stakeholders whether on the site or off the site. Hence, it is fundamental that all partners including labourers and inhabitants need to accomplish a feeling of co-existence to keep up a cool disposition and to avoid mis-happenings under such a circumstance. Thus, the scope of work included the identification of other parameters that augments the sustainability indicators already defined for the developed nations.

Further, it is observed that there are many sustainability evaluation methodologies defined, still there does not exist any single approved and established mechanism. There is a strong need of a simpler methodology for sustainability evaluation that encourages the performers to perform better in order to get them evaluated with better rating. Thus SETU rating system, a suitable as well as simpler methodology for the assessment of transportation corridors during construction stage in an urban environment has been generated.

1.6 RESEARCH FRAMEWORK

The various sustainability indicators that are identified and sustainability evaluation methodology developed in this research has been undertaken in following stages.

i. A review of existing sustainability indicators and sustainability evaluation models was carried out in order to understand the status of sustainability in transportation sector. Missing parameters were also identified.

ii. The study of growth of transportation infrastructure in Delhi Metropolitan city since independence and surge in its growth observed during the two mega evens ASIAD 1982 and commonwealth Games 2010.

iii. Identification of different Sustainability Indicators as suitable to transportation framework in a Metropolitan city Delhi after closely studying four construction sites under identical urban environment,

iv. Assessing the sustainability of the sites taking into account the identified sustainability indicators with the application of the Fuzzy-Vikor technique.

v. Developing a suitable and simpler methodology i.e. SETU rating system for the evaluation of the transportation corridors under construction in an urban area.

1.7 OUTLINE OF THESIS

This thesis is written in seven chapters. The 1st Chapter is titled as introduction and it covers the background of transportation system along with scenario in India. The

aim and objectives of the research have been defined along with scope of work and the research framework. 2nd Chapter covers with Literature review in which the available literature since the 1st international conference on Human Environment took place at Stockholm in 1972 and thereafter, when the first time sustainability term was coined during the Brundtland commissioning 1987. Subsequently, the research carried till date out on sustainability criteria and sustainability evaluation in the transportation sector has been covered in this chapter. 3rd Chapter deals with the review of transportation corridors in Delhi since independence. The two major thrust in the creation of transportation Infrastructure during the Asiad 1982 and Commonwealth Games 2020 have been discussed in details. 4th Chapter covers the initiation of research with the identification of Sustainability Indicators that are more prevalent in a developing country rather than a devolved country. The focus is on the construction site of transportation corridor in an urban environment. 5th Chapter covers the application of Fuzzy-Vikor technique to assess the sustainability that has been explained as applied on four sites selected for studies and carrying out the research. 6th Chapter covers the novelty of the research by developing the SETU rating system and SETU index for rating the transportation corridors and evaluating sustainability of the projects under construction in an Urban Environment. A set of guidelines developed for assessing the corridors have been spelled out in details in this chapter. The last Chapter i.e. 7th Chapter covers the conclusions and recommendations besides scope for the future work. Finally, the above seven chapters are followed by the references.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this progressing society, development is noticed taking place everywhere at moment, in all fields across the globe. Even a country in US or Europe, tagged as a well-developed country are striving further for excellence and keeping themselves ahead of the other competitors in the race of development. When the emphasis is on the development, it will have a meaningful impact on society, only if it is sustainable. Sustainability has been defined at various forums, but still it is felt that a perfect definition of sustainability is yet to be coined. Similarly, other connected terms are sustainability indicators and sustainability index needs an appropriate definition. Sustainability Indicators vary from the field-to-field or say areas to areas as per the demand of a particular community and that too change with the changing circumstances.

Sustainability indicators and Sustainability index are becoming very popular every day and actually it may be used for planning and designing any system, may it be managing a multinational firm or designing a regional transportation system. Sustainability index provides a fair idea of sustainability features adopted in designing any system. Even the most complicated problem can be handled suitably by adopting the tool of sustainability measures. In fact, development or growth in any sector is not really meaningful, unless it is qualified with the title of sustainability. Sustainable growth essentially needs to have a proper balance between the environment protection, socially meaningful and economically viable. Development, covers growth in all sectors like imparting education to the needy, exploring the space or deep ocean, providing latest medical facilities or say minimum infrastructure facility to everyone. But, precisely all these or any other field wherever development is desired, it is not possible to have an effective growth unless an efficient

transportation sector is available to each and every one. Thus, a sustainable transport system is most demanded area in which any developed or a developing country will rely. Transportation investments must balance the objective of financial responsibility, quality of life to community and ensuring a better environment. Besides mobility and safety [30]. Other objectives for consideration are saving of the natural resources, public health improvement, expansion of the economy, strengthening the energy security, and disadvantaged people provided mobility [22]. Various approaches have been suggested across the globe and some popular approaches as proposed at various forums world-wide have been reviewed as furnished below.

2.2 EVOLUTION OF SUSTAINABLE DEVELOPMENT

Before proceeding towards identification of various sustainability indicators and popular theories to measure the sustainability, it is necessary to understand the evolution of the sustainable development. This issue has been under discussions at various forums for nearly half a century and yet, a perfect definition of sustainable development or say sustainable growth could not be coined. Various scholars working in this area have been providing their inputs to make it as precise as possible. Tracing the literature way back, in 1972, Meadows et al. [37] highlighted the growing population to be a burning issue of that era. Along with the rising population there is an exponential growth in industries, rise in food industry, increase in pollution level and also the simultaneous depletion of available resources. It was cautioned that with this alarming situation, the growth will be limited in next one century. While cautioning the society, with the impacts of such a growth, it was emphasised that the ecological and economic conditions are essentially to be made sustainable by altering the present trend of growth. Every human being is to be provided basic necessities and their potential for meeting the target of sustainable growth along with a secure future is to be realised. Sustainable growth and a secure future can be achieved only if the sustainability is seen in every act of life rather than limiting to a few sectors.

2.2.1 World Commission on environment and development

The World Commission on Environment and Development (WCED) i.e. Brundtland commission was created in 1984 and was assigned the task to frame a global agenda for change. Its report published in 1987 along with a document "our Common future" [85]. Thus, term sustainable development that was initially coined in 1980 became popular only in this report of the WCED. The term 'sustainable development' was defined in the report of Brundtland commission as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". 'Needs' and 'Limitations' were noticed as two key words in this definition. Needs indicates the utmost requirements of the poor people across the globe, whereas limitations indicates the restrictions on the ability of the environment itself to meet the current as well as future needs. Later on, the United Nations Conference on Environment and Development (UNCED) made the sustainable development as a global mission during the conference held at Rio de Janeiro in 1992.

2.2.2 Environmentally sustainable transportation sector

After the definition of Sustainable development, environmentally sustainable transport (EST) was also explained as the transportation system meeting the mobility needs and simultaneously caring for the safe public health and safe ecosystems. Thus, the emission of nitrogen oxides (NO_x), volatile organic compounds (VOCs), carbon dioxide (CO_2), particulate matters were concerned seriously including the protection of ecosystem as well as limiting the Noise levels with an objective of achieving the Environmentally sustainable transport by 2030. Organization for Economic Co-operation and Development (OECD) had organised a 4 days conference on "Towards Sustainable Transportation" in March 1996 in Vancouver hosted by British Columbia. It was highlighted during the conference that with the growth in the mobility of people as well as goods, the society is compromising the advantages of growth in social and economic area [2]. The transportation sector is getting

more and more activated adding challenges to the society in meeting the target of sustainable development.

Triple bottom line approach provided by Belka is another appropriate approach that focuses on an integrated issues of social, economic and environmental issues [7].

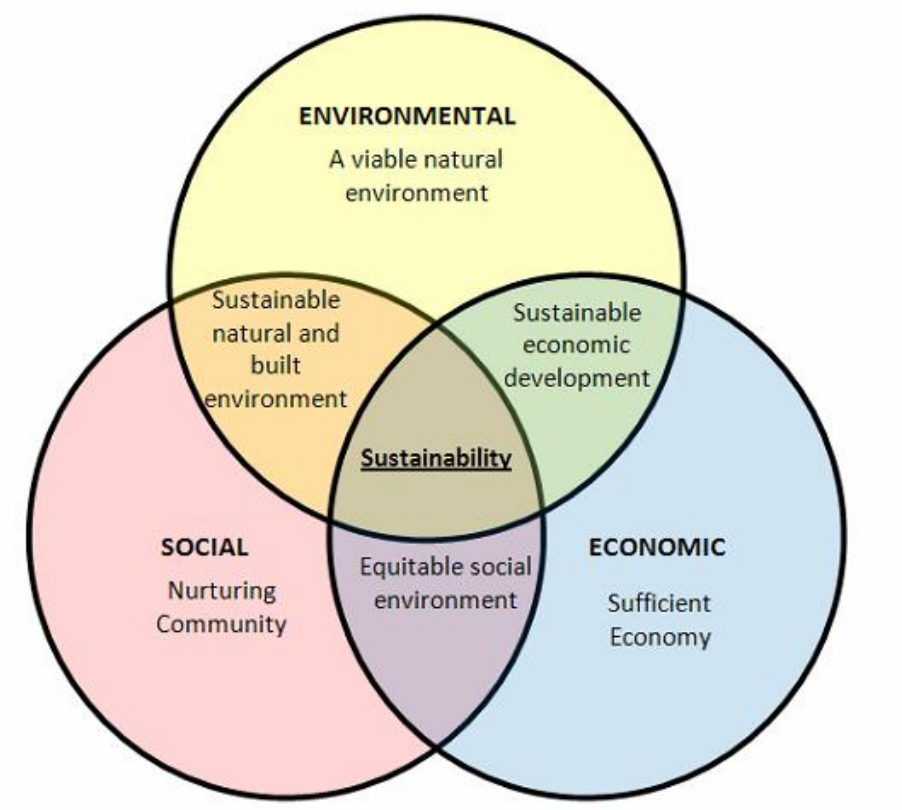

Fig. 2: TRIPLE BOTTOM LINE APPROACH [14]

Linda Steg and Robert Gifford [76 to 78] also showed their concern on the increasing use and increasing density of automobiles and its impact on quality of life. Increasing mobility may provide a short-term gain but the long-term losses to society also requires attention.

2.3 SUSTAINABILITY AND SUSTAINABILITY INDICATORS

Sustainable development or say specifically sustainable transport system demands to strike a balance between the need of the hour and demands of future as regards to the

environmental, social and economic qualities. But it was still not elucidated that which of such qualities needs to be ensured. The issue remained under discussion at various forums amongst researchers and academicians. Despite best efforts at all levels, sustainable transport indicators could not be defined suitably [5]. Sustainable development or more precisely sustainable transport was implied to be finding an adequate balance between present as well as future environmental, social and economic issues [31]. Even the indicators to appreciate the environmental, social and economic parameters could not be identified. Economic indicators may include Gross Domestic Product (GDP), income distribution amongst various sections of society and unemployment issues. Social indicators may include health, safety issues that may have an impact of the quality of one's life. Environmental indicators may cover emissions, waste management, air, water and land pollution etc. In addition to the Environmental indicators, and monitoring the data, there are many other considerations for making a decision [49].

2.3.1 Quality of life (QoL) indicators

Geurs and Van Wee [21] had explored the sustainability potential of various transport possibilities in future and suggested that the along with the technology, very stringent behavioural adaptations and improvement in spatial and economic structures will help in meeting the goal of environmentally sustainable transport. Their focus was on the social indicators like safety, health and environmental issues that gets impacted with the motorised transport. Some of the Quality of Life (QoL) indicators as suggested by them are Health, safety, family, Education, Freedom, Social justice, Comfort, self-respect, Privacy, Leisure time, Social relations, Work Security, Aesthetic, Status, Spirituality. Mean importance rating of such QoL indicators was also suggested by Geurs et al. The Brundtland Commission had also agreed with the significance of the quality of life. Thus, a sustainable transport system should have the concern with human needs and its values and the assessment of strategies is formulated for bringing the sustainable transport in these

terms. The effects of strategies with a mission to bring sustainable transport should also be evaluated in light of social needs..

According to Newman, P. and Kenworthy J. [38], the dependency on personalised mode of transport is much higher in developed in comparison to the less developed countries. Thus reduction in personalised mode will impact the quality of life in such countries. Similar observations may be noticed within the regions of any country.

Heath [24] did some experiments and concluded that public mode of transport can be improved significantly by making some change in policy like making the travel free to students after including the cost of travelling in public transport in the annual fees paid to the institutions.

Tertoolen et al. [84] highlighted the impact of the policies on the Quality of life. Restrictive policy plans may have reverse outcomes to the intention of making such policies.

2.3.2 Transportation needs and systems

M.H.P. Zuidgeest [87] highlighted the variation in traffic and transport policies from one city to another city, from one country to another country. The travel patterns of the human beings also varies from place to place. The social, economic, political, and cultural differences do exist together and it makes an impact on the transportation needs and transportation system. In the developing countries, affordability issue is also prevalent that results in their inability to have an access to efficient transport infrastructure. People due to economic backwardness mostly prefer to walk or ride a bicycle or at most two-wheeler motorised vehicles. Their dependency on public transport system is more predominant than the personalised mode of transport. The public transport system in any developed country is found to be more efficient that it is seen in lesser developed country.

2.3.3 Other transportation indicators

Jeon and Amekudzi [40] provided a detailed list of sustainability indicators. These indicators have been categorised into the four major heads i.e. related to the effectiveness of the transportation system, economic, environmental and that related to socio-cultural. Out of these four categories, the indicators that are related to the transportation and then the environment are most commonly used indicators for the sustainable transportation system. Environmental indicators are common to all these sixteen initiatives, thus appearing to be in maximum use. These are associated with the vehicular emissions and vehicular fuel consumption that are the most common environmental indicator. Thus, it can be concluded that the effectiveness of transportation system, efficiency and environmental indicators are most common indicators for a sustainable transportation in comparison to the other indicators like economic and social indicators.

Litman [32 to 36] provided important sustainability indicators for comprehensive and sustainable transportation planning. These are applicable in most of the situations. Litman [82] conducted a research program for identifying the Sustainable Transportation Indicators that are helpful for using for sustainable transportation evaluation. The objectives of the efficient transportation planning were identified and then the variables to evaluate the progress toward the goal were identified. The indicators that indicate various levels of analysis can be covered in the sustainability index. But, it is necessary to account for their relationships in analysis to eliminate duplicity in their counting. For example, reductions in vehicle-mile emission rates can reduce ambient emissions as well as reduce the damages to health of a human being. It will be useful to follow each of such factors, but it would be wrong if these are summed up as if these are reflecting different types of impacts. The principles for selecting the sustainable transportation indicators were comprehensive from each of the major categories of various issues, data that is of reasonable quality and feasible to collect as well, should be allowing the sustainability impacts to be calculated at various stages of the project, understandable easily to the

public and useful to the decision-makers, disaggregated in various manner so as to support the analysis, should also reflect the ultimate impacts of concern rather than intermediary effects.

According to Dalkmann and Huizenga [16], if sustainable transportation system has low carbon content, its substantially reduces the short term and long-term negative impacts on the environment locally and globally. It has an economical infrastructure and economic operation, and it provides safe and secure success for persons as well as for goods.

As per the document titled “Sustainable transport Evaluation” released in March 2011, amongst the various topics for discussion, the transportation sector was focus of UN commission for sustainable development process during 2010/2011. A more sustainable transportation system one that meets the social, economic, environmental dimension and degree of participation. Socially, it should be meeting the basic access and growing needs of people and promoting the equity between successive generations and within generations. Economically, it should be affordable within the restrictions imposed by internationalisation of external costs, operates efficiently and fairly, and ensure a balanced development of the region. Environmentally, emissions of GHGs should be restricted, waste and the impact on the use of land be minimised and the noise generation be reduced. It should involve relevant stakeholders in different sections of the society.

Guido Nijenhuis [44] focused on low carbon development in the recent climate change. Since the transportation sector contributes lot of GHGs, planning of sustainable transport must include CO_2 emission as a major area of concern.

Beck Tabea, Fischer Marthias [6] highlighted the lack of quantifiable sustainability criteria for making a part of tender document of bridges. Michael Grant et al. [39] highlighted the relationship between Management & Operations (M&O) and liveability with sustainability

objectives in propagating liveability and sustainability. The importance of a balanced, comprehensive approach to M&O with an objective to support those objectives was crystallised.

Mosaberpanah et al. [43] released the document titled “The Role of Transportation in Sustainable Development” according to which, it was agreed that transportation system throughout the globe are not sustainable as observed with the present trends. Adoption of latest technologies, regardless of the field, whether in developing country or a developed country, will ultimately lead to negative consequences. His concern toward the quality of environment, equity in society, economic vitality and finding a solution to climate change due to increase in level of CO_2 generated an interest in the alternatives for a sustainable development.

In an international conference sponsored by the Sustainability and Transportation Committee of the Transportation Research Board, Washington DC, US, means and ways to promote sustainability were explored and highlighted Sustainable transportation as an international issue. This sector makes climate change and sustainable transportation can be achieved only with a unified action with the support of advanced Institutions and government machinery.

The document Sustainability Evaluation Check list [15] provided the key concept of Sustainability, Evaluation, Evaluation of sustainability, Evaluation for sustainability along with the checklists. Sustainability was defined as the capacity to co-exist and evaluation was defined as finding merits, worth and significance in a systematic manner.

Hsu and Wang [25] advocated for the sustainable transportation that will ensure accessibility and mobility. The use of different means of transport may secure

environmental impacts. The use of electric buses or other rapid transit is a better alternative than the use of personal mode of transport that needs to be discouraged. Guimaraes and Junior [23] also proposed the urban transport on grounds of its economic, environmental and social impacts.

Galanisa et al. [20] a research scholar from Greece conducted a survey of the purchasing power, possession of bicycles, private vehicles and driver license ownership. A response regarding the shift from private to public mode of transport was obtained. Personal and road safety and security was found to be better when using bicycles. In the period of the economic crisis, People favoured the public transportation as a sustainable transportation primarily due to economic crisis resulting in their reduced income. Thus, the economic crisis has a positive impact on sustainable mobility favouring the ways of transportations that are economic, environmental, and sociable.

Mohammadi Chermahini et al. [1] highlighted the stereotype concept of sustainability in most of the developed countries facing rapid urbanisation due to rapid industrialisation. There is high instability in the growth and development of urban communities and important environmental indicators caution a threat to urban systems. It leads to urban dispersion and sustainable urban development Confronts. Urban transport is one of the main principles of sustainability that has an impact on the economic efficiency, environmental related issues etc.

As per the sustainability indicators frameworks, a basic and also an efficient method is ranking in order to illustrate the range of the values for a quantitative indicator. For example, Human Development Index (HDI) country ranking has become very popular. A sustainable transport system can also make use of this Ranking. It also requires a reference value in order to provide right information about the sustainability test of a respective indicator in a particular situation. For providing a reference of some kind for comparing the

performance, benchmarking scheme may be used as a useful tool. While using it as a tool, it is necessary to evaluate the deficiencies relative to the target. Finally, a set of measures essentially required to achieve the objective is generated. The Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis is another tool to examine the present scenario with challenges in the future to generate appropriate policies. As per EU INNOREF 2005, one must build on his strengths, eliminate his weaknesses, use the opportunities and finally reduce the impact of threat. Audits conducted internally or by external agencies, have also gained popularity. Auditing help in evaluating the achievement of specific pre-defined criteria and it constitute a systematic and documented process by use of tailor-made checklists. Here the attention is drawn on the development of knowledge and certain procedures that are existing instead of quantitative measure of performance. Periodic Audits can result into the certification of an organisation for certain standards (ISO, Ecological standards, etc). In the transport sector, specifically, audits help in assessing the sustainability issues and sustainability evaluation. Labels may be considered a probable result of the above implementations instead of creating a strong evaluation scheme. Organisations can be tagged with a label after a specific criteria is achieved. For example, the Eco Mobility label developed by the SHIFT-Project is specifically focused on the transport and generated with well-defined criteria for a better sustainable transportation. Similarly, an award helps in making the impression of the recipient and it help in raising the awareness for certain issues. The criteria for giving an award may be very cumbersome, and generally depend on a qualitative evaluation. For Example, a city, for its efforts in improving the sustainability of its transport systems is selected by panelist for the Sustainable Transport Award.

2.4 SUSTAINABILITY EVALUATION

With an objective of evaluating the sustainability of the transportation system, many qualitative and quantitative studies have been attempted across the world. Still there does not exist any standard model or any evaluation methodology for measuring the

sustainability. The literature available on the subject proposes various methodologies such as dynamics approach, graphical models, scenario planning, stimulation and decision analysis models, economic-based models, integrated transportation and land use models, environmental impact analysis and life cycle assessment (LCA).

2.4.1 Scenario planning approaches

Scenario planning approaches incorporate large uncertainties linked with elements in planning for e.g. the employment opportunities, population of the area, and travel demand. A detailed analysis of the scenario explores various possibilities to explain various issues linked with sustainability like environmental integrity, safety, and mobility. Several studies in Europe have used Quantitative sustainability models like SPARTACUS (Systems for Planning and Research in Towns and Cities for Urban Sustainability) that uses an integrated transportation for measuring the sustainability in the selected transportation and land use scenarios. ESCOT (Economic Assessment of Sustainability Policies of Transport) is another initiative adopted as quantitative sustainability model that has an emphasis on evaluating the "economic" feasibility of environmentally sustainable scenarios. Zietsman et al.'s [51] simulation and decision model provides some important vision for the integration of a sustainability evaluation process with the decision-making process. On the basis of the multi-attribute utility theory (MAUT) [55, 56], selected performance measures were used to evaluate as a single index for sustainable transportation. These researches used a microscopic simulation model (CORSIM) and emphasised primarily on evaluating the sustainability of selected corridor-level scenarios.

2.4.2 Multiple criteria decision making approach

Zietsman et al. [86] demonstrated the benefits of using indices in the sustainability evaluation by the application of a multiple criteria decision making (MCDM) approach. MCDM approach can consider a wide range of differing but very relevant criteria unlike single-objective decision-making models like benefit-cost or cost-effectiveness analysis.

The most popular MCDM methods are the weighted sum model (WSM), the weighted product model (WPM), and the analytic hierarchy process (AHP) method [8].

Bana e Costa and Vansnick [11] developed another methodology in the early 1990s that was used in multi-criteria decision aids known as Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) using WSM model, which employs an additive value aggregation model. The objectives of transportation planning cover many varying and conflicting objectives and care for the interests of large spectrum of stakeholders. Hence, the assessment process has to involve suitable and most appropriate techniques so that the interest of these stakeholders is not compromised. The evaluation for a sustainable transportation evaluates all the varying alternatives without ignoring those objectives that are conflicting to other objectives.

Black and Kuranami [9] brought forward the interactive multiple objective programming in the area of sustainable transport planning in metropolitan cities. The technique introduced helped the decision makers to consider the varying and conflicting objectives. Many more MCDM methods were introduced by other researchers and planners namely Aboul-Ela et al., Gomes, Tabucanon and Lee, Zografos et al., Schwartz et al., Hsu, Leviakangas and Lahesmaa, Vreeker et al., Reza Ghaeli et al., Li and Sinha, Ertugrul Karsak and Sebnem Ahiska to examine the transport related issues and evaluate the multidimensional impacts of transportation projects, programs, or policies without ignoring the conventional cost-benefit analysis.

Saaty's Analytic Hierarchy Process (AHP) [46] provided a logical approach to assign the priority and decision-making on the basis of pairwise comparisons between the various criteria. This AHP methodology is now regularly used to evaluate the transportation alternatives encompassing the multiple decision criteria. Fuzzy multicriteria decision making approach is yet another trend that is used regularly. These fuzzy-type MCDM

methods serve uncertainty, vagueness, or fuzziness that happens very commonly because of inadequate information or limitations in thinking of a human being . Most of the sustainability evaluation models are based on the economic, environmental, and social impacts. It indicates that any strong evaluation technique should account for these dimensions as decision-making criteria. Thus, multiple objective methods or multi-criteria decision-making models are far better than a single objective methods for assessing the sustainability.

Ramani et al [43] proposed a general sustainability assessment framework with processes in 5 step for stakeholders in transportation area. These steps were defined as first of all understanding the sustainability, next is the transportation sustainability goal development, followed by development of objectives, then development of performance measures and finally performance measure application.

Riccardo Rossi et al. [52] made a comparison of fuzzy-based and AHP methods in sustainability evaluation approaches to evaluate sustainable transport systems as proposed by Awasthi et al. [3], and split them into eight categories namely Life-cycle analysis (LCA) In order to evaluate a criteria, Cost-Benefit Analysis (CBA) to evaluate positive and negative impacts of a project alternative with an objective of reducing the cost as much as possible, minimising the costs related to that alternative, Environmental Impact Assessment (EIA) for a deeper analysis of alternatives, Optimisation models, to find out the optimal solutions keeping an objective to meet social, economic and environmental challenges, System Dynamics Models for complex system and assessment indicator models to evaluate a project for the sustainability. Tao and Hung further proposed three types of models i.e. composite index, multi-level index and multi-dimension matrix models. Statistical methods were used by data analysis approach like hypothesis testing in order to assess the sustainability. Multi-Criteria Decision Analysis (MCDA) methods represent many methods, including the well-known Multi-Attribute Utility Function Theory (MAUT),

Analytic Hierarchy Process (AHP) and ELECTRE methods. Although these models specifically MCDA, are popularly in use, still these are insufficient. Several authors have indicated that information on the current and future system is uncertain, generally incomplete due to its complex nature, hence different dimensions of sustainability are measured on different scales. The Fuzzy-Based Evaluation Method (FBEM) method determines an overall fuzzy index of sustainability for each assessed alternative policy accepting the concept of the "three pillars of sustainability". It further provides information about combined dimensions of sustainability. If the operational applicability and effectiveness of the proposed method is to be evaluated, a comparative analysis was made between F-BEM and AHP, by referring to different policies for reducing the pollution. Riccardo Rossi et al. [53] adopted the F-BEM fuzzy sets and systems theory in order to explain the concept of the "three pillars of sustainability" for managing the uncertainties and complexities that explains the sustainability assessment in the transportation field.

O.Ilker et al. [45] introduced the method for assessing the sustainability of the transport systems throughout the country. As an indispensable economic activity, Transportation system has complex interactions with the environment as well as with the society. Now the sustainable development has reached to the top priority for all developing and developed countries and lot of interest is generated amongst them for understanding and evaluating the sustainability of the transport systems and its performance. A decision-making framework is to be introduced in order to evaluate the sustainability of the transport networks in a multi-dimensional setting and a methodology is to be evolved to identify alternatives that are non-compromise. Now, in the recent past, sustainable development provides a big challenge to all sections of the society and an urgent requirement is there to identify appropriate methodologies to deal with this challenge and analyse the sustainability. As such, the transportation system has a deep impact on the economic, social and environmental areas and it contributes significantly in sustainable development and also its maintenance. Yet, the research in applications in the transport

sector is not sufficient when compared to the research in sustainable development in other areas.

Though well-established guidelines to identify the suitable indicators connected with the specified objective of sustainability were still missing, still many such lists of indicators proposed by researchers did exist. Since existing indicators in transportation sector reflected the economic, social and environmental impacts of a system, thus sustainability indicators were generally classified in these three dimensions. There might be many other dimensions such as technical, operational, governance or institutional those have been listed in many other studies. Alternatively, the indicators could be classified on the basis of transportation objectives and could be related to more than one category. Many different indicators defined the sustainability and a system would be analysed as sustainable if it performs reasonably good with respect to all of the specified indicators.

ICF International [26, 39] document has described various options and opportunities to include the environmental, economic, and social sustainability into the transportation decision-making through the use of their performance measures. Performance measures are widely used for planning a project and its development. It permits the decision-makers to quickly notice the outcome of a proposed transportation plan or project. It also permits to monitor trends in transportation system performance over a span of time. While many transportation agencies use it only partly, but has unlimited strength in promoting the sustainability. Many more agencies work on assessment of the ability of their systems to improve public health, conserve the natural resources, expand the economy, strengthen energy security and provide mobility to disadvantaged people. The measurement of environmental, economic, and social outcomes has already been producing the desired outcomes. Some other agencies have observed that, once they begin to report sustainable transportation performance measures, their values are immediately noticed by the stakeholders who start expecting regular reports on the measures and more explicit

linkages between the measures and decisions of the public agencies. Agencies and the stakeholders are then in comfortable position to engage in a much richer conversation about the trade-offs among policy and investment decisions and the best opportunities in their areas to reach its ambition of achieving the sustainability.

2.4.3 Sustainability evaluation of urban mobility projects

Anjali Awasthi et al. [4] challenged the negative environmental impacts such as rising fuel costs and increase in the traffic congestion. Thus, many cities are seen introducing the sustainable mobility measures such public mode of transport, cycling, walking, use of energy efficient vehicles, use of biofuels etc. in their planning in order to improve the flow of passengers and goods. The challenge before transport planners is that in absence of sufficient data on the subject, is to select the aspect and prioritise it for implementation for the sustainable transportation sector. The geographic and transport conditions of cities vary from one city to another city and thus it cannot be generalised. Every city has its own issues. Various multi-criteria decision making (MCDM) techniques namely TOPSIS [13], VIKOR [12], SAW etc. have been suggested for sustainability evaluation of urban mobility projects.

David Tremblay et al. [17] highlighted the worldwide concern of the Sustainability assessment. Appropriate tools are required for sustainability assessment to ensure the complete coverage of sustainability issues like environmental, social and economic along with the participation of multiple stakeholders. HE developed a scientifically robust and flexible tool that was tested in different cultural and development contexts to build a framework for sustainability assessment of policies, strategies, programs and projects in light of United Nations' Agenda 2030.

Jinge Xing et al. [29] appreciated the sustainability evaluation of innovative products with an objective of meeting the demands of sustainable development He proposed the

calculation process for the sustainability evaluation. First of all, the performances of the innovative products are calculated as regard to its social, economic, and environmental aspects. Then, the sustainability integrated in these three aspects is calculated by vector-cosine method.

CHAPTER 3

GROWTH IN TRANSPORTATION CORRIDORS OF DELHI

3.1 INTRODUCTION

During last four decades, Delhi, the Capital City of India, has grown many folds in all spheres of life, whether it is the availability of better education opportunities, creation of better medical amenities, expansion in information technology or the infrastructure in terms of buildings as well as transportation sector. When one claims the development or growth or expansion, the purpose is not achieved in real sense, if it is not sustainable.

The transportation infrastructure in Delhi is observed to be expanded during the last four decades i.e. just prior to IXth Asian Games hosted in 1982, then up to 2010 when XIXth Commonwealth Games were organised in this metropolitan city and then thereafter till 2020 after the signature bridge was opened to traffic in 2018 [72]. The two-mega events of sports had contributed maximum to the growth of city infrastructure in capital city, New Delhi because of the first thrust of flyovers in Delhi was observed as a preparation plan of Asiad 1982 and the history was repeated for the Commonwealth Games.

Expansion of Infrastructure includes all sorts of additional facilities from widening of a road in order to increase the traffic carrying capacity, making a standalone flyover or Underpass on a single junction with or without clover leaves for free right turning movements or a fully elevated corridor for a hassle-free journey between two ends.

In the Post-Independence era, the emphasis was on the development of road network near rail lines as railway department was dependent to an extent on trains passing through the heart of the city that was catering to the nearby areas. Accordingly, many road over-bridges and under-bridges along the railway tracks were planned to reduce their conflict with road

network. In order to further enlarge the road transport infrastructure, some flyovers, cloverleaves and few bridges were planned to improve the connectivity to the sports stadiums, games village and other important parts of the city. Many road-widening schemes were also planned with an ambition to improve the connectivity with National Highways. Ring Road and Outer Ring Road are the life lines of Delhi roads connected with radials. It was planned to make these Ring Road and Outer Ring Road along with important Radials as traffic signal free so as to improve flow of traffic within Delhi.

Prior to Asian Games, Delhi had only Rail Over Bridges (ROBs) and just 3 river Bridges namely 2 lane Bridge at Wazirabad, 4 Lanes Bridge at ITO and another 4 lane Bridge at Nizamuddin. Today, after the successful hosting the Commonwealth Games and making of Signature Bridge over Yamuna, the city claims to have hit a century of flyovers, which also includes more River Bridges at ISBT, expansion of bridges at ITO and Nizamuddin from 4 lanes to 8 lanes, new bridge at Geeta Colony, DND Flyway and lastly iconic bridge namely the Signature Bridge at Wazirabad.

Fig. 3: Jawahar Lal Nehru Stadium (venue of two mega events)

More than 20% of the city's transportation corridors were developed specifically for conducting these two mega events for the smooth movement of sports persons and sports lovers to the games venue either from the Games Village or otherwise from other important junctions in Delhi. Venue of the games in both the events was primarily the Jawahar Lal Nehru Stadium (Figure 3), while the Games village was established at Hauz Khas in South Delhi for the Asian Games and Akshardham in East Delhi for the Commonwealth Games.

When one looks at the journey of growing transportation systems during all the times, it is essential to understand the Geographical, Economical and Traffic characteristics of present Delhi after the 2010 Commonwealth Games as well as Delhi prior to Asiad 1982.

3.2 CHARACTERISTICS OF DELHI

Delhi, the capital city of India and an Urban area is the centre of attraction where all sort of activities like social, political, economic and cultural are fully active. The city has grown into a capital of business and for organising many international events. Geographically, the city is the connected with five national highways and intercity rail corridors that carry huge volume of traffic including the heterogeneous passenger and goods. Events like Asiad, Commonwealth Games etc. can be arranged only with an effective transportation system that is accessible and fast meeting the international standards.

3.2.1 Geographical and economical features

Metropolitan City Delhi lies in the North of India. Its boundary coordinates at extremities are 28°-24'-17" North, 28°-53'-00", 76°-50'-24" south and 77°-20'-37" East. The land area of Delhi is 1,483 square kilometres out of which 75% comprises of urban area and 25% rural area. Thus, Delhi is primarily an urban city having its borders partly common with the States of Haryana and Uttar Pradesh. Other geographical features of the city are the River Yamuna flowing through the heart of the city and terminal part of the ranges of Hills of Aravalli.

As per 2011 census, the population of Delhi is 16.79 million, out of which 97.5 % are living in Urban areas covering only 75% of total Delhi area confirming the Urban character of Delhi. The growth in population for Delhi during the last decade has been seen as declined from 51% in 1981-91 to 47% in 1991-2001, further to 21% in 2001-2011. During 2001-2011, the annual growth rate of population of Delhi that has been recorded is 2.12 % on an average. As the overall population of Delhi has increased to many folds, its population has also increased from 9340 persons per sqkm in 2001 to 11320 persons per sqkm in 2011 that is highest, when compared to All India and other States. If the density of only Urban area is considered, this figure gets enhanced to 14667 [18].

3.2.2 Traffic characteristics

The road system of Delhi is the lifeline of citizens of Delhi and is extremely important to run and maintain the city. The total number of motor vehicles on road in NCT of Delhi as on 31st March 2018 was 109.86 lakh, showing 5.81 percent growth from the previous year. The number of vehicles per thousand in population increased considerably from 317 in 2005-06 to 598 in 2017-18. With 11 Million registered vehicles in the city (Figure 4), the total number of registered vehicles in Capital city Delhi alone is much more than the total registered vehicles in other three metropolitan cities of the country, viz. Kolkata, Mumbai and Chennai.

The road network in Delhi is most extensive network in country. Nearly one fifth of its area is covered under road network. Still the space for the traffic is far below the requirement. Delhi had hosted the Asian Games in 1982 and at that time after the successful organising the Games, Delhi ended up with just five flyovers in its road network and those were also specifically made for the convenience of sports persons. Today, the number of flyovers in city is set to cross the century mark. Number of vehicle that are moving on Delhi Roads has multiplied 14 times after the 1981 Asian Games. Amongst all the vehicles that are registered

in country, every 10th vehicle is on Delhi Roads. Every sixth private vehicle in the country runs on Delhi's roads. The vehicles are getting incremented by 10% every year.

Fig. 4: Traffic scenario in capital city

As per the projection by the Centre for Science and Environment (CSE), the daily trips in Delhi will be exceeding 25 million by 2020. Though road spaces have been increased with an objective of decongesting the existing traffic, but the added facilities invite additional traffic that is defined as the "induced traffic". It is established that 50% of the added capacity on roads is utilised by the increased traffic immediately on the completion and operation of the new corridor, while 50% is consumed by the induced added traffic in next five years.

3.2.3 Relief Measures for traffic decongestion

As mentioned in previous para, the road system of Delhi is the Ring–Radial pattern (Figure 5) and lifeline of citizens of Delhi and is extremely important to run and maintain the city.

Whenever and wherever the city observed traffic bottlenecks, attempts have been made to resolve by providing some sort of relief measures. Depending upon the severity of the issues, the measures varied from solutions as simple as widening the road, providing traffic lights or rotaries to more engineering solutions like providing simple crossover flyovers or full grade separators with clover leaves etc. etc. But, with the further population increase and increase in number of vehicles the demands were different and required state of art inputs.

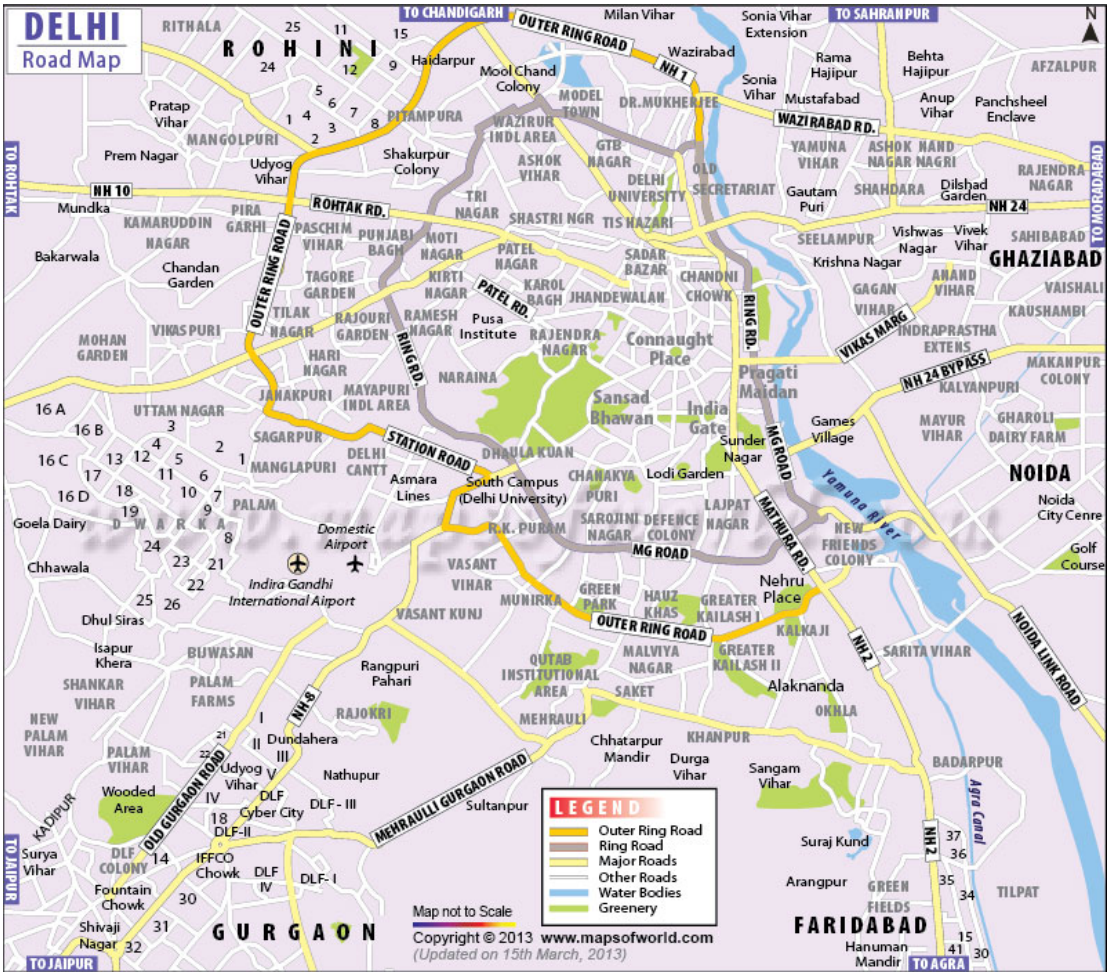

Fig. 5: Road map of Delhi

3.3 DELHI PRIOR TO ASIAN GAMES 1982

During the infancy period of free India, major bottlenecks in the transportation system of city were noticed only at the railway level crossings. Besides delays, level crossing were

prone to accidents due to temptation by pedestrians and two wheelers to cross the railway track, even when the gates were closed. Therefore, during early sixties and seventies, for removing bottlenecks in the traffic system, priority was given for construction of Railway Under/Over Bridges. Some Railway Under Bridges (RUBs) and Railway Over Bridges (ROBs) were constructed even during seventies and eighties. Gradually, for important city interconnected roads, Ring-Radial pattern of road system developed in a planned manner, as seen in the Road map of Delhi (Figure 5).

In addition to above, few bridges on River Yamuna constructed in this period are

i. 2 lane bridge at Wazirabad constructed in 1968
ii. 4 Lane bridge at ITO constructed in 1970
iii. 4 Lane bridge at Nizamuddin constructed in 1970

Fig. 6: River bridges before Asian Games

The narrow Bridge at Wazirabad was observed to be congested most of the time as it had only two lanes without a central verge. With many commercial vehicles from UP and Haryana using it every day, traffic between northeast Delhi and other parts of the city is hardly in motion or say, it just crawls. Other two bridges were sufficiently wide during their construction providing relief to Wazirabad Bridge but soon thereafter these were also seen overloaded with traffic and required addition to more lanes. Brief details of these corridors are listed in Table 1.

Table 1: Infrastructures in Delhi prior to ASIAD 1982

S. No.	Location	Year of construction	Type of Structure	Technology	Remarks
1.	Wazirabad	1968	2 lane River Bridge	Cast-in-situ construction	Connecting North Delhi to North-East Delhi
2.	ITO	1970	4 Lanes River Bridge	Cast-in-situ construction	Connecting Central Delhi to East Delhi
3.	Nizamuddin	1970	4 lane River Bridge	Cast-in-situ construction	Connecting South Delhi to East Delhi

3.4 FIRST THRUST OF FLYOVERS FOR ASIAN GAMES 1982

The first thrust for construction of flyovers in the city was given during 9th Asiad in 1982. Four flyovers constructed by Public Works Department (PWD), Govt. of Delhi at that stage were as mentioned below.

i. Near ITO on Ring Road and Vikas Road crossing
ii. Near Oberoi Hotel on Zakir Hussain Road and LBS Road crossing
iii. Near Lodi Hotel on Lodi Road and LBS Road crossing
iv. Near Mool Chand Hospital on Ring and J.B. Tito Road crossing

On looking at their locations, it is apparent that all of these four flyovers are located on route from ASIAD Village in Hauz Khas to Jawahar Lal Nehru Stadium near Lodi Road and Indira Gandhi Stadium near ITO. These flyovers were completed in a record period of about 18 months with cast-in-situ construction. During construction period, the traffic was heavily

disrupted due to in-situ construction and need of shifting of services that was another difficult task.

These works were undertaken in 1980 with cast-in-situ technology. Pre-cast technology had not evolved for execution in India by that time. It is generally observed that cast-in-situ box girders take lot of time in construction and cause lots of inconvenience to the moving traffic in its vicinity and that too for a longer duration. Thus, for a sustainable construction, it is essential that such technology should be adopted that minimises the construction duration at site.

Fig. 7: Four flyovers constructed for Asian Games

Despite cast-in-situ construction, these flyovers were planned with a target to make them fully functional before the scheduled Asian Games. These were completed in time for a smooth flow of traffic between Indira Gandhi Stadium, Jawaharlal Nehru Stadium and Asiad

Village. Later on, these flyovers also removed major bottlenecks for traffic from Central Delhi to South Delhi.

3.5 BRIDGES/ FLYOVERS UP TO NEW MILLENNIUM

In eighties, PWD undertook construction of more Bridges and flyovers, which helped in improving the traffic scenario of Delhi. ISBT Flyover-cum-8 Lane Bridge on River Yamuna was constructed with cast-in-situ, pre-stressed box girders. Curved pre-stressed girders were introduced for the first time in the country. This project solved most of the problems with regard to the traffic congestion near Inter State Bus Terminus (ISBT), Kashmere Gate and adjoining areas.

Hanuman Setu situated between Red Fort and Salimgarh Fort on Ring Road was constructed by dismantling old Arch Bridge, which was a major traffic obstruction. In this project, existing foundations of old Arch Bridge were strengthened with construction of stone columns. Cast-in-situ reinforced soil technique for retaining walls were introduced for the first time in the country. The project removed major bottlenecks for the traffic between North and South Delhi.

The Visvesvaraya Setu situated near Okhla on Mathura Road consist of flyover and railways over-bridge combined with cloverleaves for proper dispersion of turning traffic. It removed major traffic bottlenecks in area around Okhla and further eased out the flow of traffic. For this project, reinforced-soil technology along with fly ash filling was introduced.

Further, projects at that time were undertaken with new technology of pre-stressed and precast continuous beams, for the first time in the country. A casting yard was set up at Bhatti mines in Delhi for pre-casting of beams and pre-stressing them before transporting them to site. For the obligatory central span and two adjoining spans, it was not possible to have precast beams due to larger span. Hence, cast-in-situ box girders were provided

whereas for all other spans, precast pre-stressed beams were used. Thus, the projects were completed with major number of spans as Pre-cast, while just 3 spans were cast-in-situ to minimise the on-site construction activities. The projects completed with this technology were at the crossing of Loni Road and Mangal Pandey Marg near Shahadra, at the crossing of Aurobindo Road and Outer Ring Road near IIT and at the crossing of J B Tito Road and Outer Ring Road near Masjid Moth.

Table 2: Infrastructures in Delhi from ASIAD 1982 to new Millennium

S. No.	Location	Year of construction	Type of Structure	Technology	Remarks
1.	Near ISBT on ring road and connecting North- East Delhi	1990	Bridge cum flyover	Cast-in-situ, Prestressed girders	Curved Prestressed Box Girders introduced for the first time in country
2.	Crossing of Loni Road and Mangal Pandey Marg near Shahadra	1991	Flyover over single crossing	Pre-cast, Prestressed and Cast-in-situ construction	Pre-cast, Pre-stressed (Pre-tensioned) beams were introduced for the first time in country with casting Yard at Bhatti mines. Obligatory span with one adjoining spans were cast-in-situ box girders.
3.	On Mathura Road near Okhla (Visvesvaraya Setu)	1992	Flyover with Clover Leaves	Cast-in-situ construction	Reinforced-soil technology along with flyash filling
4.	Crossing of JB Tito Road and Outer Ring Road near Masjid Moth	1993	Flyover over single crossing	Pre-cast, Prestressed and Cast-in-situ construction	Pre-cast, Pre-stressed (Pre-tensioned) beams were introduced for the first time in country
5.	Crossing of Aurobindo Road and Outer Ring Road near IIT	1995	Flyover over single crossing		
6.	Between Red Fort and Salimgarh Fort on ring road	1997	Flyover on single crossing	Cast-in-situ construction	Reinforced-soil technology
7.	On Vikas Marg connecting ITO and Laxmi Nagar	1997	Expansion of River Bridge		Reinforced earth technology for the retaining wall
8.	Expansion of Nizamuddin Bridge	1998	Flyover over single crossing		Box Girders for all spans
9.	2 Cloverleaves added to the ITO flyover	1998	Flyover over single crossing	Curved, voided, Cast-in-situ girders	Curved pre-stressed and voided girders were introduced for the first time in the country.

In early Nineties, the bridge cum flyover project at ISBT in previous decade was completed and the expansion of ITO Bridge as well as Nizamuddin Bridge was started. The capacity of both the bridges was earlier 4 lanes and 4 more lanes were added to each of them to make them 8 lane bridges. Further, in order to facilitate uninterrupted flow of right turning traffic, two cloverleaves were added to the ITO flyover constructed during Asiad-82. For the first time, voided slab technology was used for construction of this project. This was the first bridge structure that is voided, prestressed, curved in plan as well as curved in elevation. For these special features introduced for the first time in country, the project bagged Bridge National Award. Brief details of these corridors are listed in Table 2.

3.6 INITIATIVES OF NINETIES, RESULTS IN NEW MILLENNIUM

While traffic problems were solved at individual locations by construction of flyovers, it was felt necessary that problems are identified in comprehensive manner and then solutions found. To find comprehensive solutions, the broad concept of improvement of corridors was conceptualised and the most important road of Delhi i.e. Ring Road was identified as the first corridor for improvement. Due to Ring–Radial pattern of road network, the traffic intensity on complete stretch of the Ring Road had always been very high and exceeded 1 Lakh PCU in one day during 2000. Most of the intersections of this road were very busy and needed improvement. At very important locations i.e. wherever Ring Road met the major radial road with heavy traffic movement, total grade separators were planned whereas at other intersections, simple flyovers were conceptualised.

With the growth of the city, traffic intensity as well as traffic density, both increased exponentially. Some important junctions were observed with heavy flow of traffic in both the directions and therefore required a need of free flow in both the directions. Since the concept of standalone flyovers on a junction was not solving the problem, multilevel grade separators like 4 level grade separator at Punjabi Bagh junction, AIIMS crossing and Dhaula Kuan with clover leaves /loops for free flow of traffic from any direction to any other

direction came into existence. On the onset of new millennium, longer flyover covering more than one junction, like Raja Garden flyover on two junctions along with Ramps and Lajpat Nagar Flyover on three junctions was built. Raja Garden flyover is located at the intersection of Ring Road and Najafgarh Road. It is long flyover covering two intersections near Rajouri Garden completed in 2001 followed by addition of two ramps for the convenience of traffic between the two intersections. These ramps were added in 2003. Prestressed precast beams have been used for this flyover and its ramps. For central span, cast-in-situ pre-stressed box girders have been provided. With the same technology, another flyover was built by DTTDC in the same period in 2001 at Peeragarhi Chowk on Outer Ring Road.

Fig. 8: Flyovers with Precast Pre-tensioned RCC beams

In addition, simple crossover flyovers were also built over at Moti Bagh and Africa Avenue on Ring Road, Savitri Cinema crossing and H R Sethi Marg on Outer Ring Road. On account of space constraint and difficulty in undertaking cast-in-situ construction work at flyover site, PWD changed the trend of construction of flyovers from cast-in-situ to precast. For the viaduct portion, precast Segmental construction technique has been adopted and for approaches, Reinforced Earth technology has been adopted. Subsequently 2 more flyovers on the same design and technology were built at B-avenue and Britannia Chowk on Ring

Road in 2003. Other simple crossover flyovers at Andrew Ganj and Mayapuri were built as composite structures for the first time in Delhi with concrete deck resting on steel plate girders for the viaduct portion. Approaches were built with Geo-grids rather than the conventional RCC retaining wall. T Junctions at Moti Nagar, Punjabi Bagh Club, NH 24, Sarai Kale Khan were treated with only one side flyover i.e. for traffic flow in one direction. Flyovers at Moti Nagar and Punjabi Bagh club were made integral connection between the deck and the pier without any bearing so as to ease out the maintenance of the structures.

Full Grade Separators were built at important Junctions like Punjabi Bagh, Dhaula Kuan and AIIMS intersection. The flyover at Punjabi Bagh is situated on the intersection of Ring Road and Rohtak Road (Figure 9). The Ring Road is designed as a flyover about 7.5 m above the ground. For right turning traffic, rotary is provided at the ground level. The pedestrian plaza with shopping complex is provided 4.5 m below the ground. The Rohtak Road is about 12 m below the existing ground.

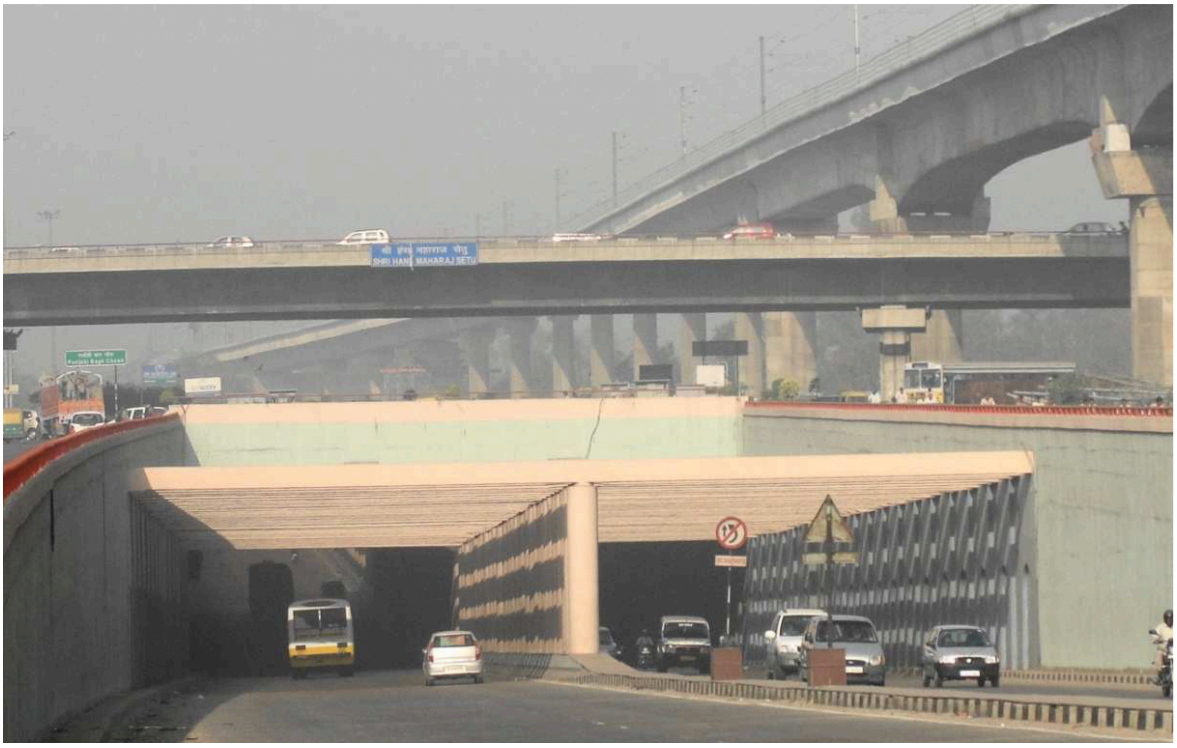

Fig. 9: Five level grade separator at Punjabi Bagh

For this project, special design techniques were used to suit the busy intersection with limited space conceptualised in a manner that traffic has to move during all stages of construction. For this flyover also, precast Pre-stressed beams were used for approach spans, but for the central span, cast-in-situ technique is used by providing special girders to facilitate construction. The underpass along Rohtak Road was located 12 m below the natural ground level. Subsequently, with the construction of metro corridor over and above the flyover, it has become 5 level grade separators with multi-modal facilities and is the first of its kind in the country. The project was awarded ISO certification.

Fig. 10: Grade separator at Dhaula Kuan (5 arms)

Dhaula Kuan was another heavily congested intersection in South Delhi at the junction of Ring Road NH-8, Sardar Patel Marg and Ridge Road. All the five roads meeting at this

junction are important and need signal free movement towards other directions (Figure 10). A unique design was evolved with Ring Road to be lowered by about 4.5 m and Sardar Patel NH-8 straight reach raised by about 3 m. Besides, cloverleaves have been provided and the total design has been made in such a manner that there will be no traffic signals and traffic in all the five directions can move uninterrupted.

Fig. 11: Rajiv Setu at AIIMS intersection

Rajiv Setu at AIIMS Intersection is located at the intersection of Ring Road and Aurobindo Marg. A unique design for free movement in all directions was evolved for this project (Figure 11). Conventional full clover leaf was not possible in this project as the land on one side was not available due to existence of world class hospital i.e. AIIMS. Hence the project was planned with all loops on one side and also managing total signal free movement in all directions. Land available on North side has been used to make a signal free intersection and a split rotary has also been near AIIMS for uninterrupted U-turn facility on Aurobindo Marg.

Brief details of these corridors are listed in Table 3.

Table 3: Infrastructures in Delhi while entering to new Millennium

S. No.	Location	Year of construction	Type of Structure	Technology	Remarks
1.	New Friends Colony	2000	Bridge over River	Precast Segmental	It reduced the distance from Delhi to Noida
2.	Raja Garden	2001	Flyover over 2 crossing	Cast-in-situ combined with precast construction	First time flyover over 2 junctions was planned
3.	Peeragarhi	2001	Flyover over single crossing		
4.	Motibagh on ring road	2001	Flyover over single crossing	Precast segmental girders and reinforced earth Retaining wall	First time PWD started the segmental construction after SIRSI flyover at Bangalore. It was carried out with solid segments of light weight (25 T) with two rows for single carriageway and crossly prestressed in addition to longitudinal pre-stressing.
5.	Africa Avenue on ring road	2001	Flyover over single crossing		
6.	H R Sethi Marg on outer ring road	2001	Flyover over single crossing		
7.	T-Junction near Savitri Cinema on outer ring road	2001	Flyover over single crossing		
8.	Ashram Chowk	2001	Flyover over single crossing	Composite construction with steel girders	Composite construction was carried out for the first time in Delhi with limited fabrication workshops in country.
9.	Mayapuri on ring road	2002	Flyover over single crossing		
10.	Punjabi Bagh junction	2003	4 level Grade separator at major crossing with 4 arms	Composite construction, iron ore layer beneath underpass for uplift pressure	First time 4 levels with Underpass along Rohtak Road at bottom, pedestrian interchange above, rotary at ground level for right turning traffic and flyover over ring road at top was introduced.
11.	Grade separator at AIIMS crossing	2003	Grade separator at major crossing	Cast-in-situ construction	Innovative design evolved due to space restriction on AIIMS side
12.	Grade separator at Dhaula Kuan	2003	Grade separator with 5 arms	Cast-in-situ construction	Innovative design evolved due to 5 arms with heavy traffic meeting at junction
13.	B -Avenue on ring road	2003	Flyover over single crossing	Precast segmental	After successful completion of four flyovers at Motibagh, Africa Avenue, H R Sethi Marg and Savitri cinema, it was repeated at these locations with same design.
14.	Britannia Chowk on ring road	2003	Flyover over single crossing		
15.	Andrew Ganj on ring road	2003	Flyover over single crossing		
16.	T Junctions at Moti Nagar on outer ring road	2005	Flyover over single crossing	Composite construction with steel girders	First time integrated flyovers were introduced by eliminating bearings thus making it maintenance friendly.
17.	T Junctions at Punjabi Bagh Club on ring road	2005	Flyover over single crossing		
18.	T Junctions at NH 24	2005	Flyover over single crossing	Precast segmental	First time 3-4 span continuous segmental with using pre-stressing couplers was introduced for the first time.
19.	T Junctions at Sarai Kale Khan on outer ring road	2005			

3.7 TRANSPORTATION CORRIDORS IN NEW MILLENNIUM

By the turn of the millennium, number of flyovers had already been built up during a period more than two decades. It was realised that flyovers, though a comparatively cost-effective solution, but results in disturbing the skyline. At many locations, even it is not feasible to construct a flyover. On the other hand, Underpasses in an Urban Environment always poses a threat of unruly underground utilities. Many of the utilities have been laid without any record of its exact location. One gets surprises when digging takes place. Despite that due to inevitable solutions, 1st underpass planned in Delhi was at Punjabi Bagh junction, followed by three more underpasses at Madhuban Chowk, Prembari and Moolchand.

Fig. 12: Underpasses constructed in new millennium

New Millennium started with longer flyovers spanning over more than one junction. The flyovers constructed during the nineties were mostly standalone flyovers on one junction with series of such crossover flyovers in a row. One such example on Ring Road is 3 flyovers on 3 continuous junctions namely Motibagh, Africa Avenue and B Avenue. Similarly, flyovers

on Outer Ring Road starting from Modi Mills, H R Sethi Marg, Savitri Cinema, Chirag Delhi, Panchsheel, IIT, Munirka and RTR Marg developed with dual carriageway of 9.0m width each and with superstructure of composite construction i.e. RCC slab over steel girders. But, in such an arrangement, travelling continuously up and down causes lots of inconvenience, as if one is travelling on a camel's back. This led to constructing longer flyovers on more than one junction.

Fig. 13: Flyovers with composite construction

Earlier Raja Garden Flyover was constructed on two crossing with in-between ramps for facilitating users to get down after one crossing in between and also to ascend after a crossing to have an advantage of using flyover for the next crossing. Flyovers over more than one crossing added in initial years of new millennium were Lajpat Nagar/ Sriniwaspuri

and 1.6 Km long flyover at Naraina. The flyover was to pass through a congested area and it was not possible to bring it down till the congested area is made through. This corridor was also constructed with segmental construction technology and opened to traffic in 2010 facilitating the movement of traffic for the commonwealth games. Brief details of these corridors are listed in Table 4.

Table 4: Infrastructures in Delhi in new Millennium

S. No.	Location	Year of Construction	Type of Structure	Technology	Remarks
1.	Raja Garden	2003	Ramps	Cast-in-situ combined with precast construction	Precast prestressed beams. Compression seal expansion joint for small expansions.
2.	Madhuban Chowk	2004	Underpass	Cast-in-situ combined with precast construction	Active soil anchors were provided for withstanding uplift pressure due to high water table. Diaphragm walls, Vacuum de-watering, mechanical couplers were introduced
3.	Lajpat Nagar/ Sriniwaspuri	2005	Single Flyover over 3 crossings	Precast segmental	First time 1 Km long flyover over 3 crossings with segmental box girder was introduced.
4.	Prembari	2007	Underpass	Cast-in-situ construction	Innovative design evolved due to space restriction due to metro corridor and Haryana canal
5.	Moolchand	2007	Underpass	Cast-in-situ construction	Innovative design evolved due to 5 arms with heavy traffic meeting at junction
6.	Panchsheel	2009	Flyover over single crossing	Composite construction with steel girders	These flyovers were made for the commonwealth Games and completed in record time. Sound barriers were installed to provide relief to nearby residents form sound pollution.
7.	IIT Delhi	2009	Flyover over single crossing		
8.	Munirka	2009	Flyover over single crossing		
9.	RTR Marg	2009	Flyover over single crossing		

3.8 PREPARATIONS FOR COMMONWEALTH GAMES

When Commonwealth Games were decided to be hosted by Delhi, 2nd major thrust in construction of flyovers/ grade separators and elevated corridors came into existence. 18 such structures took birth in the metropolitan city, (especially in East Delhi due to location of Games Village) which included 4.5 Kms long Baramulla Corridor constructed for a direct connectivity to Jawahar Lal Nehru Stadium from the Games Village at Akshardham in East Delhi.

Fig. 14: Flyovers with 3 level grade-separators

3.8.1 Three level Grade separators

Traffic in the city had gone so high at some junctions in East Delhi that it required total grade separators for traffic in both the directions. Simple cross over flyovers, even longer flyovers would not have provided the relief to traffic conditions. With the successful implementation of 4 level grade separators at Punjabi Bagh in 2000 (subsequently became 5 level after addition of Delhi Metro at 5th level), confidence level was high. Similar structures with 3 levels grade separator came into existence at number of locations. Traffic

in one direction was taken over the flyover and Underpass was built for traffic in other direction. Surface level traffic was controlled with the rotary. Other important 3 level grade separators worth mentioning are at Ghazipur, Shyam Lal College, Apsara Border and Azadpur in East Delhi [58].

3.8.2 Elevated Corridor over Barapullah Nallah

Elevated Road over Barapullah Nallah is one corridor that connects East Delhi with and South Delhi. The Project was planned for execution in 3 phases with end locations as AIIMS in South Delhi and Mayur Vihar in East Delhi with intermediate locations as Jawahar Lal Nehru Stadium and Sarai Kale Khan [66, 71]. In first phase, the mid segment of the project i.e. Jawahar Lal Nehru Stadium to Sarai Kale Khan was completed prior to the commencement of Commonwealth Games. Thereafter in second phase, the connectivity from Jawahar Lal Nehru was extended up to the AIIMS. Work in Third phase to extend the connectivity between Sari Kale Khan to Mayur Vihar in Eastern part of Delhi is in progress. This will complete the South-East link in Delhi from Mayur Vihar on East Delhi to AIIMS in South Delhi.

Fig. 15: Barapullah elevated corridor (in Phase 1)

With the target to finish the construction in the scheduled time period, precast segmental construction technique was encouraged and adopted as span-by-span construction and

providing deck continuity up to three or four spans depending upon the location and feasibility. The project is designated as an environmentally sustainable Project as the alignment of the corridor was fixed over a drain (Nallah) without acquiring land in Urban area and adopting other Environment friendly Engineering techniques like fly ash use wherever possible, high performance concrete for reducing carbon footprints etc..

3.8.3 Grade Separators with Full Clover Leaves

Amongst the number of flyovers and Underpasses with or without cloverleaves, partial cloverleaves or structures placed at 3 levels for segregating the movements in different directions, it becomes very difficult to find area sufficient enough to place all four clover leaves in a conventional manner in an Urban Environment. Wherever such a situation is not possible, other Engineering solutions by providing loops over loops or multi-levels are adopted. But, at three locations full cloverleaves have been provided by adjusting the Geometries to suit the site conditions. These locations are Mukarba Chowk, Ring Road Bye pass at Salimgarh and ITO Chungi in Trans Yamuna after crossing over the ITO Bridge.

3.8.4 Raja Ram Kohli Marg

The area across river Yamuna, particularly East Delhi, has witnessed an unprecedented growth in population and vehicular traffic over the existing Bridges resulting in traffic congestion and delays at the terminal points. In order to augment existing vehicular traffic capacity, a new bridge connecting Geeta Colony at East and the Ring Road near Shantivan intersection at West was made operational in October 2008. A new Master Plan Road over disused canal running in East–West direction that connects Karkari More with the Marginal Bund (Pusta) Road opened for traffic in April 2008.

This altered the existing traffic flow and pattern thus a Grade Separator was constructed at East end terminal of Geeta Colony Bridge i.e., Raja Ram Kohli Marg intersection for signal free flow of traffic and for accommodating additional vehicular traffic from Geeta Colony

Bridge in Eastern Side i.e. Trans-Yamuna area. It eased out the traffic on western end of Geeta Colony Bridge.

Fig. 16: GOOGLE image of Ring Road bye-pass

3.8.5 Ring Road Bypass Project

The construction of the bypass gained importance as Ring Road could not have been widened further. The Project managed to ease traffic congestion on Ring Road along the stretch between ISBT and IG stadium by 80% and has ensured signal-free movement of traffic from ISBT to Maharani Bagh. It has also de-congested the Ring Road stretch near Red Fort, the congested Rajghat and Shanti Van crossings which experiences a lot of VIP movement. Use of the bypass is compulsory For commuters coming from ISBT and going towards ITO. As a result, there is virtually no incoming traffic between ISBT and Shanti Van. For commuters coming from ISBT, it is a signal-free ride till the IP flyover. For those who are travelling to ISBT, commuters can avoid all traffic signals by using the bypass as it is much faster travel like on an expressway. One of the major benefits of the bypass is that

earlier whenever there was a rally at Ramlila Maidan, the dispersal that would take place at Rajghat would cause serious dislocation of traffic on Ring Road. Now, with traffic diverted to the bypass, the situation is greatly improved. Especially, commuters between central and north Delhi can travel unhindered. For commuters to south Delhi from ISBT, the exit near the IP flyover is an ideal option while those travelling towards Tilak Marg from ISBT can exit either at Rajghat or the IP flyover. The 5.3-km bypass project has integrated the Geeta Colony flyover and the Old Yamuna Bridge with the Ring Road bypass project. This has led to smooth traffic movement from Noida, East Delhi, towards south and north Delhi.

The Ring Road bypass comprises of six underpasses/depressed roads, including the one before the crematorium two are located near Shantivan, one at Vijay Ghat, one at Hanuman Setu and another one inside the crematorium which connects it to the parking lot. Besides this, there are four loops that help ensure that you can go in any direction and there are four slip roads along the loops for exiting the bypass.

3.8.6 Elevated corridor project to link Noida in UP

It is a 3.6 kms long elevated road project as part of corridor improvement schemes of the Commonwealth Games 2010 that was planned for providing a link from Akshardham flyover to the UP border at NOIDA. The scheme comprises of widening the existing road from current 6-lane to 8-lane right from Akshardham up to UP border at NOIDA. It also includes a single carriageway flyover over Mayur Vihar T-junction, 1 double carriageway flyover at two subsequent junctions, a steel bridge and 3 pedestrian bridges for crossing the heavy traffic roads by pedestrians, apart from cycle tracks for safe movement of cyclists, foot path for safe movement of pedestrians and service roads. This project is finally also an arterial connectivity between East Delhi, NH-24 and the Noida Expressway. It has drastically reduced the journey time from the Commonwealth Games Village to other sports venues with a signal free movement of traffic. Brief details of these corridors are listed in Table 5.

Table 5: Infrastructures as preparation for Commonwealth Games 2010 in Delhi

S. No.	Location	Year of construction	Type of Structure	Technology	Remarks
1.	Ghazipur	2009	3 level grade separator	Cast-in-situ combined with precast construction, iron ore layer beneath underpass for uplift pressure	First time 4 levels with Underpass along Rohtak Road at bottom, pedestrian interchange above, rotary at ground level for right turning traffic and flyover over ring road at top was introduced.
2.	Shyam Lal College	2009	3 level grade separator	Cast-in-situ construction	Innovative design evolved due to space restriction on AIIMS side
3.	Apsara Border	2009	3 level grade separator	Cast-in-situ construction	Innovative design evolved due to 5 arms with heavy traffic meeting at junction
4.	Azadpur	2009	3 level grade separator	Cast-in-situ combined with precast construction	First time flyover over 2 junctions was planned
5.	Raja Ram Kohli Marg	2009	Flyover over single crossing	Composite construction with steel girders and RCC deck that helped in completing the work fast so as to meet the deadlines of Common wealth Games.	Comprehensive planning of development of East Delhi and free access to North Delhi.
6.	Ring Road Bye-Pass Project	2009	Flyover over single crossing		
7.	Noida Link Project	2009	Flyover over two crossing		
8.	Mukarba Chowk	2010	Full Clover Leaf	Cast-in-situ combined with precast construction	Free access to and from Traffic from/to Haryana/Punjab on NH1
9.	Ring Road Bye pass at Salimgarh	2010	Flyover over single crossing	Precast segmental box girders	A new ring road avoiding all junctions in area around Raj Ghat was created
10.	ITO Chungi in Trans Yamuna	2010	Flyover over single crossing	Composite construction with steel girders and RCC deck	As a planning to develop Vikas Marg so as to have a free access to ITO Bridge
11.	Wazirabad	2010	Flyover over two crossing	Precast segmental girders and reinforced earth Retaining wall	Flyover with multiple loops for entry and exit from/ to all nearby areas., It was a part of approaches to signature bridge project
12.	Bhajanpura	2012	Flyover over single crossing		

3.9 POST COMMONWEALTH ERA

Now the era of standalone flyovers or even flyovers over two or three junctions was over, because at the flyovers, more lanes were added, but the corridor between two flyovers was still having lesser number of lanes that proved to be bottleneck for the moving traffic. Relief from traffic congestion after making series of standalone flyovers was no more available. PCU counts had exceeded its limits. Need was felt to adopt solutions of next generation. Standalone flyovers also cause discomfort in moving from one flyover to another in short stretch gives a feeling of moving over a camel's back. Hence the leftover areas between existing flyovers/Underpasses then had been stitched with elevated corridors.

Fig. 17: 4 Elevated corridors on Ring Road and Outer Ring Road

Four such corridors that include three corridors on the outer Ring Road between Vikaspuri and Mukarba Chowk and one on the Ring Road between Azadpur and Prembari were

completed in 2016. The corridors on outer ring road were ,4.3 Km long elevated corridor connecting Vikaspuri to Meera Bagh, 2.6 Km long Mangolpuri to Madhuban Chowk and 2.6 Km long Madhuban Chowk to Mukarba Chowk. One missing link on Ring Road was existing between Prembari and Azadpur that was connected with a 1.6 Kms long elevated corridor. All these four corridors have been provided with 6 lanes on single pier at central verge with precast segments having spine beams added with wings on either ends.

Today, when the need is fast track construction with least disturbance to urban life, two flyovers, and one underpass and connecting loops at Mahipalpur has been completed in just 13 months. The speed of work has gone up substantially. This confirms that the construction is getting more and more sustainable with the adoption of newer technologies as well as better awareness and more sensitivity towards public and environment.

Fig. 18: Mahipalpur project with two flyovers and an underpass

Brief details of these corridors are listed in Table 6.

Table 6: Infrastructures in Delhi in Post-Commonwealth era

S. No.	Location	Year of construction	Type of Structure	Technology	Remarks
1.	Azadpur to Prembari	2015	1.6 Km elevated corridor	Flyovers on single column with spine beams. Longitudinal as well as cross pre-stressing	The technology of flyovers over single column was introduced in Delhi. Segments with central spine beams were longitudinally pre-stressed and wings were added further with cross prestressing.
2.	Vikaspuri to Meera Bagh	2016	4.3 Km long elevated corridor		
3.	Mangolpuri to Madhuban Chowk	2016	2.6 Km long elevated corridor		
4.	Madhuban Chowk to Mukarba Chowk	2016	2.6 Km long elevated corridor		
5.	Wazirabad connecting North Delhi to North-East Delhi	2018	Cable stayed bridge over Rover Yamuna	Asymmetric Cable stayed Bridge	This is the iconic structure with highest asymmetric cable stayed bridge in world. 15 pairs of front cables making 251 m main span and 4 pairs of back stayed cables.
6.	Mahipalpur	2019	Two flyovers, and one underpass	Precast girders for flyovers and Box push technology for underpass	First time vehicular Underpass was made with Box push Technology completed in just 13 months
7.	RTR Marg	2019	Flyover over two crossing	Precast segmental box girders	First time complete flyover over portals was constructed due to space limitations

3.10 SUSTAINABILITY STUDIES OF 3 CORRIDORS CONSTRUCTED FOR CWG

With the study of growth of transportation infrastructure in Delhi, it is seen that with the rise in human and vehicular population, the city is getting facilitated with more transportation structures so as to cater to the needs of public. With the rise in demand, the transportation corridors were also getting improved by resorting to various means like widening the existing network and also creating new network. Also, the city has adopted the new technologies every time there was a boom in this sector.

City has seen construction of many corridors for the commonwealth Games as listed before. It was a matter of national pride in successful conducting the games in India and also convenient movement of sportspersons as well as spectators for these Games. It is quite possible that sustainable construction may not be the prime objective, but when the

objective was commonwealth Games, sustainability cannot be ignored. If we consider economics, the aim was to create more and more facilities within the limited budget. The purpose of bringing the public and sports person distant apart, the Games Venue signalises the social factor being taken care of. When the cause is an international issue, the environmental issues cannot get ignored. Keeping in mind the triple bottom line concept as met, the detailed study of the design and construction of three such corridors has been done in order to appreciate the existing sustainability features in following 3 corridors.

3.10.1 Mukarba Chowk Project: full clover leaf

There was heavy traffic in both the directions at Mukarba Chowk junction and it was considered to make the intersection signal free by designing the interaction with full clover leaves with dedicated cycle track, bus bays at all levels, ramps with desired slopes for the convenient movement of the physically challenged persons between different levels, additional provision of lift, escalator and a pedestrian underpass that facilitated the pedestrians as well as cyclists.

Fig. 19: A view of Mukarba Chowk grade separator

3.10.1.1 Geographic location: Geographically, the Mukarba Chowk lies in North Delhi and is located at the intersection of Outer Ring Road with National Highway No. 1, part of GT road at Azadpur. This junction is one of the busiest junctions of the country that carries very high amount of traffic in all directions. Traffic scenario is mixed type of traffic that carries non-motorized transport to motorized transport from 2 wheelers to four wheelers to Trucks as well as trailers with multi wheels. Traffic Intensity is also very high. As per the traffic studies carried out prior to taking up the project, it was catering to 3,30,000 PCUs every day [65, 83].

3.10.1.2 Sustainability considerations: While designing the full cloverleaf, it was identified that it is not only the traffic challenge but those structures having heritage importance or otherwise that cannot be shifted and essentially require to be protected at that location only. Such structures are Burial ground, sanitary landfill and garbage dump, electrical sub-station. Overall scheme was designed in such a manner that all these structures made a part of the scheme without demolition or shifting or causing any harm to them

i. The scheme is designed structurally in concrete and composite sections with steel plate girders supporting the deck slab in concrete. In order to reduce carbon footprint, more embankments were incorporated in scheme than the viaducts, unless absolutely essential. Blended cement was used to make concrete that was also an important consideration in order to minimise the carbon footprint. The service life of the structure has been increased by use of Blast furnace slag mixed in concrete. In addition to this, the retaining walls in the filled-up areas were constructed with geo-grids in minimise the use of concrete used thus the overall consumption of material also got reduced drastically All the structures were designed as slim structures.

ii. The construction period was drastically reduced with appropriate design and adopting suitable construction technologies.

iii. With an aim to reduce the pollution in the environment that is generated from the standing vehicles, continuous movement of traffic without need to stop at traffic signals was assured with provision of full cloverleaf.

iv. Adequate facilities have been assured for the safe, secure and convenient movement of both pedestrians as well as cyclists. Due importance has been given to the Public transport system in comparison to the personal mode of transport. Safety rights of road users were given due regard during the construction stage.

Fig. 20: Landfill area transformed into a green belt

v. The cultural and social characteristics of the existing environment were maintained by retaining the essential structures. The existing utilities, heritage structures, city garbage dump have been accounted for by making an inherent part of the overall scheme. Simultaneously the Project area has been developed with well-planned landscaping to enhance the aesthetics of structures along all around.

vi. The city's landfill and garbage dump occupying a large space thus got utilised suitably for socially useful and beneficial purposes. Nallahs (drains) have been made a part of the overall landscaping and used as an asset to the project.

3.10.2 BARAPULLAH ELEVATED ROAD PROJECT (PHASE 1)

Commonwealth games were organised by India in 2010 and it was ensured to games

federation that proper connectivity from main venue of the Games i.e. Jawahar Lal Nehru stadium to Games Village established near Akshardham temple will be provided by Government of India for about ten thousand participants. Thus, smooth road network was required to be designed between two locations. Though the corridor along the ring road negotiating Ashram, Sriniwaspuri, Defense Colony & South Extension was equipped with flyover at every such junction in order to cater to 165000 PCU/Day, but still traffic jam was a daily phenomenon during the Peak hours in morning and evening. This traffic is expected to cross Four Lakhs PCUs per day by 2021 as per the report published by NCRPB. In order to resolve the traffic issues, Barapullah corridor was planned as an independent corridor [66].

3.10.2.1 Geographic location: The Barapullah Nallah Corridor (phase 1) was planned as East-west corridor that is an alternative and independent corridor between Sarai Kale Khan and AIIMS in order to decongest this section of Ring Road. It was a solution to the urgent need of facilities required for the Commonwealth Games and after that used for the convenient movement of all modes of traffic.

The alignment of this corridor was chosen over the Barapullah Nallah (drain) that takes the discharge from many internal and peripheral drains and further discharge its contents that amounts to about 1,25,000 Kld of domestic sewage into the River Yamuna. Barapullah Nallah initiates from Ring Road in east to INA in Southern part of Delhi. On the way, it crosses major Railway lines i.e. Mathura railway track, many Arterial Roads namely Nizamuddin Railway Station Road, Mathura Road near Jangpura, Lala Lajpat Rai near CGO Complex, Bhism-Pitamaha Marg near Sewa Nagar Flyover that meets Aurobindo Marg at INA/Dilli Haat. The average width of Barapullah Nallah is 70 m and it covers an 9.60 Hectares of area. The areas falling along the Barapullah Nallah includes Seva Nagar, INA, Jangpura, Nizammuddin, JLN Stadium, CGO complex, Siddhartha Extension and Sarai Kale Khan Village.

Fig. 21: Barapullah Nallah: 12 bridges in view

3.10.2.2 Sustainability Considerations

i. The need of Commonwealth games was to have a direct alignment, economical in cost, aesthetically pleasing, having adequate traffic carrying capacity of intersections and interchanges and also speedy construction due to time constraints. The project has been planned to improve the aesthetics of the urban space utilized to construct this corridor. The alignment passing near the heritage structures were protected physically as well as visually. The execution was carried out in moving road and rail traffic without hindering the movements.

ii. Noise barriers have been installed at all sensitive areas where habitat was there so that there is no disturbance to public while the corridor is in operation. A well-designed horticulture works and landscaping works with indigenous species that includes broad-leaved evergreen and deciduous species have been provided all along the project area in order to maintain the green character of capital city Delhi. Attempt has been made to bypass the inhabited locations to the extent possible.

iii. The Barapullah Bridge (Figure 12) is visible while negotiating through the Barapullah corridor from Sarai kale khan to INA.

iv. The geometrics of the corridor were modified by shifting and raising its height so that the heritage structure namely Khan-e-Khana's Tomb remains in view and no construction is taken in prohibited Area up to 100 meters of boundary of the notified monuments.

v. On the suggestion of the Archeological Survey of India (ASI), an expert in heritage was hired for restoring the view of the Khan-e-Khana's Tomb and Barapullah corridor. As per the suggestions received, the geometrics were modified so as to ensure a distance of more than 100 m distance between the Bridge and the Monument. Further the soffit level of bridge was raised from designed height to 12 mts above Mathura Road (Figure 22).

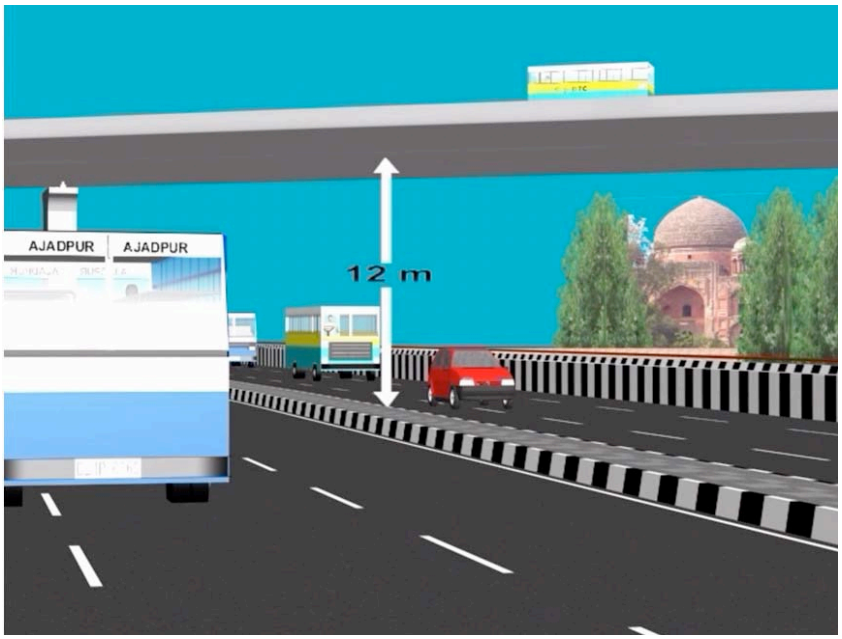

Fig. 22: Khan-e-Khana's Tomb: view restored

vi. The aesthetics of the influenced area has been given special considerations by Landscaping the entire area.

vii. Precast Segmental construction was adopted as scheme of construction to avoid the disturbance that could have been caused to road traffic as well as rail traffic. Also, the sequence of execution was so planned that the traffic movement was allowed round the clock. (Figure 23).

Fig. 23: Road and rail traffic continued during construction

viii. Turfing the area has controlled the likely erosion of the embankment slopes. Trees have been planted in the entire project area.

ix. Existing drainage pattern has been maintained without causing any disturbance. Side drains have been provided under the flyover and on embankment slopes that are connected to main outfall drain. Sections of the corridor along the cross-drainage structures have been designed suitably.

x. Providing safety gadgets like helmets, masks, safety goggles during the construction period, ensured safety of workers.

xi. In order to control the traffic during the construction stage, adequate signage, barriers and flagmen were stationed at site.

xii. The work places were provided with proper sanitation and waste disposal facilities. Waterlogging was controlled with proper drainage system around the construction

sites to avoid any water borne disease. Potable and safe drinking and washing water supply was ensured at every workplace to care for the health of workers.

3.10.3 GRADE SEPARATOR AT GHAZIPUR

With a decision to construct the Commonwealth Games village near Akshardham temple, this junction had become even more important as it existed on the route of Commonwealth Games village to Yamuna sports complex [58]. After the traffic studies carried out on this junction, it was required to provide a 3-level grade separator at this junction for making it signal free so that traffic can move in all the directions without any hindrance.

3.10.3.1 Geographic location: Ghazipur is located in Eastern Delhi of the Trans-Yamuna areas very close to UP- Delhi Border. The area across river Yamuna, particularly East Delhi, has witnessed an unprecedented growth in population and Vehicular traffic in recent past. Ghazipur is a very busy crossing between NH-24 bye-pass and Road No. 56, both being 2 main arterial roads and it provides an entry point to many of the areas in Eastern part of Delhi.

3.10.3.2 Sustainability Consideration: Sustainability is ensured not only during the construction, but during its entire service life. Facilities created for the public including motorist, cyclists as well as pedestrians:

i. 770m long main flyover with 8 lanes, dual carriageway with median on NH-24 Bye-pass to ensure uninterrupted movement of straight traffic i.e. from Delhi to Ghaziabad and vice versa.
ii. The Underpass along Road no. 56 across NH 24 to facilitate the signal free movement of traffic from ISBT Anand Vihar to Kalyanpuri and vice versa. This Underpass is 635m long, 6 lanes dual Carriage-way with median which includes 4 lanes is for Motorist vehicles and 2 lanes each of 3m width at low gradient for Non-Motorist Vehicle (i.e. Cyclists, Rickshaws etc.). Special attention was devoted to

cyclists so that they are segregated from motorized traffic. The slope for negotiating the underpass is made gentle with bare minimum headroom.

iii. There is a rotary of 85 m diameter at surface level between the Underpass and Flyover at mid-level for free movement for Right turning traffic.

Fig. 24: Pedestrian foot-over bridge

iv. Surface level Slip Roads of 3500 m length and 11 m width on either side of Flyover and Underpass are provided for free left turning.

v. Three Arch type suspension Foot Over Bridge (FOB) having clear span of 66m (two on NH-24 and one on Road No. 56) made in structural Steel, without any pier/support in the median and deck suspended with arch using Fressyinet suspender bars of varying length (Figure 24)

vi. **Ghazipur Drain:** This drain, running parallel to road no 56 is the major drain of East Delhi and serves most of its industrial and domestic requirements. There is an existing bridge across this drain on NH-24 which was only 2+2 divided lanes wide and was insufficient as per requirement of traffic. This drain could not be closed even temporarily because of reasons mentioned above. Construction of any structure in and across this drain would have to be on critical path for the overall success of the project.

vii. **Bridge on Ghazipur Drain:** There was an existing and running bridge on NH-24 over the drain mentioned above It was a 2+2 lane bridge with footpath on either side. Removal of the bridge and construction of new bridge instead would ask for lot more activities and corresponding time because of which it would have been impossible to complete the project before commonwealth games. So, there was no option left other than building flyover spanning whole length of the existing bridge over drain. The length of the existing bridge was 52m.The span was selected as 75m to avoid any conflict with the foundations of abutments of existing bridge. As it was not possible to support it from existing bridge, it was decided to go for balanced cantilever construction of this span.

Fig. 25: Ghazipur crossing before and after construction

viii. **Difference in level:** The existing level of NH-24 was approximately 3 to 5 above the developments in the near vicinity. This was a problem particularly in case of apartments constructed in one of the quadrants of the junction towards Anand Vihar ISBT opposite to the Ghazipur drain. The level of the road approaching the junction could not be raised without providing a separate service road to the apartments because of the level difference pushing the intersection development further into the drain area.

ix. **Underground Utilities:** Two high pressure sewer lines (1000 mm dia. And 900 mm dia.) of Delhi Jal Board (DJB) were crossing the junction along with one DDA sewer

line. In addition to this there was an open drain crossing road number 56 near the junction. Other underground utilities such as various telecom lines like OFC cables of Indian Army, OFC cables of BSNL, telephone lines of MTNL, high pressure IGL gas pipe lines etc.

x. **Overhead Utilities:** It included shifting of High Tension 66 kV HT line along road No. 56 and Kalyanpuri and towers along with one 11KV line of BSES.

xi. Good construction practices adopted at construction site always help to control and prevent pollution. As a good construction practice, it is required to assess the environmental risk for all the activities as well as construction materials to be used before the construction starts at site. Sustainability assessment is gaining importance very rapidly and therefore, appropriate solutions are searched for infrastructure. Grade Separators are designed with long service life period for approximately double that is expected for buildings. Therefore, durability of components and details is quite an important aspect. For durability considerations the entire underground construction in contact with earth and water was made from slag cement (GGBS) as there were issues of both chlorides and sulphates. The site characteristics making an impact on the environment directly or indirectly are detailed out in following sections.

xii. **Air Pollution:** Generally, air pollution is caused due to running of various machineries on diesel, site activities like land clearance and demolition etc.. Heavy dust is generated due to excavation of the Earth, poor handling of construction materials especially sand and aggregates brought in uncovered vehicles and raising the earthen ramps. This generated dust is generally spread over long distances with the passage of time. Air exhausts generated due to diesel engines of machineries used at construction site generate lot of PM10 and diesel particulate matter (DPM). It consists of sulphates and silicates that takes other toxins in the atmosphere and are hazardous to the health of workers at site. In this project, complete care was taken to avoid any dusty environment during excavations or carrying the building

materials to site. This has been achieved by covering the trucks carrying construction material, frequent sprinkling of water all around so as to settle the dust and does not pollute the environment. All the vehicles used were essentially to undergo pollution tests at prescribe frequency so that it does not emit any harmful gases in the environment.

xiii. **Water Pollution:** Diesel/ oil droppings, paints sprayed near water body, cleaners, harmful chemicals and construction debris, if not disposed off in proper manner, becomes a major source of water pollution on such construction sites. Soil erosion caused due to land clearance gets discharged into natural waterways makes them turbid and also cause silting of drains when discharged into drainage system in its vicinity. In the instant case a city drain is passing nearby which has a potential of getting silted or choked. In the Ghazipur grade separator, a city drain coming from Shahadra is passing through the project site. While designing the project, all care was taken to place the foundation system so as not to interfere with the drainage system. Further, the drain was protected from any kind of site disposals. Waste generated from the site was ensured to be dumped at a safe place rather than dropping them in the drain. The existing water body was incorporated in the overall landscaping which greatly enhanced the aesthetics of the project.

xiv. **Land Pollution:** Cutting/ removal of trees existing in the project corridor, uncontrolled excavation of foundations, land clearance are some of the construction activities that are generally observed at a construction site causes the land pollution. Huge amount of waste soil is generated due to excavation activities and should be disposed off properly. It may be partially used in raising of the earthen ramps in order to reduce the amount of surplus excavated soil. During boring of the deep foundations, water is likely to get accumulated in the void and requires proper disposal. Bentonite in water body, if not disposed off properly, may block the drainage system thus other drains functioning in the right of way (ROW) also get chocked. Existing infrastructure and existing utilities are prone to getting damaged.

There are numerous utilities like electric lines and electric poles, water mains, telephone cables, drainage mains, gas pipes falling within the alignment that need to be replaced to other safe zones at site only to save it from the project alignment. In the Ghazipur grade separator Project, number of utilities were to be shifted from the existing locations which includes, IGL gas pipe line, 66 KV HT line along road No. 56 and Kalyanpuri, 66 KV HT line along NH-24, 11 KV line of BSES, 1000 mm dia. sewer line of DJB, 900 mm dia. sewer line of DJB, 900 mm dia. sewer line of DDA, 1000 mm dia. storm water drain of DDA, 900 mm dia. water pipe line, 300 mm dia. water pipe line on slip road No. 7, OFC cable of Indian Army, OFC cable of BSNL, Telephone lines of MTNL. Safe corridors were assigned to all the departments for shifting their utilities in a professional manner.

xv. **Noise Pollution:** Large volume of noise and heavy vibrations is generated due to functioning of heavy machineries at site, excavation activities, dismantling top 1 m of pile head consisting of poor concrete etc. Loud noise beyond prescribed limit distracts the working atmosphere, cause irritation and ultimately may lead to undesired stress to the working people at site. In the Ghazipur intersection project, the level of noise was considerably lowered by planned handling of materials, use of modern machineries that produce less sound, Silent DG sets, silent power tools etc. The planning of various construction activities was so done that silent activities were planned at night hours and other during the day so that noise pollution is minimized and work atmosphere is pleasant and soothing at site.

xvi. **Safety Measures for workers and public:** Being an artery on National Highway with high volumes of traffic for connection to Ghazipur, Noida and other NCT areas, it was essential to evolve structural schemes and traffic diversion scheme so that at no time the traffic is inconvenienced. Safety checks were prescribed while the heavy machinery was under use in order to ensure Environmental, Health and Safety. Safety manager was deployed at all hours of working to ensure healthy and safe site conditions and that causing any damage to environment. Safe construction

practices were enforced strictly at site without any compromise. Proper barricading of suitable height was provided to cover the construction site and stopping the unauthorised persons form entering the site in order to avoid accidents and injury to public due to movement of heavy machineries like cranes, bulldozers, JCB etc. These activities were planned in such a manner that traffic is lean and faces minimum disruption. Cautionary signage was provided along with deployment of security guards round the clock. All the workers deployed at site are provided with protective gadgets/equipment like safety helmets, safety hand gloves, safety shoes, face masks, and use of appropriate safety hoists while they are performing their assigned task at height or under the foul conditions, etc.

xvii. **Social Factors:** Due consideration was given to the residents in the nearby colonies and their right to comfort level was respected. It was ensured that the disturbance caused to them is minimised by planning the project in desired manner. Mostly activities causing disturbance due to movement of heavy machineries, operation of RMC plants, movement of transit mixers etc. were planned at night to reduce the traffic congestion during day. All the workers deployed at site and also the common public passing near the project site were given due protection from the risk of accidents. No single accident was recorded during the concurrency of the project.

3.11 TECHNOLOGICAL ADVANCEMENTS IN INFRASTRUCTURES FROM ASIAD TO CWG

While highlighting the technological advancements in last 3 decades i.e. from Asiad to Commonwealth and thereafter, it is essential to evaluate whether the development was just a technological advancements or an attempt to make our construction systems more sustainable.

In the early days, when the construction of flyovers had started, the construction was just simply supported spans, whereas now with the availability of advanced software, the actual behaviour of structures under dynamic loading is better predictable and as a result of that

3 span or even more continuous structures are being designed and constructed. With the availability of modular joints capable of taking higher expansion, it was possible to extend riding comforts with modular joints placed at the ends of continuous modules of 3 or more spans. Some of the technological advancements since Asiad 82 days are given in following paras.

3.11.1 Shift from cast-in-Situ to precast or prefabricated construction

As detailed earlier, it is observed that with the population explosion and phenomenal increase in number of vehicle within the city of Delhi, it was necessary that the flyovers be constructed with the techniques that no more diversion of traffic be done and also the traffic moves through the construction area without getting disrupted or facing additional discomforts. While appreciating the traffic problems, before deciding the technology of construction of new flyovers, Public Works Department of Delhi opens the challenge to the various consultants and designers of the country, the challenge is to provide the technology and the type of construction so that people do not face the discomforts as was faced during earlier projects [57].

Though it was early nineties, when the concept of Pre-cast Pre-stressed beams was introduced for flyovers in Shahadra, IIT and Masjid Moth, yet it was limited to only short spans up to 20 m. The obligatory span measuring about 50 m and its adjoining spans about 30 m were constructed with cast-in-situ technology. In fact, it is the central and adjoining spans on both sides which demanded improvement in system, but the trend continued till the Public Works Department of Delhi, for the first time accepted the challenge of adopting total Pre-cast segmental technology.

For intersections, which are also not distantly located, trend was shifted to Precast Segmental construction or Prefabricated Steel Girders. Both these solutions were found suitable for the construction in urban environment especially of Delhi as the major activity

of construction of superstructure which otherwise demands the diversion of traffic, was to take place separately in casting yard under controlled conditions.

Accordingly, in the new millennium, Precast Segmental Construction was extended to many locations on Ring Road like Britannia Chowk, Naraina, Moti Bagh, Africa Avenue, Nehru Place, Savitri Cinema, B-Avenue, Sriniwaspuri and Wazirabad. Composite construction with steel girders was adopted on Mayapuri and Khelgaon at Ring Road, Mukarba Chowk on Outer Ring Road besides many other locations in the city like Raja Ram Kohli Marg, ITO Chungi etc. As a step ahead, the flyovers on Outer Ring Road from Vikaspuri to Mukarba Chowk have been constructed with precast segmental technique with spine beams on single pier at central verge along with wings on both sides for complete 2-way 3 lane carriageway and to further enhance the speed of construction.

Fig. 26: Longer spans to cross the major road

3.11.2 Shorter to Longer spans

In the early eighties and nineties, the spans were standardized as 20 m with precast pre-tensioned beams and about 35 m for the obligatory span with cast-in-situ box girders. The flyovers constructed for the commonwealth Games have spans as large as 80 m with cantilever construction built for Barapullah corridor (Figure 26) as well as Ghazipur flyover.

3.11.3 RCC Retaining Wall to Reinforced Earth Wall

It is not only the viaduct of the flyovers where the trend is changed from cast-in-situ box girder/solid slab and cast-in-situ beams to precast pre-stressed beams then to the precast segments, but the change from cast-in-situ to Precast has been adopted for Retaining wall also. In the earlier flyovers where the conventional RCC retaining walls have been used for the approaches, the system requires using a larger width of the adjoining road to support the shuttering of the Retaining walls specially when casting the wall at the height. This not only leaves the traffic to flow within the restricted width, but the area becomes accident prone especially due to the construction activities of the retaining wall. Now, the use of Reinforced Earth Technology is being made for retaining walls in approaches more than 1 m height (Figure 27).

Fig. 27: Reinforced earth wall

Like the segments, the panels were precast at the casting yard away from the construction sites and were simply transported to the site where these were assembled using light machinery like Hydra to lift and place the panels weighting approx. 1T and vibratory rollers to compact the filing material and create friction between the strips simultaneously annexed to the lugs pre-positioned during the casting of the panels at the yard. Thus, the system of centring and shuttering is totally eliminated, causing no hassles to the traffic

moving on the adjacent road. Another system of Pre-cast approach wall adopted in Delhi Flyovers is geo-grids as can be seen at Punjabi Bagh flyover and at Peeragarhi. Though the Reinforced soil Technology was earlier also adopted in some of the flyovers of early nineties like that in Yamuna Bazar Hanuman Setu or Visvesvaraya Setu at Okhla, but the system introduced was cast-in-situ small panels, while at present stepping further ahead, big size Precast Reinforced Earth Panels have been used to eliminate total disruption of the traffic as per the need of the hour.

3.11.4 Crash Barriers

There is change in casting of crash barriers also. Since it is almost the last activity amongst the number of activities in the construction of the flyovers, there is a tendency to make it as fast as possible. In the race of completing the construction fast, the quality and aesthetics in maintaining lines and levels gets lost. Now the trend is getting shifted to split the thickness of the crash barrier into two halves. Outer one is precast at casting yard and brought to site to fix it at perfect lines and levels. Inner surface is cast against the prefixed precast panel of crash barrier thus fixing it with perfect alignment.

3.11.5 Sub base, Base Course and Riding Surface

While Delhi is looking for the techniques which allow fast completion of the flyovers, another time-consuming activity of laying 3 to 5 layers of Water Bound Macadam under the approach roads has now changed over to Granular Sub base and Wet Mix Macadam.

3.11.6 Bearings

In the earlier flyovers during Asiad and even later on when only the cast-in-situ solid/box girders were in use, the flyovers were designed as simply supported slabs and due to lower need of movements, elastomeric bearings were in use. But with the change of trend from cast-in-situ to Precast beams and segments, continuous spans have been designed and thus bearings require to cater for larger movements. Accordingly, the trend has been shifted

to POT cum PTFE bearings or even spherical bearings have been provided in the elevated corridors under construction from Vikaspuri to Mukarba Chowk and Signature Bridge.

3.11.7 Expansion Joints

Similar to the bearings, advancement has been seen in the expansion joints. In the earlier flyovers, buried joints with sliding plate over an angle had been in used. But, with the need of more movements, single strip seal and modular strips seal expansion joints have been provided at number of Flyovers in Delhi. Signature Bridge is provided with Expansion joint with 12 modules.

3.11.8 Quality Assurance

Works executed by Govt. of Delhi are following Extra High-Quality Assurance (Q4) as per IRC:SP:47. Proper documentation of each and every activity is being done. Before taking any activity at site, a method statement is submitted by the supplier/contractor along with the tests the contractor proposed to perform and at what level. Some of the materials may require only first level check like manufacture's test certificate, but other may require more testing like at the site laboratory for the third level testing, the materials have been sent to the reputed laboratories like Shri Ram Test House, IIT Delhi, NCCBM Faridabad and CRRI Faridabad. Most of the laboratories are ISO 9002 certified. Besides this mock up for important elements like Piers with Rib finish, segments, cast-in-situ and Precast crash barriers etc. were done before executing the work at site.

3.12 SUSTAINABILITY CONSIDERATIONS IN INFRASTRUCTURES

Sustainability is now recognised as a vital parameter and to be given due consideration from planning stage, extended over to construction, maintenance till demolition of civil structures in an Engineering manner [59]. Road bridges built prior to Asian Games had been planned with a service life of more than 100 years, but some of them have started showing the signs of deterioration even before half the design life [60]. It is a point of concern and

essentially demands for establishing the parameters / methodologies to assess the service life of structures at the design stage only after considering all the environmental related issues making an adverse impact on the health and age of the structure [61].

Mother nature has been nurturing the Earth for the many years. The complex eco-systems (the biosphere) that are evolved around this planet conserve energy, and recycle energy and lot of materials. For the overall development of the community and providing the due benefits, it is necessary that civil constructions continues in rural as well as urban areas. While such construction take place around the years for so many years and never-ending process, it is utmost necessary that every such part activity should be environment friendly as the Environment also has an equal right to remain protected from destructions.

Degradation caused to the environment during construction of urban infrastructures one after the other like flyovers, elevated corridors, metro corridors, Underpasses, River Bridges and other infrastructure projects as taken up prior to the Asian Games to the Commonwealth Games and continuing thereafter in New Delhi is matter of serious consideration.

Environmental Impact Assessment has started about four decades back when its importance was recognized for ensuring a sustainable development. At that time, it was just a tool that was used arbitrarily, but five years later after the introduction of Environmental Protection Act 1986, it was made mandatory and analysis of this assessment was to be put up for approval of the proposed developmental schemes. In order to assess the degradation potential, it is rather necessary to appreciate the environmental characteristics of the area for which the development scheme has been proposed. After a fair assessment, next step was to identify the mitigation measures to minimise the assessed degradation to the environment.

Sustainable Construction can always be ensured by following some principles like use of low embodied energy materials for the construction, reduction in construction and demolition waste and recycling of such waste, improved environmental efficiency and better service life design of structures, use of local materials to minimise carbon emissions and most appropriate construction methodology to remove the shortcomings with the conventional technologies.

The construction industry is the energy intensive industry that consumes maximum amount of raw materials. Globally, it consumes more than 40% of all natural resources and emits 35% of all greenhouse gas emissions worldwide. In India, being a developing nation, the construction industry consumes about 50% virgin raw materials and resources that are naturally extracted or mined. There is a need to deploy Environment friendly systems, with reference to consumption of material and technology. Further it is the need of the hour for this industry to focus on utilisation of the industrial waste, recycled buildings materials along with waste derived raw materials for sustainable development. However, efforts should be made to consume more of the locally available material with high percentage of reusability and recyclability in order to reduce wastage.

For controlling and reducing the pollution on the construction sites, it is essential that most suitable construction practices be followed. Accordingly, the project planning should start with the preparation of Environment Impact Assessment (EIA) report for all the construction activities as well as construction materials to be used and having a potential to pollute the environment. There is an acute pressure on contractors and Engineers from Environmental protection agencies and other government organisations to minimise the pollution generation at sites by strictly following the norms prescribed for regulating the environment. Earlier the penalties for violation of Environmental rules were on much lower side there was a tendency to avoid prevention of environment protection, as stakes were not high. Today, the scenario is different and polluter has to pay a heavy price for causing

pollution besides having a stake on its reputation. It is. cost effective to adopt needful measures to minimise and control the pollution. The construction industry should adopt all mitigation measures and include such practices in the construction planning as a part of Environmental protection management at all construction sites. Such good practices are mentioned in following paras.

3.12.1 Erosion of soil and run-off

i. Need of the hour is to reduce the disturbance caused to the land and preserve the vegetation in order to reduce the soil erosion. Regular sprinkling of water at the construction sites especially during the dry weather can control dust. It is a good practice to cover the trucks carrying sand and aggregates tarpaulins sheets. Such materials should be brought to site in small consignments instead of stocking for a longer period. Moreover, whenever such material reaches the site, it should also be done in a barricaded area and by sprinkling water to control the dust generation in environment.

ii. The building materials that primarily includes cement, fine and coarse aggregates should be well covered and spillage controlled. The stocking area should be well planned and should be far away from drains to save them from getting washed away.

iii. Surplus soil should be used for useful purposes like filling up the low-lying areas.

3.12.2 Cutting and removal of trees

Whenever trees are to be uprooted to clear the alignment or construction areas, replacing the greenery with at least 10 times more such plantation as per the Forest Conservation Act-1980. Whenever the trees are to be cut and removed from the alignment, first attempt should be the relocate them by maintaining the bulb and replant at other appropriate location. Generally, the survival rate is about 60 % of all the transplanted trees.

Fig. 28: Greenery in area outside as well as under the viaduct

In addition to above, best efforts are made to develop Greenery all-around in areas adjoining Project site or even beneath the flyovers in Viaduct areas (Figure 28).

3.12.3 Contamination of drains

The drainage system at site should be properly covered so that the contamination of drains is reduced. The wastewater generated from construction activities at site should be collected separately in settlement tanks. Thereafter it should be screened and then re-circulated or disposed off as a good Engineering practice.

3.12.4 Shifting of infrastructure/utilities

All the underground utilities like telephone lines, water pipes, sewerage lines etc. should be verified before taking up any excavation work at site. This is possible by collecting the required information form the various service departments or by physically verifying at site by deep cuts at certain intervals. There has to be proper planning to identify a suitable corridor to shift these utilities. Proper record should also be maintained so that such information is readily available whenever the required information is called for during next construction assignment. Further while taking up the assignment of relocation of services, care should be taken to intimate the users by public notice and to compensate them by

additional services so as to minimise their disturbance.

3.12.5 Social aspects

Proper and right information of the construction activities that may include its nature, construction duration and likely negative impacts of the construction activities should be provided to all the nearby Resident Welfare Associations (RWAs), public residing in vicinity and other effected establishments like business, schools, hospitals etc.. Best mitigation measures should be adopted to minimise impact on nearby residents. Public information and cautionary signage be provided at site along with the relevant information of project like title, project cost, construction agency, time schedule of work, details pertaining to designed traffic diversions, restriction in movements. Contact details of the officers to be contacted for public complaints may be provided. Information regarding the alternative traffic routes for convenience of public through media and TV Channels or pamphlets be provided for minimising the disturbance to the residents in nearby areas. Service roads and pedestrian walkways have to be well- maintained in good useful condition to allow the smooth movement of traffic. Adequate and trained guards be deployed at site for guiding and controlling the traffic.

3.12.6 Safety and health measures adopted for public and workers

Generally, following the standard, safe and well tested construction methodologies is a practice in all mega projects. If the site is not properly and adequately protected by providing suitable barricades of required height, then it may have an impact on the complete construction site. It becomes more critical, when heavy machineries like heavy duty cranes are under operation and some launching operation is going on at site. Such activities should be performed when traffic is comparatively less if cannot be stopped totally. Entry of unauthorized traffic, either pedestrian or vehicular has to be totally controlled by providing adequate warning/ cautionary signage at site. In addition, security guards should also be deployed round the clock at site to stop any unauthorised entry to

the site. All workers working at site should be provided suitable protective gadgets like safety helmets, hand gloves, boots, masks, safety hoists, safety belts when working at height or in foul conditions, etc. Established standard practices and safety checks are to be adopted religiously while using heavy moving machinery such as cranes, hoists, etc. An Environmental, Health and Safety (EHS) expert should be deployed at site round the clock. A regular training on health and safety aspects should be provided to all site staff working at construction site. Any untoward incident or accident that may happen at site may be reported to the authorities promptly and relevant record of such mis-happenings has to be maintained.

3.12.7 Noise pollution

Noise pollution can be substantially reduced by use of silent power tools, equipment and silent diesel generators. Activities like rock blasting that generate high noise and vibrations should not be permitted at all in construction activities in Urban Environment. Manual methods should be used as far as possible. Noise generating activities should be totally eliminated at night. New vehicles and machinery machineries maintained in proper working conditions are deployed with the requisite adaptations to minimise the noise and exhaust emissions and ensuring that these are well maintained as per the manufacturers' specifications.

3.12.8 Environmentally friendly materials and technologies

3.12.8.1 Utilising locally available construction material: Transportation of construction materials like fine and coarse aggregates, cement and steel is a key factor in the embodied energy of the construction materials. The travel distances vary as per the specific location of the project. Major construction materials like cement and steel are brought from even longer distances may be 300-700 km. In urban areas of India, construction materials like coarse and fine aggregates etc. may be transported from 100-250 kms. The energy consumed during transportation of a material increases the embodied

energy of the construction materials. Hence as far as possible, locally available materials should be utilized during construction.

3.12.8.2 Use of blended cement: Use of Blended Cement indicates that cement is having the highest impact in terms of various environmental impacts out of other construction materials used during the construction. Life cycle assessment (LCA) study of various types of cement has shown that the replacement of OPC by industrial waste like fly ash or granular blast furnace slag always reduces the total environmental impact due to use of cement during the construction. It has also been highlighted in various studies that utilisation of blended cement not only helps in reduction of environment impact but also improves the performance of various parameters of the concrete produced. However, industrial waste is not only used in the production of blended cement but also consumed during ready mix concrete.

3.12.8.3 Use of recycled coarse and fine aggregates: Large quantities of coarse aggregates and sand are used for any construction activity. Aggregates constitute nearly 70% of the total resources consumed during construction phase. The environmental issues regarding the use of these aggregates are depletion of virgin natural resources and the energy required for crushing and transportation. The energy consumption for transportation of 1 cum of natural sand and crushed aggregates is 1.75 MJ per km. Due to use of natural aggregates in the concrete all over the world, land patterns have changed in some areas, dredging of water bodies is being done, rivers are being mined for sand and mountains are being cut. To avoid the rapid depletion of natural resources for providing aggregates for concrete, it is essential to explore the possibility of utilising the waste generated from the demolition of structures or from the construction sites as useful aggregates for sustainable development. Sand can also be replaced by sintered fly ash. This will also help in diverting large quantities of C & D waste from landfills and dumps of our country.

3.12.8.4 Chemical admixtures used for performance enhancement: If cement manufactures in India employ fairly satisfactory practices of waste utilisation, concrete constructions have scope of improvement with the use of fly ash, granulated slag and silica fume as otherwise their disposal is also an issue. Such materials can be used either as constituent additives in manufacture of blended cements or as mineral admixture to be added in the concrete mixer. From the point of chemistry of hydration reactions and performance of concrete, both approaches should yield similar effects.

3.12.8.5 Fibre reinforced concrete (FRC): Any concrete, howsoever good it may be is brittle in nature and has inadequate tensile strength. Concrete quality can be improved by better controls over production, but to improve its qualities like tensile strength, fibre reinforced concrete (FRC) is one of the solution as it has better mechanical properties like compressive strength, modulus of elasticity, flexural strength and toughness. It further delays the corrosion in RCC structures, permeability of water and finally improve its service life.

3.12.8.6 Concrete with fly ash and recycled aggregates: Concrete is a nano-structured material whose durability is affected in aggressive atmospheres because of its inherent porosity. However, adding fly ash can improve its durability. Adding a combination of Fly ash, a superplasticizer and a water proofing admixture, can improve this property even more. Thus, Concrete with fly ash content varying from 25-50% and having recycled coarse and fine aggregates up to 40-80% may result in saving non-renewable energy up to 35% and resources up to 74%.

3.12.8.7 Treatment of embankment slopes: The slopes of the embankments have been provided with turfing as a recommended practice to treat the slopes and control the erosion of soil. Plantation has also been carried out on road sides as well as inside the

traffic islands formed near the rotaries.

3.12.8.8 Precast concrete systems: Precast concrete systems offer tremendous advantages. Some of the major advantages are faster construction, lesser cost of project and better control over the quality of work, better durability of structure, lesser waste of construction material, more flexibility in designing, sustainability, better health and safety of the occupants, aesthetically pleasing structure, better standardisation and modularisation of RCC components in comparison to in-site construction and has hence gained worldwide recognition.

3.12.8.9 Self-compacting concrete: The creation of a durable concrete structure is highly dependent on compaction, which is an important part of the construction sequence. In spite of technological advances in the field of compaction, its effectiveness is far from consistent in areas with congested reinforcement and complex forms and depends significantly on the workers involved. With an objective of achieving durable structures without depending upon the vibrations, self-compacting concrete (SCC), has been developed which has an advantages of not requiring any compaction.

3.12.8.10 Ready mix concrete: At present, Ready Mix Concrete (RMC) is used in most of the major cities. In last one-decade RMC industry has grown exponentially that has ensured better-quality control. Usage of RMC should not be limited to large construction projects in metropolitan cities. It is required to popularize RMC in smaller towns and urban areas also by making it mandatory in contract documents.

3.12.8.11 No disruption to running traffic near project site: With an aim of continuously allowing the movement of road traffic as well as rail traffic without any disruption, the construction techniques were planned as precast segmental construction to reduce the working at site. Even the Sequence of construction activities should be so

planned that the traffic on road and rail lines continues during the construction and launching periods also.

3.12.8.12 Protection of heritage structure: The alignment of the Project with reference to Heritage Structures should be such that it is at least 100 meters away from the boundary of notified heritage monuments because this area is the designated as Prohibited Area, where no construction activity is permitted up to the prescribed limits.

Fig. 29: Khan-e-Khana's tomb (heritage structure remains in view)

Khan-e-Khana's Tomb existed near the alignment of Barapulla corridor. Its Alignment was modified by partly shifting it towards its east in order to provide more than 100m distance from the Monument. Its soffit was also raised to 12 m above Mathura Road Level in order to maintain the view of Khan-e-Khana's tomb (Figure 29).

CHAPTER 4

IDENTIFICATION OF SUSTAINABILITY INDICATORS

4.1 Introduction

The term sustainability indicators was first coined during the Brundtland commission held in 1987, when it was conceptualised as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". 'Needs' and 'Limitations' were two key words incorporated in this definition. It was explained that Needs indicates the utmost requirements of the poor people across the globe, whereas limitations indicates the restrictions on the ability of the environment itself to meet the current as well as future needs.

In this research, carried out on the construction of transportation infrastructures, the two terms 'needs' and 'limitation' are redefined in present context i.e. construction of infrastructure corridor to solve the traffic congestion problem as need of the day. This need is to be fulfilled within the limitations imposed by thick Urban environment. Thus the term sustainability is redefined as development of transportation infrastructures as a relief measure from the heavy traffic congestion without compromising with the right of the people living in the vicinity to have a respectful, safe and healthy living. Thus the tern need in this context is the creation of transportation corridors and limitation is the thick Urban area with people all around using the existing corridor at same location and living in the colonies right in its vicinity. Thus Sustainability will be there if the need is fulfilled within the limitations without compromising the right of respectful living.

4.2 SUSTAINABILITY INDICATORS

Once the sustainability in transportation framework is understood, it is required to understand what constitutes an execution sustainable. In order to find the sustainability

indicators, it is essential that some construction sites of transportation infrastructure projects are studies in detail and the sustainability indicators are identified. Earlier studies in US and Europe recommended the concept of triple bottom line that means the sustainability constitutes of three parameters i.e. economic, social and environmental. Any activity that is economic in cost, environmentally friendly and socially useful will be termed as sustainable. But this concept cannot be followed in strict sense for all places and all activities. In India, a developing country, it must constitute more parameters. These three pillars will not be sufficient and needs an extension or modification. The parameters required to make an execution sustainable are defined as sustainability indicators. Hence, four sites in Delhi has been chosen to identify the more relevant sustainability indicators that are more appropriate in an urban environment and for a developing country. The four sites selected, selection criteria and identification of sustainability indicators are explained in subsequent paras.

4.3 SELECTION OF SITES FOR SUSTAINABILITY STUDIES

It was observed that number of transport infrastructure projects were in progress in metropolitan city Delhi. Delhi was choked due to heavy traffic density on its roads. In order to ease out the traffic conditions and reduce the travelling time, construction of road infrastructure as well as metro rail corridors were observed coming up to augment the city transport infrastructure. During this period, major infrastructure projects in Delhi were executed by Public Works Department (PWD), Delhi Metro Rail Corporation (DMRC), Delhi Tourism and Transportation Development Corporation Ltd. (DTTDC).

4.3.1 Available sites under construction

The projects being executed by Public Works Department, Delhi Metro Rail Corporation, Delhi Tourism and Transportation Development Corporation Ltd. are listed below.

i. Two Elevated Corridors on Outer Ring Road namely Vikas Puri to Meera Bagh in West Delhi and Mangolpuri to Mukarba Chowk in North Delhi (PWD)

ii. Mukarba Chowk to Wazirabad with three stand-alone flyovers (PWD)

iii. One Elevated Corridor on Inner Ring Road from Prembari to Azadpur (PWD)

iv. Barapullah Phase II (PWD)

v. Barapullah Phase III (PWD)

vi. ROB/ RUB at Nand Nagri (DTTDC)

vii. Signature Bridge Project (DTTDC)

viii. Phase III Metro project in different Packages from Majlis Park to Shivpur (DMRC)

4.3.2 Site selection

Out of the above projects, following four projects were identified for sustainability analysis.

i. Elevated Road Corridor from Vikaspuri to Meera Bagh, PWD Project

ii. Metro Rail Corridor from Azadpur to Raja Garden, DMRC Project

iii. Barapullah Elevated Road Project (Phase II), PWD Project

iv. Signature Bridge Project, DTTDC Project

The reason for choosing the above projects was their different geographical locations so as to represent Delhi as a whole. The geographical, demographical, social and economic issues of all the areas were well represented. Moreover, these projects represent three different departments working for the development of Delhi. Thus, the issues related to different departments in manner of their functioning are well represented by selecting these four corridors. There is also a technical similarity that all these are new elevated corridor. These have been planned in such a manner that no additional land was required for their construction. Out of the above four corridors, two iconic bridges of Delhi i.e. Signature Bridge and Barapulla elevated Corridor have been constructed on water bodies while the Vikaspuri-Meera Bagh corridor is an elevated road project on central verge of road. DMRC Corridor from Azadpur to Raja Garden is rail corridor constructed in an area adjoining slip road. None of these projects,, located on different parts of the city have compromised with the city's existing traffic system. All these corridors are built in almost same period i.e. 2nd

decade of present century. Thus, making a comparison amongst these four corridors and carrying out the sustainability analysis was perfectly in order. Since these are executed by three different Govt, departments, it covers the practices being followed in different departments and thus provides a good coverage of sustainability indicators.

Fig. 30: GOOGLE map of corridor from Vikaspuri to Meera Bagh

4.3.2.1 Elevated road corridor from Vikaspuri to Meera Bagh: 4 KM long Elevated Corridor from Vikaspuri to Meera Bagh was constructed with single pier at centre and deck made of spine beam and wings. Spine beams and wings were precast separately in casting yard and transported to site where these were assembled. While the spine beam segments were pre-stressed longitudinally to act as a single unit, the wings were cross pre-stressed with Spine beam at centre so that the overall deck with spine beams and wings acts as a single unit. 3 to 4 spans were made continuous to make the structure economical as well as for improving the riding quality on the bridge. With the adoption of this technology, it

was possible to construct the elevated section without using any additional land as only central verge was used to provide the single pier.

4.3.2.2 Metro Rail corridor from Azadpur to Raja Garden: DMRC corridor is also a prestressed segmental construction on a single pier, but due to lesser width of the segments, it was made of single unit of segments unlike Vikaspuri -Meera Bagh corridor. These corridors are simply supported on piers with single span.

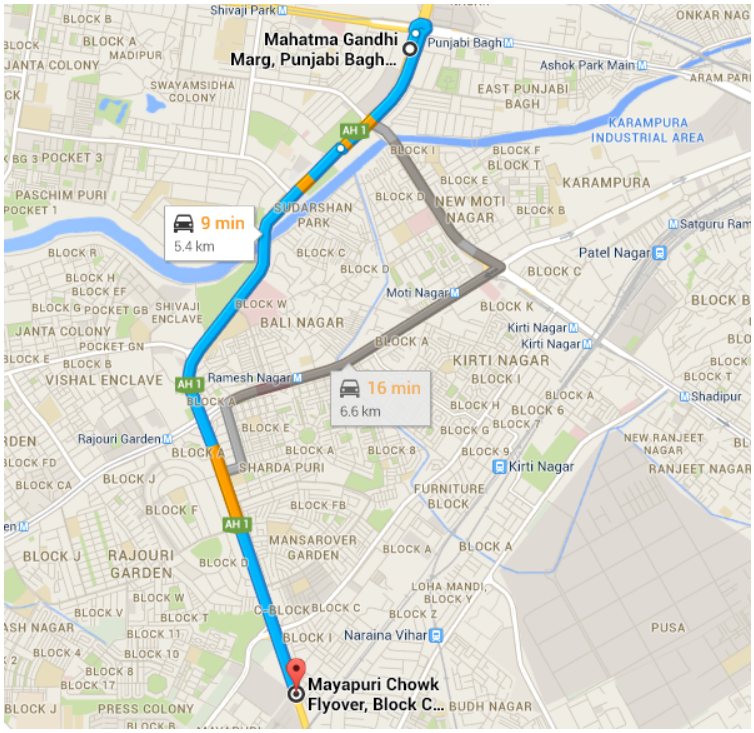

Fig. 31: GOOGLE map of DMRC corridor from Azadpur to Raja Garden

4.3.2.3 Barapullah Elevated Road Project (Phase II)

Elevated Road Project over Barapulla Nallah is corridor connecting East and South Delhi. The project has been planned to be executed in three parts i.e. in three phases with end locations as Mayur Vihar in Eastern part of Delhi and Ring Road near AIIMS in the Southern part of Delhi. Intermediate locations between the end points are JLN (Jawahar Lal Nehru) Stadium and Sarai Kale Khan [64, 66]. The middle segment was taken up in 1st phase in which 4 KM long elevated corridor connecting Sarai Kale Khan to Jawahar Lal Nehru Stadium. 2nd

Phase consisted of extension of the corridor from Nehru Stadium to Ring Road near AIIMS and the 3rd Phase under construction is extension of corridor on other side i.e. from Sarai Kale Khan to Mayur Vihar. The Precast Segmental Construction Technique with span-by-span construction and having deck continuity up to four spans was adopted so as to complete the project within the target time period [64, 66].

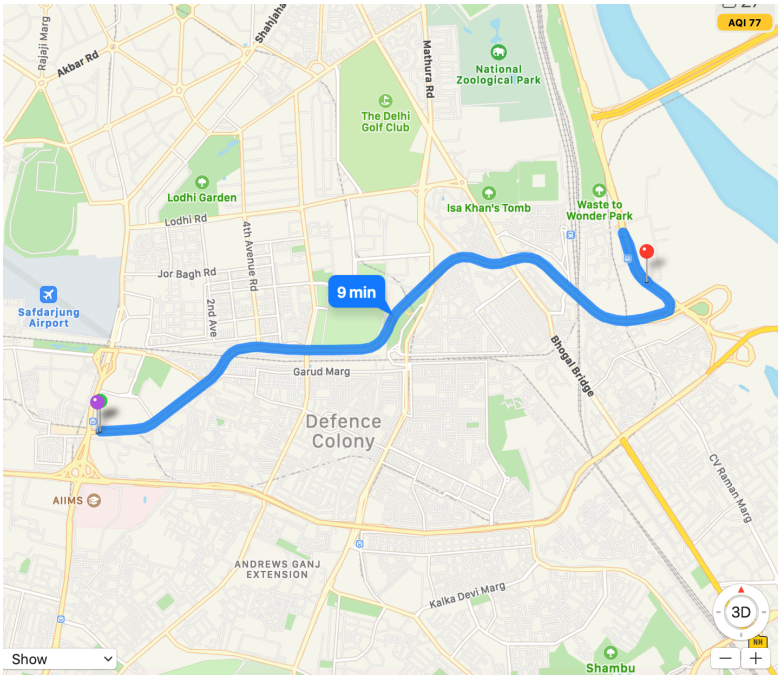

Fig. 32: GOOGLE map of Barapullah elevated road project

4.3.2.4 Signature Bridge project: The bridge connecting North Delhi to North East Delhi, is designed as asymmetric cable stayed bridge with bow shaped asymmetrical inclined 154 m high pylon and clear waterway of 251 m over River Yamuna. There are 15 pairs of cables on front holding the deck over river Yamuna. With the provision of lifts, it is possible to reach to the top of the pylon and have a panoramic view of Delhi through the Glass Facade. When the Project was planned, all the mandatory clearances from various local bodies were obtained. Matter was referred to Ministry of Environment and Forests for their clearance, but it was returned with remarks that “bridges are not covered under EIA notification 2006 and Environmental clearance for such projects is not required”. Subsequently, a case was filed by a social activist before the National Green Tribunal against the construction of this

Bridge on the same grounds that the requisite Environment Clearance has not been obtained. Finally, as per the judgment pronounced on 12.02.2015, the environmental clearance was obtained and thus this project has become the 1st bridge project to get the environmental clearance.

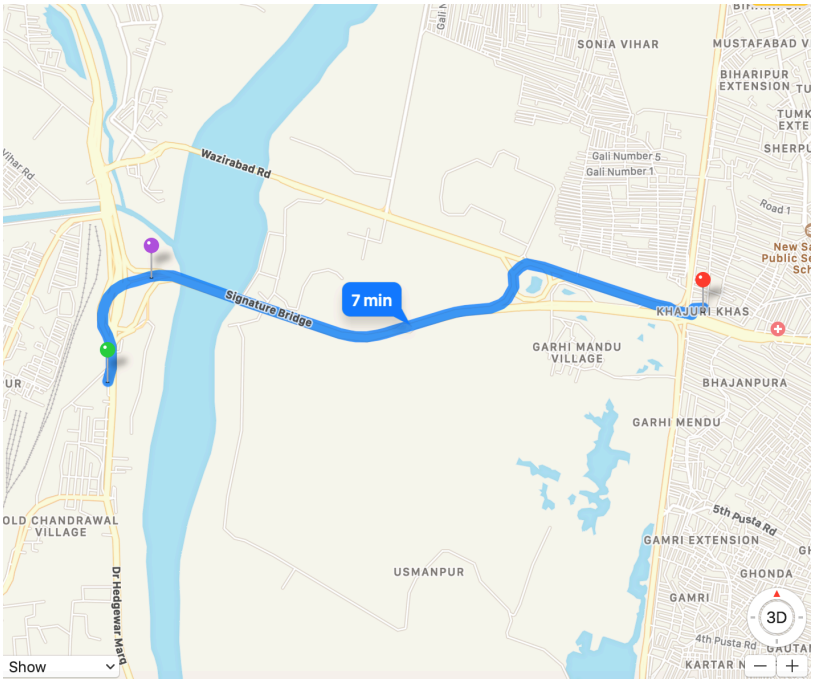

Fig. 33: GOOGLE map of Signature Bridge Project

4.4 IDENTIFICATION OF SUSTAINABILITY INDICATORS AND EVALUATION

The sustainability analysis of the selected four sites after identifying the sustainability indicators from these four sites is carried out by Fuzzy-Vikor method. The detailed procedure followed in this research to identify the suitable sustainability indicators, categorise them and carry out the sustainability analysis was a 5 step procedure as mentioned in flow chart given below and explained subsequently. The five step procedure as mentioned in above flow chart is detailed out as selection of a corridor under construction, site visits and recording still images, identifying sustainability indicators and categorise them, devising a proforma for rating of these indicators by experts and public and finally applying suitable methodology (Fuzzy-Vikor) for the sustainability analysis.

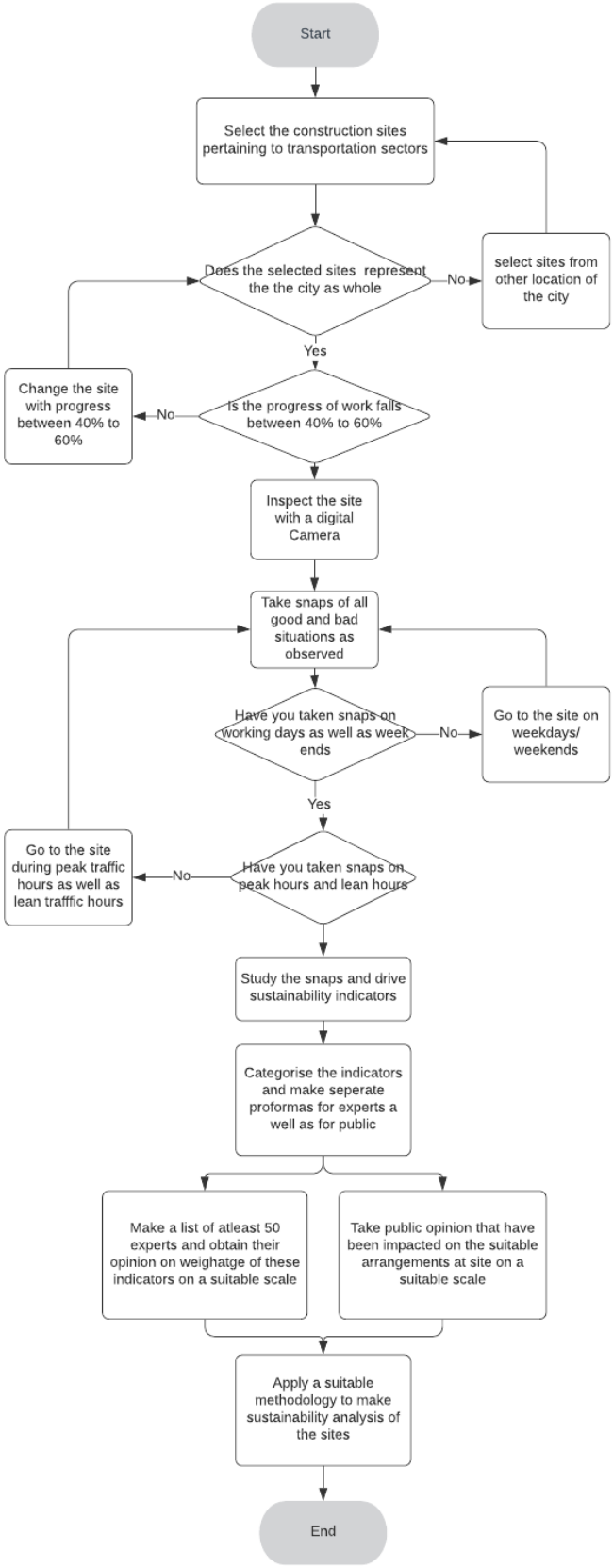

Fig. 34: Flow-Chart for the sustainability analysis procedure

4.4.1 Site visits and recording still images

The construction studies have been carried out in two phases. In phase 1, the two corridors of West Delhi i.e. PWD corridor from Vikaspuri to Meera Bagh and other DMRC corridor from Azadpur to Raja Garden were studied [67, 68]. Later in phase 2, two other corridors in North East Delhi and South Delhi i.e. Signature Bridge Project and Bahaullah Elevated Corridor (Phase 2 and 3) were studied [69, 73]. The site visits in phase 1 were done from June 2014 to December 2014, while the visit to other two sites in phase 2 were carried out from January 2015 to June 2015.

The site has been visited during the peak of the construction when the progress is about 40% to 60%. By that time the project was completely stable as regard to any site arrangements. In the initial period of construction, the construction agency is still adding the machineries and augmenting the necessary arrangements. Similarly, after the considerable progress of work at site, the agency starts taking ff the machineries that are no more required for execution. Even the labour engaged is reduced and it does not reflect the actual image of site from the sustainability point of view. Hence the best period to study the corridor is wen the progress is on mid-way. Accordingly the period of study was chosen when the progress was between 40% to 60%. It has given a better reflection of the site than what would have been during the initial stages or near completion when many of the arrangements gets lifted off. Similarly for a realistic data, the visit was made on different days of the week and different hours of the day in order to capture all activities and arrangements, good or bad with shortcomings or having strengths. Different days were selected as week days and weekends. Different hours were selected ass peak traffic hours and off-peak hours.

The images as captured at random from these sites are given in Figures 35 to 37 without specific mention of the site from where the image has been captured.

Fig. 35: Site images -1

Fig. 36: Site images -2

Fig. 37: Site images -3

4.4.2 Identifying Sustainability Indicators and categorising

All the images and site records were analysed to identify the possible sustainability indicators in the next step. This process began with the extension of the existing three pillars of sustainability i.e. Economic, Social and Environmental aspects with the development of three more vital categories namely Inner Engineering, Technical and Governance. It was realised that three categories popularly called three pillars are more suitable for developed countries whereas in India, it requires to have more categories.

Technical parameters play an important role in infrastructure projects. The designs are generally prepared by the consultants and their wisdom prevails in designing the structure. In the instant case, it is observed that three corridors, Vikaspuri-Meera Bagh, DMRC line in Raja Garden and Western Approach of Signature bridge had to negotiate a drain popularly called "Najafgarh Nallah" that is flowing from Najafgarh and falls into river Yamuna near Wazirabad with its width varying from 30 to 50m. In all these 3 corridors, different technologies have been adopted while same drain is to be crossed over for 50m. In Vikaspuri-Meera Bagh corridor, pillars have been placed inside the drain to continue with the standard span of 35 m throughout the corridor. DMRC adopted the conventional cantilever construction while the signature bridge crossed it by designing the 50 m span segmental construction and thus created a record of maximum span in an segmental construction. Even the launching girder was to be specially designed for this one span. Thus, another 4th category, **"Technical"** emerged. Governance in this country is a big issue. Everyone tries to look into the gaps in law and tries to deviate for his own convenience rather than looking for the convenience of complete society as a whole. Thus a new 5th category "**Governance"** was created. Further, rich heritage in form of spirituality was considered as an essential category that uplifts the morale of workers and helps stakeholders to raise their tolerance. This 6th category **"Inner Engineering"** was considered as an independent category.

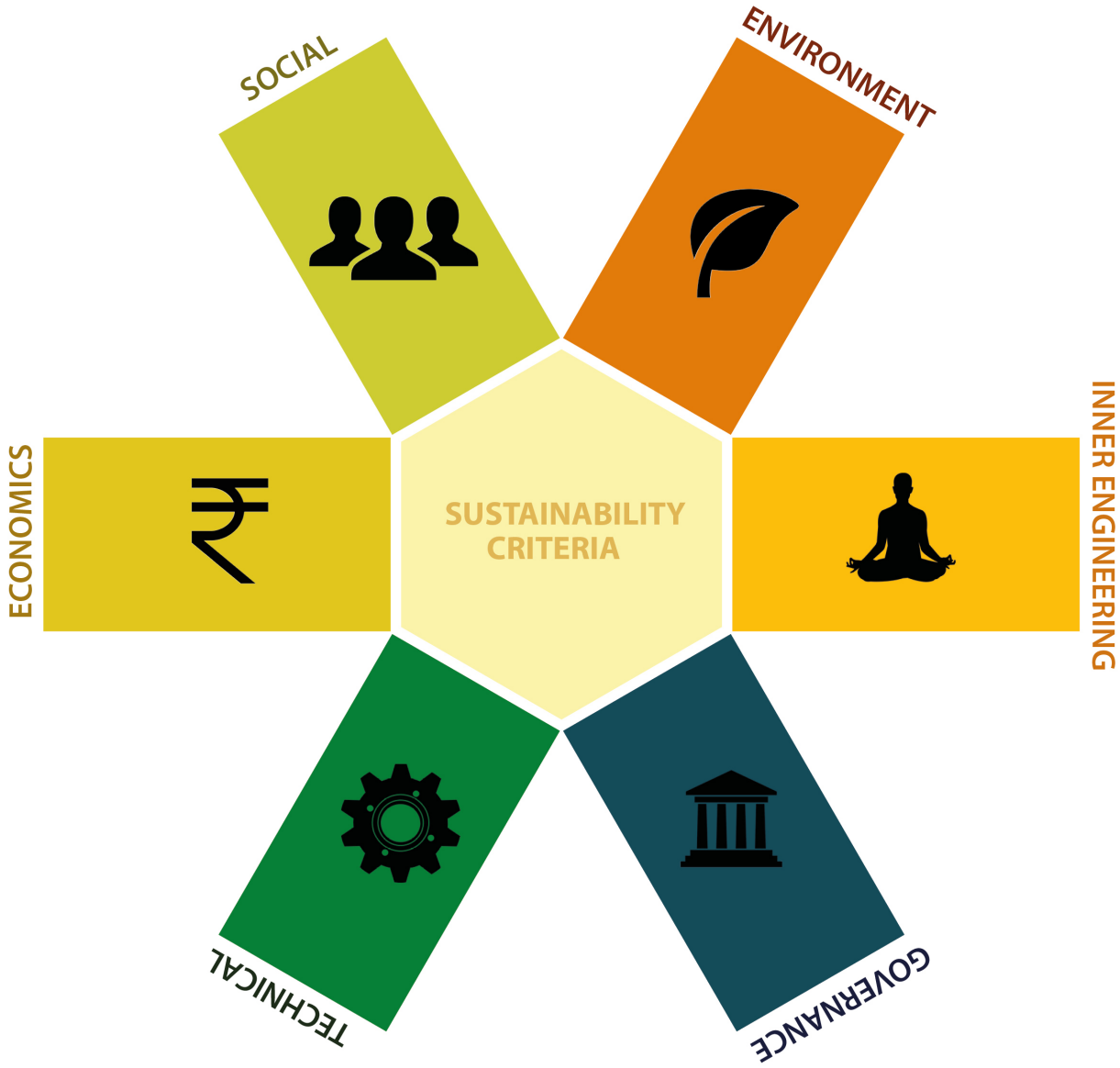

Fig. 38: Categories of sustainability indicators

These 43 indicators under 6 categories are Pictorially shown in Figure 39. These 43 indicators are identified that make an impact on surroundings, environment, human beings etc. as listed in Table 7.

Table 7: Sustainability Indicators

S. No.	SUSTAINABILITY INDICATORS
A.	ENVIRONMENTAL
1.	Air Pollution
2.	Existing Drainage system
3.	Noise pollution during day
4.	Noise pollution during night
5.	Depletion of Green Belt
6.	Plantation scheme
7.	Alternate schemes for make the project more sustainable
B.	SOCIAL
8.	Health of workers
9.	Welfare activities for family of workers
10.	Sanitation conditions
11.	First Aid facilities
12.	Safety measures
13.	Increase in stress level of residents/commuters
14.	Impact on Health of residents/commuters
15.	Impact on safety of residents/ commuters
16.	Preserving the social spaces like cremation ground, Sur Ghat
17.	Public attraction with the aesthetics of the Project
18.	Utility of the Project to Public
19.	Preserving the heritage structures
C.	ECONOMICAL
20.	Increase in Travel time
21.	Increase in travel cost
22.	Disturbance to the business/Employment of nearby residents
23.	Increase in cost of Construction due to lack of funds
24.	Increase in cost of Construction due to time overrun
D.	TECHNICAL
25.	Display of Project Details
26.	Traffic Diversions
27.	Visibility and sight distance to moving traffic
28.	Lighting of Construction site
29.	Barricading the site
30.	Effectiveness of Technology used
31.	Handling of C & D Waste
32.	Quality Assurance on the Project
E.	GOVERNANCE
33.	Ensuring the mobility of Traffic within the project area by traffic Marshalls
34.	Maintenance of existing drainage system
35.	Maintenance of Barricades
36.	Maintenance of existing utilities
37.	Maintenance of existing greenery
38.	Time over run due to delay in Govt. decisions
39.	Time over run due to mismanagement at site
F.	INNER ENGINEERING
40.	Facilities of Yoga/meditation
41.	Performance of Rituals at site like Vishvakarma Puja, May Day
42.	Celebration during Festivals at site
43.	Motivation to workers by reward policy or otherwise

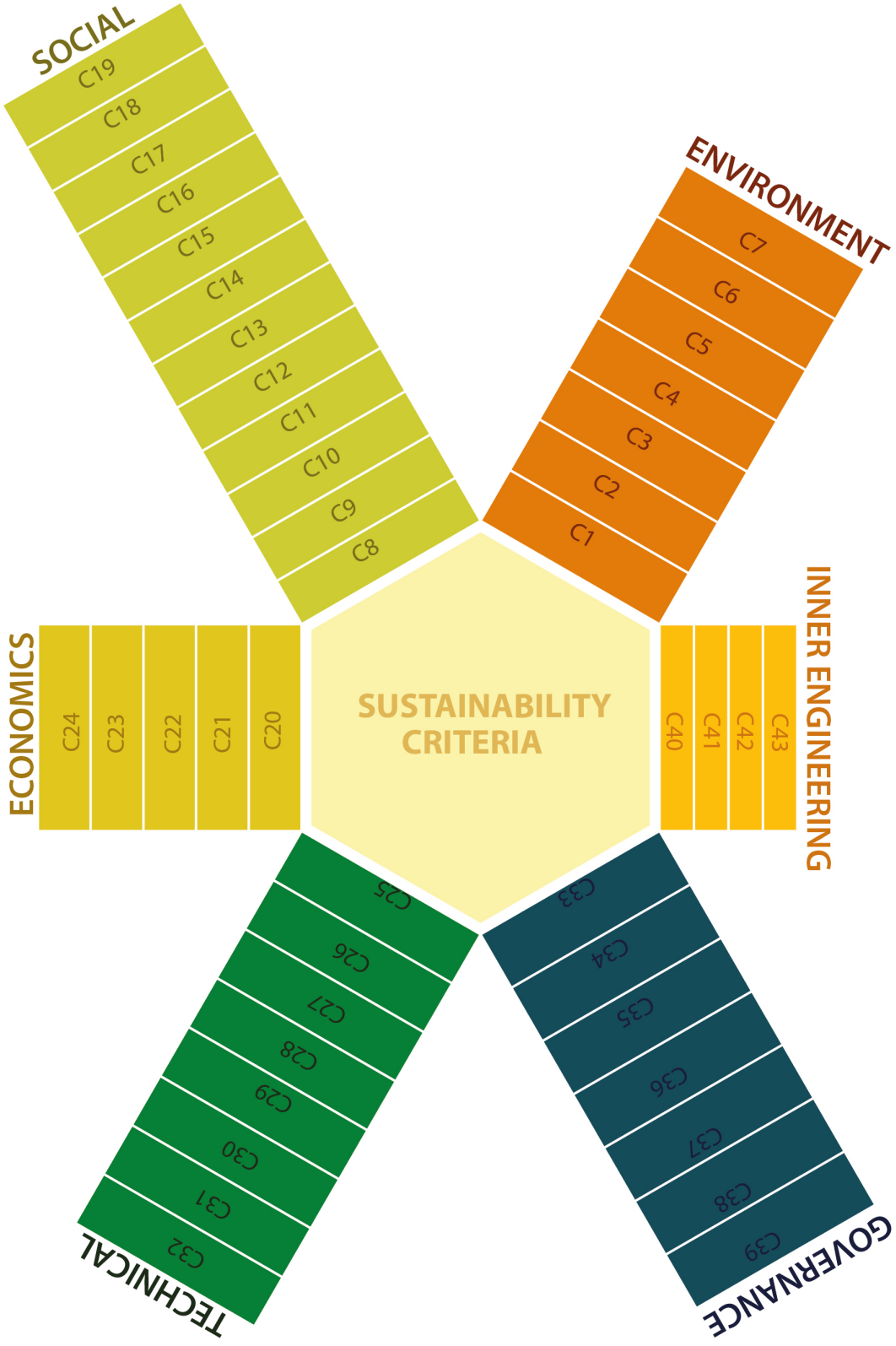

Fig. 39: 43 Sustainability Indicators in 6 categories

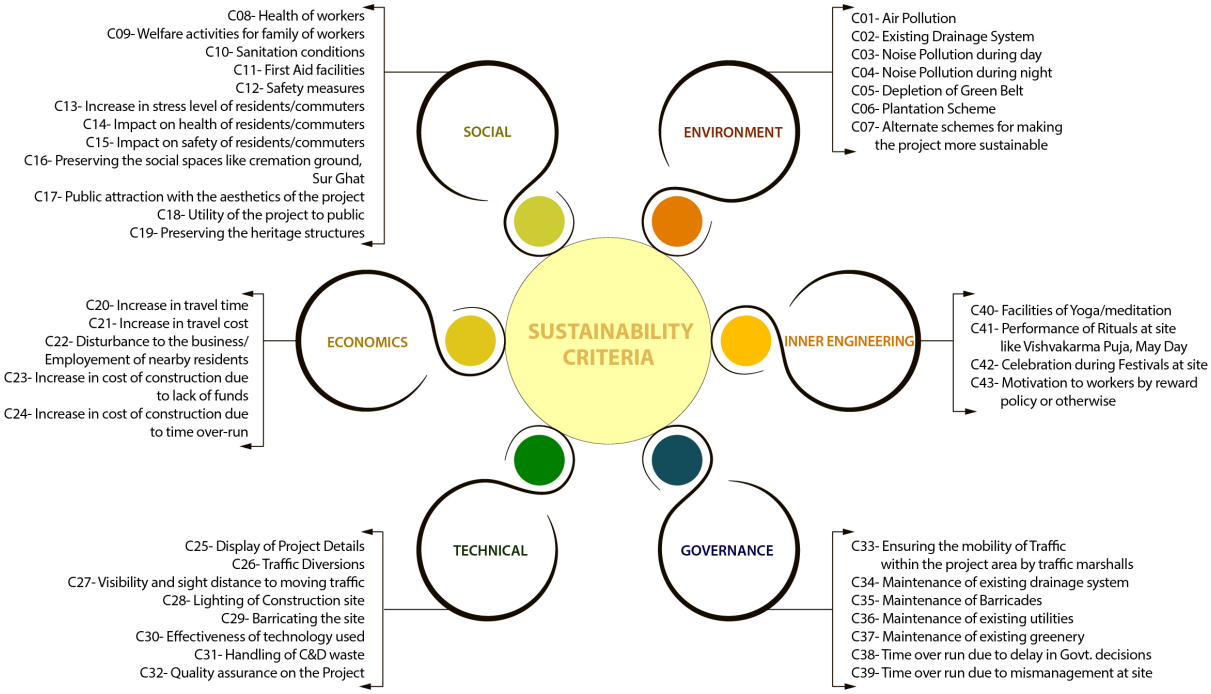

Fig. 40: Sustainability indicators and criteria at a glance

CHAPTER 5

APPLICATION OF FUZZY-VIKOR TECHNIQUE TO ASSESS SUSTAINABILITY

5.1 INTRODUCTION

Identification of suitable sustainability indicators is key to the accomplishment of a record for rating the framework. Bossel (1999) built up four key strides for going from an entire framework to the distinct indicators and later applying them into the participating procedures [10]. The 4 main steps as defined by him are to understand & conceptualise the overall system, to identify the representative indicators, to quantify the basic orienteer satisfaction and lastly to conduct a participative procedure. The 1st step i.e. understanding the total framework, is vital to the practicality of the orienteers and the indicators that will be produced at later stage. The 2nd step i.e. recognising the signifying indicators and further representing indicators are picked from the colossal number of possible indicators. The 3rd step involves the prioritisation of the indicators keeping in mind the end goal to change over indicator information into orienteer satisfaction. The 4th step involves input through the expert opinions to compensate the decisions of the person who has established the indicators. With the proper outer analysts, a wide gamut of learning, mental models, experience, and social/ecological apprehensions can be highlighted.

Mitchell [41] had introduced a practice, particular to the sustainable development, for identifying suitable indicators for the entire structure. As per his procedure, it is required to explain the system goals, stating the purpose of indicators along with their user group. Thereafter the sustainable development principles and definitions that can be related are specified. The issues those are important on a local and global scale are to be defined. The indicator properties are to be compared against the types of users and the goals of rating

system. The indicators are to be evaluated against desirable characteristics and objectives of rating system.

5.2 SUSTAINABILITY ASSESSMENT BASED ON FUZZY LOGIC METHODOLOGY

Fuzzy Logic was initiated by Lotfi A. Zadeh in 1965, who was a teacher of software engineering in University of California, Berkeley [32]. Essentially, it is a multivalued rationale, which permits moderate qualities that are characterised within routine assessments like true or false, yes or no, high or low and so forth. This system can be utilised to handle fragmented information and dubious information in an exceptionally orderly manner. Fuzzy Logic is an approach of "reasoning with uncertainty." It gives an all-around characterised system to manage dubious and not completely characterised information, so one can make exact findings from uncertain information. The fuzzy theory provides a mechanism for representing linguistic constructs such as "many," "low," "medium," "often" and "few." Notions like "rather tall" or "quick" can be figured numerically and prepared by PCs with a specific end goal to apply a more human-like mindset in the programming of PCs. As a rule, the fuzzy rationale gives a surmising structure that empowers suitable human thinking capacities. Fuzzy logic provides an inference morphology that empowers surmised human thinking capacities to be connected to learning based frameworks. The fuzzy rationale hypothesis gives a numerical quality to catch the vulnerabilities connected with human subjective procedures, for example thinking and reasoning. The conventional approaches to knowledge representation lack the means for representing the meaning of fuzzy concepts [74, 75]. As a consequence, the approaches based on first order logic and classical probability theory do not provide an appropriate conceptual framework for dealing with the representation of common sense knowledge, since such knowledge is by its nature both lexically imprecise and non-categorical. Some of the crucial qualities of fuzzy logic are:

i. exact reasoning is viewed as a limiting case of approximate reasoning.
ii. everything is a matter of degree.

iii. information is deciphered as collection of elastic or equivalently fuzzy constraint on a collection of variables.

iv. Inference is viewed as a process of propagation of elastic constraints.

v. Any consistent framework can be fuzzified

5.2.1 Sustainability using Fuzzy Logic

Sustainability is a multifaceted idea for which we do not have any extensively acknowledged definition or estimation system. The guidelines of customary mathematics can't depict the flow of any socio-environmental system. As sustainability is an inherently vague and complex idea, it is extremely hard to characterise or measure it.

One uses statistics and system identification to make models for framework wherever structure is not known. A large number of input-output measurements, a collection of candidate models and a criteria for selection of the best model based on these measurements are required. The primary issue while evaluating sustainability using these methods is lack of output data. Despite the fact that a considerable lot of the inputs can be measured, yet it is difficult to gauge the yield. On the other hand, Fuzzy logic is quite suitable for evaluating sustainability on the grounds that it can show complex frameworks for which we have just a little or inadequate information about their dynamics, the parameters that affect them and the values of those parameters. Fuzzy logic is capable of handling knowledge and data represented in different ways such as mathematical models, linguistic rules or expressions, numerical values.

5.2.2 Characteristics of Fuzzy logic

It is universally accepted that a reliable measure of sustainability should be the outcome of integrating economic as well as natural resources accounts. However, this is not easily achievable due to the lack of unsolved methodological problems (Kaufmann and Cleveland,

1995) and sufficient data availability. The following basic features justify the use of the Fuzzy logic reasoning for assessing sustainability.

i. Fuzzy logic has the ability to deal with complex and polymorphous concepts, which are not pliable to a straightforward quantification and contain uncertainties. In addition, reasoning with such vague concepts may not be clear and evident, but rather fuzzy.
ii. Fuzzy logic offers the mathematical tools to handle vague concepts and reasoning. It finally gives tangible answers ('crisp' as they are known) to problems fraught with subjectivity. Sustainability is, indeed, quite subjective. What seems unsustainable to an environmentalist may be sustainable for an economist and the elements signifying sustainability may vary for these specialists.

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

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

i. IF one has "much" cash AND "great" wellbeing, THEN he is "exceptionally" upbeat.
ii. IF one has "much" cash AND "terrible" wellbeing, THEN he is "inadequately" cheerful.
iii. IF one has "little" cash AND "great" wellbeing, THEN he is "attractively" upbeat.

iv. IF one has "little" cash AND "terrible" wellbeing, THEN at that point he is "inadequately" cheerful.

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

5.2.3 Preliminaries of Fuzzy set theory

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

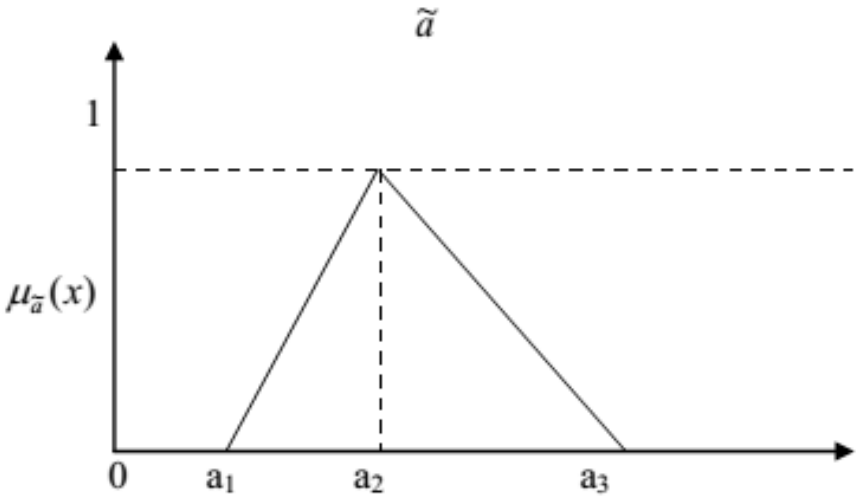

Fig. 41: Triangular Fuzzy number 'a'

5.2.3.1 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 as 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.

Now if you get crisp interval by α-cut operation, interval 'a' shall be obtained as follows

∀ α ∈ [0, 1],

From

$$\frac{a1(\alpha) - a1}{a2 - a1} = \alpha \qquad \frac{a3(\alpha) - a3}{a3 - a2} = \alpha \qquad \text{…. 5.1}$$

we get,

$$a1(\alpha) = (a2 - a1)\alpha + a1 \qquad \text{…. 5.2}$$

$$a3(\alpha) = (-a3 - a2)\alpha + a3 \qquad \text{…. 5.3}$$

Thus,

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

$$= [(a2 - a1)\alpha + a1, -(a3 - a2)\alpha + a3] \qquad \text{…. 5.4}$$

5.2.3.2 Definition 2: A triangular fuzzy number (Figure 41) 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. The membership function of $\mu_a(x)$ triangular fuzzy number is given by:

$$\mu_a(x) = \begin{cases} 0, & x \le a1 \\ \dfrac{x - a1}{a2 - a1}, & a1 < x \le a2 \\ \dfrac{a3 - x}{a3 - a2}, & a2 < x \le a3 \\ 0, & x > a3 \end{cases} \qquad \text{….5.5}$$

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.

5.2.4 Linguistic variables and Fuzzy set theory

In fuzzy set theory, conversion scales are used to transform the qualitative terms into fuzzy numbers. A scale of 0–9 is used to rate the criteria and the alternatives. Tables 8 and 9 represent the conversion schemes for the qualitative alternative site ratings and criteria ratings [79 to 81].

Table 8: Fuzzy transformation for qualitative 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)

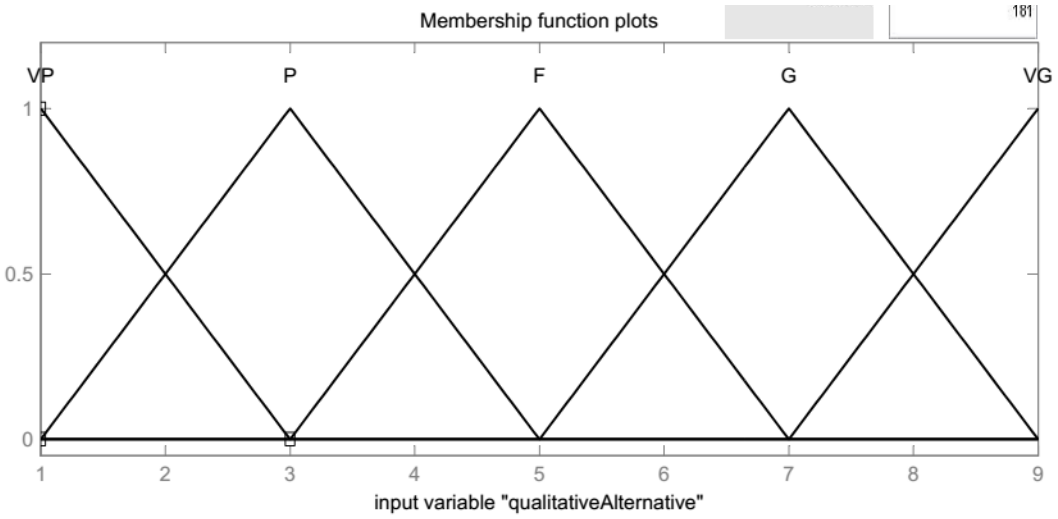

Fig. 42: Triangular Fuzzy from membership function for the qualitative site rating

Table 9: 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)

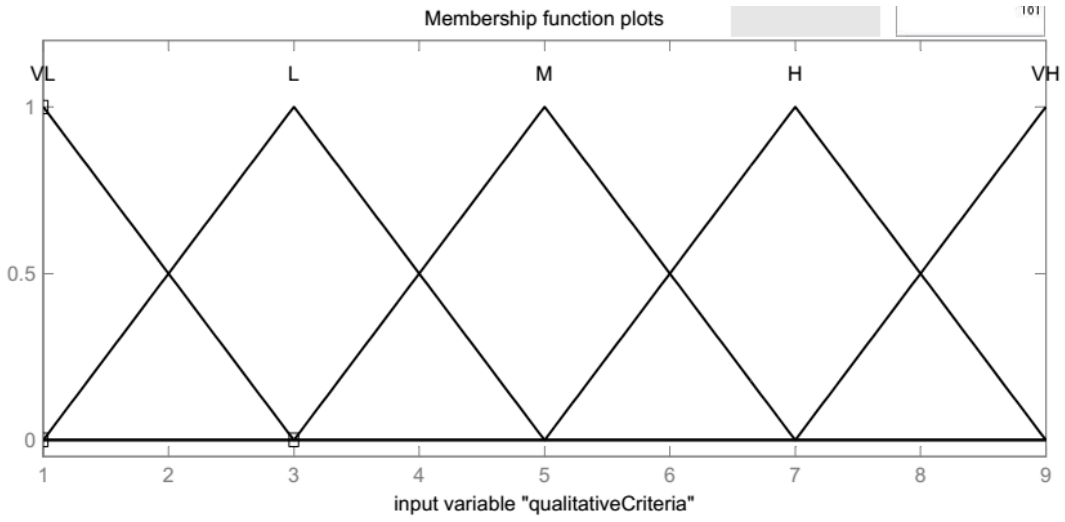

Fig. 43: Triangular Fuzzy from membership function for qualitative criteria rating

5.3 VIKOR METHOD

VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje) method was developed by Opricovic for the multi-criteria optimisation of the complex systems in 1998. VIKOR method focuses on ranking and sorting a set of alternatives against various decision criteria assuming that compromising is only adequate to resolve conflicts. Like some other MCDM methods like TOPSIS, VIKOR depends on an aggregating function that signifies closeness to the ideal, but unlike the TOPSIS, introduces the ranking index based on the particular measures of closeness to the ideal solutions and hence this method uses linear normalisation for eliminating units of the criterion functions [46, 47]. The VIKOR strategy was introduced as one appropriate method for actualizing within MCDM issue and was produced as a multi-criteria choice for making a procedure to tackle a discrete decision-making problem with non-commensurable and clashing criteria. This method focuses on the ranking and selection from a set of alternatives and evaluates the compromise solution for a problem within conflicting criteria, which can aid the decision makers to reach a final solution. The multi-criteria measure for bargain positioning is produced from the LP–metric utilized as a totalling capacity as a part of a trade-off programming method.

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

$$L_{p,i} = \left\{ \sum_{j=1}^{n} \left[w_j \frac{\left(f_j^* - f_{ij}\right)}{\left(f_j^* - f_j^-\right)} \right]^p \right\}^{1/p}, \quad 1 \le p < \infty \qquad \text{…. 5.7}$$

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

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

i. Determine the best f_j^* and the worst f_j^- values of all criterion functions j=1, 2,….,n. If the j^{th} function represents a benefit then:

$f_j^* = \max_i \{f_{ij}\}$ …. 5.8

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

ii. Compute the values Si and Ri; i = 1, 2,……,m, by these relations:

$$S_i = \sum_{j=1}^{n} w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \qquad \text{…. 5.9}$$

$$R_i = max\, w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \qquad \text{…. 5.10}$$

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

iii. Compute the values Q_i; i = 1, 2, ……,m by the following relation:

$$Q_i = v\frac{s_i - s^*}{s^- - s^*} + (1 - v)\frac{R_i - R^*}{R^- - R^*} \qquad \text{…. 5.11}$$

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

here suppose v = 0:5

iv. Rank the alternatives, sorting by the values S, R and Q in decreasing order. The results are three ranking lists.

v. 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) ≥ DQ

Where A is the alternative with second position in the ranking list by Q.

$$DQ = \frac{1}{m-1} \quad \text{…. 5.12}$$

Where m is the number of alternatives.

vi. 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>0:5 is 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").

vii. 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 condition C2 is not satisfied, or

Alternatives A_1, A_2, …., Am if condition Cl is not satisfied;

A_m is determined by the relation $Q(A_m) – Q(A_1) < DQ$ for maximum M (the positions of these alternatives are "in closeness").

viii. 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 decision makers could accept the obtained compromise solution 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.

5.4 DEVISING A PROFORMA FOR RATING BY EXPERTS AND PUBLIC

In order to assess the sustainability of a transportation corridor in urban environment, assessment of an urban transportation corridor, it was required to collect the information on Social-Economic-Environmental-Technical-Governance-Inner Engineering indicators. The finalised list containing 43 indicators is given in Table 9.

After the sustainability indicators were identified, two proformas were developed, one for the experts to have their opinion regarding the weightage to be given to each of the sustainability indicator and other proforma for the public or whosoever gets impacted with the project to have the public opinion about the implementation by the construction agency/ Project Managers at site.

5.4.1 Survey to assign weightage to the various sustainability indicators

A survey was carried out to assign weightage to the various sustainability indicators that have been identified for an infrastructure project during the construction stage and being executed in an urban environment. This survey was conducted amongst the experts in the field of infrastructure. Such experts included designers, consultants, architects,

construction agencies, executing departments like PWD, CPWD, NHAI, CRRI, DDA, RITES etc. Since this segment of society are real experts in the field of transportation infrastructure, their opinion is valuable in assigning the weightage to the various indicators identified after the site survey by the research team.

A Performa (as Proforma 1 furnished on page 130) with identified sustainability indicators was devised and these experts were requested to submit their opinion regarding its importance on qualitative scale.

Qualitative scale includes **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 their opinion was assigned from **VL** to **VH** on the basis of its importance.

As mentioned in previous paras the experts were chosen from different departments in Delhi that are engaged in transportation infrastructure projects in city either in the capacity of planners, project management or consultants primarily because they have a fair idea about the city and its needs. In the instant case opinion of 51 such experts has been obtained. Subsequently, the weightage of each criteria as obtained from the set of experts was converted into the fuzzy membership function as per table 10.

5.4.2 Survey to evaluate the construction of infrastructure projects

A survey of the residents and the commuters either residing in vicinity or passing through the construction site of Infrastructure projects in Delhi was undertaken to assess the construction of infrastructure projects in New Delhi from the sustainability point of view. It was primarily because the residents and the commuters passing through the corridors are the most affected group of the society due to the ongoing construction activities of the projects. Many times, the regular commuters have to divert their route for complete

period of construction. But such option may not be available for all commuters. Most of them have to essentially bear the side effects of constructions and face the pollution every day. Nearby residents are disturbed all days and nights besides facing rise in pollution. Hence their opinion on the arrangements at site matter most. In order to have the best opinion of the residents/ commuters, a Performa (Proforma 2) with identified sustainability indicators is enclosed herewith and this section of the society was requested to submit their opinion regarding the functioning of site on qualitative scale.

Qualitative scale includes **VP** (Very poor), **P** (Poor), **F** (Fair), **G (**Good) and **VG** (Very Good). The sustainability indicator with least arrangements or least sensitivity may be assigned **'VP'** value and indicators with best arrangements or best sensitivity may be assigned **'VG'** value. Accordingly their opinion was obtained from **VP** to **VG** on the basis of the arrangements at site. The qualitative ratings of the four alternative sites was obtained from the residents and commuters passing nearby the site because this category of the society is the most affected and most impacted due to the construction activities going in their vicinity. Such residents/commuters were requested to rate the indicators of either one of the site or more than one site depending on the knowledge of the sites under consideration. About 250 such opinions for each of the site was obtained for sustainability analysis of the four alternative sites. Subsequently, the weightage of each criteria as obtained from the residents/commuters were converted into the fuzzy membership function as per table 10.

Table 10: Fuzzy transformation for qualitative criteria and alternative site ratings

Qualitative rating for 43 criteria by experts	Qualitative rating for 4 alternative sites by public	Membership Function
Very low (VL)	Very poor (VP)	(1,1,3)
Low (L)	Poor (P)	(1,3,5)
Medium (M)	Fair (F)	(3,5,7)
High (H)	Good (G)	(5,7,9)
Very High (VH)	Very Good (VG)	(7,9,9)

PROFORMA 1: FOR WEIGHTAGE BY EXPERTS

S. NO.	SUSTAINABILITY INDICATORS	WEIGHTAGE IN TERMS OF QUALITATIVE SCALE
	A. ENVIRONMENTAL	
C1	Air Pollution	
C2	Existing Drainage system	
C3	Noise pollution during day	
C4	Noise pollution during night	
C5	Depletion of Green Belt	
C6	Plantation scheme	
C7	Alternate schemes for make the project more sustainable	
	B. SOCIAL	
C8	Health of workers	
C9	Welfare activities for family of workers	
C10	Sanitation conditions	
C11	First Aid facilities	
C12	Safety measures	
C13	Increase in stress level of residents/commuters	
C14	Impact on Health of residents/commuters	
C15	Impact on safety of residents/ commuters	
C16	Preserving the social spaces like cremation ground, Sur Ghat	
C17	Public attraction with the aesthetics of the Project	
C18	Utility of the Project to Public	
C19	Preserving the heritage structures	
	C. ECONOMICS	
C20	Increase in Travel time	
C21	Increase in travel cost	
C22	Disturbance to the business/Employment of nearby residents	
C23	Increase in cost of Construction due to lack of funds	
C24	Increase in cost of Construction due to time overrun	
	D. TECHNICAL	
C25	Display of Project Details	
C26	Traffic Diversions	
C27	Visibility and sight distance to moving traffic	
C28	Lighting of Construction site	
C29	Barricading the site	
C30	Effectiveness of Technology used	
C31	Handling of C & D Waste	
C32	Quality Assurance on the Project	
	E. GOVERNANCE	
C33	Ensuring the mobility of Traffic within the project area by traffic Marshalls	
C34	Maintenance of existing drainage system	
C35	Maintenance of Barricades	
C36	Maintenance of existing utilities	
C37	Maintenance of existing greenery	
C38	Time over run due to delay in Govt. decisions	
C39	Time over run due to mismanagement at site	
	F. INNER ENGINEERING	
C40	Facilities of Yoga/meditation	
C41	Performance of Rituals at site like Vishvakarma Puja, May Day	
C42	Celebration during Festivals at site	
C43	Motivation to workers by reward policy or otherwise	

PROFORMA 2: FOR OPINION OF RESIDENTS/COMMUTERS

S. NO.	***SUSTAINABILITY INDICATORS***	***OPINION IN TERMS OF QUALITATIVE SCALE***
	A. ENVIRONMENTAL	
C1	*Control on Air Pollution*	
C2	*Maintenance of Existing Drainage system*	
C3	*Control on Noise pollution during day*	
C4	*Control on Noise pollution during night*	
C5	*Saving the Green Belt from getting depleted*	
C6	*Implementation of Plantation scheme*	
C7	*Considering other alternate schemes for make the project more sustainable*	
	B. SOCIAL	
C8	*Caring for the health of workers*	
C9	*Caring for the Welfare activities for family of workers*	
C10	*Maintenance of Sanitation conditions*	
C11	*Provision of First Aid facilities*	
C12	*Provision of Safety measures*	
C13	*Control on increase in stress level of residents/commuters*	
C14	*Controlling the impact on Health of residents/commuters*	
C15	*Controlling the impact on safety of residents/ commuters*	
C16	*Preserving the social spaces like cremation ground, Sur Ghat*	
C17	*Providing public attraction with the aesthetics of the Project*	
C18	*Considering the utility of the Project to Public*	
C19	*Preserving the heritage structures*	
	C. ECONOMICS	
C20	*Result in increase in Travel time*	
C21	*Result in increase in travel cost*	
C22	*Disturbance to the business/Employment of nearby residents*	
C23	*Result in increase in cost of construction due to lack of funds*	
C24	*Result in increase in cost of construction due to time overrun*	
	D. TECHNICAL	
C25	*Displaying the Project Details*	
C26	*Providing convenient Traffic Diversions*	
C27	*Providing the visibility and sight distance to moving traffic*	
C28	*Lighting of construction site*	
C29	*Barricading the site*	
C30	*Effectiveness of Technology used*	
C31	*Handling of C & D Waste*	
C32	*Quality Assurance on the Project*	
	E. GOVERNANCE	
C33	*Ensuring the mobility of Traffic within the project area by traffic Marshalls*	
C34	*Maintenance of existing drainage system*	
C35	*Maintenance of Barricades*	
C36	*Maintenance of existing utilities*	
C37	*Maintenance of existing greenery*	
C38	*Causing the time over run due to delay in Govt. decisions*	
C39	*Causing the time over run due to mismanagement at site*	
	F. INNER ENGINEERING	
C40	*Providing the Facilities of Yoga/meditation*	
C41	*Performance of Rituals at site like Vishvakarma Puja, May Day*	
C42	*Celebration of Festivals at site*	
C43	*Motivation to workers by reward policy or otherwise*	

5.5 SUSTAINABILITY EVALUATION BY FUZZY-VIKOR TECHNIQUE

Sustainability evaluation of four transportation corridors namely A1, A2, A3 and A4, in various locations of Delhi that are under the construction stage have been carried out by application of Fuzzy VIKOR technique. A committee of 51 experts (E1, E2... E51) was formed to obtain the qualitative ratings for the criteria and the alternative construction sites. The fuzzy VIKOR technique helps in assessment of criteria and alternatives, while the analysis is carried out by Vikor methodology. It measures the closeness of the alternative with respect to the positive ideal solution for evaluation [4, 42]. Following steps have been followed in carrying out the evaluation with Fuzzy-Vikor technique

i. Four alternate sites that needed to be rated are taken as A = {A1, A2, A3 and A4} These are to be rated against a set of 43 criteria, that is C = {C1, C2, C3,..., C43 }. The criteria weights are represented by w_j where (j=1, 2, 3,.., 51). The performance ratings of the decision maker D_k (k = 1, 2, 3,..., 250) for each alternative Ai (I = 1, 2,.3,4) according to the criteria Cj (j= 1, 2, 3,..., 43) are denoted by $R_k = x_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})$, where i= 1, 2, 3,....,4; j = 1, 2, 3,..., 51; k = 1, 2, 3,.., 250 with membership function $\mu R_k(x)$.

ii. The aggregate fuzzy ratings corresponding to alternatives and criteria are computed. When fuzzy ratings for all the experts (decision makers) are described as the triangular fuzzy number $R_k = (a_k, b_k, c_k)$, where k = 1, 2, 3,..., 250, then the aggregated fuzzy rating is defined by R = (a, b, c), k = 1, 2, 3,..., 250 where;

$$a = \min\{a_k\}, \quad \text{.... 5.13}$$

$$b = \frac{1}{250}\sum_{k=1}^{250} b_k \quad \text{.... 5.14}$$

$$c = \max\{c_k\} \quad \text{.... 5.15}$$

iii. The aggregated fuzzy weights (w_{ij}) corresponding to each criterion are calculated as

$w_j = (w_{j1}, w_{j2}, w_{j3})$, where

$w_{j1} = \min\{w_{jk1}\}$, ... 5.16

$w_{j2} = \frac{1}{51}\sum_{k=1}^{51} w_{jk2}$ 5.17

$w_{j3} = \max\{w_{jk3}\}$, ... 5.18

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

$$D = \begin{array}{c} \\ A1 \\ A2 \\ A3 \\ A4 \end{array} \begin{array}{c} \begin{array}{cccc} C1 & C2 & \ldots\ldots & C43 \end{array} \\ \begin{bmatrix} X_{11} & X_{12} & \ldots\ldots & X_{143} \\ X_{21} & X_{22} & \ldots\ldots & X_{243} \\ \ldots & \ldots & \ldots\ldots & \ldots \\ X_{41} & X_{42} & \ldots\ldots & X_{443} \end{bmatrix} \end{array}, \quad i = 1, 2, 3, 4 ; \quad j = 1, 2, 3,\ldots,43 \qquad \ldots. \ 5.19$$

$W = (w_1, w_2 \ldots w_{51})$

v. The elements of the fuzzy decision matrix corresponding to the alternatives afer de-fuzzified and the criteria weights into crisp values. For example, a fuzzy number $a\sim (a_1, a_2, a_3)$ can be converted into a crisp number a by employing the below equation:

$$a = \frac{a_1 + 4a_2 + a_3}{6} \qquad \ldots. \ 5.20$$

vi. The best f_{j^*} and worst values f_{j^-} of criteria rating are determined as

$f_{j^*} = \max \{x_{ij}\}$, ... 5.21

$f_{j^-} = \min \{x_{ij}\}$ 5.22

vii. The values of S_i and R_i are computed using the equations given below

$$S_i = \sum_{j=1}^{43} w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \qquad \ldots. \ 5.23$$

$$R_i = max\ w_j \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \qquad \ldots. \ 5.24$$

viii. The values of Q_i is computed using

$$Q_i = v\frac{s_i - s^*}{s^- - s^*} + (1 - v)\frac{R_i - R^*}{R^- - R^*} \qquad \ldots. \ 5.25$$

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

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

ix. The four alternatives are ranked by sorting the values Q, R and S in ascending order.

Table 11: Criteria, Aggregate fuzzy rating and Crisp Values

Criteria	Aggregate Fuzzy Rating	Crisp Values
C1	(5,8.255,9)	7.84
C2	(3,7.902,9)	7.27
C3	(3.5.275,9)	5.52
C4	(3,7.824,9)	7.22
C5	(3,7.353,9)	6.90
C6	(3,7.314,9)	6.88
C7	(3,7.745,9)	7.16
C8	(5,7.588,9)	7.39
C9	(1,6.176,9)	5.78
C10	(3,8.020,9)	7.35
C11	(5,7.863,9)	7.58
C12	(3,7.863,9)	7.24
C13	(1,5.392,9)	5.26
C14	(3,7.588,9)	7.06
C15	(1,7.039,9)	6.36
C16	(3,7.627,9)	7.08
C17	(1,6.020,9)	5.68
C18	(1,6.569,9)	6.05
C19	(1,6.255,9)	5.84
C20	(1,6.353,9)	5.90
C21	(1,6.294,9)	5.86
C22	(1,5.137,9)	5.09
C23	(5,7.941,9)	7.63
C24	(3,7.588,9)	7.06
C25	(1,5.314,9)	5.21
C26	(3,7.941,9)	7.29
C27	(3,7.314,9)	6.88
C28	(5,8.059,9)	7.71
C29	(5,7.980,9)	7.65
C30	(3,7.627,9)	7.08
C31	(3,7.431,9)	6.95
C32	(5,7.745,9)	7.50
C33	(1,5.353,9)	5.24
C34	(5,7.980,9)	7.65
C35	(3,9.353,9)	8.24
C36	(5,8.000,9)	7.73
C37	(3,7.784,9)	7.19
C38	(5,7.745,9)	7.50
C39	(3,7.392,9)	6.93
C40	(1,4.843,9)	4.90
C41	(1,5.157,9)	5.10
C42	(1,5.039,9)	5.03
C43	(3,7.039,9)	6.69

Table 12: Fuzzy decision matrix for the four alternative construction sites

Criteria	A1 (PWD)	A2 (DMRC)	A3 (PWD)	A4 (DTTDC)	Minimum	Maximum
C1	(1,3.28,9)	(1,5.12,9)	(1,6.72,9)	(1,6.52,9)	1	9
C2	(1,4.08,9)	(1,4.92,9)	(1,6.76,9)	(1,6.72,9)	1	9
C3	(1,4.72,9)	(1,4.80,9)	(1,6.92,9)	(1,6.76,9)	1	9
C4	(1,4.16,9)	(1,5.12,9)	(3,6.48,9)	(3,6.28,9)	1	9
C5	(1,3.40,9)	(1,4.68,9)	(3,7.24,9)	(3,6.80,9)	1	9
C6	(1,4.11,9)	(1,4.28,9)	(1,4.16,9)	(1,4.36,9)	1	9
C7	(1,3.86,9)	(1,4.80,9)	(3,7.12,9)	(3,6.88,9)	1	9
C8	(1,4.86,9)	(1,4.48,9)	(1,6.72,9)	(1,6.52,9)	1	9
C9	(1,5.12,9)	(1,4.67,9)	(1,4.00,9)	(1,4.28,9)	1	9
C10	(1,4.56,9)	(1,4.20,9)	(1,4.04,9)	(1,4.36,9)	1	9
C11	(1,4.63,9)	(1,4.92,9)	(3,7.28,9)	(3,6.80,9)	1	9
C12	(1,5.72,9)	(1,5.80,9)	(1,6.72,9)	(1,6.52,9)	1	9
C13	(1,4.14,9)	(1,4.32,9)	(1,6.64,9)	(1,6.68,9)	1	9
C14	(1,4.20,9)	(1,5.08,9)	(3,6.96,9)	(3,6.88,9)	1	9
C15	(1,4.80,9)	(1,4.13,9)	(3,7.20,9)	(3,6.76,9)	1	9
C16	(3,6.80,9)	(3,7.12,9)	(3,6.96,9)	(3,6.80,9)	3	9
C17	(1,4.24,9)	(1,4.36,9)	(1,6.72,9)	(1,6.52,9)	1	9
C18	(1,5.80,9)	(1,5.56,9)	(3,7.28,9)	(3,6.76,9)	1	9
C19	(3,7.60,9)	(3,6.76,9)	(3,7.28,9)	(3,6.80,9)	3	9
C20	(1,2.44,7)	(1,3.73,9)	(3,7.40,9)	(3,6.92,9)	1	9
C21	(1,4.80,9)	(1,4.44,9)	(3,7.28,9)	(3,6.80,9)	1	9
C22	(1,4.32,9)	(1,3.92,9)	(3,7.24,9)	(3,6.80,9)	1	9
C23	(1,4.52,7)	(1,3.40,7)	(3,7.28,9)	(3,6.84,9)	1	9
C24	(1,3.73,9)	(1,3.86,9)	(3,7.12,9)	(3,6.76,9)	1	9
C25	(1,3.80,9)	(1,4.80,9)	(3,7.24,9)	(3,6.80,9)	1	9
C26	(1,5.24,9)	(1,4.72,9)	(3,7.24,9)	(3,6.88,9)	1	9
C27	(1,4.96,9)	(1,4.42,9)	(3,7.24,9)	(3,6.76,9)	1	9
C28	(1,6.08,9)	(1,5.45,9)	(3,7.28,9)	(3,6.88,9)	1	9
C29	(1,3.40,9)	(1,4.52,9)	(3,7.24,9)	(3,6.80,9)	1	9
C30	(1,5,56,9)	(1,5.80,9)	(3,7.32,9)	(3,6.84,9)	1	9
C31	(1,3.81,7)	(1,3.76,7)	(3,7.28,9)	(3,6.80,9)	1	9
C32	(3,6.84,9)	(3,7.24,9)	(3,6.96,9)	(3,6.80,9)	3	9
C33	(1,2.64,7)	(1,4.68,9)	(3,6.96,9)	(3,6.84,9)	1	9
C34	(1,2.48,7)	(1,4.96,9)	(3,6.88,9)	(3,6.80,9)	1	9
C35	(1,4.68,9)	(1,5.56,9)	(3,7.24,9)	(3,6.84,9)	1	9
C36	(1,3.56,7)	(1,4.56,9)	(3,6.92,9)	(3,6.84,9)	1	9
C37	(1,2.60,7)	(1,4.32,9)	(1,5.00,9)	(1,6.08,9)	1	9
C38	(1,4.52,7)	(1,3.81,9)	(3,7.28,9)	(3,6.80,9)	1	9
C39	(1,3.76,7)	(1,3.80,9)	(3,6.88,9)	(3,6.80,9)	1	9
C40	(1,2.50,7)	(1,2.33,7)	(3,6.96,9)	(3,6.84,9)	1	9
C41	(1,2.16,5)	(1,2.00,5)	(3,6.96,9)	(3,6.84,9)	1	9
C42	(1,2.66,7)	(1,2.85,7)	(1,7.16,9)	(1,6.72,9)	1	9
C43	(1,4.56,9)	(3,6.84,9)	(3,6.96,9)	(3,6.76,9)	1	9

Table 13: The worst (f_j-), best (f_j*) and S_i values of the 43 criteria

Criteria	Crisp Rating				Worst Value f_j^-	Best Value f_j^*	Weightage (w_j)	S_i			
	A1 (PWD)	A2 (DMRC)	A3 (PWD)	A4 (DTTDC)				A1	A2	A3	A4
C1	3.85	5.08	6.15	6.01	3.85	6.15	7.84	7.84	3.65	0	0.48
C2	4.39	4.95	6.17	6.15	4.39	6.17	7.27	7.27	4.98	0	0.08
C3	4.81	4.87	6.28	6.17	4.81	6.28	5.52	5.52	5.29	0	0.41
C4	4.44	5.08	6.32	6.19	4.44	6.32	7.22	7.22	4.76	0	0.50
C5	3.93	4.79	6.83	6.53	3.93	6.83	6.90	6.90	4.85	0	0.71
C6	4.41	4.52	4.44	4.57	4.41	4.57	6.88	6.88	2.15	5.59	0
C7	4.24	4.87	6.75	6.59	4.24	6.75	7.16	7.16	5.36	0	0.46
C8	4.91	4.65	6.15	6.01	4.65	6.15	7.39	6.11	7.39	0	0.69
C9	5.08	4.78	4.33	4.52	4.33	5.08	5.78	0	2.31	5.78	4.32
C10	4.71	4.47	4.36	4.57	4.36	4.71	7.35	0	5.04	7.35	2.94
C11	4.75	4.95	6.85	6.53	4.75	6.85	7.58	7.58	6.86	0	1.16
C12	5.48	5.53	6.15	6.01	5.48	6.15	7.24	7.24	6.70	0	1.51
C13	4.43	4.55	6.09	6.12	4.43	6.12	5.26	5.26	4.89	0.09	0
C14	4.47	5.05	6.64	6.59	4.47	6.64	7.06	7.06	5.17	0	0.16
C15	4.87	4.42	6.80	6.51	4.42	6.80	6.36	5.16	6.36	0	0.77
C16	6.53	6.75	6.64	6.53	6.53	6.75	7.08	7.08	0	3.54	7.08
C17	4.49	4.57	6.15	6.01	4.49	6.15	5.68	5.68	5.41	0	0.48
C18	5.53	5.37	6.85	6.51	5.37	6.85	6.05	5.40	6.05	0	1.39
C19	7.07	6.51	6.85	6.53	6.51	7.07	5.84	0	5.84	2.29	5.63
C20	2.96	4.15	6.93	6.61	2.96	6.93	5.90	5.90	4.13	0	0.48
C21	4.87	4.63	6.85	6.53	4.63	6.85	5.86	5.23	5.86	0	0.84
C22	4.55	4.28	6.83	6.53	4.28	6.83	5.09	4.55	5.09	0	0.60
C23	4.35	3.60	6.85	6.56	3.60	6.85	7.63	5.87	7.63	0	0.68
C24	4.15	4.24	6.75	6.51	4.15	6.75	7.06	7.06	6.82	0	0.65
C25	4.20	4.87	6.83	6.53	4.20	6.83	5.21	5.21	3.88	0	0.59
C26	5.16	4.81	6.83	6.59	4.81	6.83	7.29	6.03	7.29	0	0.87
C27	4.97	4.61	6.83	6.51	4.61	6.83	6.88	5.76	6.88	0	0.99
C28	5.72	5.30	6.85	6.59	5.30	6.85	7.71	5.62	7.71	0	1.29
C29	3.93	4.68	6.83	6.53	3.93	6.83	7.65	7.65	5.67	0	0.79
C30	5.37	5.53	6.88	6.56	5.37	6.88	7.08	7.08	6.33	0	1.50
C31	3.87	3.84	6.85	6.53	3.84	6.85	6.95	6.88	6.95	0	0.74
C32	6.56	6.83	6.64	6.53	6.53	6.83	7.50	6.75	0	4.75	7.50
C33	3.09	4.79	6.64	6.56	3.09	6.64	5.24	5.24	2.73	0	0.12
C34	2.99	4.97	6.59	6.53	2.99	6.59	7.65	7.65	3.44	0	0.13
C35	4.79	5.37	6.83	6.56	4.79	6.83	8.24	8.24	5.90	0	1.09
C36	3.71	4.71	6.61	6.56	3.71	6.61	7.73	7.73	5.06	0	0.13
C37	3.07	4.55	5.00	5.72	3.07	5.72	7.19	7.19	3.17	1.95	0
C38	4.35	4.21	6.85	6.53	4.21	6.85	7.50	7.10	7.5	0	0.91
C39	3.84	4.20	6.59	6.53	3.84	6.59	6.93	6.93	6.02	0	0.15
C40	3.00	2.89	6.64	6.56	2.89	6.64	4.90	4.76	4.9	0	0.10
C41	2.44	2.33	6.64	6.56	2.33	6.64	5.10	4.97	5.10	0	0.09
C42	3.11	3.23	6.44	6.15	3.11	6.44	5.03	5.03	4.85	0	0.44
C43	4.71	6.56	6.64	6.51	4.71	6.64	6.69	6.69	0.28	0	0.45
Total								256.48	216.25	31.34	49.9

Table 14 represents the values of Si, Ri and Qi for all the four alternatives calculated using equations 5.23, 5.24 and 5.25.

Table 14: S_i, R_i and Q_i for the four alternative construction sites

	A1 (PWD)	A2 (DMRC)	A3 (PWD)	A4 (DTTDC)
S_i	256.48	216.25	31.34	49.9
R_i	8.24	7.71	7.35	7.5
Q_i	1	0.605	0	0.12

The values of S*, S^-, R* and R^- as computed using equation 5.25 are 0.11, 0.89, 0.0256 and 0.0287 respectively. Table 15 ranks the four alternative sites, by ranking the values of Si, Ri and Qi obtained from Table 14 after arranging them in the ascending order.

Table 15: Ranking of the four alternatives

S_i	A3	A4	A2	A1
R_i	A3	A4	A2	A1
Q_i	A3	A4	A2	A1

It is inferred from the results presented in Table 15 that site A1 that is Barapulla Elevated Corridor by the PWD is best ranked by the measure of least value of Q_i. Therefore, we now cross-examine it for the given two conditions those have been earlier discussed.

i. **C1: acceptable advantage i.e. equation 5.12**

Using equation 5.12

$DQ = 1/43\text{-}1 = 1/42 = 0.0238$ 5.26

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

We have $Q(A2) - Q(A1) = 1 - 0 = 1 > 0.0238$ 5.27

Hence, the condition $QA^{(1)} - QA^{(2)}$ DQ is fulfilled.

ii. **C2: Acceptable stability in decision**

As the site A1 is best ranked by the figures of S_i and R_i, therefore it is declared to be a more sustainable corridor.

5.6 RESULTS AND DISCUSSIONS

The Fuzzy VIKOR technique was applied for sustainability evaluation of four major transportation corridors under construction i.e. (A1, A2, A3 and A4) in New Delhi city. These projects were Elevated road project from Vikaspuri to Meera Bagh (A1) and Barapulla elevated corridor (A3) have been constructed by PWD, Metro corridor from Azadpur to Raja Garden (A2) constructed by DMRC and Signature Bridge project (A4) constructed by DTTDC. Results of this study has been illustrated in Table 15, which depicts the four sites as below in terms of more sustainable.

i. **A3: Barapullah Elevated Corridor (Phase II)**
ii. **A4: Signature Bridge Project**
iii. **A2: Metro Corridor from Azadpur to Raja Garden**
iv. **A1: Elevated corridor from Vikaspuri to Meera Bagh**

Thus, A3 i.e. Barapulla Elevated Corridor (Phase II) by PWD is a more sustainable corridor in light of the identified sustainability indicators, as regards to the construction stage amongst the four corridors chosen for the case study.

5.7 CONCLUSIONS

i. Fuzzy-Vikor technique is a good tool for substantiality analysis when more than one alternatives are to be assessed and compared relative to each other.
ii. There is an advantage of Fuzzy membership function in defining a criteria under the situation when there is lack of clarity.
iii. The fuzzy membership functions convert the qualitative rating to the quantitative rating as a crisp number. It has got a minimum value that is higher than zero and also a maximum value that is lesser than 100 %. Thus, any weak criteria for an

alternative gets a minimum value and a strongest criteria gets its rating depreciated on conversion of qualitative rating into a crisp number.

iv. This technique compares an alternative for a particular criteria with the best rated amongst all alternatives. This it is the proximity with the best rating that is reflected in the results obtained by Fuzzy-vikor technique. In the instant case amongst the four corridors, construction of Barapullah corridor Phase II was found to be most sustainable in comparison to the other three corridors.

v. Fuzzy -Vikor technique cannot be used for sustainability analysis of a stand-alone corridor. In such a situation, a different technique is required to be used. Such a technique has been developed in this research work that has been covered in next chapter of this thesis.

CHAPTER 6

DEVELOPMENT OF SETU INDEX AND SETU RATING SYSTEM

6.1 INTRODUCTION

It is generally observed that there is always a challenge to design a building and construct it as a green building. Depending upon the budget and expertise of an Architect/ builder, the buildings are in competition and in race for the best green rating as per the existing rating system. Leadership in Energy and Environment Design (LEED) rating system that was generated by United States Green Building Council (UNGBC) is the most popular rating system worldwide for the buildings as regard to its design, construction, operation and their maintenance. Similarly, in India, Green Rating for Integrated Habitat Assessment (GRIHA) is most popular system for rating the buildings with 33 criteria to assess its green characteristics. Green rating system can be applied to the real estate and can quantify credits for certification of any building. A set of requirements has been defined to determine the green status of a building. If the requirements of the credits are met, then allotted points are granted against each criteria and total aggregate credit points are evaluate to grade a building from green rating system [40].

There is no such rating system available for the assessment or rating of transportation infrastructure works. Hence there was an immediate need to develop a system for sustainability evaluation of transportation corridors. An attempt has bene made in this research and SETU rating system has been developed for the sustainability evaluation of transportation corridors in an Urban Environment during the construction stage.

6.2 GRIHA RATING SYSTEM

GRIHA is a Sanskrit word meaning – 'Abode' i.e. Human Habitats (buildings). The 33 criteria covered in GRIHA rating system starts with the selection of the site and includes surroundings like greenery, soil conservation, soft paving, utilities, safety aspects, lighting

efficiency, air pollution, noise pollution, water pollution including its efficiency, recycling of wastes, reduction in embodied energy, renewal of energy, facilities for differently abled persons and maintenance issues etc. All such factors play an important role in efficient functioning of a building and its maintenance. GRIHA is a performance-oriented system where points are assigned for compliance to these 33 criteria. Each criterion has a pre-defined weightage. There are total 100 points ion GRIHA rating system that also includes certain essential compulsory criteria for making a building eligible for assessment. A building is judged on such 33 criteria, before assigning it a rating from 5 star as best rated to minimum 1 star rating.

6.3 SETU RATING SYSTEM

GRIHA rating system is applicable to the assessment of building infrastructure projects only. There does not exist any standard system worldwide to assess the green characteristics of transport infrastructure projects. The GRIHA rating system cannot be applied to infrastructure projects and two categories are almost different in character and purpose for which a building or flyover is built, The energy requirement of these two categories of infrastructure projects is different. With the studies carried out on the transportation system of Delhi, which is a thick urban area of the country, a green rating system with the title SETU Index has been generated. **SETU** in Sanskrit means bridge or bond. Otherwise, SETU here stands for **S**ustainability **E**valuation of **T**ransportation system in **U**rban Environment. Hence on the lines of GRIHA rating system with 33 criteria, SETU rating system has been developed with 43 criteria for a typical construction site of transportation infrastructure project during the construction stage that has been carried out in an Urban Environment.

6.4 METHODOLOGY OF GENERATION OF SETU RATING SYSTEM

On the basis of the studies carried out on 4 transportation infrastructure projects during the construction stage, constructed in Delhi/New Delhi in recent past, a set of 43 criteria called sustainability indicators have been identified . These 43 indicators have been listed

under 6 categories as elaborated in Table 7. These criteria were assessed by the experts in this field and assigned a qualitative weightage varying from very low to very high. Thereafter with the application of the membership function defined by Fuzzy and furnished in Table 10, these were converted into a crisp value. Thus each of such indicator was assigned a crisp number primarily based on the assessment by the experts in this field. This assessment has been given under Table 11.

6.4.1 Limitations with Fuzzy crisp values

It is observed that The crisp values, so assigned using Fuzzy membership function has certain limitations. The qualitative values varies from Very Low to very high. For very low qualitative assessment, the corresponding membership function is (1,1,3) and for the best assessment as very high, the corresponding membership function is (7,9,9).

Now considering the worst scenario as a particular indicator has been assigned worst rating as very low by all experts then its crisp value is 1.33 out of 10

$$\text{Crisp value} = \frac{1 + (4 \times 1) + 3}{6}$$

Similarly, considering the best scenario as a particular indicator has been assigned best rating as very high by all experts then its crisp value is 8.67 out of 10.

$$\text{Crisp value} = \frac{7 + (4 \times 9) + 9}{6}$$

Thus for the crisp value of all indicators varies between 1.33 to 8.67, while in fact it should be from 0 to 10 out of 10.

Similar is the situation of the assessment of the site. Here also the minimum qualitative assessment will be very poor for which the fuzzy membership function is same as for very

low i.e. (1,1,3) and minimum assessment against a particular indicator will be 1.33 and for best assessment it cannot exceed 8.67. In actual, it is possible that a particular indicator is totally ignored and deserves '0' (zero) assessment while it is granted as 1.33. On the contrary, if a particular indicator has been given extra ordinary care and deserves assessment as 10 out of 10, but the Fuzzy assessment will not allow to assign more than 8.67.

6.4.2 Indicators with SETU weightage

In order to overcome the limitation of Fuzzy rating system, the crisp values are converted into SETU Weightage. Following steps have been used to convert the crisp value to SETU weightage.

i. The range of the crisp values as obtained from Fuzzy rating system has been identified. It is observed that minimum Crisp Value = 4.9 and Maximum Crisp Value = 8.24

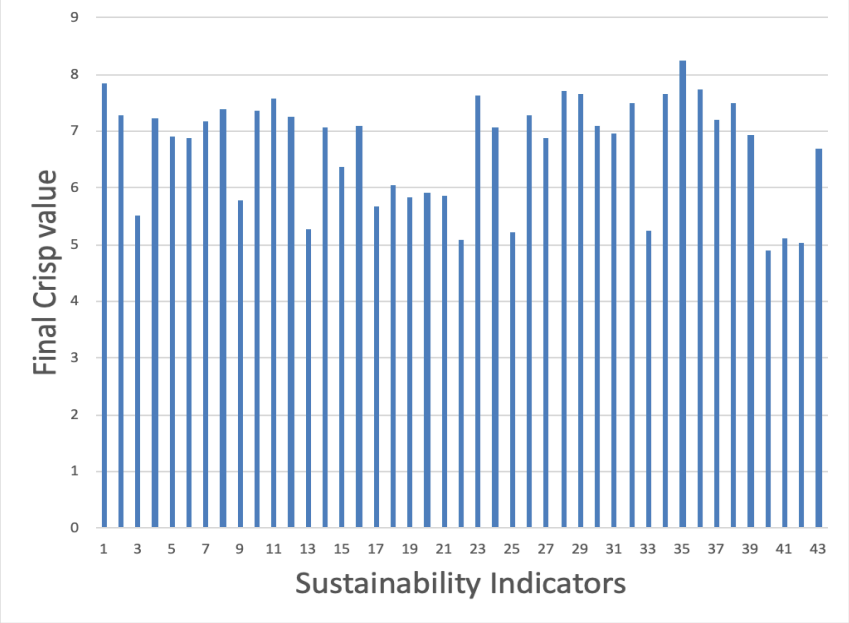

Fig. 44: Sustainability indicators with crisp values

ii. It is observed that the range from 4.9 to 8.24 is very small range and hence this range is required to be widened. The Crisp Values ranging from 4.9 to 8.24 were then arranged in ascending order are split into 5 regions equally.

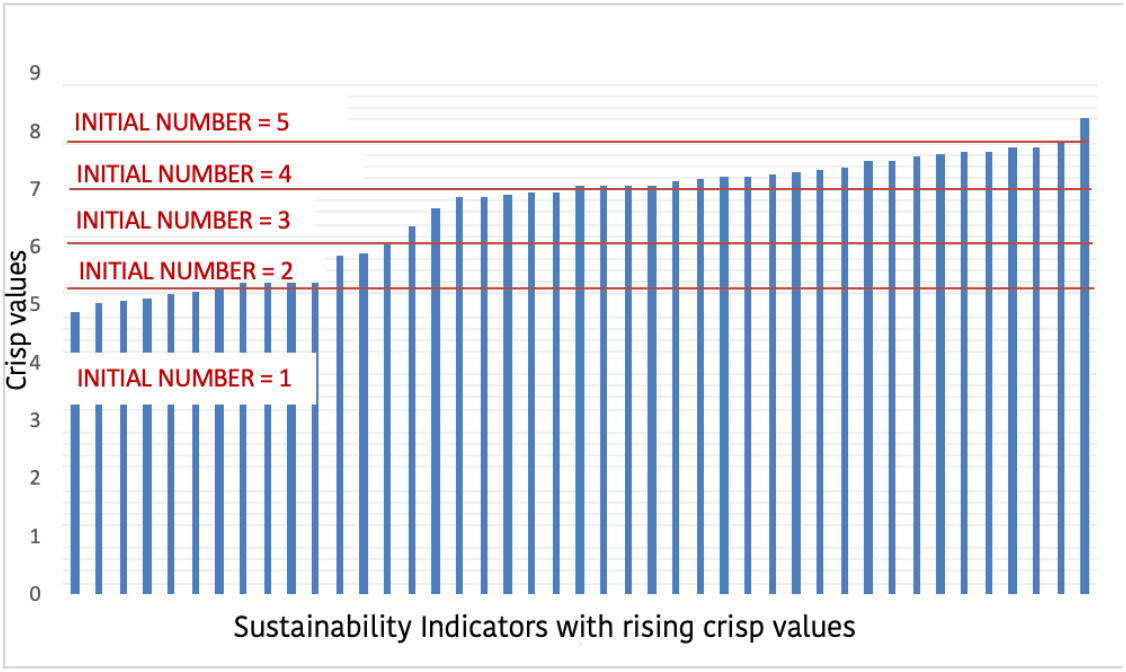

Fig. 45: Crisp values in ascending order

iii. For different regions, the crisp values are assigned an initial number on a scale of 1 to 5 by the following formula

If Crisp Value < 5.32, initial number = 1

If 5.32 Crisp Value < 6.15, initial number =2

If 6.15 Crisp Value < 6.99, initial number =3

If 6.99 Crisp Value < 7.82, initial number =4

If 7.82 Crisp Value, initial number =5

iv. Total sum of Initial number comes to 132. In order to make it to 100, the initial values were further divided by 1.32 and rounded off to get the whole number SETU Weightage. After rounding off, the sum still remains 103. Hence the values were visually examined and with best judgement, few of them adjusted to make the total as 100.

v. Once the SETU Weightage has been assigned to each of the criteria, the site rating of each alternative site has been converted into the SETU assessment by converting

the crisp rating against each criteria and for each site proportionately to the SETU weightage.

For e.g. For site A1 and criteria C1, the crisp rating of site assessed against this criteria = 3.85 out of 10. Then SETU weightage of this criteria = 4. Hence the SETU assessment of site A1 against sustainability indicator C1 is 1.54 as per following calculations.

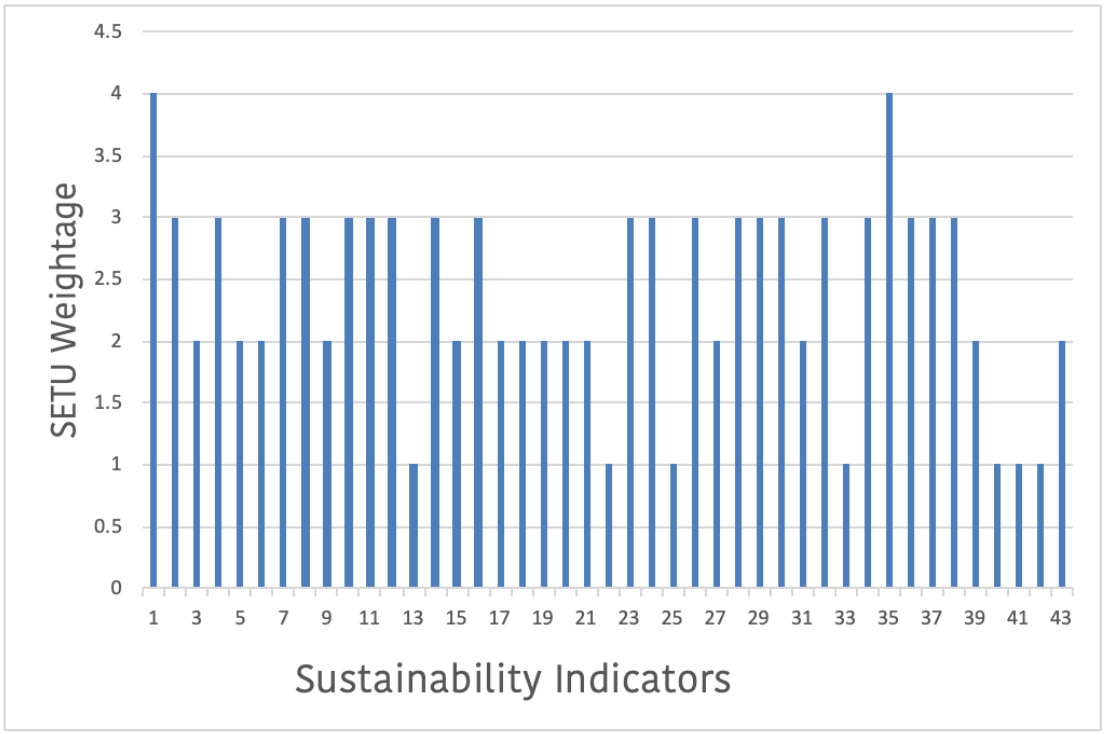

Fig. 46: Sustainability indicators with SETU weightage (in graphical form)

vi. $\text{SETU assessment} = \frac{3.85}{10} \times 4 = 1.54$

The assessment is rounded to one decimal and recorded as 1.5. In this manner all 4 sites were assigned SETU assessment against each of the 43 indicators. Total sum of assessment against each criteria is added finally to get the SETU Index for each of the alternative site. The SETU assessment of each site against each criteria and SETU Index for each alternative site is furnished in Table 17.

Table 16: SETU marking system for each criteria

Criteria No.	Criteria Title	Crisp Value	Initial Number	SETU Weightage
	ENVIRONMENTAL = 18 POINTS			
C1	Air Pollution	7.84	5	4
C2	Existing Drainage system	7.27	4	3
C3	Noise pollution during day	5.52	1	1
C4	Noise pollution during night	7.22	4	3
C5	Depletion of Green Belt	6.9	3	2
C6	Plantation scheme	6.88	3	2
C7	Alternate schemes for make the project more sustainable	7.16	4	3
	SOCIAL = 27 POINTS			
C8	Health of workers	7.39	4	3
C9	Welfare activities for family of workers	5.78	1	1
C10	Sanitation conditions	7.35	4	3
C11	First Aid facilities	7.58	4	3
C12	Safety measures	7.24	4	3
C13	Increase in stress level of residents/commuters	5.26	1	1
C14	Impact on Health of residents/commuters	7.06	4	3
C15	Impact on safety of residents/ commuters	6.36	3	2
C16	Preserving the social spaces like cremation ground, Sur Ghat	7.08	4	3
C17	Public attraction with the aesthetics of the Project	5.68	1	1
C18	Utility of the Project to Public	6.05	2	2
C19	Preserving the heritage structures	5.84	2	2
	ECONOMICS = 11 POINTS			
C20	Increase in Travel time	5.9	2	2
C21	Increase in travel cost	5.86	2	2
C22	Disturbance to the business/Employment of nearby residents	5.09	1	1
C23	Increase in cost of Construction due to lack of funds	7.63	4	3
C24	Increase in cost of Construction due to time overrun	7.06	4	3
	TECHNICAL = 20 POINTS			
C25	Display of Project Details	5.21	1	1
C26	Traffic Diversions	7.29	4	3
C27	Visibility and sight distance to moving traffic	6.88	3	2
C28	Lighting of Construction site	7.71	4	3
C29	Barricading the site	7.65	4	3
C30	Effectiveness of Technology used	7.08	4	3
C31	Handling of C & D Waste	6.95	3	2
C32	Quality Assurance on the Project	7.5	4	3
	GOVERNANCE = 19 POINTS			
C33	Ensuring the mobility of Traffic within the project area by traffic Marshalls	5.24	1	1
C34	Maintenance of existing drainage system	7.65	4	3
C35	Maintenance of Barricades	8.24	5	4
C36	Maintenance of existing utilities	7.73	4	3
C37	Maintenance of existing greenery	7.19	4	3
C38	Time over run due to delay in Govt. decisions	7.5	4	3
C39	Time over run due to mismanagement at site	6.93	3	2
	INNER ENGINEERING = 5 POINTS			
C40	Facilities of Yoga/meditation	4.9	1	1
C41	Performance of Rituals at site like Vishvakarma Puja, May Day	5.1	1	1
C42	Celebration during Festivals at site	5.03	1	1
C43	Motivation to workers by reward policy or otherwise	6.69	3	2

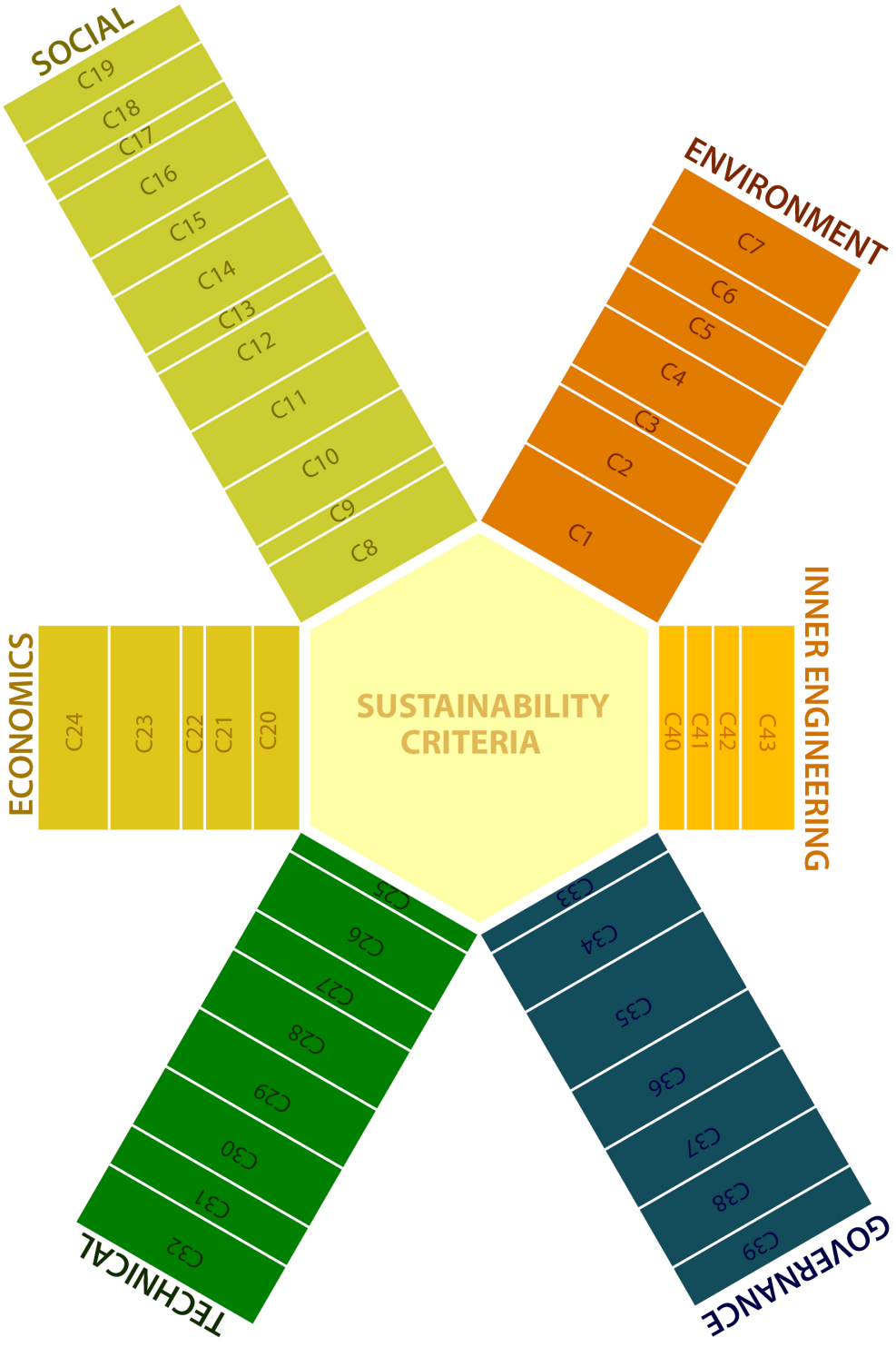

Fig. 47: Sustainability indicators with SETU weightage (in pictorial form)

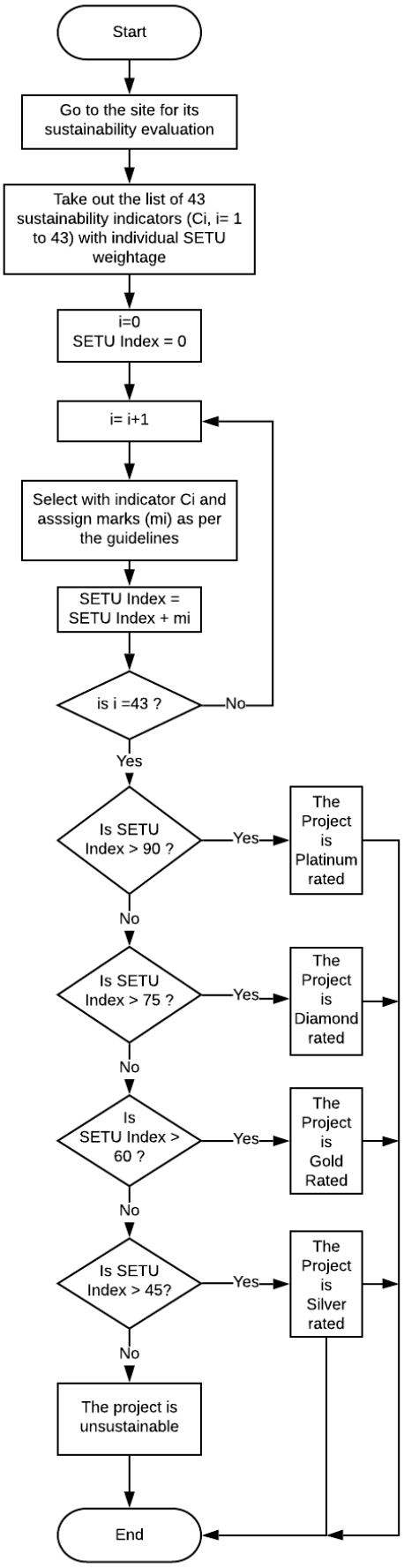

Fig. 48: Flow chart for the sustainability evaluation of a construction site

Table 17: SETU rating of the four construction sites

Criteria	A1 (PWD)		A2 (DMRC)		A3 (PWD)		A4 (DTTDC)	
	Crisp Rating	SETU Assessment	Crisp Rating	SETU Assessment	Crisp Rating	SETU Assessment	Crisp Rating	SETU Assessment
C1	3.85	1.50	5.08	2.00	6.15	2.50	6.01	2.40
C2	4.39	1.30	4.95	1.50	6.17	1.90	6.15	1.80
C3	4.81	0.50	4.87	0.50	6.28	0.60	6.17	0.60
C4	4.44	1.30	5.08	1.50	6.32	1.90	6.19	1.90
C5	3.93	0.80	4.79	1.00	6.83	1.40	6.53	1.30
C6	4.41	0.90	4.52	0.90	4.44	0.90	4.57	0.90
C7	4.24	1.30	4.87	1.50	6.75	2.00	6.59	2.00
C8	4.91	1.50	4.65	1.40	6.15	1.80	6.01	1.80
C9	5.08	0.50	4.78	0.50	4.33	0.40	4.52	0.50
C10	4.71	1.40	4.47	1.30	4.36	1.30	4.57	1.40
C11	4.75	1.40	4.95	1.50	6.85	2.10	6.53	2.00
C12	5.48	1.60	5.53	1.70	6.15	1.80	6.01	1.80
C13	4.43	0.40	4.55	0.50	6.09	0.60	6.12	0.60
C14	4.47	1.30	5.05	1.50	6.64	2.00	6.59	2.00
C15	4.87	1.00	4.42	0.90	6.80	1.40	6.51	1.30
C16	6.53	2.00	6.75	2.00	6.64	2.00	6.53	2.00
C17	4.49	0.40	4.57	0.50	6.15	0.60	6.01	0.60
C18	5.53	1.10	5.37	1.10	6.85	1.40	6.51	1.30
C19	7.07	1.40	6.51	1.30	6.85	1.40	6.53	1.30
C20	2.96	0.60	4.15	0.80	6.93	1.40	6.61	1.30
C21	4.87	1.00	4.63	0.90	6.85	1.40	6.53	1.30
C22	4.55	0.50	4.28	0.40	6.83	0.70	6.53	0.70
C23	4.35	1.30	3.6	1.10	6.85	2.10	6.56	2.00
C24	4.15	1.20	4.24	1.30	6.75	2.00	6.51	2.00
C25	4.2	0.40	4.87	0.50	6.83	0.70	6.53	0.70
C26	5.16	1.50	4.81	1.40	6.83	2.00	6.59	2.00
C27	4.97	1.00	4.61	0.90	6.83	1.40	6.51	1.30
C28	5.72	1.70	5.3	1.60	6.85	2.10	6.59	2.00
C29	3.93	1.20	4.68	1.40	6.83	2.00	6.53	2.00
C30	5.37	1.60	5.53	1.70	6.88	2.10	6.56	2.00
C31	3.87	0.80	3.84	0.80	6.85	1.40	6.53	1.30
C32	6.56	2.00	6.83	2.00	6.64	2.00	6.53	2.00
C33	3.09	0.30	4.79	0.50	6.64	0.70	6.56	0.70
C34	2.99	0.90	4.97	1.50	6.59	2.00	6.53	2.00
C35	4.79	1.90	5.37	2.10	6.83	2.70	6.56	2.60
C36	3.71	1.10	4.71	1.40	6.61	2.00	6.56	2.00
C37	3.07	0.90	4.55	1.40	5	1.50	5.72	1.70
C38	4.35	1.30	4.21	1.30	6.85	2.10	6.53	2.00
C39	3.84	0.80	4.2	0.80	6.59	1.30	6.53	1.30
C40	3	0.30	2.89	0.30	6.64	0.70	6.56	0.70
C41	2.44	0.20	2.33	0.20	6.64	0.70	6.56	0.70
C42	3.11	0.30	3.23	0.30	6.44	0.60	6.15	0.60
C43	4.71	0.90	6.56	1.30	6.64	3.00	6.51	1.30
SETU INDEX		45.30		49.00		66.60		63.70

Once the SETU Index is calculated, the four alternative sites are assigned rating as given in Table 18.

Table 18: SETU rating system

SETU INDEX	RATING
More Than 90	Platinum Rating
75-90	Diamond Rating
60-75	Gold Rating
45-60	Silver Rating
Below 45	Unsustainable project

6.5 VALIDATION OF RESULT

Based on the SETU Index evolved after the sustainability studies of four corridors under study have been assigned SETU rating. The SETU rating as assigned to these four alternative sites is furnished in Table 19 below.

Table 19: SETU rating to four projects under study

S. No.	PROJECTS UNDER STUDY	SETU INDEX	RATING
1.	A1: Elevated road Corridor from Vikaspuri to Meera Bagh	45.3	Silver Rating
2.	A2: Metro Rail Corridor from Azadpur to Raja Garden	49.0	Silver Rating
3.	A3: Barapullah elevated Road Project (Phase II)	66.6	Gold Rating
4.	A4: Signature Bridge Project	63.7	Gold Rating

These four alternative construction sites are arranged in order of SETU Index from Maximum to minimum. The resultant sequence is A3, A4, A2, A1 that is same as obtained by FUZZY-VIKOR Method of sustainability analysis.

6.6 ANALYSIS OF RESULTS BY SETU INDEX

In order to analyse the results and compare the two systems, we need to find some statistical values, like standard deviation of both the system, correlation coefficient and rank correlation between the two systems.

Table 20: Standard Deviation (σ) of four sites by SETU Index

S. No.	FOUR ALTERNATIVE SITES	SETU INDEX	μ = 56.15 $(x_i - \mu)^2$
1.	A1: Elevated road Corridor from Vikaspuri to Meera Bagh	45.3	117.72
2.	A2: Metro Rail Corridor from Azadpur to Raja Garden	49.0	51.12
3.	A3: Barapullah elevated Road Project (Phase II)	66.6	109.20
4.	A4: Signature Bridge Project	63.7	57.00
			$\sigma = 9.15$

Table 21: Standard Deviation (σ) of four sites by FUZZY VIKOR method

S. No.	FOUR ALTERNATIVE SITES	S	S' = S/4.3	μ = 32.21 $(x_i - \mu)^2$
1.	A1: Elevated road Corridor from Vikaspuri to Meera Bagh	256.48	59.65	752.95
2.	A2: Metro Rail Corridor from Azadpur to Raja Garden	216.25	50.29	326.89
3.	A3: Barapullah elevated Road Project (Phase II)	31.34	7.29	621.01
4.	A4: Signature Bridge Project	49.90	11.60	424.77
				$\sigma = 23.05$

Table 22: Correlation Coefficient (r) between SETU Index and FUZZY-VIKOR method

S. No.	ALTERNATIVE SITES	SETU INDEX (S) $\mu_s = 56.15$	FUZZY-VIKOR (S') $\mu_{s'} = 32.21$	$(S - \mu_s)*(S' - \mu_{s'})$
1.	A1: Elevated road Corridor from Vikaspuri to Meera Bagh	45.3	59.65	-297.724
2.	A2: Metro Rail Corridor from Azadpur to Raja Garden	49.0	50.29	-129.272
3.	A3: Barapullah elevated Road Project (Phase II)	66.6	7.29	-260.414
4.	A4: Signature Bridge Project	63.7	11.60	-155.6055
				Cov. = -52.69 $r = -1$

Table 23: Rank Correlation Coefficient (ρ) between SETU Index and FUZZY-VIKOR method

S. No.	ALTERNATIVE SITES	SETU INDEX (S) μ_s = 1.12	FUZZY-VIKOR (S') $\mu_{s'}$= 1.12	$(S- \mu_s)*(S'- \mu_{s'})$
1.	A1: Elevated road Corridor from Vikaspuri to Meera Bagh	4	4	2.25
2.	A2: Metro Rail Corridor from Azadpur to Raja Garden	3	3	0.25
3.	A3: Barapullah elevated Road Project (Phase II)	1	1	0.25
4.	A4: Signature Bridge Project	2	2	2.25
				Cov. = 1.25 $\rho = +1$

It is interestingly observed that

i. Standard Deviation ($\boldsymbol{\sigma}$) in case of Fuzzy Vikor method is too large in comparison to SETU rating system

ii. Correlation Coefficient (**r**) between two system is -1, while the rank correlation (ρ) is +1.

6.7 ANALYSIS OF THE STATISTICAL RESULTS BY TWO METHODS

In Statistics, the Standard Deviation measures the amount of variation or dispersion of a set of values from its mean value. A low standard deviation is an indication of the figures values quite close to the mean value of the variables, while on contrary, a high standard deviation is an indication of spreading of the figures out over a wider range. In the instant case, if we look into the Fuzzy-Vikor method that indicates greater dispersion, it is observed that the outcome is highly dependent upon the difference between the best and worst figures as well as deviation from the best values. So, this system is more suitable when a comparison is to be made between the alternatives. In the SETU rating system, each alternative is analysed independently and not dependent on the rating of the other alternatives. Hence,

each alternative site in this research work can be analysed independently and be graded as its own as per the defined rating system.

In the Fuzzy-Vikor method, lesser value of 'S' indicates that in a particular alternative, for most of criteria, the crisp values are placed closer to the best crisp rating amongst various alternatives. Accordingly, lesser is the value, better is the ranking. Hence the alternatives have been assigned ranking in the reverse order of the value of S. It explains the negative correlation co-efficient between two systems. Further the value of covariance being -1, it explains the perfectness in the correlation between two system. It also justifies the rank correlation between two methodology found to be perfect +1. The four alternative sites have been found to have the same ranking by SETU rating system as well as Fuzzy-Vikor method. Although the SETU rating system is not meant for making any comparison between various alternatives.

6.8 JUSTIFICATION OF THE BEST PROJECT (BARAPULLAH, PHASE II)

As per the outcome of sustainability analysis by Fuzzy-Vikor Method and further validation of the results by SETU indices, it was concluded that amongst the four alternative sites chosen from the different scattered locations of the Metropolitan city Delhi, the construction of the Barapullah elevated corridor connecting Jawaharlal Nehru Stadium to INA and missing loops of the Phase 1 from Sarai Kale Khan to Jawahar Lal Nehru stadium was the most sustainable. The analysis has been carried based on the inputs from 3 categories of stakeholders.

i. Sustainability Indicators identified as a part of research and based on the deep study of the four alternative sites during construction stage in different period of the construction.
ii. Weightage to these indicators by the team of experts

iii. Weightage to the site against 43 criteria by the public directly impacted due to the construction activities.

Thereafter Fuzzy-Vikor method was applied to assess the best alternative site. The results were validated by SETU index established based on the crisp numbers evolved during analysis by Fuzzy-Vikor method. The best alternative site was again studied in further details with regard to the 43 sustainability indicators.

6.8.1 Background of the project

The Barapullah elevated Project has been planned for execution in 3 phases. In phase 1, an Elevated road, 4 Kms long connecting Sarai Kale Khan and Jawahar Lal Nehru Stadium has been completed in recent past in 2010 to facilitate the movement of sports persons and sports lovers to reach Jawahar Lal Nehru Stadium and enjoy the Common Wealth Games 2010 without facing the traffic hassles of Delhi. This Phase was defined as a sustainable corridor due to various features qualifying it as supportive to society, environment friendly and economically viable. One of the key features noticed is avoiding the eclipsing of a heritage structure namely Khan-e-khan tomb by realigning the corridor to move more than 100 m away from its surroundings and also elevating the deck to 12 m height so that full view from any distance is not disturbed. Moreover, the Cantilever segmental construction over the major road and railway crossings helped in maintaining the free flow of road and rail traffic In Phase 2, the construction of connectivity from Jawahar Lal Nehru Stadium to INA has been completed. In addition to this connectivity, there are certain intermediate loops connecting the elevated road constructed in Phase 1 with the major arterial roads crossing on the way. Also, the missing facilities for ascending to and descending from the elevated corridor at Sarai Kale Khan were added in 2nd phase. The works in Phase 2 was completed and made operational in July 2017**.** In phase 3, the major link to connect the elevated corridor with East Delhi at Mayur Vihar after crossing Yamuna is being provided. The work has started in April 2015 and expected to be operational by 2021.

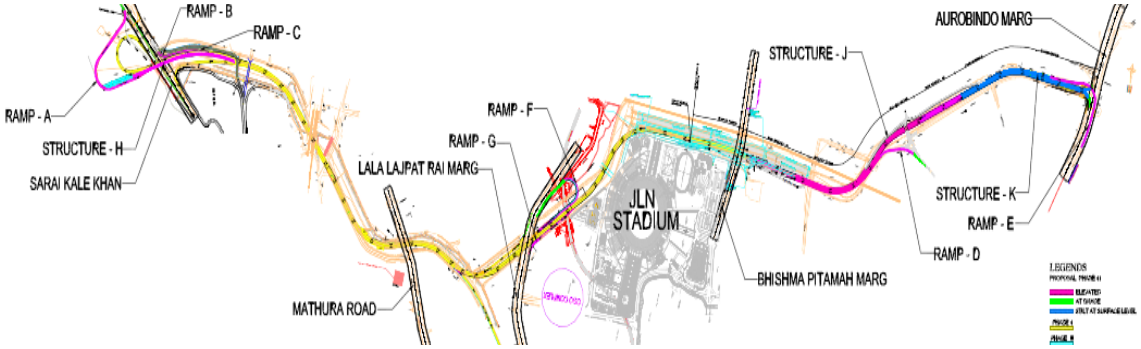

Fig. 49: Combined layout plan of phase I and II

In phase 2 of the project, the corridor dropped at Jawahar Lal Nehru Stadium in the phase 1 is being taken ahead to INA to touch the Aurobindo Marg as well as further elevated to facilitate the traffic from Ring Road to enter this corridor. In addition to this, certain loops not taken up in Phase 1 due to paucity of time that have been added to make the corridor better functional and useful to a larger number of citizens. In Phase 1 there was limited facility of ascending and descending in this corridor at Sarai Kale Khan i.e. only ascending for the traffic coming from ITO side and descending to ITO side was permitted. Now with the addition of two more loops at this location, traffic coming from Ashram side will be able to ascend to this corridor and traffic bound for Ashram will be able to descend from this corridor. Also, at the location where this corridor is crossing Lal Lajpat Rai Marg, two loops have been added to get down to this road from both the carriageways. There are many more intricacies involved in Phase 2 due to which the distinct types of designing technologies have been adopted as detailed below. In fact, the structure provided in this phase covers 7 types of structures namely Precast Segmental Construction using pre-stressing couplers, Precast Pre-tensioned beams, Solid slabs, Voided slabs, Cantilever Construction, Steel arch Bridge, Composite Steel girders with concrete slab, RCC Slab over single Pier. There was switch over of technologies from one location to other depending upon the site conditions, hindrances and geometrics.

6.8.1.1 Pre-cast segmental for 4 span continuous structure: Most of the spans have been designed with pre-cast segmental technique with 3 or 4 spans continuous. In most of the segmental construction works taken in the country, the continuity is limited to deck by providing the continuous reinforcement over simply supported structures so as to have Expansion joints after 3 or 4 spans thus having a better riding quality. In this case is that the continuity is not limited to deck, but the entire 3 or 4 span structure is made continuous by use of pre-stressing couplers between pre-stressing cables.

Fig. 50: Ground launching of spans making it continuous

In the first stage of launching for three (or four) span continuous structure, 1¼ span is launched and pre-stressed in the usual manner. The pre-stressing cables can be taken further by joining next set of cables through the pre-stressing couplers and the launching of 2¼ (or 3¼) span is completed and so on till last ¾ span is left over for final launching of a module and finally pre-stressed. This system proves to be economical in comparison to conventional system of providing Deck slab Continuity by about 10%. Moreover, the constructability is also simplified.

6.8.1.2 Cantilever construction (CLC): The corridor was required to cross the Ring road at one location at Sarai Kale Khan. Due to deeper segments, it was not be possible to transfer the segments through the heavy traffic and decision was been taken to substitute from precast to in-situ balanced cantilever structure. Accordingly, this crossing has been constructed as in-situ Cantilever structure technique monolithic with the twin flexible piers.

Fig. 51: Cantilever construction for long spans

As seen in Figure 51 above, the cantilever construction was used to cross only the Ring road with span of 45 m but also many services (water mains and HT cables) were saved from shifting. Thus, lot of time and money was saved besides saving the public from inconvenience during the shifting period.

Fig. 52: Precast Pre-tensioned beams stacked in casting yard

6.8.1.3 Precast I-Girders: There were locations at Sarai Kale Khan where the radius of the curve was too sharp to cast the segment with sufficient accuracy and launch them at site. At such locations, the construction has been carried out with pre-cast pre-tensioned RCC I Girders of approximately 20 m Length. In addition to above locations, the structure meeting Aurobindo Marg for a length of about 300 m will be just over the Nallah. In such a location, there is a limitation of the depth of the structure as deeper segments will cause obstruction to the free flow of Nallah. At such locations, the structure has been designed as pre-tensioned, pre-cast I-Girders with a pre cast and in-situ slab for the ease of constructability.

Fig. 53: Pre-tensioned beams for structure over nallah

6.8.1.4 Steel arch bridge: During the midst of the construction, it was noticed that DMRC has planned an underground tunnel that was crossing the Barapullah Corridor at grade. Interestingly, their construction was also executed around the same period. It was essential to have a perfect coordination between two executing bodies as well as monitoring of structures during the course of construction. The locations of pile and piles caps were to be tailor made along the direction of the Tunnel so as to avoid any conflict between the two structures. Again, there was a limitation of depth of the structure to be provided and span of the structure varying from 45-65 m in order to accommodate tunnels between the

pile caps. Here, steel arch truss was provided with 3 spans of 45 m each on one carriageway and 2 span of 65 m each on the other carriage way.

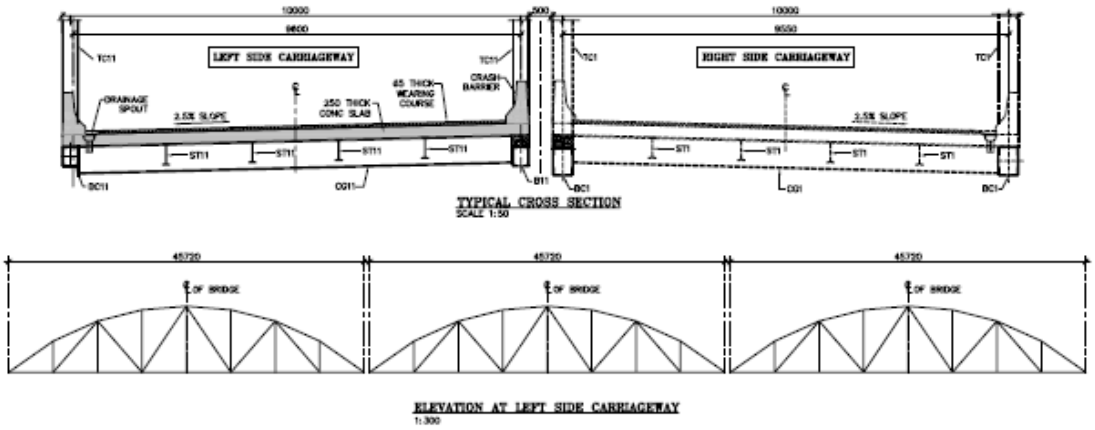

Fig. 54: Steel structure arch bridge over DMRC tunnel

6.8.1.5 Slab over single pier: The starting point of phase II beyond Nehru Stadium was found to be having underground cellular foundation structure provided for DTC bus depot constructed over the Nallah just abutting the Barapullah Corridor. Since the foundation structure was continuous, it was not advisable to puncture or dismantle the foundation for boring the piles and therefore, the alignment was to be shifted slightly by about 10 m. This shifting resulted into very limited areas for the placement of foundation and substructure. Accordingly, structure over single pier for a length of about 200 m was provided. For such a length of corridor, the structure is being provided as in-situ pre-stressed voided slab with shorter spans for making it lighter in weight and casting monolithically with single piers.

Fig. 55: Flyover over single pier due to restricted width

6.8.1.6 In-situ solid/ voided slab: There are certain locations like a structure passing through Silver Oak Park where the only solution was to negotiate the curve with in-situ solid slab monolithic with the piers due to non-standard spans [70].

Fig. 56: Voided slab monolithic over circular piers

6.8.2 Sustainability considerations

It is seen that there was a versatility in the design of the corridor as per the situation. The moment, any crisis was seen at site, appropriate design technology was used to make the corridor function despite hindrance of new kind at every location. In addition, other sustainability features observed were as following.

i. The alignment wherever possible has been modified to save maximum number of trees. In complete project of Phase II, only 79 trees have been removed and out of them about 20 trees are being transplanted.

ii. The work has been executed without disrupting the traffic by carefully planning the sequence of operations so that the traffic moves unhindered at all times.

iii. Safety of workers during construction was ensured by providing helmets, masks, safety goggles, etc. Adequate signage, barriers and persons with flags to control traffic had been provided during construction. Adequate drainage, sanitation, and waste disposal facilities were provided at work places. Proper drainage was ensured around the sites to avoid water logging leading to any illness. At every workplace,

potable and sufficient drinking and washing water supply is maintained to avoid water-related diseases and to secure the health of workers.

iv. All the construction and demolition waste has been taken to recycling plant, where it is converted into useful products like bricks, tiles, paver blocks etc. [63]

v. High grade concrete like M60 is being used to save overall cement and in turn reducing CO2 emission to atmosphere.

vi. A perfect coordination has been done with DMRC to allow the execution of both the projects simultaneously without any adverse impact on other project.

6.8.3 Critical analysis based on sustainability indicators

During the studies carried out at four sites, 43 indicators under 6 categories were identified. As per the opinion of public, the Barapullah corridor Phase II was graded as the most sustainable construction carried out at site. Applicability of each of the category and indicators have been discussed hereinafter.

6.8.3.1 Environmental

i. **C1: Air pollution:** Daily and continuous sprinkling of water was a practice at site. The material carrying vehicles were found covered with tarpaulin. Batching plant installed at casting yard was provided with dust arrester.

ii. **C2: Existing drainage system:** Existing drainage system was found well Protected. Additional drain to divert water the into the channel was provided and the flow of Barapullah Nallah was ensured at all times specifically during Monsoon.

iii. **C3: Noise pollution during the day:** Silent DG set were used at site. Movement of material carrying vehicles was restricted to night only.

iv. **C4: Noise pollution during the night:** Construction site as well as Casting yard location was chosen away from the urban areas to save the public from getting disturbed due to noise pollution during the night.

v. **C5: Depletion of Green belt: Existing** greenery was well maintained. Minimum trees were removed from site. Silver Oak Park was maintained and saved from getting split up.

vi. **C6: Plantation Scheme:** Additional greenery was created wherever feasible on the complete site. 10 times the trees uprooted were planted at site.

vii. **C7: Alternate schemes for make the project more sustainable:** Alignment was modified to reduce the number of trees to be removed. One Gurudwara and its approach was well saved by modifying the alignment and structural system.

6.8.3.2 Social

viii. **C8: Health of workers: Regular** medical check-up for the workers was ensured at site. A qualified doctor was assigned the job who was visiting the site on weekly basis to ensure the health of workers in good condition. He was providing medicines to the workers on regular basis, whenever anyone was noticed sick.

ix. **C9: Welfare activities for family of workers:** Creche facility for young children of the workers was provided at site by CPWD officers' wives association.

x. **C10: Sanitation conditions:** Proper washrooms and drainage facility was provided for labour at casting yard. Septic tanks were provided at site and periodic cleaning of these septic tanks was also being done.

xi. **C11: First Aid facilities:** Well-equipped First aid van was made available round the clock at site. Whenever any emergency happened at site, the first aid-van was very useful in provided immediately relief to the victim.

xii. **C12: Safety measures: Safety** gadgets like helmets, safety belts were provided to all the workers and made mandatory for its use for their safety.

xiii. **C13: Increase in stress level of residents/commuters:** Since the Site was far away from habitation, it didn't make any impact on the stress level of residents/ commuters

xiv. **C14: Impact on Health of residents/commuters:** Canteen facility with healthy food was provided at site. Site activities were so controlled that there was least impact on the health of workers.

xv. **C15: Impact on safety of residents/ commuters: Site** was property barricaded to secure the commuters and traffic was diverted wherever required.

xvi. **C16: Preserving the social spaces like cremation ground, Ghat: Land** of Gurudwara and its approach was preserved by modifying the alignment in that area. Two independent roads were merged to reduce the need of land that saved Gurdwara from any kind of hassles.

xvii. **C17: Public attraction with the aesthetics of the Project: Pleasant** aesthetes provided wherever feasible like crash barriers, Piers etc.

xviii. **C18: Utility of the Project to Public:** Travel time from East Delhi to South Delhi reduced by about 40 minutes. Moreover, it also shortened the distance from Sarai Kale Khan to INA reducing the traffic on Ring Road.

xix. **C19: Preserving the heritage structures:** The alignment was so chosen that no heritage structure was found falling within the prescribed limits of the alignment of phase 2.

6.8.3.3 Economical

xx. **C20: Increase in Travel time:** Only one diversion was required where travel time increased by about 20 minutes, but after the corridor was opened to traffic, travel time reduced by about 40 minutes.

xxi. **C21: Increase in travel cost:** The travel cost was increased marginally during construction stage as traffic had to be diverted for execution of work at one location. But, after the complete corridor was opened to traffic, travel cost reduced drastically.

xxii. **C22: Disturbance to the business/Employment of nearby residents:** There was no disturbance to business or employment of the nearby residents.

xxiii. **C23: Increase in cost of construction due to lack of funds:** There was never any shortage of funds, hence this factor did not contribute to the increase in cost of construction.

xxiv. **C24: Increase in cost of construction due to time overrun: There** was time overrun due to change in alignment and other hindrances beyond the control of Project team. The cost of construction increased marginally due to these factors.

6.8.3.4 Technical

xxv. **C25: Display of Project Details**: All the project details were well displayed throughout the progress of work.

xxvi. **C26: Traffic Diversions: Traffic** diversion was required and provided at one location with proper signages

xxvii. **C27: Visibility and sight distance to moving traffic:** Visibility and sight distance to moving traffic was fully ensured.

xxviii. **C28: Lighting of Construction site:** The site was well-lit at night to ensure proper visibility.

xxix. **C29: Barricading the site:** The site was fully protected with proper barricades enveloping the site.

xxx. **C30: Effectiveness of Technology used:** Most appropriate technology was used depending upon the location. Total 8 types of structures were provided to suit the site conditions.

xxxi. **C31: Handling of C & D Waste:** Contractor was bound with agreement condition to transfer all C & D waste to recycling plant

xxxii. **C32: Quality Assurance on the Project:** 3rd party quality assurance team was deployed at site

6.8.3.5 Governance

xxxiii. **C33: Ensuring the mobility of Traffic within the project area by traffic Marshalls:** Adequate number of traffic Marshalls were deployed in project area to ensure the mobility of Traffic within the project area.

xxxiv. **C34: Maintenance of existing drainage system:** The existing drainage system Well maintained and thee was never any problem faced during monsoons. Even the main drain was desilted prior to monsoons.

xxxv. **C35: Maintenance of Barricades:** The barricades provided at site were well maintained throughout the execution of the project.

xxxvi. **C36: Maintenance of existing utilities:** All existing utilities were preserved and well-maintained without making any shift or disturbance.

xxxvii. **C37: Maintenance of existing greenery:** All existing greenery was very well maintained

xxxviii. **C38: Time over run due to delay in Govt. decisions:** There was substantial time overrun, as one of the loop near INA was modified to reverse direction. Moreover, it took little extra time in getting permission from DDA to work in Silver Oak Park.

xxxix. **C39: Time over run due to mismanagement at site:** There were delays at site, but these were due to technical reasons. There was hardly any delay due to mismanagement at site.

6.8.3.6 Inner Engineering

xl. **C40: Facilities of Yoga/meditation:** There was no such facilities provided at site or at the casting yard.

xli. **C41: Performance of Rituals at site like Vishvakarma Puja, May Day:** Yes, regular celebration of Vishvakarma Puja, labour days etc. was being organised at casting yard.

xlii. **C42: Celebration during Festivals at site:** Yes, some festivals like Holi, Diwali were celebrated at site.

xliii. **C43: Motivation to workers by reward policy or otherwise:** Yes, best workers were given due recognition every month.

From the above details, it is observed that there was a compliance of most of the criteria that makes it to have a higher SETU rating and better rating in comparison to other sites. If we observe the other projects, it is seen that about 800 trees were uprooted in Vikaspuri -Meera Bagh Corridor, site was not properly maintained during the construction period, same technology continued to be used even when the locations at crossings and negotiating the Najafgarh Nallah demanded a different technology. The work of signature bridge was abnormally delayed that pulls it down in ranking. Moreover the cost in this case was also enhanced that makes it an uneconomical project. The bridge is definitely an iconic structure but cost benefit ratio is much lower in this case. The project was also dragged to the courts for the Environmental issues, though these were resolved with 100% compliance. In DMRC corridor at Azadpur, there was use of conventional technology while negotiating over Najafgarh Nallah.

6.9 APPLICATION OF SETU RATING SYSTEM FOR SUSTAINABLE EXECUTION

Once the SETU rating system is established, it has now become possible to evaluate even a single standalone transportation infrastructure project from sustainability point of view. Any such any infrastructure project can be assigned a rating as Platinum rating, Diamond rating, Gold rating or a Silver rating depending upon the sustainability index of such a project that has bene carried out during the construction stage [76]. Sustainability Index is worked out on the basis of the rating of the site against 43 indicators with different weightage. There has to be a uniform guidelines for assigning the rating of the site against each of such criteria, otherwise it will lead to subjectivity. Hence in order to avoid any such subjectivity, guidelines have been framed for assessing any site independently.

6.10 GUIDELINES FOR MARKING SYSTEM FOR CALCULATING THE SETU INDEX

The SETU rating system is based on 43 sustainability indicators grouped under 6 categories. It is required to have a well-defined guidelines for its marking system for a fair sustainability evaluation of a construction site that has been defined below.

6.10.1 Criteria 1: Environmental (18 points)

i. **Indicator C1, Air Pollution with SETU weightage as 4:** If the Air quality parameters are within the limits of National Ambient Air Quality Standards, assign 4 marks. If it does not meet the National Ambient Air Quality Standards, but it is better than Air quality before start of the work, assign 3 Marks. If it meets the same standards (up to 10% deterioration) assign 2 marks and if is deteriorated up to 25%, assign 1 mark. If it is deteriorated by more '0' mark.

ii. **Indicator C2, Drainage system with SETU weightage as 3:** If fresh drainage system within the site is provided for catering the monsoon is provided at site, assign 3 marks. If the site gets flooded during monsoons, assign 0 marks and depending upon the partial provision of drainage system, marks can be assigned 1 or 2. If flooding is repeatedly observed during monsoons, then assign 0 marks. If it happens and then drainage system provided by the construction agency, assign 2 marks, but for another offense, reduce it to 1. Further for offence more than twice, assign 0 marks.

iii. **Indicator C3, Noise pollution during day with SETU weightage as 1:** If Leq is less than 65 dB(A), assign 1 mark, otherwise assign '0' mark.

iv. **Indicator C4, Noise pollution during night with SETU weightage as 3:** If Leq is less than 55 dB(A), assign 3 mark. If Leq is less than 65 dB(A), assign 2 mark. If Leq is less than 75 dB(A), assign 1 mark, otherwise assign '0' mark.

v. **Indicator C5, Depletion of Green Belt with SETU weightage as 2:** If green belt is increased than that before start of construction, assign 2 marks. If it is just maintained at par, assign 1 marks. If it is depleted, then assign '0' mark.

vi. **Indicator C6, Plantation scheme with SETU weightage as 2:** If there is specific plantation specific for the project and 30% implemented during the course of construction assign 2 marks. If the scheme exists, but no action initiated then assign 1 mark. If there is no such scheme assign '0' mark.

vii. **Indicator C7, Alternate schemes for making the project more sustainable with SETU weightage as 3:** If there is specific consideration to provide alternative schemes for making the project better sustainable, assign 3 marks. If there is no such plan, but otherwise sustainability consideration with the deployment of an independent environmental engineer at site, assign 2 marks. If there is sustainability consideration but without any independent environmental engineer, assign 1 mark, otherwise assign '0' mark.

6.10.2 Criteria 2: Social (27 points)

viii. **Indicator C8, Health of workers with SETU weightage as 3:** If more than 75% regular worker are provided health insurance, assign 3 marks, if there is no such insurance, but medical aid is provided as and when required without any cost to workers, assign 2 marks. If the regular health check-up facility at an interval of six months is there, assign 1 mark, otherwise assign '0' mark.

ix. **Indicator C9, Welfare activities for family of workers with SETU weightage as 1:** If there is some welfare facility for the health of workers like crèche for infants at site, then assign 1 mark otherwise assign '0' mark.

x. **Indicator C10, Sanitation conditions with SETU weightage as 3:** If proper and adequate number of toilets provided as per the agreement conditions, assign 3 marks.

xi. **Indicator C11, First Aid facilities, with SETU weightage as 3:** If all first aid facilities with doctor on call and well equipped ambulance is provided at site, assign 3 marks. If the facility is limited to first aid room and ambulance, assign 2 marks. If only first aid room is provided assign 1 mark, otherwise assign '0' mark.

xii. **Indicator C12, Safety measures with SETU weightage as 3:** If all amenities like Helmets, Safety shoes, Safety belts, torch etc. provided and made compulsory then give 3 marks otherwise 0 to 3 depending upon the facilities provided at site.

xiii. **Indicator C13, Increase in stress level of residents/commuters with SETU weightage as 1:** If there no untoward incident is noticed due to increase in level of residents/ commuters, assign 1 mark, otherwise assign '0' mark.

xiv. **Indicator C14, Impact on Health of residents/commuters with SETU weightage as 3:** If due to increase in pollution level (air, water, land, noise level etc.), there is no reported incident on the health of residents/commuters, and there is no change in their routine life, assign 3 marks. If there is little change in their routine life like changing the routes of morning and evening walks, assign 2 marks. if few cases like up to 2 cases are reported with temporary impact like illness or infection limited to confinement at home, assign 1 marks, but if more than 2 cases with temporary illness or even 1 resident/commuter resulting in hospitalisation, assign '0' mark.

xv. **Indicator C15, Impact on safety of residents/ commuters with SETU weightage as 2:** If the safety aspects of nearby residents/commuters are taken into consideration like safe movement of heavy machinery, precautions on deep excavations and working at height along with the deployment of safety Engineer at site, then assign 2 marks. If there is no independent safety Engineer, but adequate precautions are taken, assign 1 mark, otherwise assign '0' mark

xvi. **Indicator C16, Preserving the social spaces like cremation ground, Sur Ghat with SETU weightage as 3:** If the alignment is so chosen so avoiding any social space in its vicinity or in alignment, assign 3 marks. If, the alignment is essentially to be taken over it and sufficient arrangements are done to make it still useful with alternative entry etc., assign 2 marks. If shifting is done safely at the cost of project, assign 1 marks. If any of such social space is abandoned, assign '0' mark.

xvii. **Indicator C17, Public attraction with the aesthetics of the Project with SETU weightage as 1:** If there are specific aesthetics considerations like festive lightening of work, assign 1 mark, otherwise assign '0' mark.

xviii. **Indicator C18, Utility of the Project to Public with SETU weightage as 2:** If there is substantial time and distance saving, assign 2 marks. If there is only time or only distance saving, assign 1 mark. Otherwise assign '0' mark.

xix. **Indicator C19, Preserving the heritage structure, with SETU weightage as 2:** If there is no heritage structure up to 100 m distance, assign 2 marks. If there are structures, but they are taken care of or granted special permission, assign1 mark, otherwise assign '0' mark.

6.10.3 Criteria 3: Economics (11 points)

xx. **Indicator C20, Decrease in Travel time, with SETU weightage as 2:** If travel time after implementation of project is likely to be reduced through the corridor by 50% or more, assign 2 marks. If travel time after implementation of project is likely to be reduced by 25% or more, assign 1 mark, otherwise assign '0' mark.

xxi. **Indicator C21, Decrease in Travel cost, with SETU weightage as 2:** If fuel consumption after implementation of project is likely to be reduced through the corridor by 50% or more, assign 2 marks. If fuel consumption after implementation of project is likely to be reduced by 25% or more, assign 1 mark, otherwise assign '0' mark.

xxii. **Indicator C22, Disturbance to the business/Employment of nearby residents, with SETU weightage as 1:** If there is no disturbance to the business/employment of nearby residents, assign 1 mark, otherwise assign '0' mark.

xxiii. **Indicator C23, Increase in cost of Construction due to lack of funds, with SETU weightage as 3:** If the increase in cost of project due to delay caused because of lack of funds is within 10%, then 3 marks, if within 10% to 20%, then 2 mark, if within 20% to 30%, then assign 1 mark and if more than 30%, then 0 marks.

xxiv. **Indicator C24, Increase in cost of Construction due to time overrun, with SETU weightage as 3:** If the increase in cost of project due to delay caused because of lack of time overrun is within 10%, then 3 marks, if within 10% to 20%, then 2 mark, if within 20% to 30%, then assign 1 mark and if more than 30%, then 0 marks.

6.10.4 Criteria 4: Technical (20 POINTS)

xxv. **Indicator C25, Display of Project Details, with SETU weightage as 1:** If all the project details including the cost of project, agency and expected date of completion etc. are displayed boldly and clearly and visible to public, assign 1 mark, otherwise '0' mark.

xxvi. **Indicator C26, Traffic Diversions with SETU weightage as 3:** If traffic diversions are required and provided with display of diverted routes, properly advertised in newspapers, radio etc., assign 3 marks. If routes are provide , but sufficiently efforts to make public aware are not there, assign 2 marks. If routes are there but much longer and inconvenient, assign1 mark, otherwise assign '0' mark for no diverted routes.

xxvii. **Indicator C27, Visibility and sight distance to moving traffic with SETU weightage as 2:** If there are sufficient arrangements for the visibility of project sites with al informatory and cautionary sign boards, asign2 marks. If boards are provided with inadequate sight distance, provide 1 mark, otherwise asign'0'; mark.

xxviii. **Indicator C28, Lighting of Construction site with SETU weightage as 3:** If the site is well lit at night with all warning illuminated signages, and lighting on the machineries to notice its movement from a distance, assign 3 marks. If the site is lit at night with warning signages, but working machinery at night is not separately illuminated at night, assign 2 marks. If the site is lit but warning signs are not well illuminated at night or dimly lit, assign 1 mark. otherwise assign '0' mark.

xxix. **Indicator C29, Barricading the site with SETU weightage as 3**: If the if completely barricaded with standard barricades and display of project details, assign 3 marks.

If the site is fully barricaded but with non-standard barricades, assign 2 marks. If the site is not fully barricaded but with upto 10% openings, assign 1 mark. Otherwise if openings are more than 10%, assign '0' mark.

xxx. **Indicator C30, Effectiveness of Technology used with SETU weightage as 3:** If a new technology that reduced the time of construction as well as cost of constriction assign 3 marks. If new technology as well as old conventional technology is used, assign 2 marks. If the new technology partially used but has not resulted in any time and cost reduction, assign 1 mark. If no new technology is used, assign '0 mark.

xxxi. **Indicator C31, Handling of C & D Waste with SETU weightage as 2:** If the recycling plant for the use of Construction and demolition waste is installed at site itself, assign 2 marks. If the Construction and demolition waste is recycled at other recycling plant, assign 1 marks, otherwise assign '0' mark.

xxxii. **Indicator C32, Quality Assurance on the Project with SETU weightage as 3:** If 3rd party quality assurance team is deployed with Quality engineer at site, assign 3 marks. If there is no Quality engineer separately, but 3rd party QA team is deployed, assign 2 marks. If no 3rd party QA team, but an independent Quality Engineer at site, assign 1 mark, otherwise assign '0;' mark.

6.10.5 Criteria 5: Governance (19 POINTS)

xxxiii. **Indicator C33, Ensuring the mobility of Traffic within the project area by traffic Marshals with SETU weightage as 1:** If Traffic marshals are deployed to guide the traffic within the project area, assign 1 mark, otherwise assign '0' mark.

xxxiv. **Indicator C34, Maintenance of existing drainage system with SETU weightage as 3:** If existing drainage system is fully maintained, assign 3 marks. If not maintained at all, assign 0 marks and depending upon the partial maintenance of existing drainage system, marks can be assigned 1 or 2. If water logging is repeatedly observed during monsoons, then assign 0 marks. If it happens and then controlled

by the construction agency, assign 2 marks, but for another offense, reduce it to 1. Further for offence more than twice, assign 0 marks.

xxxv. **Indicator C35, Maintenance of Barricades with SETU weightage as 4:** If barricades provided at site are well maintained and properly lit at night in an uniform manner and motivational quotes written on barricades, assign 4 marks. If the barricades are not standard, but site completely barricaded with all cautionary signages and properly lit at night, assign 3 marks. If the site is fully barricaded with cautionary signages but not lit properly, assign 2 marks. If the site is fully barricaded but without any cautionary signages and lighting arrangements, assign 1 mark. Otherwise, if there is no maintenance, lighting or cautionary signages, assign '0' mark.

xxxvi. **Indicator C36, Maintenance of existing utilities with SETU weightage as 3:** If there is no shifting of any utility, assign 3 marks. If the utilities re shifted without increasing the cost of project and delay in work, assign 2 marks. If the utilities are shifted without delay in work then assign1 mark. If the shifting causes delay as well as cost to the project, assign '0' mark.

xxxvii. **Indicator C37, Maintenance of existing greenery with SETU weightage as 3:** If the existing greenery is well maintained without uprooting any trees assign 3 marks. If the existing greenery is reasonably maintained with removal of not more than 10 trees per Km length of site, assign 2 marks. If the existing greenery is reasonably maintained with removal of not more than 50 trees per Km length of site, assign 1 mark, otherwise assign '0'mark.

xxxviii. **Indicator C38, Time over run due to delay in Govt. decisions with SETU weightage as 3:** If there is no time overrun die to any delay in Govt. decisions, assign 3 marks, If there is time overrun by less than 10% due to delay in Govt. decisions, assign 2 marks. If there is time overrun up to 20% due to delay in Govt. decisions, assign 1 marks, otherwise assign '0' mark.

xxxix. **Indicator C 39, Time over run due to mismanagement at site with SETU weightage as 2:** If there is no time overrun die to any mismanagement at site, assign 2 marks. If there is time overrun by less than 10% due to mismanagement at site, assign 1 mark, otherwise assign '0' mark.

6.10.6 Criteria 6: Inner engineering (5 points)

xl. **Indicator C40, Facilities of Yoga/meditation with SETU weightage as 1:** If there are facilities like Yoga/ meditation for the staff and workers at least once in an year, assign 1 mark, otherwise assign '0' mark.

xli. **Indicator C41, Performance of Rituals at site like Vishvakarma Puja, May Day with SETU weightage as 1:** If the labour specific days like Vishwakarma Puja or May day are celebrated at least once in a year, assign 1 mark, otherwise assign '0' mark.

xlii. **Indicator C42, Celebration during Festivals at site with SETU weightage as 1:** If the festivals like Diwali, Holi or other regional main festival is celebrated with workers together at site at least once a year, assign 1 mark, otherwise assign '0' mark.

xliii. **Indicator C43, Motivation to workers by reward policy or otherwise with SETU weightage as 2:** If the workers are motivated by some reward cash policy then assign 2 marks. If the policy is there to recognise the best workers without any incentive, assign I mark, otherwise assign '0' mark.

The total weightage of above 43 criteria is 100 and after assigning score against these 43 criteria, a total score is to be calculated. As per the score obtained a project is assigned SETU rating. These guidelines will be useful to assess a project against all 43 indicators and thus calculating SETU index and assigning a SETU rating to a project in the construction stage. A project that does not qualify any of these ratings

will be called an unsustainable project. Thus, there will develop an urge to get the best rating to a project for which all stakeholders will strive for best rating.

6.11 SUMMARY

On the basis of the sustainability studies carried out on the four transportation corridors during the construction stage, sustainability indicators have been identified and categorised under six categories. Subsequently, Fuzzy-Vikor technique was applied for carrying out the sustainability evaluation of the four construction sites. But this technique is used for making a comparison between more than one alternatives, which were taken as four construction sites. In case, only single construction site is to be evaluated from sustainability point of view, it is not possible with Fuzzy-Vikor technique. Hence a different technique was required for carrying out the sustainability evaluation of a standalone project site. In order to solve this issue SETU rating system has bene developed during this research. SETU stands for **S**ustainability **E**valuation of **T**ransportation corridors in an **U**rban Environment. The procedure of evaluating a construction site as per SETU rating system against of the sustainability indicator has been defined. With this evaluation procedure, a SETU Index for each of the project can be worked out. The detailed procedure has also been explained in a flow chart. Finally, on the basis of SETU index worked out for a project, it can be graded from Platinum at top to silver at bottom. A project that does not qualify any of these ratings will be called an unsustainable project. Thus, there will always be an urge to get the best rating to a project for which all stakeholders will strive their best. This will make them to perform in a better manner with a focus on each of the sustainability indicator in order to get the best or closer to the best rating. Thus, SETU rating system is a very

simple and a useful tool to carry out the sustainability evaluation of a transportation corridor under construction in an Urban Environment.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Based on the sustainability studies on the transportation corridors, sustainability indicators and sustainability evaluation technique has been worked out as per the objectives of the research carried out on the subject. Broadly, it is identified that sustainability of the transportation corridors during the construction stage in an urban environment is just not limited to three Pillars, but is actually much beyond that. Every activity or any Project has been looked into the right perspective to understand its relevance to all those it matters. Transportation sector is an area that affects the life of every individual in all areas say education sector, commercial activities, availing of medical amenities or say movement of the public at large for any purpose they need to commute. It is not only the operation stage, but the construction stage also that makes an impact on the residents living nearby as well as on the commuters passing through the corridor on the route or through the diverted route.

7.1 CONCLUSIONS

With the focus on the objectives of the research carried out, following conclusions have been drawn.

i. Based on the literature review, it is concluded that when a city is changing its fabric from the under-developed to developing and further to the developed stage, lot of social, economic, educational and general behaviour level gets modified. It was mainly the cultural, economic and social difference between Delhi and other developed cities worldwide. While any developed city worldwide has a well-developed public transportation system, other cities still depend upon the personalised mode of transport that results in slowing down of their development activities. Hence, the sustainability indicators identified for a developed city of US

or Europe cannot be accepted for a city like Delhi that has been facing a big challenge of existence due to human as well as vehicular population explosion. Sustainability of the transportation corridors during construction stage in an urban environment is just not restricted to three Pillars, but rather much beyond that. The three popular pillars of the sustainability are environmental, economic and social viability. But these pillars are applicable only in developed countries. Developing countries have a bigger challenge that cannot sustain with these three pillars. Based on the research carried out and studies conducted on four transportation corridors during the construction stage in metropolitan city Delhi, these three pillars were extended to six pillars with three more categories of sustainability indicators.

ii. During the studies carried out on the construction sites, It was observed that People have a tendency to avoid following the rules and regulations. Instead they tend to find loopholes in the system and break the laws frequently. Despite the fact that every constituted agreement is a complete document with incorporation of all mandatory provision for the safety and welfare of labour working at site and traffic moving off the site in the vicinity of the corridor. But, instead of abiding by the agreement conditions and following the traffic system regulated by traffic marshals, a kiosk is seen everywhere. Accordingly, an additional sustainability category “Governance” was added as the fourth pillar to the existing list of three pillars.

iii. It is observed that Delhi is a fast developing metropolitan city with deployment of latest state of the art technologies and utilisation of advancements that have been tried in developed nations. Generally, it is seen that for the deployment of technology, owner is dependent on the consultant and his wisdom. It was observed that there were three elevated corridors under construction across the Najafgarh during the same period. In all three cases, the technology used was different as the consultants were different in all three cases and the work was being executed by

different Govt. organisations. Thus, it was felt that there is a need of a strong technical base and accordingly 5th category titled as “Technical” has been introduced for sustainable transportation through development as an important parameter.

iv. It was observed that tolerance during the adverse circumstances is an utmost need in order to meet the ultimate objective of keeping the cool temperament. It is fundamental that all stakeholders’ like development organisations, proprietors, labour and inhabitants need to accomplish a feeling of co- existence to keep up a cool disposition and to reduce the mis-happenings in such a circumstance. While working in hot sunny summer or a cold winter night, there is a necessity for mental strength for working in adverse situation. All such strengths can be developed only with the creation of an healthy environment and developing a festive environment at site. Accordingly, last extra parameter, i.e. spirituality or say “Inner Engineering” is added to the extended list.

Sustainability in an Urban Environment and developing country like India is standing over 6 pillars. These 6 pillars are Environmental-Economic-Social-Technical-Governance-Inner Engineering.

v. Fuzzy-Vikor technique is a good tool for carrying out the sustainability evaluation and can be applied suitable for the construction sites. The alternatives can be selected as various construction sites and criteria are taken as the sustainability indicators. Thus, this tool is suitable when more than one site are studied together and a fair comparison can be made between them. However, it cannot be used for a standalone construction project.

vi. SETU Rating system is a simpler evaluation criteria for sustainability evaluation of a transportation project in an Urban Environment. It can be applied to a single

standalone project also unlike Fuzzy-Vikor methodology. This system is developed on line of GRIHA rating system already available for the assessment of buildings. There was no such system available for the transportation infrastructure. Accordingly, SETU rating system is developed for the sustainability evaluation of transportation corridors in Urban environment.

vii. SETU rating system assign a rating to a project on the basis of SETU index. Accordingly rating from Platinum at top for SETU index more than 90 to silver at bottom for SETU index between 45 and 60 has been defined after the sustainability studies carried out on the construction sites. A project that does not qualify any of these ratings will be called an unsustainable project. Thus, there will always be an urge to get the best rating to a project for which all stakeholders will strive for best rating. This will make them to perform in best manner against all criteria in order to get the best or close to best rating.

7.2 RECOMMENDATIONS

Based on the conclusions of the research carried out, following recommendations are made for implementation in future projects in Urban areas during the construction stage for making the project sustainable with best possible rating.

i. All transportation infrastructure projects under construction in an Urban Environment should be essentially evaluated from sustainability pointy of view. Every construction activity may be seen form sustainability pointy of view and all the parameters of substantiality should be taken into consideration during the construction stage.

ii. SETU rating system is a simpler methodology that may be used suitably for carrying out the Sustainability Evaluation of Transportation corridors in an Urban Environment. Based on the SETU Index, a project can be assigned rating from Platinum, Diamond, Gold or Silver.

iii. An independent team comprising of expert members having adequate knowledge and experience of assessment of infrastructure projects based on the sustainability Indicators should be deployed for carrying out the sustainability evaluation based on the 43 criteria under 6 categories.

iv. There should compulsory be a provision in all construction agreements for sustainability evaluation with an incentive clause for meeting the best rating. Incentive will vary depending on the SETU rating that a project achieve. Simultaneously there has to be a penalty clause if the project does not qualify a minimum bench mark rating set for the project.

7.3 SCOPE FOR FUTURE WORK

In this research work, sustainability evaluation of the four alternative sites during the construction stage has been carried out. In fact, any transportation infrastructure undergoes many stages in its life from conception to commissioning and thereafter till its service life after which it is replaced with new structure as per the changed needs at the time of replacement. Precisely, on the basis of the life cycle, the different stages can be distinguished as planning and designing stage, construction stage, routine maintenance, major repairs, strengthening and rehabilitating, restricting its use before finally its replacement with new structure with fresh alignment in new corridor as per the needs in future at the time of its replacement.

These structures are built in rural areas or urban areas. These may be on a national Highway or a state highway. These may be on road, over a River or a sea. These may be rail under bridge (RUB) or rail over bridge (ROB). Hence on the basis of the location and functional requirement, these can be classified as structures in rural area, urban area, Metropolitan city, rail line, National highways, State highways, minor rivers, major rivers or sea.

The research carried out in the instant case is on the transportation structure in an Urban area precisely during the construction stage. Accordingly, the SETU rating system and SETU index generated in this work are more suitable and applicable for urban areas during the construction stage.

This research can be further extended to the transportation infrastructure projects in other stages during the life time of structure from planning stage until its replacement and other areas as per locational and functionality requirements. As far as Urban areas are concerned, the most dominating stage that impacts the environment and the public is the construction stage that has been covered up in detail in this research.

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