Green transportation systems for any city are the obvious demand of modern times in terms of economic, social and environmental aspects bearing the recent global phenomenon of climate change. Thus it has become a challenge for the decision makers to evaluate and select the suitable transportation options. In this research, two MCDA approaches namely AHP and Fuzzy TOPSIS have been discussed for selecting the best sustainable transport options (both High and Low cost) for the Megacity. To come across a reliable solution, a list of criteria has been selected for the two approaches i.e. Five broad criteria for AHP and Twenty-one specific criteria for Fuzzy TOPSIS approach. Then the potential alternatives (Three High Cost and Three Low Cost) have been rated by the Experts with respect to each of the criteria in separate way for the two approaches. Finally, the AHP and fuzzy TOPSIS method have been applied to produce aggregate scores for the evaluation of sustainability criteria and choosing the appropriate alternative for both categories.

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To my parents
whose blessings & inspiration
accompany me to each foot-step.

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ABSTRACT

Green transportation systems for any city are the obvious demand of modern times in terms of economic, social and environmental aspects bearing the recent global phenomenon of climate change.

There has been an increasing growth of transportation demands for Dhaka Megacity over the years to cope up with its growing number of population and the resulting environmental costs are noticeably associated with this which is eventually demeaning the living of its residents.

Thus it has become a challenge for the decision makers to evaluate and select the suitable transportation options. In this research, two MCDA approaches namely AHP and Fuzzy TOPSIS have been discussed for selecting the best sustainable transport options (both High and Low cost) for the Megacity. To come across a reliable solution, a list of criteria has been selected for the two approaches i.e. Five broad criteria for AHP and Twenty-one specific criteria for Fuzzy TOPSIS approach. Then the potential alternatives (Three High Cost and Three Low Cost) have been rated by the Experts with respect to each of the criteria in separate way for the two approaches. Finally, the AHP and fuzzy TOPSIS method have been applied to produce aggregate scores for the evaluation of sustainability criteria and choosing the appropriate alternative for both categories.

The key strength of the AHP approach is its flexibility, insightful appeal to the decision makers and its ability to check inconsistencies; while the key strength of Fuzzy TOPSIS approach is its practical applicability having a generation of good quality solution even under uncertainty.

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
BRT	Bus Rapid Transit
BTS	Bangkok Mass Transit System
CBA	Cost-Benefit Analysis
CC	Closeness Coefficient
CDM	Clean Development Mechanism
CEA	Cost-Effectiveness Analysis
CI	Consistency Index
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CR	Consistency Ratio
DIT	Dhaka Improvement Trust
DITS	Dhaka Integrated Transport Study
DMA	Dhaka Metropolitan Area
DMDP	Dhaka Metropolitan Development Plan
DMRC	Delhi Metro Rail Corporation
DOE	Department of Environment
DUTP	Dhaka Urban Transport Project
EIA	Environmental Impact Assessment
ELECTRE	Elimination and Choice Expressing Reality
ERP	Emission Reduction Potential
FES	Fuel Economy Standards
FNIS	Fuzzy Negative Ideal Solution
FPIS	Fuzzy Positive Ideal Solution
GHG	Greenhouse Gas
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
HC	Hydrocarbons
ICLEI	International Council for Local Environmental Initiatives
ICTP	International Consultants and Technocrats Pvt.
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Analysis
MAUT	Multi-Attribute Utility Function Theory
MAVT	Multi-Attribute Value Function Theory
MCDA	Multi Criteria Decision Analysis
MMULT	Matrix Multiplication
MRT	Mass Rapid Transit
NAAQS	National Ambient Air Quality Standards

NMT	Non Motorized Transport
NO	Nitrogen Oxide
OECD	Organization for Economic Cooperation and Development
PM	Particulate Matter
RI	Random Consistency Index
SO	Sulfur Oxide
SPM	Suspended Particulate Matter
STP	Strategic Transport Plan
SUVs	Sport Utility Vehicles
TA	Technological Availability
TOPSIS	Technique Ordered Preference by Similarity to the Ideal Situation
UNEP	United Nations Environment Programme
USD	United States Dollar
WHO	World Health Organization

CHAPTER 1
INTRODUCTION

1.1 Background of the Thesis

Cities are treated as the powerhouses of a country. Dhaka, a city with 400 years of tradition and culture is now facing severe critical phenomena with respect to various urban concerns. The capital city of Bangladesh stands as the sixth largest city in the world with a population over 14 million within 360 sq.km; which has emerged it as the most densely populated city around the world. Being the centre of administrative, commercial and cultural activities; the city serves around 40 percent of the total urban population. The megacity has the current urbanization rate of about 30 percent and expected to be 50 percent by the year 2025 which is found to be one of the highest in the world and Dhaka will be home to more than 20 million populations being larger than Shanghai, Beijing or Mexico City as some predictions exhibit (Shafi, 2010). The blow of such massive speedy growth would result more significance on the transport sector in providing mobility for its entire population as they look for taking benefit of employment, health and social opportunities.

Generally motor vehicles add extensively to emission inventories in certain regions especially on urban areas. Carbon Monoxide (CO), Hydrocarbons (HC), Photochemical Oxidants (e.g., ozone (O_3)), Nitrogen Oxides (NO_x), Particulate Matter (PM) and Lead (Pb) are treated as the pollutant species most often of concerned with respect to transportation facilities. The concentration of Nitrogen Oxides (NO_X), Sulphur Oxides (SO_X), Carbon Monoxide (CO) and Suspended Particulate Matter (SPM) are found about 500, 1200, 7500 and 2500 $\mu g/m^3$ respectively in the roads of Dhaka city, which are far beyond the tolerable level set by World Health Organization

(WHO). As a consequence, the city environment has been worsening rapidly during the last few years. Nevertheless transportation sector is one of the prime sources of greenhouse gas emission bearing the potential to contribute to global warming.

Air pollution in the city has been deemed as serious and damaging to public health. In the winter of 1996-97, the lead (Pb) concentration in the atmosphere of Dhaka city was reported higher than any other place of the world (Ahmed, 1997). According to a recent report released Dhaka ranked as the 10th most polluted city around the globe (Economist Intelligence Unit, UK, 2010). The same study also conceded that nearly 6.1 lakh children showing symptom of asthma in Dhaka. Nearly 1.5 lakh old and junk vehicles of the city are reported to be blamed for emitting thick black smoke (The Daily Star, 2010). Concern over air pollution rate eventually led to the promulgation of National Ambient Air Quality Standards (NAAQS) in Bangladesh in 1997.

The needs for alternative transport options thus draw a rigorous consideration assessing the future population trends and associated land use planning with the advancement of economic developments and upcoming environmental challenges. Also transportation system developments require sufficient financial assurance and substantial allocation of time. Adopting such crucial grounds, decision regarding transport sectors needs comprehensive study to justify the application of any planned options.

Transport professionals need to apprehend a greater visibility of current and projected scenarios comparing the benefit of potential system improvement options in order to perform effective dealing with traffic congestion and associated environmental problems.

Fig. 1.1 Map of Bangladesh

This study is devoted to come across understanding an appropriate approach to evaluate the prospective green transport options considering a wide range of criteria associated with for the betterment of their acceptance from social, environmental and economic aspects as well.

1.2 Statement of the Problems

In Dhaka city, the transport structure poses a mix of motorized and non-motorized transport having an entirely irregular pattern. However, in recent years the growing number of private automobiles has been creating a severe pressure on the existing limited infrastructure. Furthermore, these large fleets of motorized vehicles are blamed to deteriorate the air quality level of the city. “Air pollution kills 15.000 Bangladeshis each year” as recently reported by the

World Bank. With the existing overall scenario, the following problems are considered as a priority basis;

a. The number of private vehicles grasped an alarming increase in recent times contributing to jam-packed traffic on the roads of the city.
b. The air quality of the city has been greatly affected by the growing number of vehicle emission rate.
c. Absence of sustainable mass transit systems further allows the existing traffic to continue their operation in a disordered manner creating a major public hassle.
d. Lack of coordination exists among various transport-service providing agencies including both government and private sector initiatives.

1.3 Objectives of the Research

Development of a sustainable transportation system requires rigorous planning, long before its application. In this regard, resources involved in transportation sector needs to be thoroughly analyzed. Usually such analyses are executed through transportation models as well as applying different decision making approaches (e.g., CBA, CEA, EIA, System dynamics models etc.) to evaluate the sustainability of the system. The key purpose of this research was to evaluate any proposed transportation system applying Multi-Criteria Decision Analysis (MCDA) approach which comprises the cost and benefit criteria as well as environmental aspects that are associated with the whole system. The detailed objectives of the study under the broad concept of sustainability can be summarized as:

1. Suggesting alternative green transportation options judging the associated criteria for reducing vehicle energy consumption and pollution emissions (Environmental aspect).

2. Developing an effective transportation structure for the city dwellers ensuring transportation affordability, equity and comfort (Social aspect).
3. Promoting an efficient transportation system for reducing the traffic congestion level towards advancing the economy of the state (Economic aspect).

1.4 Scope of the Study

This study is designed to develop an overall strategy for decision support in coming years to adopt a better systematic way of transportation judging a wide range of criteria especially focusing the challenged environmental concerns. In view of limitations, like computational facilities, time allocation and information resources; the study is bestowed to only the central urban portion of Dhaka (area under jurisdiction of Dhaka City Corporation) and evaluation of selected alternative options including elimination of rickshaw/auto-rickshaw, improvement of public bus services, promotion of mass transit options, improvement of walking way or infrastructure of cycle bay etc. In addition, it is well recognized that any particular changes in transportation system will always have some long-term effects with resultant modification of land use pattern. Such long-term effects with changes in land use pattern are also out of the scope of this study. Figure 1.1 below shows a map of the study area.

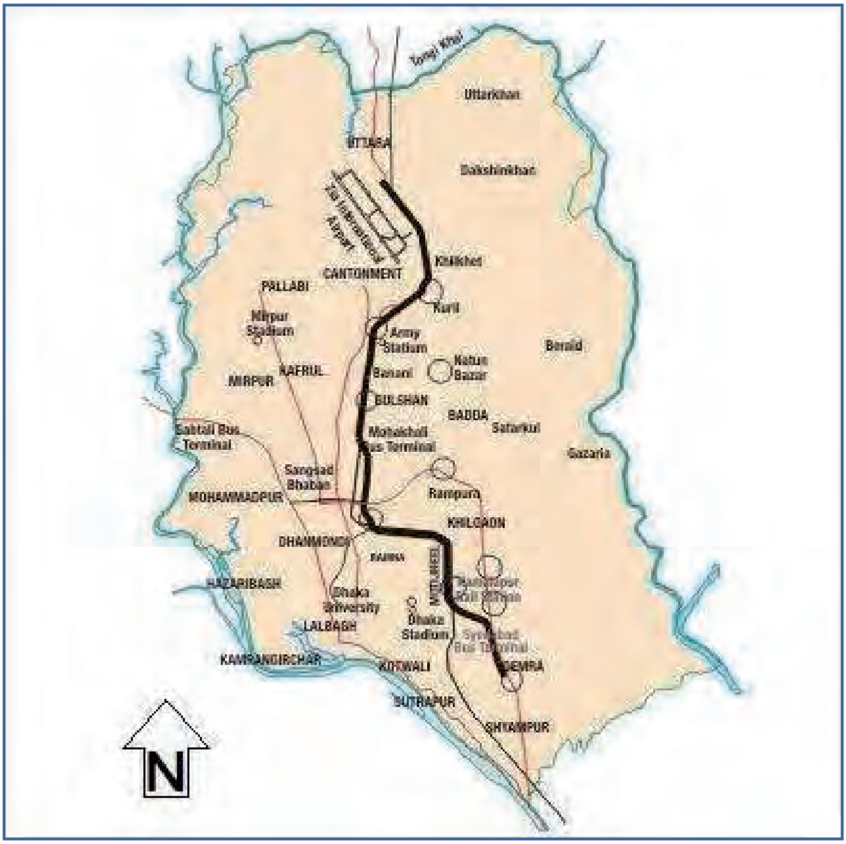


Fig.1.2: Map of Dhaka City

CHAPTER 2
LITERATURE REVIEW

This chapter illustrates a review of literature pursued from a range of transportation researches on Dhaka city's traffic congestion and consequent air pollution, planning and policy related studies etc. In addition, summary from a remarkable number of studies on sustainable urban transport systems, their evaluation processes as well as the concept of green transport are also incorporated as a preference. In this regard, an extensive study on relevant researches and studies conducted both at home and abroad was performed to gather far-reaching information.

2.1 Traffic Induced Air Pollution in Dhaka City

Air pollution is documented as a major health risk. Emissions due to transport activity are increasingly being recognized as the leading cause of air pollution and health problems in Dhaka city (Bhuiyan, 2001). The imperative demands for motorized form of personal mobility are breeding pressures on the existing road network and resulting in congestion, which warning the sustainability of the socio-economic advancement. A few meaningful research works were conducted in this regard.

According to Jaigirdar (1998), the maximum instantaneous concentrations of SO_2, NO_2 and CO were found 0.7 ppm, 0.3 ppm, and 93 ppm respectively. Immediate concentration of SO_2 and NO_2 were found higher at two intersections namely Gulistan and Mohakhali where the mobility was dominated by diesel run vehicles. The concentration of CO found higher where car, microbus, two stroke vehicles like baby taxi and tempo movements comprised a greater portion of the total vehicle fleets. However, most of the road intersections found highly exposed to SO_2 and NO_2 concentration. Being seemed to be moderate as compared with SO_2 and NO_2, the concentration of CO in most of the intersections found harmful for heart patients (Stewart, 1975). Rickshaws are claimed to be slowed down the traffic creating severe traffic jam and eventually led to high concentration of pollutants over a longer period posing a serious threat to the city dwellers. Estimated total emissions of SO_2, NO_2 and CO in Dhaka city were stated as 5.43, 21.57 and 215.34 tons per day respectively. Bus/minibuses were found emitting the highest amount of SO_2 (23% of daily emission) and NO_2 (32% of daily emission). In the case of CO, private cars took the lead and found to be emitted 40% of total daily emission. Baby taxi was also found contributing a significant portion (26%) of the total daily emission.

Ahmed and Begum (2010) argued that the concentration of Suspended Particulate Matter (SPM) significantly varies with weather conditions and is found 150 $\mu g/m^3$. The same study suggested that decreasing tendency of particulate matter emission is related to large-scale introduction of CNG vehicles along with promotion of efficient mass transit public transportation system thereby discouraging having the ownership of private automobiles. In 1995, Bangladesh emitted 20 millions of tons CO (International Energy Agency, 1995).

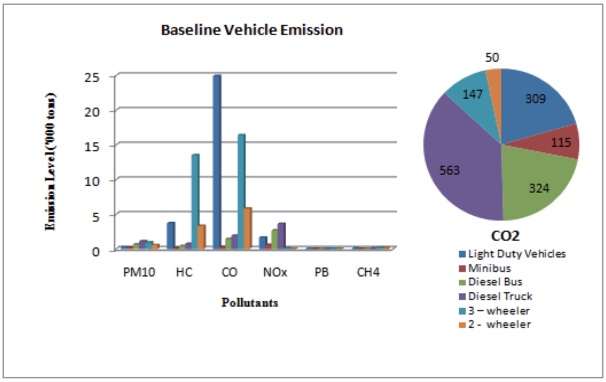
Moniruzzaman (2011) conducted an in-depth study on Dhaka City's growing number of private vehicles and their overall effect on air pollution level. It was found that from 2004 to 2010 all categories of vehicles increased by around 20 percent than the immediate preceding years. Table 2.2 visualizes the growth of vehicles in the roads of Dhaka city in recent times estimated as registered vehicles. However, based on a study only about 25-50% of the actual number of vehicle is registered (Intercontinental Consultants and Technocrats Pvt. [ICTP] 2001).

Table 2.1: Growing number of vehicles in Dhaka city

Type of Vehicles	Up to 2003	2004	2005	2006	2007	2008	2009	2010	**Grand Total**
Private car	87866	4734	5633	7403	10244	13749	17654	19557	166840
Jeep/ Microbus	32391	2114	3303	4548	4372	5077	6803	6687	65295
Taxi	9369	523	514	266	0	0	10	0	10682
Bus	2614	779	728	949	1082	1144	914	1101	9311
Minibus	7460	368	118	75	77	107	112	142	8459
Truck	20342	1437	1104	1480	830	1642	3180	4543	34558
Auto-rickshaw/ tempo	10687	2344	139	230	121	155	1144	1362	16182
Motor cycle	119299	7872	12879	16284	17303	23713	22093	30264	249707
Others	13187	1300	2361	2728	2913	2550	4868	12225	42132
Total	303215	21471	26779	33963	36942	48137	56778	75881	603166

Source: BRTA, 2010.

Initial estimates show that motor vehicles annually emit 3,700 tons of particulate matters (PM_{10}), 8,550 tons of nitrogen oxides, 50,700 tons of carbon dioxide, etc. CO_2 and CO recorded as much higher than other pollutants in terms of 1000 tons units. Fig.2.1 and Table 2.2 below represent the baseline vehicle emission inventory situation and PM concentration level in Dhaka respectively.



Source: Working Paper No.23, GDMAITS (1996)

Fig. 2.1: Baseline Vehicle Emission inventory in Dhaka

The same study claimed that with the current progression rate by 2016 the mean concentration level of PM_{10} and $PM_{2.5}$ will reach at 350 and 240 µg/m^3 respectively; correspondingly which will be 18 and 24 times the acceptable limit set by World Health Organization (WHO).

Table 2.2: Particulate Matter concentration in Dhaka city (µg/m^3)

Pollutant	Year 2003	Year 2004	Year 2008
PM_{10}	330	238	291
$PM_{2.5}$	266	147	191.83

Source: AQMP, 2008.

Meanwhile it was evident by the research that the present CNG conversion rate is not in satisfactory level to cope the upcoming environmental pressure which will be created by a large number of vehicle fleets in near future due to the consistency of rapid urban growth into the city and its surroundings. Therefore, old and worn-out vehicles (which are nearly 25% of total number of vehicles) have to be replaced and an efficient mass transit system has become a requisite to replace the private automobile use, thereby reducing the total emission level.

2.2 Alternative Suitable Transport Options

Taking into consideration the overall pollution scenario and overwhelming traffic congestions, the city authorities are now thinking to promote alternative transport options which will be sustained in the long run providing an extensive and comfort service to the city commuters. A few alternative options and strategies which are in practice even in many of the developing cities are presented in this regard.

2.2.1 Definition of Sustainable Transport

Sustainable transport holds the issues concerned with the broader concept of sustainability and is used in describing transport modes, transport planning etc. following the term sustainable development (Victoria Transport Policy Institute, 2009). According to the European Union Council of Ministers of Transport, a sustainable transportation system is one that provides the basic access of individuals and society, which is fairly operated, affordable to all, reduces emissions and also supports the economy of a region.

2.2.2 Concept of Green Transport

Green Transport: The term signifies any means of transport that have low impact on the environment such as transit oriented development, Car-sharing, walking and cycling etc.; A transport system which is fuel-efficient, space-saving and promote healthy lifestyles (Wikipedia, 2011).

Green Vehicle: A green vehicle or environment friendly vehicle is one that produces less harmful impacts on the environment comparing with conventional vehicles that operate by gasoline or diesel (Green Vehicle Guide, 2010). These vehicles are operated by alternative fuels applying advanced technologies such as natural gas vehicles, clean diesel vehicles, flexible-fuel vehicles including vehicles which use blends of biodiesel and ethanol fuel or gasohol (U.S. Department of Energy, 2010).

International Benchmark: Sustainable transport strategies generate utmost impact at city levels. Outside the Western Europe, cities such as Curitiba, Bogota, and Vancouver have considered the sustainability issue as a prime consideration in land use and transport planning.

2.3 Sustainable Transportation System related study

Hoque et. al. (2002) proposed that in order to manage the traffic situation in Dhaka city, bicycle should be promoted as an important travel mode considering its low initial and operating costs; and mass transit systems should be improved examining various MRT options.

Tanvir (2010) argued that in the near future the roads of Dhaka city will not be able to cope with the growing number of vehicles and expanded passengers without a massively expanded road network and a collaborative public Mass Rapid Transport (MRT) system or otherwise the whole transportation system will collapse. The same study also claimed that considering the economic situation of the country, the programme could be run as an entirely public sector venture or alternatively as joint public and private sector initiative. In case of public sector venture the financing could constitute a donor agency funding or contributions from the central government and the city government also. Funds could also be raised from private sector through issuance of Bonds and shares etc.

Earlier in 2005, an initiative was taken to develop a coherent long-term Strategic Transport Plan (2004-2024) by GOB with the assistance of World Bank, and with Louis Berger Inc. as Principal Consultants and Bangladesh Consultant Ltd. as local partner; in a phased program for the 20 year period (STP, 2005). This Strategic Transport Plan (STP) proposed a MRT system with components:

a) Three Bus Rapid Transit (BRT) Routes of total length of about 200km. at a total cost of U. S. $ 1.0 billion
b) Three Metro Lines with an estimated cost of about U. S. $ 2.1 billion, or Taka 14,500 crore

Therefore introducing the Mass Rapid Transit options have become a need for the time being to manage the overall traffic situation of such a densed city like Dhaka.

2.3.1 Mass Rapid Transit Activities in Developing Cities

The distinction between MRT concepts is fluid, and many different approaches are commonly used to distinguish the different modes and features of various MRT systems. Currently a good number of developing cities are experiencing the fast and efficient services of Mass Rapid Transit options. Some typical MRT systems in developing cities are outlined below in Table 2.3.

Table 2.3: Performance and Cost of various MRT systems (in developing cities)

Example	Caracas (line 4)	Bangkok (BTS)	Kuala Lumpur (PUTRA)	Bogota TransMilenio	Calcutta Metro
Category	Rail metro	Rail elevated	Light Rail	Busway	Rail Metro

Technology	Electric, steel rail	Electric, steel rail	Electric, Driverless	Articulate Diesel buses	Electric, steel rail
Length (Km)	12.3	23.1	29	41	16.45
Vertical Segregation	100% tunnel	100% elevated	100% elevated	At grade, Mainly segregated	Mainly underground
Stop spacing (Km)	1.5	1.0	1.3	0.7	0.97
Capital cost (millions, $)	1110	1700	1450	213	365
Capital cost/route –km (millions, $)	90.25	73.59	50	5.2	22.2
Maximum passen-ger capacity	32,400	50,000	30,000	35,000	18,000
Avg. operating speed (Km/h)	50	45	50	20	30
Revenue/Operating cost ratio	NA	100	>100	100	NA
Ownership	Public	Private (BOT)	Private (BOT)	Public infrastructure, private vehicles	Public
Year completed	2004	1999	1998	2000	1984

Note: NA indicates that the information is not available.
Source: GTZ, 2005; World Bank, 2001; DMRC, 2008; MRK, 2008.

MRT alternatives are the mass transit systems that put forward good service quality with swift operational speed, making them a competitive mode of travel in the city. Each has its own strengths and weaknesses. Such mass rapid transit systems usually involve huge investments that will serve a city for a long time. Therefore, policy makers have to cautiously decide a proper alternative, or a combination of them, that best fit the conditions of the jurisdiction. BRT is the least-expensive form of MRT especially for short-term investments and along small to medium demand corridors it can serve as an efficient urban transport system (GAO, 2001).

2.3.2 Some Successful Stories

Improvement of transport sustainability requires measuring the efficiency of the vehicle, the carbon content of the fuel and the amount of travel activity. Nevertheless, differing situations among nations, regions or cities have resulted to adopt a range of best practices; some of which considered more on one specific factor and less on other. Some approaches are best deployed might be at the national level, while others are most effective and indeed most possible to apply at local level. This section encompasses a summary of some pioneering examples found effective in different countries as reported (Centre for Clean Air Policy Report, 2009).

Vehicle Efficiency: China's FES for Passenger Vehicles

Among non-OECD countries, only China has implemented her own Fuel Economy Standards (FES) considering a range of factors such as improving energy security, modernizing the vehicle fleet technology, improving the competitiveness of domestic manufacturers etc. and it was applied to vehicles (cars, vans, SUVs, and mini-buses) manufactured within the country only. However at the end, the approach served to significantly improve the GHG emissions level as well as encouraging China's own manufactured vehicles. The result showed a significant improvement of 11-12% in fuel efficiency in the new passenger vehicle fleet in China between 2002 and 2006.

Fuels: Brazil's Bioethanol Program

Due to global oil crisis in 1973, Brazil adopted her own policy to reduce the dependence on imported oil introducing an innovative strategy such as National Alcohol Program (NPA) in 1975. Today Brazil is known globally for the production and use of ethanol in transport sector. Such improvements in ethanol yields have led this fuel to be economically competitive with gasoline in Brazil without a need for subsidies. The result showed that Brazil has reduced the emissions from its vehicles by more than 600 Mt CO2 since the inception of PNA.

Travel Activity: Bogota's development of Mass Transit and Non-motorized Travel Modes

The City of Bogota introduced the model combining some ambitious goals such as education and public awareness of mass transit and non-motorized travel options, construction of Bus Rapid Transit and bike infrastructure and restrictions on automobile use. Education involved *ciclovias*, which led to creation of network of 329 km of bike paths that allow nearly 182,000 people to circulate every day. *TransMilenio*, the iconic Bus Rapid Transit system, was opened in 2000. The system received CDM credits, mainly for the replacement of about 9000 dirty busses with 1200 new busses run in a more efficient manner. *Pica y Placa*, the vehicle restriction program restricts both private and public use vehicles based on the last digit of the license plate numbers. The strategy indeed worked effectively to transform a developing country's transportation system toward sustainability.

2.3.3 Other Sustainable Transport Best Practices

This section provides a wide range of best practices implemented worldwide. Based on the type of policy instruments, the strategies are presented below into five categories (Centre for Clean Air Policy Report, 2009).

i. Infrastructure and Land use
   - Transit oriented compact, walkable, mixed use neighborhoods (Curitiba, Brazil)
   - High quality rail or bus based mass transit (Manila, Philippines)

- Extensive bicycle and pedestrian infrastructure and programs (Changwon, Korea - bike sharing)

ii. Regulation

- Restriction of all vehicle access to certain urban areas (Buenos Aires, Argentina)

iii. Public Awareness

- Driver education for “Eco-driving” (Jakarta bus drivers)

iv. Technology

- Electric vehicles (Lujiang, China - substitute electric bikes and mini busses for motorcycles)
- Improved non-motorized vehicles (Delhi, India- rickshaws)
- Information technology applications (Klang Valley, Malaysia - traffic information system)

v. Pricing

- Road pricing (tolls, congestion pricing, time of day pricing, etc) (Singapore)
- Fuel taxes (Costa Rica)

2.4 Planning and Policy related study

Although Dhaka is a very old city, introduction of detailed study and research based planning is somewhat new. “Dhaka City Master Plan” was prepared in 1959 by the then Dhaka Improvement Trust (DIT), covering roughly 830 square kilometer area with a population slightly exceeding 0.5 million. It presented a detailed plan for future structure of roads in the metropolis (Khan, 2001).

Kiwan (1988) performed a study on pedestrianization in Dhaka city. He worked on pedestrian traffic safety, mobility, accessibility and environment.

The study mostly focused on pedestrian-vehicle conflicts and offered a package of recommended measures and guidelines termed as Environmental Traffic Safety Planning and Management.

With new viewpoint, the Dhaka Metropolitan Development Plan (DMDP, 1995-2015) was prepared considering sustainable growth of Dhaka. The plan comprised of three levels namely “The Structural Plan (long term strategy included transport network for the 20 years)”, “The Urban Area Plan (provided an interim mid-term strategy for 10 years)” and “The Detailed Area Plan (provided detailed planning proposals and transport network for specific sub-areas of Dhaka)” (Hafiz, 2001). Another initiative Dhaka Urban Transport Project (DUTP) was launched with the assistance of World Bank. The two phases of the project: DUTP I was ended in 1998 and DUTP II started in effect from 1998 with reference to performance of DUTP I and ended in 2005. The technical assistance project aimed at detailed planning along with addressing a broad context of environmental issues.

Jaigirdar (1998) conducted a study to assess the ambient air quality of Dhaka City. The study suggested that improved bus service might be the best option for a mass transit system in Dhaka.

2.4.1 Strategic Transport Plan (STP, 2005) for Dhaka

In order to give a new shape to the city’s transport infrastructure, a long term strategic plan (STP, 2005) for Dhaka city was carried out by the Government of Bangladesh with the assistance of World Bank. The following ***Key Policy Issues*** were identified by the STP conducting an in-depth study to remove the detriments that pose the development;

- Safety

- ➢ Pedestrians
- ➢ Public Transport
- ➢ Non-Motorized Transport
- ➢ Travel Demand Management
- ➢ Urban Freight Transport
- ➢ Mass Transit
- ➢ Systems Integration
- ➢ Traffic Management
- ➢ Parking
- ➢ Environment
- ➢ Land Use/Transport Planning
- ➢ Social and Political Aspects
- ➢ Institutional & Financial
- ➢ Privatization and Subsidies

Policy Making Priorities: The STP was charged with the task to recognize the first priority projects and complement them with policies within the first five years. Therefore, considering the advantage of international experience and expertise and local experience achieved by working in Bangladesh for a long time, the STP Consultants have suggested the following aspects of policy over the next five years:

- ✓ Institutional Changes creating a Unitary Authority
- ✓ Establishment of a Mass Transit Authority as a Public Private Partnership to proceed the MRT/BRT systems
- ✓ Implementation of a city-wide traffic management program to enhance capacity and safety
- ✓ The complete overhaul of the vehicle and driver licensing system Re-organization of the existing city bus services to balance the

New BRT/ MRT system.

- ✓ Stronger control on noise and air pollution incorporating environmental testing into the annual roadworthiness certificates.

2.4.2 CNG conversion as a priority option

CNG conversion of all motorized vehicles could offer better climate change benefits, air quality (health) benefits, energy security benefits and economic benefits as well (Zia Wadud, 2008). The same study confirmed that CO_2 emissions would be reduced up to 25%, NO_x emissions would be lessen up to 35 – 60% along with lower PM emissions if better conversion technology could be introduced. As motor vehicles have been treated as the major contributor of pollution emission, a significant push from the policy makers to convert motor vehicles to CNG could help make the situation even better.

2.4.3 Walking and Cycling: Sharing the Road

Walking/Cycling is likely to be the safer, efficient and healthy way to travel for individuals. Cities with higher percentages of NMT trips have lower per capita energy use, which turns into less reliance on fossil fuels which is a huge burden on the developing countries who import oil, less pressure on other scarce resources such as land, and less emissions of air pollutants and greenhouse gases (GHG). In Dhaka city, there are only 400 km of footpaths or walkway for the city dwellers of which 40 percent are occupied by street vendors, garbage bins, or construction materials at any given time (The Daily Star, 2010). However, in Dhaka city, about 60 percent of journeys to work are done on foot (Islam, 2005). Therefore it has become an urgent need to free the existing walkway and additionally, more investment is required to construct more walkways for adding cycling along with this infrastructure.

In Copenhagen (Denmark), 37% of residents' bike to work and the city authority has planned to invest more than USD 200 million in bike facilities from 2006 to 2024 with the goal of 50% of residents' biking to work or school by 2015. In Amsterdam (Netherlands), cycling shares 55% of journeys to jobs less than 7.5 Km and the government has pledged USD 160 million from 2006 to 2010 to bicycle paths, parking and safety (UNEP, 2010).

2.5 Decision Making Approaches for Sustainable Transport Alternatives

Towards identifying, comparing and selecting sustainable transportation options, several number of effective decision making strategies are practiced. The following approaches are commonly followed;

1. ***Life Cycle Analysis (LCA):*** Currently the use of LCA is increasing in evaluating environmental impacts of transportation system which was originally developed for industrial processes. This method is capable to judge a very few criteria (e.g. pollution emissions and resources used throughout the life of any product) but does not consider the social aspects (Goedkoop, 2000; Guine, 2002).

2. ***Cost-Benefit Analysis (CBA)*** and ***Cost-Effectiveness Analysis (CEA):*** CBA approach, normally used to judge the positive or negative impact of any project quantifying in monetary term. When the advantages of a project is impossible to quantify in monetary terms, in that case CEA approach is applied. By CBA and CEA methods it is quite complex to approximate external and social costs (e.g. noise, air pollution, congestions etc.). Application of CBA approach for better transportation can be seen in Jonsson (2008).

3. ***Environmental Impact Assessment (EIA):*** Normally EIA is applied to judge the environmental impacts of a pollution source i.e. industry or highway and its surrounds (Bond, Lee, Kirkpatrick & Curran 2001; Jones & Wood, 2002). The advantage of this approach is that it can take into account the environmental, economic and social aspects of sustainability.

4. ***Optimization models:*** This is a mathematical approach comprising an objective function and listed constraints forms inequalities or equations. Linear programming is commonly used in this purpose. The model approaches to find a favorable solution under the restraints of environmental, economic and social objectives. An application of dynamic optimization model toward sustainable urban transport development can be found in Zuidgeest (2005).

5. ***System Dynamics models:*** Typically this approach models complex system. In this method the elements are displayed over the time through stocks, flows and a feedback mechanism. It is applied to design and evaluate a relationship between cause and effect within an integrated transportation system (Hung & Tao, 2003).

6. ***Assessment Indicator models***: This type of models applies a range of indicators
   to evaluate the transport sustainability. These models are categorized as composite index models, multi-level index models and multi-dimension matrix models by Hung and Tao (2003); which represent degree of satisfying economic, social and environmental objectives; different goals and hierarchies and interaction among

different indicators respectively. However, it is difficult to achieve a universal single composite index of sustainable transportation (Phillis & Andriantiantsahoiiniaina, 2001).

7. ***Data Analysis method:*** Statistical data are used in this model and data analysis techniques (e.g., surveys, equation, and hypothesis) are incorporated to examine sustainable transport systems. Mohan (1999) used statistical data to explain the necessity of NMT and design of the associated infrastructure for proposing sustainable transportation systems focusing on urban areas.

8. ***Multi-Criteria Decision Analysis (MCDA) methods:*** A wide spectrum of MCDA methods are currently available such as Multi-Attribute Value Function Theory (MAVT), Multi-Attribute Utility Function Theory (MAUT), Analytic Hierarchy Process (AHP), ELECTRE, Fuzzy TOPSIS analysis etc. This type of methods facilitates the selection of alternatives evaluating a set of criteria. And the criteria must have to be measurable even if possible at the nominal scale (i.e., yes/no, present/absent). But in this method only experts' opinion are considered. Yedla and Sreshtha (2003) used AHP in evaluating six sustainable transportation modes. Recently an approach comprising AHP and belief theory has been offered for evaluating sustainable transport solutions (Awasthi & Omrani, 2009).

2.5.1 AHP Analysis

The Analytic Hierarchy Process (AHP) has been developed by T. Saaty (1977, 1980, 1988, 1995) AHP is a mathematical technique used for multi-criteria decision-making and rooted in a special structure. By this method users are allowed to assess the relative weight of multiple criteria or multiple options against given criteria in an intuitive manner. Even if the quantitative ratings are not available for a given case, policy makers or assessors can still distinguish whether one criterion is more important than another. Saaty established a reliable way of converting pairwise comparisons (X is more important than Y) into a set of numbers indicating the relative priority of each of the criteria. Applications of AHP can be seen in a wide range of areas like environmental impact assessment (Ramanathan R, 2001), selection of alternative transportation options (Yedla S & Shrestha RM, 2003), performance measurement system (Suwignjo P et al, 2000), evaluation of highway transportation (Weiwu W & Jun K, 1994) etc. The use of AHP leads to both, more transparency of the quality of management decisions and an increase in the importance of AHP (Ossadnik W& Lange O, 1999).

Strengths and Weaknesses

The main advantage of this method over other multi-criteria techniques is that it can incorporate tangible as well as non-tangible factors especially where the subjective judgments of different individuals constitute an important part of decision making (Saaty, 980). Another important thing is that this method generates intuitive appeal and flexibility along with its easy handling process. Additionally, it has the distinct advantage that it decomposes a decision problem into its constituent parts and builds hierarchies of criteria and also checks the inconsistency of the prioritized values (Macharis et.al 2004).

Despite the popularity the AHP approach gains, it has a few disadvantages as well. For instance, rank reversal might occur when a copy or a near copy of an existing option is added to the set of alternatives which are being evaluated. Another thing is that the pairwise comparisons to be made may become very large as (n (n – 1)/2) and thus become a lengthy task (Macharis et.al 2004).

2.5.2 Fuzzy TOPSIS Analysis

The Fuzzy set theory is applied in decision making processes to model ambiguity and uncertainty that might occur in lacking complete information (Zadeh, 1965). In this theory, linguistic terms are used to represent the preferences of decision makers. For instance, the possibility of raining on Friday can be shown in linguistic terms as very low, low, medium etc. The fuzzy TOPSIS (Technique Ordered Preference by Similarity to the Ideal Situation) approach entails the fuzzy assessments of criteria and alternatives (Yoon & Hwang, 1981). Alternative that is closest to the fuzzy positive ideal solution (FPIS) and farthest from the fuzzy negative ideal solution (FNIS) is chosen by this approach. A positive ideal solution FPIS comprises the best performance values for each criterion whereas the FNIS comprises the worst performance values.

Definition 1. A fuzzy set ***a*** in a universe of discourse **X** is characterized by a membership function μ_a (x) that maps each element x in X to a real number in the interval [0, 1]. The nearer the value of μ_a (x) to unity, the higher the grade of membership of x in ***a***.

Definition 2. A triangular fuzzy number is illustrated as a triplet ***a*** = (a_1, a_2, a_3). Fig. 2.2 represents a triangular fuzzy number ***a***. Triangular fuzzy numbers are commonly used in practical applications owing to their conceptual as well as computation simplicity (Klir & Yuan, 1995; Pedrycz, 1994; Yeh & Deng, 2004). The membership function μ_a (x) of triangular fuzzy number ***a*** is given by:

$$\mu_a(x) = \begin{cases} 0, & x \leq a_1, \\ (x - a_1) / (a_2 - a_1), & a_1 \leq x \leq a2, \\ (a_3 - x) / (a_3 - a_2), & a_2 \leq x \leq a3, \\ 0, & x \geq a3 \end{cases}$$

where a_1, a_2, a_3 are real numbers and $a_1 < a_2 < a_3$.

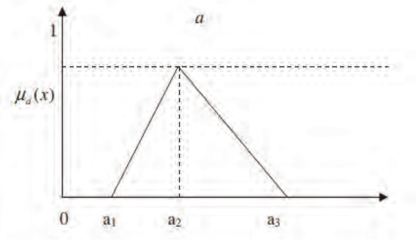


Fig. 2.2: Triangular fuzzy number ***a***

The value of x at a_2 gives the maximal grade of μ_a (x), i.e., $\mu_a(x) = 1$; it is the most probable value of the evaluation data. The value of x at a_1 gives the minimal grade of μ_a (x), i.e., $\mu_a(x) = 0$; it is the least probable value of the evaluation data. The fuzziness of the evaluation data are indicated through the area offered by the constants a_1 and $a_{3;}$ which represent the lower and upper bound of the area (Liang, 1999). The broader the interval $[a_1, a_3]$, the higher is the fuzziness of the evaluation data.

Strengths and Weaknesses

The main benefit of fuzzy TOPSIS method is that, in case of application in evaluating sustainable transport options, it can generate good quality solution even under uncertainty (Omrani H, 2011).

However, the detrimental fact of the approach is that it deals with reasoning rather than what is fixed or exact (Klir, 1988).

2.6 An Overview

From the above review, it appeared that there were a very few studies (planning and policy related) dealt with mass transit options in Dhaka city and also on the possibility of introducing CNG conversion vehicles as well as expanding walking/cycling infrastructure; which are considered the most acceptable strategy to alleviate traffic congestion and consequent environmental degradation. And now are in practice worldwide, especially in many new emerging cities such as Bangkok, Jakarta, Tokyo and Bogota as well as in the developed countries. However, no study is found to evaluate the mass transit options for the city which seems to be the best state-of-the-art alternative to reduce the overwhelming transportation crisis the city poses to face in near future. Furthermore, a remarkable number of studies were found about air quality degradation in Dhaka city due to transportation activities.

CHAPTER 3
METHODOLOGY

This chapter portrays the selection of alternative Green Transportation options for the Megacity proposing an efficient and faster movement to its entire population. It also describes about the components of the questionnaire survey to be responded by respective experts on this ground judging a wide range of criteria associated with the selected transport options. Furthermore, the overall process of AHP analysis and fuzzy TOPSIS analysis methods are fully described which have been applied to find out the best alternative transport option for the Megacity based on experts' rating.

3.1 Selection of alternative Green Transportation options

The following six potential alternatives (Table 3.1) based on cost category have been chosen reviewing various researches on Dhaka city's transport development proposals as well as guidelines offered by some similar government initiatives (e.g. STP, 2005 and others) to overcome the existing critical situation so that the Megacity could meet the needs of future transportation demands generated by the projected future population and potential boost of economic activities.

Table 3.1: Selected Potential Alternative Transport Options

Alternative Options		Type of transport facility
High Cost	H_1	Metro (Underground Rail Rapid Transit)
	H_2	BRT (On-surface Bus Rapid Transit)
	H_3	Skytrain (Elevated Rail Rapid Transit)
Low Cost	L_1	Bus (CNG conversion)
	L_2	Car (CNG conversion)
	L_3	Walking/ Cycling

3.2 Questionnaire Design

In order to measure the overall performance of the above mentioned potential alternative green transportation options, a questionnaire (attached as Appendix A) has been developed taking into account a wide range of criteria. The criteria have been chosen as the parameters reviewing similar previous studies and also considering the socio-economic aspects of transport users of the city.

For AHP analysis, experts were asked to assign the selected criteria in numerical scales (i.e., 1, 2 etc.) to measure the sustainability assessment of each criterion and also assign the potential alternatives thinking about the influential weightage of the criteria upon them. Table 3.2 below shows the criteria been set to evaluate the alternative.

Table 3.2: Selected criteria for AHP analysis

Criteria	Definition
Energy Efficiency	Energy efficiency signifies the ability to response to the minimal use of the available energy; or on the basis of consumption of energy by any mode for a desired service.
Emission Reduction Potential (ERP)	Emission Reduction Potential indicates the ability of response towards less emission; or on the judgment of pollution emission (e.g., CO, NOx, PM, CHGs etc.) by any mode for an expected level of service.
Economic Feasibility	Economic Feasibility refers the ability regarding the feasibility of the cost of execution along with the cost of investment for providing a better transport service in meeting the growing demands of the users.
Technological Availability	Technological Availability represents the availability of the required technology for the application of any alternatives and how conveniently that can be met for such options to execute.
Implementability/ Adoptability	Implementability/Adoptability denotes the ability of perfect implementation of any alternative options considering all associated factors.

Similarly for fuzzy TOPSIS analysis, Experts were asked to assign linguistic ratings (i.e., Very poor, Poor, Fair etc.) to the criteria and also to evaluate the alternative transport options (i.e., Very low, Low, Medium etc.) against the criteria been set. Table 3.3 below illustrates a list of criterion with respective category as well.

Table 3.3: Selected Criteria for fuzzy TOPSIS analysis

Criteria	Definition	Category*
Operating costs (C1)	Costs to operator for running the transportation service	C
Safety (C2)	Safety offered by the transportation system	B
Security (C3)	Security from theft, damage offered by the transportation system	B
Reliability (C4)	Ability to perform the promised service reliably and accurately	B
Air pollutants (C5)	Air pollutants from the transportation system	C
Noise (C6)	Noise from the transportation system	C
Travel costs (C7)	Costs for travel between any given stations	C
Energy consumption (C8)	Energy consumption by the transportation system	C
Land usage (C9)	Land space used for running the transportation service	C
Accessibility (C10)	Access to residential areas, activity areas and other transportation modes	B
Benefits to economy (C11)	Benefits to economy from the transportation mode e.g. labor employment, resource usage	B
Competency (C12)	State of the art technology, equipment and infrastructure employed by the transportation mode	B
Equity (C13)	Equity across genders, age groups, handicapped people	B

Possibility of expansion (C14)	Ability to expand the service if required	B
Mobility (C15)	Ability to service over the transportation area	B
Productivity (C16)	Ability to achieve performance targets	B
Occupancy rate (C17)	Capacity utilization of transportation mode	B
Share in public transit (C18)	Contribution to public transport	B
Convenience to use (C19)	Convenience in using the transportation service	B
Quality of service (C20)	Quality of service provided by the transportation staff	B
Tangibles (C21)	Physical facilities, equipment, and appearance of personnel	B

* B = Benefit; C = Cost**.**

3.3 Categorization of Criteria

The selected criteria for both the approaches has been mutually categorized and presented below in Table 3.4.

Table 3.4: Criteria categorization for AHP and Fuzzy TOPSIS

AHP	**Energy Efficiency**	**Emission Reduction Potential**	**Economic Feasibility**	**Technological Availability**	**Implementability/ Adoptability**
Fuzzy TOPSIS	Energy Consumption (C8)	Air pollutants (C5)	Operating costs (C1) Travel Costs (C7) Accessibility (C10) Benefits to Economy (C11) Mobility (C15) Occupancy rate (C17) Share in public	Safety (C2) Security (C3) Reliability (C4) Competency (C12) Possibility of Expansion (C14) Productivity (C16) Quality of service (C20)	Land Usage (C9) Convenience to use (C19) Tangibles (C21)

	transit (C18)
Noise (C6) & Equity (C13) are additionally added criteria to Fuzzy TOPSIS approach	

3.4 Selection of Experts

It's needless to explain that this study required the incorporation of experts' opinion as an imperative part of the methodological input to reach the goal. Therefore, it was a hard task to select the experts who are experienced and quite knowledgeable in various aspects related to transportation such as infrastructure, energy, pollution emission etc. At the end, four national and four international experts have been selected for this research who evaluated the criteria and potential alternatives based on their own experiences. The experts were from different grounds such as Transportation Engineer/Planner, Transport Consultant etc. However, international experts have been chosen considering their prior work experience on Dhaka city whereas national experts pose vast experiences being involved in various transport related projects on the same study area.

3.5 Framework of MCDA approach

The framework of the two selected approaches has been discussed below in Section 3.5.1 and Section 3.5.2 respectively for AHP and Fuzzy TOPSIS.

3.5.1 Framework of AHP analysis

In order to evaluate the alternatives with respect to the criteria experts were asked to rate them on 9 point scale. The conversion scale for AHP application has been presented below in Table 3.5.

Table 3.5: Conversion scale for AHP analysis

Goal: Prioritization of alternative green transport options for Dhaka Megacity		
Comparing Scale		Intensities of 2, 4, 6 and 8 are used to express intermediate values.
Scale	**Intensity**	
1	Equal importance	
3	Moderate importance	
5	Strong importance	
7	Very strong importance	
9	Extreme importance	

The priority has been derived from a series of measurements: *pairwise comparisons* involving all the nodes. Pairwise comparisons could have been done in any sequence but for this research the following steps have been followed;

Step 1: The Goal, Criteria and Alternatives have been defined.

Step 2: The alternatives have been compared with respect to their importance in meeting each of the criteria. Then the results have been entered into a matrix and normalized it and processed mathematically to derive the priority.

Step 3: The criteria have been compared with respect to their importance to meeting the Goal. And similar method has been followed to derive the priority.

Step 4: The overall priority of the alternatives has been derived combining the priority value of step 2 and step 3 by simple multiplication and adding process.

In brief, for example, the expert compared pairs of High Cost alternatives with respect to one single criterion 'Energy Efficiency' and gave a rated score of 3 to 'BRT' against 'Metro' and a score of 2 to 'BRT' against 'Skytrain'; which indicates that 'BRT' as an option is, three times better than 'Metro' and two times better than 'Skytrain' in meeting the significance of the criterion and vice versa to the reciprocal value of the rated score. Likewise, all the alternatives have been evaluated against each of the criteria. Again, a pairwise comparison among the criteria has been conducted in the same way, for example, if 'Energy Efficiency' seems to be twice important than 'ERP' then the rated score of 'Energy Efficiency' against 'ERP' would be 2 to measure the sustainability assessment of the criteria in reaching the Goal. The detail calculation has been discussed and presented in Section 4.1. The framework of AHP hierarchy is presented below in Fig. 3.1.

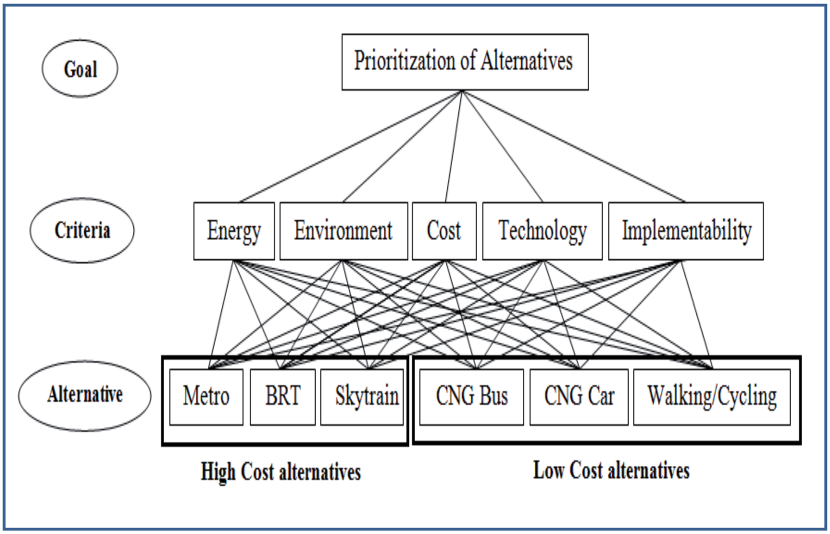


Fig. 3.1: AHP hierarchy for the prioritization of Green Transportation options

3.5.2 Framework of fuzzy TOPSIS Analysis

The fuzzy TOPSIS approach has been used to decide the best alternative Green Transport options for Dhaka city based on decision makers' evaluation. In fuzzy set theory, linguistic terms are transformed into fuzzy numbers applying the conversion scale. In this study, a scale of 1 to 9 has been used in rating the sustainability of the criteria and the alternatives with respect to each of the criteria. The corresponding conversion scale has been presented below in Table 3.6.

Table 3.6: Conversion scale for alternative ratings and criteria ratings

For alternative ratings		For criteria ratings	
Linguistic term	**Membership function**	**Linguistic term**	**Membership function**
Very Poor (VP)	(1, 1, 3)	Very Low (VL)	(1, 1, 3)
Poor (P)	(1, 3, 5)	Low (L)	(1, 3, 5)
Fair (F)	(3, 5, 7)	Medium (M)	(3, 5, 7)
Good (G)	(5, 7, 9)	High (H)	(5, 7, 9)
Very Good (VG)	(7, 9, 9)	Very High (VH)	(7, 9, 9)

The step-wise application of the approach is presented below:

Step 1: Assigning the criteria rating and the alternatives rating.

Let, there are J possible alternatives like $A = \{A_1, A_2, . . . , A_j\}$; are to be rated against n criteria, $C = \{C_1, C_2, . . . , C_i\}$. The weights of the criteria are denoted by w_i (i = 1, 2, . . , m). The performance ratings of each decision maker D_k (k = 1, 2, . . . , K) for each alternative A_j (j = 1, 2, . . . , n) with respect to criteria C_i (i = 1, 2, . . . , m) are denoted by $R_k = X_{ijk}$ with membership function μR_k (x).

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

If the fuzzy ratings of all decision makers is described as triangular fuzzy number $R_k = (a_k, b_k, c_k)$, k = 1, 2, 3, …., K; then the aggregated fuzzy rating is given by R = (a, b, c), k = 1, 2, ….., K; where;

$$a = \min_{k} \{a_k\}, \quad b = \frac{1}{K}\sum_{k=1}^{K} b_k, \quad c = \max_{k} \{c_k\}$$

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

$$a_{ij} = \min_{k} \{a_{ijk}\}, \quad b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ijk}, \quad c_{ij} = \max_{k} \{c_{ijk}\} \qquad (1)$$

The aggregated fuzzy weights (w_{ij}) of each criterion are calculated as $w_j = (w_{j1}, w_{j2}, w_{j3})$ where

$$W_{j1} = \min_{k} \{w_{jk1}\}, \quad w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{jk2}, \quad w_{j3} = \max_{k} \{w_{jk3}\} \qquad (2)$$

Step 3: Computing the fuzzy decision matrix.

The fuzzy decision matrix for the alternatives ($\underline{D}$) and the criteria ($\underline{W}$) is constructed as follows:

$$\underline{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots\ldots & C_n \end{array} \\ \begin{pmatrix} x_{11} & x_{12} & \ldots\ldots & x_{1n} \\ x_{21} & x_{22} & \ldots\ldots & x_{2n} \\ x_{31} & x_{32} & \ldots\ldots & x_{3n} \\ x_{41} & x_{42} & \ldots\ldots & x_{4n} \end{pmatrix} \end{array} \qquad i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n \qquad (3)$$

$$\underline{W} = (w_1, w_2, \ldots\ldots, w_n) \qquad (4)$$

Step 4: Normalizing the fuzzy decision matrix.

The raw data are normalized to bring the criteria scales into a comparable scale using linear scale transformation. The normalized fuzzy decision matrix $\underline{R}$ is given by:

$\underline{R} = [\, \underline{r}_{ij} \,]_{m*n,}$ i = 1, 2, ….., m; j = 1, 2, ….., n (5)

$\underline{r}_{ij} = (a_{ij}/c_j^*,\ b_{ij}/c_j^*,\ c_{ij}/c_j^*)$ and $c_j^* = \max_i c_{ij}$ (benefit criteria) (6)

$\underline{r}_{ij} = (a_j^-/c_{ij},\ a_j^-/b_{ij},\ a_j^-/a_{ij})$ and $a_j^- = \min_i a_{ij}$ (cost criteria) (7)

Step 5: Computing the weighted normalized matrix.

The weighted normalized matrix $\underline{V}$ for all criteria is calculated by multiplying the weights ($\underline{w}_j$) of evaluation criteria with the normalized fuzzy decision matrix $\underline{r}_{ij}$

$\underline{V} = [\, \underline{v}_{ij} \,]_{m*n}$, i = 1, 2, ……., m; j = 1, 2, …….., n where $\underline{v}_{ij} = \underline{r}_{ij} * \underline{w}_j$ (8)

Step 6: Computing fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS).

The FPIS and FNIS of the alternatives are figured out as follows:

$A^* = (\underline{v}_1^*,\ \underline{v}_2^*, ..\ \underline{v}_n^*)$ where $\underline{v}_j^* = \max_i\{v_{ij3}\}$, i =1, 2,.., m; j = 1, 2, .., n (9)

$A^- = (\underline{v}_1^-, \underline{v}_2^-, …\ \underline{v}_n^-)$ where $\underline{v}_j^- = \min_i\{v_{ij1}\}$, i =1, 2,…, m; j = 1, 2, …., n (10)

Step 7: Computing the distance of each alternative from FPIS and FNIS.

The distance (d_i^*, d_i^-) of each weighted alternative i = 1, 2,. . . , m; from the FPIS and the FNIS is computed as follows:

$$d_i^* = \sum_{j=1}^{n} d_v(\underline{v}_{ij}, \underline{v}_j^*), \quad i = 1, 2, \ldots\ldots, m \qquad (11)$$

$$d_i^- = \sum_{j=1}^{n} d_v(\underline{v}_{ij}, \underline{v}_j^-), \quad i = 1, 2, \ldots\ldots, m \qquad (12)$$

where, $d_v(\underline{a}, \underline{b})$ is the distance measurement between two fuzzy numbers $\underline{a}$ and $\underline{b}$.

Step 8: Computing the closeness coefficient (CC_i) of each alternative. The closeness coefficient CC_i represents the distances to the fuzzy positive ideal solution (A^*) and the fuzzy negative ideal solution (A^-) simultaneously. The closeness coefficient of each alternative is calculated as:

$$CC_i = d_i^- / (d_i^- + d_i^*), \quad i = 1, 2, \ldots\ldots, m \qquad (13)$$

Step 9: Ranking the alternatives.

In step 9, the different alternatives have been ranked according to the closeness coefficient (CC_i) in decreasing order. The best alternative is closest to the FPIS and farthest from the FNIS for ‘Benefit criteria’ and vice-versa for the ‘Cost criteria’. The alternative with the highest score is chosen as the most suitable transport option.

Sensitivity Analysis

After evaluating and selecting the best alternative; a sensitivity analysis has been conducted to measure the influence of criteria weights over the alternatives to select the best one. This is helpful particularly in situations; if there lays any uncertainty in defining the importance of different associated factors. The framework of the Fuzzy methodology has been presented in Fig. 3.2.

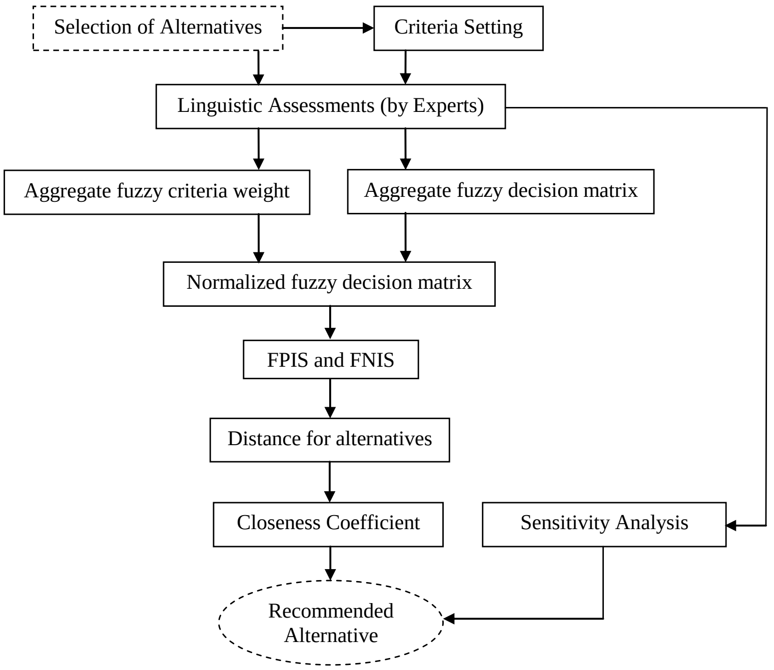


Fig 3.2: Framework of Fuzzy TOPSIS approach

CHAPTER 4
RESULTS AND DISCUSSION

In this chapter, the analyzed outcome of the study has been presented step by step for the two MCDA approaches namely Analytic Hierarchy Process (AHP) and Fuzzy TOPSIS. In addition, the discussion or explanation on the outcome whether the computed end results are expected or unexpected has also been involved. Furthermore the outcome of the study helps stand on a basis to decide the best choice (in this case alternative) desired to be come into effect in future policy level as well. A format of the Experts' opinion survey has been provided in Appendix A.

4.1 Result of AHP Analysis

For AHP analysis, a pairwise comparison has been followed. In the first step each alternative (both for High Cost and Low Cost alternatives) has been compared with respect to their strengths in meeting each specific criterion (in this case five criteria) based on expert's rating. Later on all the criteria have been evaluated with their importance in reaching the goal. All the calculations have been conducted using Microsoft Excel spreadsheet. The Experts' rating has been provided in Appendix B.

Criteria 1: Energy Efficiency

The overall rating by the experts' of each alternative (both for High cost and Low cost) with respect to the selected criteria 'Energy Efficiency' has been shown below in Table 4.1 and the resulting normalized AHP matrix along with the priorities and Consistency Factor has been presented in Table 4.2.

Table 4.1: Alternatives compared with respect to "Energy Efficiency"

High Cost Alternatives					Low Cost Alternatives			
Energy Efficiency	Metro	BRT	Skytrain		Energy Efficiency	Bus (CNG conv.)	Car (CNG conv.)	Walking/ Cycling
Metro	1	1.223	2.128		Bus (CNG conv.)	1	5.663	0.755
BRT	0.818	1	1.315		Car (CNG conv.)	0.177	1	0.152
Skytrain	0.470	0.761	1		Walking/ Cycling	1.324	6.560	1

For example, in case of High Cost alternatives the rating of Metro against BRT (i.e. the priority of Metro is how much higher than BRT) with respect to the criteria "Energy Efficiency" by eight (8) experts are like: 0.2, 5, 5, 0.125, 5, 2, 4 and 0.2. To find out the overall rating for this component, the geometric mean of the eight (8) numbers has been computed (i.e.1.223) which is the weighted value of Metro over BRT system. On the contrary, the reciprocal of 1.223 (i.e. 0.818) is the weighted value that describes the priority of BRT over the alternative Metro as well. Similarly for the case of Low Cost alternatives, it can be understood that Walking/Cycling has a significant higher weighted value of 1.324 and 6.560 times correspondingly over the proposed Bus (CNG conv.) and Car (CNG conv.) systems.

The λ_{max} has been computed by Matrix Multiplication following the formula "= MMULT (column sum of the ratings for each alternative, priority value of each alternative)".

The Consistency Index (C.I) has been calculated following the formula C.I = $(\lambda_{max} - n)/(n - 1)$, where n denotes the number of alternatives or the matrix size (i.e. 3×3 matrix , 4×4 matrix, etc.). For example, in the case of High Cost alternatives, C.I = (3.009 - 3)/(3 - 1) = 0.0045 (i.e. Here, n =3); shown below in Table 4.2.

And the Consistency Ratio (C.R) has been computed following the formula C.R = C.I / R.I, where R.I means 'Random Consistency Index' and whose value varies with the matrix size 'n'. For example, in the case of Low Cost alternatives, C.R = 0.0015/0.58 = 0.002586 (i.e. Here, R.I = 0.58 for n = 3); also shown below in table 4.2. [The R.I chart has been provided in Appendix D.]

Table 4.2: Normalized AHP matrix with respect to "Energy Efficiency"

High Cost Alternatives					**Low Cost Alternatives**			
Energy Efficiency	Metro	BRT	Skytrain		**Energy Efficiency**	Bus (CNG conv.)	Car (CNG conv.)	Walking/ Cycling
Metro	0.437	0.410	0.479		Bus (CNG conv.)	0.400	0.428	0.396
BRT	0.357	0.335	0.296		Car (CNG conv.)	0.071	0.076	0.080
Skytrain	0.205	0.255	0.225		Walking/ Cycling	0.530	0.496	0.524
Priority	**0.442**	**0.330**	**0.228**		**Priority**	**0.408**	**0.075**	**0.517**
Sum of Priorities = 1.00 λ_{max} = 3.009 Consistency Index (C.I) = 0.0045 Consistency Ratio (C.R) = 0.007759					Sum of Priorities = 1.00 λ_{max} = 3.003 Consistency Index (C.I) = 0.0015 Consistency Ratio (C.R) = 0.002586			

From Table 4.2, it could be realized that in case of High Cost alternatives, the Metro system with priority value of 0.442 has a fair dominance over BRT and Skytrain. Although in general it was expected that with respect to the criteria "energy efficiency" the BRT system should stand with a higher priority than the Metro or Skytrain system, the result shows that might be some of the experts weighted the alternatives much from different perspectives. For example, some of them might have thought that in terms of per hour passenger carrying capacity against energy consumption the Metro system could be the better option over other alternatives for such a dense city that has eventually influenced the initial expected outcome. Whereas regarding the Low Cost alternatives, Walking/Cycling has stood as a dominant choice over other options which was normally expected in terms of energy consumption comparing other alternatives.

However the C.I (i.e. Inconsistency) and C.R values for both the High Cost and Low Cost alternatives represent an accepted methodical analysis of the data that should be less than 0.1.

Criteria 2: Emission Reduction Potential (ERP)

The overall evaluation by the experts' of the proposed alternatives with respect to the selected criteria 'Emission reduction Potential (ERP)' and the corresponding normalized AHP matrix along with the priority values of the alternatives and Consistency Factor has been presented below in Table 4.3 and Table 4.4 respectively.

Table 4.3: Alternatives compared with respect to "Emission Reduction Potential (ERP)"

High Cost Alternatives					**Low Cost Alternatives**			
ERP	Metro	BRT	Skytrain		**ERP**	Bus (CNG conv.)	Car (CNG conv.)	Walking/ Cycling
Metro	1	4.019	1.162		Bus (CNG conv.)	1	2.711	0.266
BRT	0.249	1	0.433		Car (CNG conv.)	0.369	1	0.168
Skytrain	0.860	2.310	1		Walking/ Cycling	3.761	5.958	1

From Table 4.3, it could be observed by the rating that for the case of High Cost alternatives, the Metro has been chosen as a 4.019 and 1.162 times better option than BRT and Skyrain correspondingly; whereas the Skytrain has stood as a 2.310 times better choice than the BRT system with respect to emission reduction aspect. Similarly in the case of Low Cost alternatives, the

Walking/Cycling option has come out as a dominant choice over the proposed Bus (CNG conv.) and Car (CNG conv.) systems as a 3.761 and 5.958 times better alternative correspondingly; whereas the Bus (CNG conv.) system has stood as a 2.711 times better choice than the Car (CNG conv.) system.

Table 4.4: Normalized AHP matrix with respect to "Emission Reduction Potential (ERP)"

High Cost Alternatives					Low Cost Alternatives			
ERP	Metro	BRT	Skytrain		**ERP**	Bus (CNG conv.)	Car (CNG conv.)	Walking/ Cycling
Metro	0.474	0.548	0.448		Bus (CNG conv.)	0.195	0.280	0.185
BRT	0.118	0.136	0.167		Car (CNG conv.)	0.072	0.103	0.117
Skytrain	0.408	0.315	0.385		Walking/ Cycling	0.733	0.616	0.697
Priority	**0.490**	**0.140**	**0.370**		**Priority**	**0.220**	**0.098**	**0.682**
Sum of Priorities = 1.00 λ_{max} = 3.022 Consistency Index (C.I) = 0.011 Consistency Ratio (C.R) = 0.018965					Sum of Priorities = 1.00 λ_{max} = 3.050 Consistency Index (C.I) = 0.025 Consistency Ratio (C.R) = 0.043103			

From Table 4.4, it could be noticed that among the High Cost alternatives, the Metro system with a priority value of 0.490 has become a relatively higher dominant over the Skytrain system (Priority value: 0.370) and a much higher dominant over the BRT system (Priority value: 0.140) with respect to pollution emission viewpoint. Similarly among the Low Cost alternatives, the Walking/Cycling option with a priority value of 0.682 has shown a remarkably higher dominance over the proposed Bus (CNG conv.) (Priority value: 0.220) and Car (CNG conv.) system (Priority value: 0.098).

The Experts' judgment seemed quite rational as normally Metro responses to lower emission comparing to Skytrain and BRT. Similarly the Walking/Cycling is more feasible in response to pollution emission comparing to Bus (CNG conv.) and Car (CNG conv.) which normally emit green house gases (GHGs). Additionally, the C.I and C.R values (which should be less than 0.1) for both the High Cost and Low Cost alternatives also support the methodical analysis of the data in a meaningful sense.

Criteria 3: Economic Feasibility

Likewise the overall rating by the experts' of the proposed High Cost and Low Cost alternatives with respect to the selected criteria 'Economic Feasibility' has been demonstrated below in Table 4.5 and the resultant normalized AHP matrix along with the priorities and Consistency Factor has been shown in Table 4.6.

Table 4.5: Alternatives compared with respect to "Economic Feasibility"

High Cost Alternatives					**Low Cost Alternatives**			
Economic Feasibility	Metro	BRT	Skytrain		**Economic Feasibility**	Bus (CNG conv.)	Car (CNG conv.)	Walking/ Cycling
Metro	1	0.323	0.818		Bus (CNG conv.)	1	5.824	0.536
BRT	3.099	1	3.503		Car (CNG conv.)	0.172	1	0.163
Skytrain	1.223	0.285	1		Walking/ Cycling	1.866	6.145	1

From Table 4.5, it could be observed that regarding the "Economic Feasibility" of the High Cost alternatives, BRT alone has been chosen as a 3.503 and 3.099 times better option than the Skytrain and Metro system correspondingly; whereas a slightly higher dominance has been shown by the Skytrain with a value of 1.223 times over the Metro system. On the other side, in the case of Low Cost alternatives, the proposed Walking/Cycling alternative alone has been chosen as a 6.145 and 1.886 times better option over the proposed Car (CNG conv.) and Bus (CNG conv.) system in the same order; whereas a fair dominance has been experienced by the Bus (CNG conv.) system over the alternative Car (CNG conv.) with a value of 5.824 times.

Table 4.6: Normalized AHP matrix with respect to "Economic Feasibility"

High Cost Alternatives					**Low Cost Alternatives**			
Economic Feasibility	Metro	BRT	Skytrain		**Economic Feasibility**	Bus (CNG conv.)	Car (CNG conv.)	Walking/ Cycling
Metro	0.188	0.201	0.154		Bus (CNG conv.)	0.329	0.449	0.315
BRT	0.582	0.622	0.658		Car (CNG conv.)	0.057	0.077	0.096
Skytrain	0.230	0.178	0.188		Walking/ Cycling	0.614	0.474	0.589
Priority	**0.181**	**0.621**	**0.198**		**Priority**	**0.365**	**0.076**	**0.559**
Sum of Priorities = 1.00 λ_{max} = 3.016 Consistency Index (C.I) = 0.008 Consistency Ratio (C.R) = 0.013793					Sum of Priorities = 1.00 λ_{max} = 3.049 Consistency Index (C.I) = 0.0245 Consistency Ratio (C.R) = 0.042224			

Again from Table 4.6, it could be observed that among the High Cost alternatives, the proposed BRT system with a priority value of 0.621 has become as the highly preferred alternative over the Metro (Priority value: 0.181) and the Skytrain (Priority Value: 0.198) system with respect to economic feasibility viewpoint. Whereas in the case of Low Cost alternatives, the Walking/Cycling alternative with a priority value of 0.559 has turned as a fairly dominant option over the proposed Bus (CNG conv.) system (Priority value: 0.365) and a much higher dominant over the Car (CNG conv.) system (Priority value: 0.076).

The Experts' opinion looked quite expected from the economic viewpoint since BRT can be operated on the same existing infrastructure comparing to Skytrain and BRT which require massive infrastructure to build with. Similarly Walking/Cycling also remains as a better option in comparison with Bus (CNG conv.) and Car (CNG conv.) as it can also be operated within the existing footpaths along the roads which are now not in proper operation due to presence of various types of small shops and other barriers.

Also the C.I and C.R values for both categories of alternatives suggest an acceptable orderly analysis of the data.

Criteria 4: Technological Availability (TA)

The overall evaluation by the experts' of the proposed alternatives with respect to the selected criteria 'Technological Availability' has been shown below in Table 4.7 and the consequent normalized AHP matrix along with the priority values of the alternatives and Consistency Factor has been presented later on in Table 4.8.

Table 4.7: Alternatives compared with respect to "Technological Availability"

High Cost Alternatives					**Low Cost Alternatives**			
TA	Metro	BRT	Skytrain		**TA**	Bus (CNG conv.)	Car (CNG conv.)	Walking/ Cycling
Metro	1	0.215	1.476		Bus (CNG conv.)	1	2.707	0.209
BRT	4.660	1	4.420		Car (CNG conv.)	0.369	1	0.147
Skytrain	0.678	0.226	1		Walking/ Cycling	4.779	6.817	1

From table 4.7, it could be understood that among the High Cost alternatives, the proposed BRT system has been stated as a fairly equal dominant choice over the Metro and the Skytrain system respectively by 4.660 and 4.420

times of those on a comparative basis. Similarly regarding the Low Cost alternatives, the proposed Walking/Cycling option has been emerged as a quite dominant choice over the proposed Bus (CNG conv.) and Car (CNG conv.) system by 4.779 and 6.817 times of those correspondingly from the technological preparedness viewpoint.

Table 4.8: Normalized AHP matrix with respect to "Technological Availability"

High Cost Alternatives				Low Cost Alternatives			
TA	Metro	BRT	Skytrain	**TA**	Bus (CNG conv.)	Car (CNG conv.)	Walking/ Cycling
Metro	0.158	0.149	0.214	Bus (CNG conv.)	0.163	0.257	0.154
BRT	0.735	0.694	0.641	Car (CNG conv.)	0.060	0.095	0.108
Skytrain	0.107	0.157	0.145	Walking/ Cycling	0.777	0.648	0.738
Priority	**0.174**	**0.690**	**0.136**	**Priority**	**0.191**	**0.088**	**0.721**
Sum of Priorities = 1.00 λ_{max} = 3.034 Consistency Index (C.I) = 0.017 Consistency Ratio (C.R) = 0.029310				Sum of Priorities = 1.00 λ_{max} = 3.078 Consistency Index (C.I) = 0.039 Consistency Ratio (C.R) = 0.067241			

From Table 4.8, it could be noticed that in the case of High Cost alternatives, the BRT system with a priority value of 0.690 has been appeared as the highly preferred alternative comparing with the Metro system (Priority value: 0.174) and the Skytrain (Priority value: 0.136). On the other hand, concerning about Low Cost alternatives, the proposed Walking/Cycling option has been sighted as a quite favored alternative over the Bus (CNG conv.) and Car (CNG conv.) system having a priority value of 0.721.

The experts' opinion deemed as quite logical as the BRT system could be operated on the existing infrastructure just adding technical supports to function it properly whereas the Metro or Skytrain system requires huge application of technical skills along with massive infrastructure and a longer period of time to finally come into effect. Similarly since the Walking/Cycling service could be executed on the existing footpaths along the roadways without investing much technical skill to its counterparts like Bus and Car to be CNG converted over a period of time, therefore the expert's opinion about the alternatives could be realized as a feasible choice.

In addition, the C.I and C.R values of the two types of alternatives also support the systematic analysis of the data.

Criteria 5: Implementability/Adoptability

The overall assessment of the proposed alternatives by the experts' with respect to the selected criteria 'Implementability/Adoptability' has been structured below in Table 4.9 and the resultant normalized AHP matrix along with the priorities and Consistency Factor has been presented in Table 4.10.

Table 4.9: Alternatives compared with respect to "Implementability"

High Cost Alternatives					**Low Cost Alternatives**			
Implemen-tability	Metro	BRT	Skytrain		**Implemen-tability**	Bus (CNG conv.)	Car (CNG conv.)	Walking/ Cycling
Metro	1	0.179	0.951		Bus (CNG conv.)	1	2.759	0.578
BRT	5.589	1	4.356		Car (CNG conv.)	0.362	1	0.305
Skytrain	1.052	0.230	1		Walking/ Cycling	1.729	3.283	1

From the rating presented above in Table 4.9, it could be clearly observed that in the case of High Cost alternatives, BRT has been chosen as a highly preferred option over the Metro and the Skytrain as a 5.589 and 4.356 times better alternative correspondingly; whereas the Skytrain has been emerged as a slightly fair dominant over the Metro system like 1.052 times better option. Likewise among the Low Cost alternatives, the proposed

Walking/Cycling option has been stated as a 3.283 and 1.729 times better alternative than the Bus (CNG conv.) and Car (CNG conv.) system in the same order; whereas the Bus (CNG conv.) has been chosen as a fair dominant like 2.759 times better option over the Car (CNG conv.) system.

Table 4.10: Normalized AHP matrix with respect to "Implementability"

High Cost Alternatives					**Low Cost Alternatives**			
Impleme-ntability	Metro	BRT	Skytrain		**Impleme-ntability**	Bus (CNG conv.)	Car (CNG conv.)	Walking/ Cycling
Metro	0.131	0.127	0.151		Bus (CNG conv.)	0.323	0.392	0.307
BRT	0.731	0.710	0.691		Car (CNG conv.)	0.117	0.142	0.162
Skytrain	0.138	0.163	0.159		Walking/ Cycling	0.559	0.466	0.531
Priority	**0.136**	**0.711**	**0.153**		**Priority**	**0.341**	**0.140**	**0.519**
Sum of Priorities = 1.00 λ_{max} = 3.007 Consistency Index (C.I) = 0.0035 Consistency Ratio (C.R) = 0.006034					Sum of Priorities = 1.00 λ_{max} = 3.019 Consistency Index (C.I) = 0.0095 Consistency Ratio (C.R) = 0.016379			

From the computed normalized matrix presented above in Table 4.10, it could be noticed that among the High Cost alternatives, BRT has been appeared as the highly preferred alternative with a priority value of 0.711 over the proposed Metro (Priority value: 0.136) and the Skytrain (Priority value: 0.153) system with respect to Implementability/Adoptability viewpoint. On the other side, regarding the Low Cost Alternatives, the Walking/Cycling has been sought as the highly preferred alternative with a priority value of 0.519 over the Bus (CNG conv.) system (Priority value: 0.341) and Car (CNG conv.) system (Priority value: 0.140).

The experts' rating seemed quite acceptable as the BRT system could be easily implemented on the existing infrastructure comparing with the Metro or Skytrain system. Likewise the Walking/Cycling service could also be easily implemented in the footpaths along the roadways comparing with the Bus and Car to be CNG converted having other requirements such as investment on purchasing of new public buses along with establishment of new CNG conversion stations etc.

Also the computed C.I and C.R values of both categories of alternatives recommend the orderly analysis of the data in an exact manner.

Criteria vs. the Goal

The experts' overall rating of the criteria with respect to their importance in reaching the goal has been formulated below in Table 4.11 and the corresponding normalized AHP matrix along with the priorities and Consistency Factor has been subsequently represented in Table 4.12.

Table 4.11: Criteria compared with respect to reaching the Goal

Criteria	**Energy Efficiency**	**ERP**	**Economic Feasibility**	**Technological Availability**	**Implemen-tability**
Energy Efficiency	1	2.42	0.62	3.191	1.039
ERP	0.413	1	0.389	1.573	0.578
Economic Feasibility	1.613	2.573	1	2.551	1.542
Technological Availability	0.313	0.636	0.392	1	0.497
Implemen-tability	0.962	1.731	0.648	2.012	1

From Table 4.11, it could be visualized that the criterion 'Energy Efficiency' has been chosen as a higher dominant over the criteria Emission Reduction Potential (ERP), Technological Availability (TA) and Implementability as 2.42, 3.191 and 1.039 times higher dominant respectively whereas 'Implentability' has been appeared as 1.731 and 2.012 times higher dominant than ERP and Technological Availability correspondingly. On the other hand, 'Economic

Feasibility' alone has been emerged as a much preferred dominant criterion against all other single criterion.

Table 4.12: Normalized AHP matrix for the selected Criteria

Criteria	**Energy Efficiency**	**ERP**	**Economic Feasibility**	**Technological Availability**	**Implemen-tability**
Energy Efficiency	0.232	0.289	0.203	0.309	0.223
ERP	0.096	0.12	0.127	0.152	0.124
Economic Feasibility	0.375	0.308	0.328	0.247	0.331
Technological Availability	0.073	0.076	0.129	0.097	0.107
Implemen-tability	0.224	0.207	0.213	0.195	0.215
Priority	**0.252**	**0.124**	**0.317**	**0.096**	**0.211**
Sum of Priorities = 1.00 λ_{max} = 5.0608 Consistency Index (C.I) = 0.0152 Consistency Ratio (C.R) = 0.013571					

From Table 4.12, it could be easily noticed that among the selected criteria 'Economic Feasibility' has been acknowledged as the most influential criterion in reaching the goal having a priority value of 0.317 followed by 'Energy Efficiency' (Priority value: 0.252), 'Implementability' (Priority value: 0.211) and the rest.

The priority result appeared above suggests that the experts' rating reflected a fairly acceptable scenario although it was likely that the criterion 'Emission Reduction Potential (ERP)' should have been emerged with higher priority values followed by 'Economic Feasibility' comparing with other criteria. It slightly deviated as all or most of the experts' were not from the ground associated with pollution emission aspect or environment (i.e. some of them were from transport planning background whereas others were transport consultant or core civil engineers etc.)

However, the computed C.I and C.R values support the methodical analysis of the data in a proper way forwarding an accepted view.

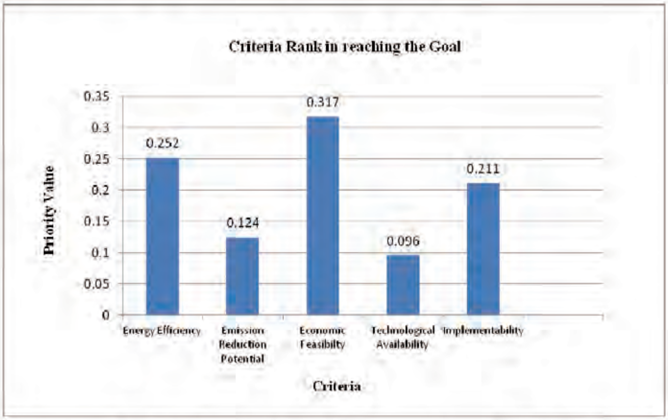


Figure 4.1: Criteria Rank in reaching the Goal

Synthesizing Final Priorities

The ultimate priorities of the alternatives with respect to the goal have been presented below in Table 4.13 (with calculation):

Table 4.13: Priority calculation of the Alternatives with respect to Criteria

Criteria	Priority vs. Goal	Alternative	A[1]		B[2]		C[3]
Energy Efficiency	0.252	Metro	0.442	×	0.252	=	0.111
		BRT	0.330	×	0.252	=	0.083
		Skytrain	0.228	×	0.252	=	0.058
			1.000				0.252
		Bus (CNG conv.)	0.408	×	0.252	=	0.103
		Car (CNG conv.)	0.075	×	0.252	=	0.019
		Walking/Cycling	0.517	×	0.252	=	0.130
			1.000				0.252

ERP	0.124	Metro	0.490	×	0.124	=	0.061
		BRT	0.140	×	0.124	=	0.017
		Skytrain	0.370	×	0.124	=	0.046
			1.000				0.124
		Bus (CNG conv.)	0.408	×	0.124	=	0.027
		Car (CNG conv.)	0.075	×	0.124	=	0.012
		Walking/Cycling	0.517	×	0.124	=	0.085
			1.000				0.124
Economic Feasibility	0.317	Metro	0.181	×	0.317	=	0.057
		BRT	0.621	×	0.317	=	0.197
		Skytrain	0.198	×	0.317	=	0.063
			1.000				0.317
		Bus (CNG conv.)	0.191	×	0.317	=	0.116
		Car (CNG conv.)	0.088	×	0.317	=	0.024
		Walking/Cycling	0.721	×	0.317	=	0.177
			1.000				0.317
TA	0.096	Metro	0.174	×	0.096	=	0.017
		BRT	0.690	×	0.096	=	0.066
		Skytrain	0.136	×	0.096	=	0.013
			1.000				0.096
		Bus (CNG conv.)	0.191	×	0.096	=	0.018
		Car (CNG conv.)	0.088	×	0.096	=	0.009
		Walking/Cycling	0.721	×	0.096	=	0.069
			1.000				0.096
Implementability	0.211	Metro	0.136	×	0.211	=	0.029
		BRT	0.711	×	0.211	=	0.150
		Skytrain	0.153	×	0.211	=	0.032
			1.000				0.211
		Bus (CNG conv.)	0.341	×	0.211	=	0.072
		Car (CNG conv.)	0.140	×	0.211	=	0.030
		Walking/Cycling	0.519	×	0.211	=	0.109
			1.000				0.211

Note: A^1 = Priority of Alternatives with respect to the Criterion. B^2 = Priority of the Criterion in reaching the Goal. C^3 = The overall Priority of Alternatives with respect to criteria in reaching the Goal.

Therefore, the overall priorities of alternatives with respect to criteria in reaching the Goal have been summarized as follows:

Table 4.14: Overall Priority of Alternatives

Criteria / Alternatives	Energy Efficiency	ERP	Economic Feasibility	TA	Impleme-ntability	Goal
Metro	0.111	0.061	0.057	0.017	0.029	**0.275**
BRT	0.083	0.017	0.197	0.066	0.150	**0.513**
Skytrain	0.058	0.046	0.063	0.013	0.032	**0.212**
Total	**0.252**	**0.124**	**0.317**	**0.096**	**0.211**	1.000
Bus (CNG conv.)	0.103	0.027	0.116	0.018	0.072	**0.336**
Car (CNG conv.)	0.019	0.012	0.024	0.009	0.030	**0.093**
Walking/Cycling	0.130	0.085	0.177	0.069	0.109	**0.571**
Total	**0.252**	**0.124**	**0.317**	**0.096**	**0.211**	1.000

Making the Decision

Based on the Experts' judgments about the relative importance of each criteria and on their judgments on each alternative with respect to each of the criteria, in the case of High Cost alternatives, BRT with a priority of 0.513, has been viewed by far the most suitable alternative to be implemented followed by Metro with a priority of 0.275 and Skytrain with a priority of 0.212. Similarly regarding the Low Cost alternatives, Walking/Cycling with a priority of 0.571, has been emerged as the most preferred alternative to be executed followed by Bus (CNG conv.) with a priority of 0.336 and Car (CNG conv.) with a priority of 0.093 in the same order.

4.2 Result of Fuzzy TOPSIS analysis

For Fuzzy TOPSIS analysis, the guided steps have been followed comparing the alternatives (both High Cost and Low Cost) with the selected 21 criteria (both Cost and Benefit criteria). In addition a Sensitivity Analysis has been conducted for both types of alternatives. The Experts' rating has been provided in Appendix C.

The linguistic assessment by the Experts' for the selected criteria has been presented below in Table 4.15. In the first step, aggregate fuzzy ratings for the criteria have been computed that appeared in the same table. Later on aggregate fuzzy ratings for High Cost and Low Cost alternatives has been subsequently presented in Table 4.16.

Table 4.15: Linguistic Assessments for the 21 criteria

Criteria	Experts								Aggregate fuzzy ratings
	E1	E2	E3	E4	E5	E6	E7	E8	
Operating costs (C1)	M	L	M	H	M	VH	M	L	(1, 5.25, 9)
Safety (C2)	H	L	H	H	M	H	H	H	(1, 6.25, 9)
Security (C3)	M	L	L	M	M	H	M	M	(1, 4.75, 9)
Reliability (C4)	M	M	L	L	M	VH	L	H	(1, 5, 9)
Air pollutants (C5)	L	M	L	VH	VL	M	L	L	(1, 4, 9)
Noise (C6)	L	M	L	H	L	M	L	L	(1, 4, 9)
Travel costs (C7)	H	L	H	VH	L	VH	H	L	(1, 4.75, 9)
Energy consumption (C8)	M	M	VH	VH	L	H	H	VL	(1, 5.75, 9)
Land usage (C9)	H	H	H	M	VH	H	H	L	(1, 6.5, 9)
Accessibility (C10)	H	H	H	VH	M	VH	H	VH	(3, 7.5, 9)
Benefits to economy (C11)	M	H	M	H	VH	H	M	VH	(1, 6.75, 9)
Competency (C12)	M	M	L	M	M	M	M	M	(1, 4.75, 7)
Equity (C13)	H	H	H	VH	M	M	H	VH	(3, 7, 9)
Possibility of expansion (C14)	H	H	M	L	H	M	M	H	(1, 5.75, 9)
Mobility (C15)	M	H	M	H	M	H	M	H	(3, 6, 9)
Productivity (C16)	M	H	M	L	H	M	M	VH	(1, 5.75, 9)
Occupancy rate (C17)	L	H	VL	M	VH	H	L	H	(1, 5.25, 9)
Share in public transit (C18)	H	H	H	H	H	M	M	VH	(3, 6.75, 9)
Convenience to use (C19)	H	M	M	M	L	M	M	H	(1, 5.25, 9)
Quality of service (C20)	H	M	M	M	M	H	H	M	(3, 5.75, 9)
Tangibles (C21)	L	M	VL	L	M	H	L	M	(1, 4, 9)

The aggregate fuzzy weight (w_j) of each criterion has been given using Eq. (2) [Chapter 3].

For example, for criteria C1' Operating Costs', the aggregate fuzzy weight has been given by $w_j = (w_{j1}, w_{j2}, w_{j3})$ where:

$$w_{j1} = \min_{k} (3, 1, 3, 5, 3, 7, 3, 1), \qquad w_{j2} = 1/8 \sum_{k=1}^{8} (5+3+5+7+5+9+5+3), \text{ and}$$

$$w_{j3} = \max_{k} (7, 5, 7, 9, 7, 9, 7, 5). \qquad \text{Therefore, } w_j = (1, 5.25, 9).$$

Likewise, for the remaining 20 criteria, the aggregate weights have been computed.

From Table 4.15, it could be observed that among the selected criteria, Accessibility (C10), Equity (C13), Mobility (15), Share in public Transit (C18) and Quality of service (C20) have been come out with lower fuzziness of evaluation area or being more influential in sustainability assessment having aggregate ratings of (3, 7.5, 9), (3, 7, 9), (3, 6, 9), (3, 6.75, 9) and (3, 5.75, 9) respectively; while others are represented as intermediate or less influential having lower bound value of 1 ($a_1 = 1$) and upper bound value of 9 ($a_3 = 9$).

Table 4.16: Aggregate Fuzzy decision matrix for the Alternatives

Criteria	High Cost Alternatives			Low Cost Alternatives		
	Metro	BRT	Skytrain	Bus (CNG conv.)	Car (CNG conv.)	Walking/ Cycling
C1	(1, 3.25, 7)	(3, 7.25, 9)	(1, 3.75, 7)	(3, 7, 9)	(1, 4, 9)	(3, 7.25, 9)
C2	(3, 7.75, 9)	(3, 6.5, 9)	(5, 8.25, 9)	(3, 6.75, 9)	(1, 5.25, 9)	(7, 9, 9)
C3	(3, 6, 9)	(3, 7.5, 9)	(3, 7, 9)	(1, 6.25, 9)	(1, 5.75, 9)	(5, 8, 9)
C4	(3, 8, 9)	(5, 7.5, 9)	(3, 7.75, 9)	(3, 6.5, 9)	(3, 7.25, 9)	(7, 9, 9)
C5	(5, 7.75, 9)	(1, 4.75, 9)	(3, 7.75, 9)	(3, 6.5, 9)	(1, 4, 9)	(1, 6.75, 9)
C6	(5, 7.75, 9)	(1, 6.25, 9)	(3, 5.75, 9)	(1, 5.25, 9)	(1, 4.75, 9)	(1, 5.75, 9)

C7	(1, 3.75, 7)	(3, 7.25, 9)	(1, 5.25, 9)	(1, 6, 9)	(1, 5.25, 9)	(3, 7.25, 9)
C8	(1, 3.75, 7)	(1, 5.25, 9)	(1, 5.75, 9)	(1, 5.5, 9)	(1, 4.75, 9)	(3, 7.25, 9)
C9	(3, 8, 9)	(1, 5.25, 9)	(3, 6.75, 9)	(3, 6.75, 9)	(1, 4.75, 9)	(1, 5.25, 9)
C10	(1, 5.25, 9)	(5, 7.5, 9)	(1, 5.5, 9)	(1, 4, 7)	(3, 7.5, 9)	(5, 8.25, 9)
C11	(3, 7.25, 9)	(3, 7.25, 9)	(1, 5.5, 9)	(3, 7, 9)	(1, 5, 9)	(5, 8, 9)
C12	(1, 3.5, 7)	(3, 6.25, 9)	(1, 4, 7)	(1, 5.75, 9)	(1, 5.25, 9)	(3, 7.25,9)
C13	(3, 6.25, 9)	(3, 7.25, 9)	(1, 5.75, 9)	(3, 6.5, 9)	(1, 3, 7)	(5, 8.5, 9)
C14	(1, 4.25, 7)	(5, 8.25, 9)	(1, 3.75, 9)	(3, 7, 9)	(1, 5.5, 9)	(5, 7.5, 9)
C15	(3, 7.5, 9)	(3, 6.5, 9)	(3, 6.25, 9)	(1, 5.75, 9)	(3, 7.5, 9)	(3, 7, 9)
C16	(3, 6.5, 9)	(3, 6.25, 9)	(1, 5.5, 9)	(3, 7, 9)	(1, 5.25, 9)	(3, 6.5, 9)
C17	(5, 8.5, 9)	(3, 7.25, 9)	(3, 7.25, 9)	(3, 6.5, 9)	(1, 3, 7)	(3, 7.25, 9)
C18	(5, 8.25, 9)	(3, 6.5, 9)	(3, 7, 9)	(3, 7.5, 9)	(1, 2.5, 7)	(3, 5.75, 9)
C19	(3, 7, 9)	(3, 7.5, 9)	(3, 6.75, 9)	(3, 6.25, 9)	(3, 7.25, 9)	(5, 7.5, 9)
C20	(5, 8, 9)	(3, 6.5, 9)	(5, 8.25, 9)	(3, 6.5, 9)	(3, 7.25, 9)	(3, 7.5, 9)
C21	(3, 6.5, 9)	(3, 7.25, 9)	(3, 6.25, 9)	(3, 6, 9)	(3, 5.5, 9)	(3, 7.25, 9)

Then the aggregate fuzzy weights of the alternatives with respect to the criteria have been figured out by Eq. (1) [Chapter 3]. For example, the aggregate rating for the High Cost alternative ‘Underground Metro’ for criteria C1 (Operating Costs) using the rating given by the eight decision makers has been computed as follows:

$a_{ij} = \min_k (1, 1, 1, 1, 1, 3, 1, 3)$, $b_{ij} = 1/8 \sum_{k=1}^{8} (1+3+3+3+3+5+3+5)$ and

$c_{ij} = \max_k (3, 5, 5, 5, 5, 7, 5, 7)$. Therefore, $x_{ij} = (1, 3.25, 7)$.

Likewise, the aggregate ratings for the alternatives (both High Cost and Low Cost) with respect to all the criteria have been computed.

Once the aggregate weight been computed for the criteria and alternatives, in the next step, the normalized decision matrix has been calculated and presented below in Table 4.17 and Table 4.18.

Table 4.17: Normalized Fuzzy decision matrix for High Cost alternatives

Criteria	Alternatives		
	Metro	**BRT**	**Skytrain**
C1	(0.14, 0.31, 1)	(0.11, 0.14, 0.33)	(0.14, 0.27, 1)
C2	(0.33, 0.86, 1)	(0.33, 0.72, 1)	(0.56, 0.92, 1)
C3	(0.33, 0.67, 1)	(0.33, 0.83, 1)	(0.33, 0.78, 1)
C4	(0.33, 0.89, 1)	(0.56, 0.83, 1)	(0.33, 0.86, 1)
C5	(0.11, 0.13, 0.2)	(0.11, 0.21, 1)	(0.11, 0.13, 0.33)
C6	(0.11, 0.13, 0.2)	(0.11, 0.16, 1)	(0.11, 0.17, 0.33)
C7	(0.14, 0.27, 1)	(0.11, 0.14, 0.33)	(0.11, 0.19, 1)
C8	(0.14, 0.27, 1)	(0.11, 0.19, 1)	(0.11, 0.17, 1)
C9	(0.11, 0.13, 0.33)	(0.11, 0.19, 1)	(0.11, 0.15, 0.33)
C10	(0.11, 0.58, 1)	(0.56, 0.83, 1)	(0.11, 0.61, 1)
C11	(0.33, 0.81, 1)	(0.33, 0.81, 1)	(0.11, 0.61, 1)
C12	(0.11, 0.39, 0.78)	(0.33, 0.69, 1)	(0.11, 0.44, 0.78)
C13	(0.33, 0.69, 1)	(0.33, 0.81, 1)	(0.11, 0.64, 1)
C14	(0.11, 0.47, 0.78)	(0.56, 0.92, 1)	(0.11, 0.42, 1)
C15	(0.33, 0.83, 1)	(0.33, 0.72, 1)	(0.33, 0.69, 1)
C16	(0.33, 0.72, 1)	(0.33, 0.69, 1)	(0.11, 0.61, 1)
C17	(0.56, 0.94, 1)	(0.33, 0.81, 1)	(0.33, 0.81, 1)
C18	(0.56, 0.92, 1)	(0.33, 0.72, 1)	(0.33, 0.78, 1)
C19	(0.33, 0.78, 1)	(0.33, 0.83, 1)	(0.33, 0.75, 1)
C20	(0.56, 0.89, 1)	(0.33, 0.72, 1)	(0.56, 0.92, 1)
C21	(0.33, 0.72, 1)	(0.33, 0.81, 1)	(0.33, 0.69, 1)

The normalization of fuzzy decision matrix of alternatives has been performed using Eqs. (5) – (7) [Chapter 3]. For Cost criteria, for example, the normalized rating for the High Cost alternative ‘Underground Metro’ for criteria C1 (Operating Costs) has been given by:

$a_j = \min (1, 3, 1) = 1$, $\underline{r}_{ij} = (1/7, 1/3.25, 1/1) = (0.14, 0.31, 1)$

i

Table 4.18: Normalized Fuzzy decision matrix for Low Cost alternatives

Criteria	Alternatives		
	Bus (CNG conv.)	**Car (CNG conv.)**	**Walking/ Cycling**
C1	(0.11, 0.14, 0.33)	(0.11, 0.25, 1)	(0.11, 0.14, 0.33)
C2	(0.33, 0.75, 1)	(0.11, 0.58, 1)	(0.78, 1, 1)
C3	(0.11, 0.69, 1)	(0.11, 0.64, 1)	(0.56, 0.89, 1)
C4	(0.33, 0.72, 1)	(0.33, 0.81, 1)	(0.78, 1, 1)
C5	(0.11, 0.15, 0.33)	(0.11, 0.25, 1)	(0.11, 0.15, 1)
C6	(0.11, 0.19, 1)	(0.11, 0.21, 1)	(0.11, 0.17, 1)
C7	(0.11, 0.17, 1)	(0.11, 0.19, 1)	(0.11, 0.14, 0.33)
C8	(0.11, 0.18, 1)	(0.11, 0.21, 1)	(0.11, 0.14, 0.33)
C9	(0.11, 0.15, 0.33)	(0.11, 0.21, 1)	(0.11, 0.19, 1)
C10	(0.11, 0.44, 0.78)	(0.33, 0.83, 1)	(0.56, 0.92, 1)
C11	(0.33, 0.78, 1)	(0.11, 0.56, 1)	(0.56, 0.89, 1)
C12	(0.11, 0.64, 1)	(0.11, 0.58, 1)	(0.33, 0.81, 1)
C13	(0.33, 0.72, 1)	(0.11, 0.33, 0.78)	(0.56, 0.94, 1)
C14	(0.33, 0.78, 1)	(0.11, 0.61, 1)	(0.56, 0.83, 1)
C15	(0.11, 0.64, 1)	(0.33, 0.83, 1)	(0.33, 0.78, 1)
C16	(0.33, 0.78, 1)	(0.11, 0.58, 1)	(0.33, 0.72, 1)
C17	(0.33, 0.72, 1)	(0.11, 0.33, 0.78)	(0.33, 0.81, 1)
C18	(0.33, 0.83, 1)	(0.11, 0.28, 0.78)	(0.33, 0.64, 1)
C19	(0.33, 0.69, 1)	(0.33, 0.81, 1)	(0.56, 0.83, 1)
C20	(0.33, 0.72, 1)	(0.33, 0.81, 1)	(0.33, 0.83, 1)
C21	(0.33, 0.67, 1)	(0.33, 0.61, 1)	(0.33, 0.81, 10

For Benefit criteria, for example the normalized value of the Low Cost alternative 'Walking/ Cycling' for criteria C2 (Safety) has been computed as:

$c_j^* = \max (9, 9, 9) = 9$, $\underline{r}_{ij} = (7/9, 9/9, 9/9) = (0.78, 1, 1)$

i

In the next step, Table 4.17 and Table 4.18 have been used to compute fuzzy weighted normalized matrix correspondingly for High Cost and Low Cost alternatives and the computed outcome are presented below in Table 4.19 and Table 4.20 respectively.

Table 4.19: Weighted normalized High Cost alternatives, FPIS and FNIS

Criteria	Alternatives			FNIS (A^-)	FPIS (A^+)
	Metro	BRT	Skytrain		
C1	(0.14, 1.62, 9)	(0.11, 0.72, 3)	(0.14, 1.40, 90	(0.11, 0.11, 0.11)	(9, 9, 9)
C2	(0.33, 5.38, 9)	(0.33, 4.51, 9)	(0.56, 5.73, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C3	(0.33, 3.17, 9)	(0.33, 3.96, 9)	(0.33, 3.69, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C4	(0.33, 4.44, 9)	(0.56, 4.17, 9)	(0.33, 4.31, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C5	(0.11, 0.52, 1.8)	(0.11, 0.84, 9)	(0.11, 0.52, 3)	(0.11, 0.11, 0.11)	(9, 9, 9)
C6	(0.11, 0.52, 1.8)	(0.11, 0.64, 9)	(0.11, 0.7, 3)	(0.11, 0.11, 0.11)	(9, 9, 9)
C7	(0.14, 1.27, 9)	(0.11, 0.66, 3)	(0.11, 0.9, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C8	(0.14, 1.53, 19)	(0.11, 1.10, 9)	(0.11, 1, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C9	(0.11, 0.81, 3)	(0.11, 1.24, 9)	(0.11, 0.96, 3)	(0.11, 0.11, 0.11)	(9, 9, 9)
C10	(0.33, 4.38, 9)	(1.67, 6.25, 9)	(0.33, 4.58, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C11	(0.33, 5.44, 9)	(0.33, 5.44, 9)	(0.11, 4.13, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C12	(0.11, 1.85, 5.4)	(0.33, 3.30, 7)	(0.11,2.11, 5.4)	(0.11, 0.11, 0.11)	(7, 7, 7)
C13	(1, 4.86, 9)	(1, 5.64, 9)	(0.33, 4.47, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C14	(0.11, 2.72, 7)	(0.56, 5.27, 9)	(0.11, 2.4, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C15	(1, 5, 9)	(1, 4.33, 9)	(1, 4.17, 9)	(1, 1, 1)	(9, 9, 9)
C16	(0.33, 4.15, 9)	(0.33, 3.99, 9)	(0.11, 3.51, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C17	(0.56, 4.96, 9)	(0.33, 4.23, 9)	(0.33, 4.23, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C18	(1.67, 6.19, 9)	(1, 4.88, 9)	(1, 5.25, 9)	(1, 1, 1)	(9, 9, 9)
C19	(0.33, 4.08, 9)	(0.33, 4.38, 9)	(0.33, 3.94, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C20	(1.67, 5.11, 9)	(1, 4.15, 9)	(1.67, 5.27, 9)	(1, 1, 1)	(9, 9, 9)
C21	(0.33, 2.89, 9)	(0.33, 3.22, 9)	(0.33, 2.78, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)

For example, for the High Cost alternative ‘Underground Metro’, the fuzzy weight for criteria C1 (Operating costs) has been given by:

$$v_{ij} = (0.14, 0.31, 1) (\cdot) (1, 5.25, 9) = (0.14, 1.62, 9)$$

Likewise, fuzzy weights for both types of alternatives have been computed for the remaining criteria as well.

Table 4.20: Weighted normalized Low Cost alternatives, FPIS and FNIS

Criteria	Alternatives			FNIS (A^-)	FPIS (A^+)
	Bus (CNG conv.)	Car (CNG conv.)	Walking/ Cycling		
C1	(0.11, 0.75, 3)	(0.11, 1.31, 9)	(0.11, 0.72, 3)	(0.11, 0.11, 0.11)	(9, 9, 9)
C2	(0.33, 4.69, 9)	(0.11, 3.65, 9)	(0.78, 6.25, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C3	(0.11, 3.30, 9)	(0.11, 3.03, 9)	(0.56, 4.22, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C4	(0.33, 3.61, 9)	(0.33, 4.03, 9)	(0.78, 5, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C5	(0.11, 0.62, 3)	(0.11, 1, 9)	(0.11, 0.59, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C6	(0.11, 0.76, 9)	(0.11, 0.84, 9)	(0.11, 0.7, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C7	(0.11, 0.79, 9)	(0.11, 0.9, 9)	(0.11, 0.66, 3)	(0.11, 0.11, 0.11)	(9, 9, 9)
C8	(0.11, 1.05, 9)	(0.11, 1.21, 9)	(0.11, 0.79, 3)	(0.11, 0.11, 0.11)	(9, 9, 9)
C9	(0.11, 0.96, 3)	(0.11, 1.37, 9)	(0.11, 1.24, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C10	(0.33, 3.33, 7)	(1, 6.25, 9)	(1.67, 6.88, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C11	(0.33, 5.25, 9)	(0.11, 3.75, 9)	(0.56, 6, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C12	(0.11, 3.03, 7)	(0.11, 2.77, 7)	(0.33, 3.83, 7)	(0.11, 0.11, 0.11)	(7, 7, 7)
C13	(1, 5.06, 9)	(0.33, 2.33, 7)	(1.67, 6.61, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C14	(0.33, 4.47, 9)	(0.11, 3.51, 9)	(0.56, 4.79, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C15	(0.33, 3.83, 9)	(1, 5, 9)	(1, 4.67, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C16	(0.33, 4.47, 9)	(0.11, 3.35, 9)	(0.33, 4.15, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C17	(0.33, 3.79, 9)	(0.11, 1.75, 7)	(0.33, 4.23, 9)	(0.11, 0.11, 0.11)	(9, 9, 9)
C18	(1, 5.63, 9)	(0.33, 1.88, 7)	(1, 4.31, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C19	(0.33, 3.65, 9)	(0.33, 4.23, 9)	(0.56, 4.38, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)
C20	(1, 4.15, 9)	(1, 4.63, 9)	(1, 4.79, 9)	(1, 1, 1)	(9, 9, 9)
C21	(0.33, 2.67, 9)	(0.33, 2.44, 9)	(0.33, 3.22, 9)	(0.33, 0.33, 0.33)	(9, 9, 9)

In the following step, the fuzzy positive ideal solution (A^+) and the fuzzy negative ideal solution (A^-) have been computed using Eqs. (9) & (10)

[Chapter 3] and represented in Table 4.19 and Table 4.20 both for the High Cost and Low Cost alternatives respectively.

Then the distance d^+ of each alternative from the fuzzy positive ideal solution (A^+) and the distance d^- from the fuzzy negative ideal solution (A^-) has been computed and presented in Table 4.21 and Table 4.22 correspondingly for the High Cost and Low cost alternatives.

Table 4.21: Distances d^- (A_i, A^-) and d^+ (A_i, A^+) for High Cost alternatives

Criteria	d^-			d^+		
	Metro	**BRT**	**Skytrain**	**Metro**	**BRT**	**Skytrain**
C1	5.21	1.71	5.19	6.66	7.82	6.74
C2	5.79	5.56	5.90	5.42	5.63	5.23
C3	5.26	5.42	5.37	6.03	5.79	5.87
C4	5.54	5.47	5.50	5.65	5.62	5.69
C5	1.00	5.15	1.68	8.22	6.97	7.89
C6	1.00	5.14	1.70	8.22	7.05	7.83
C7	5.18	1.70	5.15	6.79	7.85	6.94
C8	5.20	5.16	5.16	6.69	6.87	6.90
C9	1.72	5.17	1.74	7.79	6.81	7.74
C10	5.52	6.11	5.57	5.67	4.52	5.62
C11	5.98	5.98	5.63	5.41	5.41	5.85
C12	3.24	4.38	3.29	5.05	4.40	4.96
C13	5.66	5.88	5.55	5.20	5.01	5.65
C14	4.25	5.94	5.30	6.39	5.33	6.39
C15	5.16	5.00	4.97	5.16	5.35	5.40
C16	5.64	5.60	5.50	5.73	5.78	6.03
C17	5.67	5.49	5.49	5.41	5.71	5.71
C18	5.52	5.13	5.23	4.53	5.20	5.10
C19	5.45	5.52	5.42	5.75	5.67	5.79
C20	5.21	4.96	5.25	4.79	5.40	4.75
C21	5.22	5.27	5.20	6.12	6.01	6.16

Note: A_i denotes the alternatives.

For example, for the High Cost alternative 'Underground Metro' and criteria C1 (Operating Costs) the distances d^- (A_i, A^-) and d^+ (A_i, A^+) have been computed as follows:

$$d^- (A_i, A^-) = [1/3\{(0.14 – 0.11)^2 + (1.62 – 0.11)^2 + (9 – 0.11)^2\}]^{1/2} = 5.21$$

$$d^+ (A_i, A^+) = [1/3\{(0.14 – 9)^2 + (1.62 – 9)^2 + (9 – 9)^2\}]^{1/2} = 6.66$$

Likewise, the distances for the remaining criteria for both types of alternatives have been computed.

From the above table, it could be understood that considering the distance values, Metro has been secured better positions with respect to criteria Security (C3), Reliability (C4), Air pollutants (C5), Noise (C6), Land usage (C9), Mobility (C15), Productivity (C16), Occupancy rate (C17) and Share in public transit (C18) based on the farthest distance from FNIS and Closest distance to FPIS for 'Benefit criteria' and vice-versa for the 'Cost criteria'. Similarly, BRT has been emerged out having better positions with respect to criteria Operating Costs (C1), Travel costs (C7), Accessibility (C10), Competency (C12), Equity (C13), Possibility of expansion (C14), Convenience to use (C19) and Tangibles (C21); while Skytrain has been come out with respect to criteria Safety (C2), Energy consumption (C8) and Quality of service (C20). However, criterion Benefits to economy (C11) has been securely positioned both by Metro and BRT.

Table 4.22: Distance d^- (A_i, A^-) and d^+ (A_i, A^+) for Low Cost alternatives

Criteria	**d^-**			**d^+**		
	Bus (CNG conv.)	**Car (CNG conv.)**	**Walking/ Cycling**	**Bus (CNG conv.)**	**Car (CNG conv.)**	**Walking/ Cycling**
C1	1.71	5.18	1.71	7.81	6.79	7.82
C2	5.77	5.52	6.25	5.59	5.99	5.01
C3	5.45	5.40	5.66	6.10	6.18	5.60

C4	5.35	5.44	5.69	5.89	5.77	5.28
C5	1.69	5.16	5.14	7.86	6.90	7.06
C6	5.15	5.15	5.14	7.00	6.97	7.02
C7	5.15	5.15	1.70	6.99	6.94	7.85
C8	5.16	5.17	1.71	6.89	6.82	7.80
C9	1.74	5.18	5.17	7.74	6.76	6.81
C10	4.22	6.07	6.32	6.09	4.88	4.41
C11	5.93	5.55	6.16	5.45	5.96	5.17
C12	4.32	4.26	4.52	4.59	4.67	4.26
C13	5.71	4.02	6.23	5.15	6.42	4.45
C14	5.72	5.50	5.81	5.65	6.03	5.45
C15	5.40	5.70	5.61	5.83	5.16	5.25
C16	5.72	5.46	5.64	5.65	6.08	5.73
C17	5.56	4.09	5.66	5.84	6.72	5.71
C18	5.88	3.95	5.52	5.01	6.58	5.35
C19	5.36	5.49	5.52	5.88	5.71	5.56
C20	4.96	5.07	5.11	5.40	5.26	5.22
C21	5.18	5.15	5.27	6.20	6.27	6.01

Note: A_i denotes the alternatives.

From the above table, it could be easily observed that in case of Low cost alternatives, Bus (CNG conversion) has been come out having better positions with respect to criteria Air pollutants (C5), Land usage (C9), Productivity (C16) and Share in public transit (C18) based on the farthest distance from FNIS and Closest distance to FPIS for 'Benefit criteria' and vice-versa for the 'Cost criteria'. Similarly, Car (CNG conversion) has been emerged securing better position with respect to only the criteria Mobility (C15); while Walking/Cycling has been appeared having better positions with respect to the remaining criteria such as Operating costs (C1), Safety (C2), Security (C3), Reliability (C4), Noise (C6), Travel costs (C7), Energy consumption (C8), Accessibility (C10), Benefits to economy (C11), Competency (C12), Equity (C13), Possibility of expansion (C14), Occupancy rate (C17), Convenience to use (C19), Quality of service (C20) and Tangibles (C21).

In the final step, Closeness coefficient (CC_i) has been computed for both type of alternative using Eqs. (11) – (13) [Chapter 3] and presented below in Table 4.23.

Table 4.23: Closeness coefficient of the alternatives

	High Cost alternatives			**Low Cost alternatives**		
	Metro	**BRT**	**Skytrain**	**Bus (CNG conv.)**	**Car (CNG conv.)**	**Walking/ Cycling**
d_i^-	98.42	105.8	99.77	101.12	107.7	105.5
d_i^+	126.7	124.2	128.2	128.58	128.9	122.8
CC_i	**0.437**	**0.460**	**0.438**	**0.440**	**0.455**	**0.462**

For example, for the High Cost alternative ‘Underground Metro’, the CC_i has been given by:

$CC_i = d_i^- / (d_i^- + d_i^+) = 98.42/ (98.42 + 126.7) = 0.437$; where d_i^- = sum of d^- and d_i^+ = sum of d^+ for each alternative.

By comparing the CC_i values for both categories of alternatives (Table 4.23), it has been found that for the High Cost alternatives BRT > Skytrain > Metro and for the Low Cost alternatives Walking/Cycling > Car (CNG conv.) > Bus (CNG conv.). Therefore, alternative BRT as High Cost alternative and Walking/Cycling as Low Cost alternative could be recommended as the paramount transportation options for the city.

4.2.1 Sensitivity Analysis

For investigating the impact of criteria weights (denoted by W_{Ci} for criteria C_i where i = 1, 2, 3, ..., n) on the priority of Green Transportation options, a sensitivity analysis has been performed. In total, Twenty-eight experiments have been conducted. The details of the 28 experiments have been presented in Table 4.24 and Table 4.25 correspondingly for High Cost and Low Cost alternatives.

Table 4.24: Experiments for Sensitivity Analysis (High Cost alternatives)

Sl. No.	Definition	Overall Score (CC_i)			Ranking
		H1	H2	H3	
Expt. 1	$W_{C1 - C21}$ = (1, 1, 3)	0.396	0.420	0.399	H2 > H3 > H1
Expt. 2	$W_{C1 - C21}$ = (1, 3, 5)	0.430	0.454	0.432	H2 > H3 > H1
Expt. 3	$W_{C1 - C21}$ = (3, 5, 7)	0.440	0.467	0.438	H2 > H1 > H3
Expt. 4	$W_{C1 - C21}$ = (5, 7, 9)	0.446	0.475	0.442	H2 > H1 > H3
Expt. 5	$W_{C1 - C21}$ = (7, 9, 9)	0.474	0.508	0.464	H2 > H1 > H3
Expt. 6	W_{C1} = (7, 9, 9), $W_{C2 - C21}$ = (1, 1, 3)	0.402	0.401	0.404	H3 >H1 > H2
Expt. 7	W_{C2} = (7, 9, 9), $W_{C1, C3 - C21}$ = (1, 1, 3)	0.412	0.431	0.421	H2 > H3 > H1
Expt. 8	W_{C3} = (7, 9, 9), $W_{C1 - C2, C4 - C21}$ = (1, 1, 3)	0.407	0.434	0.413	H2 > H3 > H1
Expt. 9	W_{C4} = (7, 9, 9), $W_{C1 - C3, C5 - C21}$ = (1, 1, 3)	0.412	0.438	0.415	H2 > H3 > H1
Expt. 10	W_{C5} = (7, 9, 9), $W_{C1 - C4, C6 - C21}$ = (1, 1, 3)	0.374	0.422	0.382	H2 > H3 > H1
Expt. 11	W_{C6} = (7, 9, 9), $W_{C1 - C5, C7 - C21}$ = (1, 1, 3)	0.374	0.421	0.383	H2 > H3 > H1
Expt. 12	W_{C7} = (7, 9, 9), $W_{C1 - C6, C8 - C21}$ = (1, 1, 3)	0.401	0.402	0.403	H3 >H2 > H1
Expt. 13	W_{C8} = (7, 9, 9), $W_{C1 - C7, C9 - C21}$ = (1, 1, 3)	0.401	0.422	0.402	H2 > H3 > H1
Expt. 14	W_{C9} = (7, 9, 9), $W_{C1 - C8, C10 - C21}$ = (1, 1, 3)	0.378	0.422	0.382	H2 > H3 > H1
Expt. 15	W_{C10} = (7, 9, 9), $W_{C1 - C9, C11 - C21}$ = (1, 1, 3)	0.409	0.447	0.412	H2 > H3 > H1
Expt. 16	W_{C11} = (7, 9, 9), $W_{C1 - C10, C12 - C21}$ = (1, 1, 3)	0.419	0.441	0.412	H2 > H1 > H3
Expt. 17	W_{C12} = (7, 9, 9), $W_{C1 - C11, C13 - C21}$ = (1, 1, 3)	0.398	0.438	0.403	H2 > H3 > H1
Expt. 18	W_{C13} = (7, 9, 9), $W_{C1 - C12, C14 - C21}$ = (1, 1, 3)	0.416	0.441	0.413	H2 > H1 > H3
Expt. 19	W_{C14} = (7, 9, 9), $W_{C1 - C13, C15 - C21}$ = (1, 1, 3)	0.400	0.449	0.407	H2 > H3 > H1
Expt. 20	W_{C15} = (7, 9, 9), $W_{C1 - C14, C16 - C21}$ = (1, 1, 3)	0.411	0.431	0.410	H2 > H1 > H3

Expt. 21	W_{C16} = (7, 9, 9), $W_{C1-C15, C17-C21}$ = (1, 1, 3)	0.417	0.438	0.412	H2 > H1 > H3
Expt. 22	W_{C17} = (7, 9, 9), $W_{C1-C16, C18-C21}$ = (1, 1, 3)	0.419	0.433	0.413	H2 > H1 > H3
Expt. 23	W_{C18} = (7, 9, 9), $W_{C1-C17, C19-C21}$ = (1, 1, 3)	0.418	0.431	0.413	H2 > H1 > H3
Expt. 24	W_{C19} = (7, 9, 9), $W_{C1-C18, C20-C21}$ = (1, 1, 3)	0.410	0.434	0.412	H2 > H3 > H1
Expt. 25	W_{C20} = (7, 9, 9), $W_{C1-C19, C21}$ = (1, 1, 3)	0.417	0.431	0.421	H2 > H3 > H1
Expt. 26	W_{C21} = (7, 9, 9), W_{C1-C20} = (1, 1, 3)	0.408	0.433	0.410	H2 > H3 > H1
Expt. 27	$W_{C1, C5-C9}$ = (7, 9, 9), $W_{C2-C4, C10-C21}$ = (1, 1, 3)	0.364	0.397	0.371	H2 > H3 > H1
Expt. 28	$W_{C1, C5-C9}$ = (1, 1, 3), $W_{C2-C4, C10-C21}$ = (7, 7, 9)	0.514	0.546	0.499	H2 > H1 > H3

In case of first five experiments, all criteria have been set equal to (1, 1, 3), (1, 3, 5), (3, 5, 7), (5, 7, 9) and (7, 9, 9) respectively. In experiments 6 – 26, the weight of one criterion has been set as highest (7, 9, 9) one by one and the remaining criteria have been set to the lowest value (1, 1, 3).

Table 4.25: Experiments for Sensitivity Analysis (Low Cost alternatives)

Sl. No.	**Definition**	**Overall Score (CC_i)**			**Ranking**
		L1	**L2**	**L3**	
Expt. 1	W_{C1-C21} = (1, 1, 3)	0.405	0.424	0.423	L2 > L3 > L1
Expt. 2	W_{C1-C21} = (1, 3, 5)	0.435	0.451	0.456	L3 > L2 > L1
Expt. 3	W_{C1-C21} = (3, 5, 7)	0.446	0.458	0.480	L3 > L2 > L1
Expt. 4	W_{C1-C21} = (5, 7, 9)	0.453	0.462	0.495	L3 > L2 > L1
Expt. 5	W_{C1-C21} = (7, 9, 9)	0.481	0.483	0.541	L3 > L2 > L1
Expt. 6	W_{C1} = (7, 9, 9), W_{C2-C21} = (1, 1, 3)	0.388	0.426	0.404	L2 > L3 > L1
Expt. 7	W_{C2} = (7, 9, 9), $W_{C1, C3-C21}$ = (1, 1, 3)	0.425	0.434	0.460	L3 > L2 > L1
Expt. 8	W_{C3} = (7, 9, 9), $W_{C1-C2, C4-C21}$ = (1, 1, 3)	0.420	0.435	0.451	L3 > L2 > L1
Expt. 9	W_{C4} = (7, 9, 9), $W_{C1-C3, C5-C21}$ = (1, 1, 3)	0.417	0.436	0.451	L3 > L2 > L1
Expt. 10	W_{C5} = (7, 9, 9), $W_{C1-C4, C6-C21}$ = (1, 1, 3)	0.388	0.426	0.423	L2 > L3 > L1

Expt. 11	W_{C6} = (7, 9, 9), $W_{C1-C5, C7-C21}$ = (1, 1, 3)	0.408	0.425	0.424	L2 > L3 > L1
Expt. 12	W_{C7} = (7, 9, 9), $W_{C1-C6, C8-C21}$ = (1, 1, 3)	0.407	0.425	0.404	L2 > L1 > L3
Expt. 13	W_{C8} = (7, 9, 9), $W_{C1-C7, C9-C21}$ = (1, 1, 3)	0.408	0.425	0.404	L2 > L1 > L3
Expt. 14	W_{C9} = (7, 9, 9), $W_{C1-C8, C10-C21}$ = (1, 1, 3)	0.388	0.425	0.424	L2 > L3 > L1
Expt. 15	W_{C10} = (7, 9, 9), $W_{C1-C9, C11-C21}$ = (1, 1, 3)	0.408	0.444	0.452	L3 > L2 > L1
Expt. 16	W_{C11} = (7, 9, 9), $W_{C1-C10, C12-C21}$ = (1, 1, 3)	0.426	0.433	0.451	L3 > L2 > L1
Expt. 17	W_{C12} = (7, 9, 9), $W_{C1-C11, C13-C21}$ = (1, 1, 3)	0.418	0.434	0.444	L3 > L2 > L1
Expt. 18	W_{C13} = (7, 9, 9), $W_{C1-C12, C14-C21}$ = (1, 1, 3)	0.425	0.422	0.453	L3 > L1 > L2
Expt. 19	W_{C14} = (7, 9, 9), $W_{C1-C13, C15-C21}$ = (1, 1, 3)	0.426	0.434	0.450	L3 > L2 > L1
Expt. 20	W_{C15} = (7, 9, 9), $W_{C1-C14, C16-C21}$ = (1, 1, 3)	0.418	0.444	0.443	L2 > L3 > L1
Expt. 21	W_{C16} = (7, 9, 9), $W_{C1-C15, C17-C21}$ = (1, 1, 3)	0.426	0.434	0.442	L3 > L2 > L1
Expt. 22	W_{C17} = (7, 9, 9), $W_{C1-C16, C18-C21}$ = (1, 1, 3)	0.425	0.422	0.444	L3 > L1 > L2
Expt. 23	W_{C18} = (7, 9, 9), $W_{C1-C17, C19-C21}$ = (1, 1, 3)	0.428	0.421	0.439	L3 > L1 > L2
Expt. 24	W_{C19} = (7, 9, 9), $W_{C1-C18, C20-C21}$ = (1, 1, 3)	0.416	0.436	0.441	L3 > L2 > L1
Expt. 25	W_{C20} = (7, 9, 9), $W_{C1-C19, C21}$ = (1, 1, 3)	0.417	0.435	0.436	L3 > L2 > L1
Expt. 26	W_{C21} = (7, 9, 9), W_{C1-C20} = (1, 1, 3)	0.415	0.431	0.436	L3 > L2 > L1
Expt. 27	$W_{C1, C5-C9}$ = (7, 9, 9), $W_{C2-C4, C10-C21}$ = (1, 1, 3)	0.373	0.431	0.384	L2 > L3 > L1
Expt. 28	$W_{C1, C5-C9}$ = (1, 1, 3), $W_{C2-C4, C10-C21}$ = (7, 7, 9)	0.520	0.493	0.597	L3 > L1 > L2

In experiment 27, the weights of all the ‘Cost’ category criteria have been set as highest i.e. criteria C1, C5 – C9 = (7, 9, 9) while the weights of the remaining criteria have been set to the lowest = (1, 1, 3). In experiment 28, the criteria weights have been set as the reverse of experiment 27. The results of the sensitivity analysis have been presented in Fig. 4.2 and Fig. 4.3 respectively for High Cost and Low Cost alternatives.

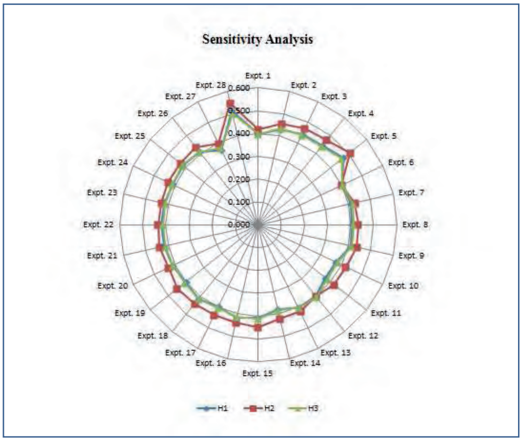


Fig. 4.2: Results of Sensitivity Analysis (High Cost alternatives)

From Table 4.24 and Fig. 4.2 it could be observed that for High Cost alternatives, alternative H2 (BRT) has been scored as highest in 26 experiments. In the remaining experiments (Exp. Nos. 6 & 12), alternative H3 (Skytrain) has been emerged as the winner.

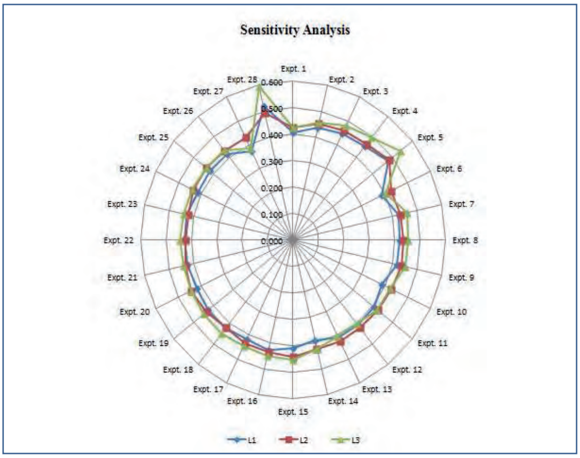


Fig. 4.3: Results of Sensitivity Analysis (Low Cost alternatives)

Similarly from Table 4.25 and Fig. 4.3 in the case of Low Cost alternatives, alternative L3 (Walking/Cycling) has been scored as highest in 19 experiments. In the remaining experiments (Exp. Nos. 1, 6, 10, 11, 12, 13, 14, 20 & 27), alternative L2 (Car – CNG conv.) has been sought as the winner.

Therefore for Dhaka megacity, BRT (for High Cost alternative) and Walking/Cycling (for Low Cost alternative) could be recommended as most prioritized Green Transportation options to be implemented.

4.3 Resemblance between AHP and Fuzzy TOPSIS analysis

For AHP approach, Five (5) broad criteria have been chosen to evaluate the selected Green Transportation options which cover various aspects such as economic, environmental, energy, technological and adoptability; while in the case of Fuzzy TOPSIS approach, Twenty-one (21) in-detail specific criteria like Operating costs, Travel costs, Air pollutants, Noise, Energy consumption, Land use, Benefits to economy etc. have been selected likely under the same aforementioned aspects. In total, Eight (8) experts have been confirmed who rated the alternatives with respect to the selected criteria for both approaches among whose Four (4) were national experts and the rest Four (4) were international experts (posing previous work experiences on Dhaka city as well) in transportation sectors along with energy and environmental issues. After the completion of the analysis of the same Experts' ratings by using both approaches an expected similarity has been emerged in choosing the best transportation options for both categories (High Cost and Low Cost) of alternatives; i.e. BRT has been sought as the most prioritized High Cost alternative while Walking/Cycling has been appeared as the most prioritized Low Cost alternative. However, in the case of AHP approach, 4 steps have been followed while for Fuzzy TOPSIS approach 9 steps have been followed to derive the decisive priority of the alternatives. The benefit of AHP approach was the simplicity of pairwise comparisons that helped to achieve priority rank for alternatives and also for the criteria; while the key strength of Fuzzy TOPSIS approach was reaching the priority rank even under uncertainty that left the criteria only with aggregate criteria weights rather than their rank. The overall scenario has been presented below in Table 4.26.

Table 4.26: Resemblance scenario between AHP and Fuzzy TOPSIS approach

<table>
<tr><th rowspan="2">Approach</th><th rowspan="2">Criteria</th><th colspan="2">No. of Expert</th><th colspan="2">Most prioritized alternative</th></tr>
<tr><th>National</th><th>International</th><th>High Cost</th><th>Low Cost</th></tr>
<tr><td>AHP</td><td>5</td><td rowspan="2">4</td><td rowspan="2">4</td><td>BRT</td><td>Walking/ Cycling</td></tr>
<tr><td>Fuzzy TOPSIS</td><td>21</td><td>BRT</td><td>Walking/ Cycling</td></tr>
</table>

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The effectiveness of the used approaches was that the assessment of the proposed Green Transportation alternatives has been done from two ways; i.e. one was Five broad criteria for applying the AHP method and another was Twenty-one individual specific criteria for applying the Fuzzy TOPSIS method. Although the Experts were from various grounds related to transport sector, the final evaluation showed a rationale decision that went to the same direction for both categories of alternatives; i.e. BRT has been chosen as the High Cost alternative and Walking/Cycling has been chosen as the Low Cost alternative for the city. In case of AHP analysis, among the five selected criteria, BRT has been scored higher priority values over other High Cost alternatives with respect to the criteria 'Economic Feasibility' 'Technological Availability' and 'Implementability'; while Walking/Cycling has been possessed higher priority values over other Low Cost alternatives with respect to all the five criteria. Similarly, regarding the Fuzzy TOPSIS analysis, among the twenty-one chosen criteria, BRT has been come out having better distance values with respect to eight criteria such as Operating Costs (C1), Travel costs (C7), Accessibility (C10), Competency (C12), Equity (C13), Possibility of expansion (C14), Convenience to use (C19) and Tangibles (C21) concerning the distances d^- and d^+ from Table 4.21; while Walking/Cycling alone has been sought having better distance values with respect to sixteen criteria such as Operating costs (C1), Safety (C2), Security (C3), Reliability (C4), Noise (C6), Travel costs (C7), Energy consumption (C8), Accessibility (C10), Benefits to economy (C11), Competency (C12), Equity (C13), Possibility of expansion (C14), Occupancy rate (C17), Convenience to use (C19), Quality of service (C20) and Tangibles (C21) regarding the distances d^- and d^+ from Table 4.22. Nevertheless, the ranking of all the alternatives slightly deviated from one method to another that reflects the variation of evaluation judged by experts from various grounds related to sustainable transportation. For example, for high cost alternatives, the ranking achieved from both the approaches seemed quite similar; while in case of low cost alternatives, the ranking achieved from AHP analysis sought more rational than the ranking reached by Fuzzy TOPSIS analysis. And the end result of this study could not been compared with other findings due to unavailability of exact similar studies.

However, the proposed approaches can be applied for different cities in evaluating and selecting suitable transportation systems as well. In that case, criteria should be cautiously selected considering the potential alternatives along with various aspects related to the concept of sustainability. For example, for the application of AHP approach, imitation or near imitation of any existing criteria must not be considered to avoid the situation of rank reversal; while for Fuzzy TOPSIS analysis, criteria should be chosen as specific as possible for in-depth analysis covering all related aspects. Additionally, due to the sensitiveness of decision making process in response to number of experts to be involved and their relevant expertise with the concerned ground, they should be carefully selected for any further research.

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APPENDICES

Appendix A: Expert Opinion Survey Format

This Questionnaire was a part of master student thesis under the program of Transportation Engineering, School of Engineering & Technology, Asian Institute of Technology (AIT), Thailand; on "Evaluating Green Transportation options for Dhaka Megacity using MCDA approach."

General Information

Name:
Age:
Sex:
Position:
Organization:
Email:

Survey 1: for AHP analysis

Goal: Prioritization of alternative green transport options for Dhaka Megacity			
Comparing Scale			**Selected Criteria**
Scale	**Intensity**		
1	Equal importance		Criteria -1: Energy efficiency
3	Moderate importance		Criteria -2: Emission reduction potential (ERP)
5	Strong importance		Criteria -3: Economic feasibility
7	Very strong importance		Criteria -4: Technological preparedness/ availability
9	Extreme importance		Criteria -5: Implementability/ adoptability
Intensities of 2, 4, 6 and 8 can be used to express intermediate values.			

Scoring pattern **LHS** **MIDDLE** **RHS**

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←					A						B					→

If 'A' is more important, use left hand side (LHS) of the scale.
If 'A' and 'B' are equally important, put tick mark on center portion (MIDDLE) of the scale (i.e. 1).
If 'B' is more important, use right hand side (RHS) of the scale.

Opinion – 1:

Which criterion is more important regarding "Prioritization of alternative green transport options for Dhaka Megacity"?

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←				Energy efficiency							ERP					→

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
				ERP							Economic feasibility					→

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←			Economic feasibility						Technological availability							→

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←			Technological availability						Implementability							→

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←			Energy efficiency						Economic feasibility							→

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←			ERP						Technological availability							→

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←			Energy efficiency						Technological availability							→

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←			Economic feasibility						Implementability							→

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←			Energy efficiency						Implementability							→

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←			ERP						Implementability							→

<u>Opinion – 2:</u>
Which alternative is more important regarding the criteria **"ENERGY EFFICIENCY"**?

[High Cost ALTERNATIVES]

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←			**Metro**						**BRT**							→

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←			**BRT**						**Skytrain**							→

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
←			**Metro**						**Skytrain**							→

[Low Cost ALTERNATIVES]

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Bus (CNG conv.)**									**Car (CNG conv.)** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Car (CNG conv.)**									**Walking/Cycling** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Bus (CNG conv.)**									**Walking/Cycling** →							

Opinion – 3:
Which alternative is more important regarding the criteria **"EMISSION REDUCTION POTENTIAL (ERP)"**?

[High Cost ALTERNATIVES]

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Metro**									**BRT** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **BRT**									**Skytrain** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Metro**									**Skytrain** →							

[Low Cost ALTERNATIVES]

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Bus (CNG conv.)**									**Car (CNG conv.)** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Car (CNG conv.)**									**Walking/Cycling** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Bus (CNG conv.)**									**Walking/Cycling** →							

Opinion – 4:
Which alternative is more important regarding the criteria **"ECONOMIC FEASIBILITY"**?

[High Cost ALTERNATIVES]

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Metro**									**BRT** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **BRT**									**Skytrain** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Metro**									**Skytrain** →							

[Low Cost ALTERNATIVES]

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Bus (CNG conv.)**									**Car (CNG conv.)** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Car (CNG conv.)**									**Walking/Cycling** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Bus (CNG conv.)**									**Walking/Cycling** →							

Opinion – 5:
Which alternative is more important regarding the criteria **"TECHNOLOGICAL AVAILABILITY"**?

[High Cost ALTERNATIVES]

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Metro**									**BRT** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **BRT**									**Skytrain** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Metro**									**Skytrain** →							

[Low Cost ALTERNATIVES]

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Bus (CNG conv.)**									**Car (CNG conv.)** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Car (CNG conv.)**									**Walking/Cycling** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Bus (CNG conv.)**									**Walking/Cycling** →							

Opinion – 6:
Which alternative is more important regarding the criteria **"IMPLEMENTABILITY/ ADOPTABILITY"**?

[High Cost ALTERNATIVES]

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Metro**									**BRT** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **BRT**									**Skytrain** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Metro**									**Skytrain** →							

[Low Cost ALTERNATIVES]

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Bus (CNG conv.)**									**Car (CNG conv.)** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Car (CNG conv.)**									**Walking/Cycling** →							

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
← **Bus (CNG conv.)**									**Walking/Cycling** →							

Survey 2: ***for fuzzy TOPSIS analysis***

Opinion – 1:

Please assign the following sustainability criteria in linguistic terms according to their weight preferences for selection of any sustainable transport options.

Sustainability Criteria	**Rating***				
	VL	**L**	**M**	**H**	**VH**
Operating costs (C1)					
Safety (C2)					
Security (C3)					
Reliability (C4)					
Air pollutants (C5)					
Noise (C6)					
Travel costs (C7)					
Energy consumption (C8)					
Land usage (C9)					
Accessibility (C10)					
Benefits to economy (C11)					
Competency (C12)					
Equity (C13)					
Possibility of expansion (C14)					
Mobility (C15)					
Productivity (C16)					
Occupancy rate (C17)					
Share in public transit (C18)					
Convenience to use (C19)					
Quality of service (C20)					
Tangibles (C21)					

* **VL** – Very Low, **L** – Low, **M** – Medium, **H** – High, **VH** – Very High.

Opinion – 2:

Please assign the performance (linguistic rating) of the following alternatives (high cost) with respect to the selected criteria.

Sustainability Criteria	Alternative Options Rating**														
	Metro					BRT					Skytrain				
	VP	P	F	G	VG	VP	P	F	G	VG	VP	P	F	G	VG
Operating costs (C1)															
Safety (C2)															
Security (C3)															
Reliability (C4)															
Air pollutants (C5)															
Noise (C6)															
Travel costs (C7)															
Energy consumption (C8)															
Land usage (C9)															
Accessibility (C10)															
Benefits to economy (C11)															
Competency (C12)															
Equity (C13)															
Possibility of expansion (C14)															
Mobility (C15)															
Productivity (C16)															
Occupancy rate (C17)															
Share in public transit (C18)															
Convenience to use (C19)															
Quality of service (C20)															
Tangibles (C21)															

** VP – Very Poor, P – Poor, F – Fair, G – Good, VG – Very Good.

Opinion – 3:

Please assign the performance (linguistic rating) of the following alternatives (low cost) with respect to the selected criteria.

Sustainability Criteria	Alternative Options Rating***														
	Bus (CNG converted)					Car (CNG converted)					Walking/Cycling				
	VP	P	F	G	VG	VP	P	F	G	VG	VP	P	F	G	VG
Operating costs (C1)															
Safety (C2)															
Security (C3)															
Reliability (C4)															
Air pollutants (C5)															
Noise (C6)															
Travel costs (C7)															
Energy consumption (C8)															
Land usage (C9)															
Accessibility (C10)															
Benefits to economy (C11)															
Competency (C12)															
Equity (C13)															
Possibility of expansion (C14)															
Mobility (C15)															
Productivity (C16)															
Occupancy rate (C17)															
Share in public transit (C18)															
Convenience to use (C19)															
Quality of service (C20)															
Tangibles (C21)															

*** VP – Very Poor, P – Poor, F – Fair, G – Good, VG – Very Good.

End of Surveys!

Appendix B: Data, Processed for AHP analysis

Opinion – 1:
Which criterion is more important regarding "Prioritization of alternative green transport options for Dhaka Megacity"?

Expert 1					
	EE	**ERP**	**EF**	**TA**	**IM**
EE	1	7	1/7	4	1/4
ERP	1/7	1	2	1/3	1/4
EF	7	1/2	1	2	8
TA	1/4	3	1/2	1	5
IM	4	4	1/8	1/5	1

Expert 2					
	EE	**ERP**	**EF**	**TA**	**IM**
EE	1	1	3	3	4
ERP	1	1	1/4	3	5
EF	1/3	4	1	8	8
TA	1/3	1/3	1/8	1	1/8
IM	1/4	1/5	1/8	8	1

Expert 3					
	EE	**ERP**	**EF**	**TA**	**IM**
EE	1	1	1/7	4	1/3
ERP	1	1	1/4	5	1/7
EF	7	4	1	5	1
TA	1/4	1/5	1/5	1	1/8
IM	3	7	1	8	1

Expert 4					
	EE	**ERP**	**EF**	**TA**	**IM**
EE	1	3	1	2	1/2
ERP	1/3	1	1/5	1/2	1/2
EF	1	5	1	4	4
TA	1/2	2	1/4	1	1
IM	2	2	1/4	1	1

Expert 5					
	EE	**ERP**	**EF**	**TA**	**IM**
EE	1	1	5	4	7
ERP	1	1	1/3	5	5
EF	1/5	3	1	7	1
TA	1/4	1/5	1/7	1	1/7
IM	1/7	1/5	1	7	1

Expert 6					
	EE	**ERP**	**EF**	**TA**	**IM**
EE	1	4	1/2	1	1/2
ERP	1/4	1	1/4	1/3	1/2
EF	2	4	1	1	0.5
TA	1	3	1	1	1/3
IM	2	2	2	3	1

Expert 7					
	EE	**ERP**	**EF**	**TA**	**IM**
EE	1	2	1/7	4	1/3
ERP	1/2	1	1/4	3	1/6
EF	7	4	1	4	1
TA	1/4	1/3	1/4	1	1/5
IM	3	6	1	5	1

Expert 8					
	EE	**ERP**	**EF**	**TA**	**IM**
EE	1	7	1	7	7
ERP	1/7	1	1	3	1/3
EF	1	1	1	1/5	1/4
TA	1/7	1/3	5	1	5
IM	1/7	3	4	1/5	1

Opinion – 2:
Which alternative is more important regarding the criteria **Energy Efficiency**?

[High Cost ALTERNATIVES]

Expert 1			
EE	Metro	BRT	Skytrain
Metro	1	1/5	1/4
BRT	5	1	5
Skytrain	4	1/5	1

Expert 2			
EE	Metro	BRT	Skytrain
Metro	1	5	6
BRT	1/5	1	5
Skytrain	1/6	1/5	1

Expert 3			
EE	Metro	BRT	Skytrain
Metro	1	5	4
BRT	1/5	1	1/3
Skytrain	1/4	3	1

Expert 4			
EE	Metro	BRT	Skytrain
Metro	1	1/8	7
BRT	8	1	9
Skytrain	1/7	1/9	1

Expert 5			
EE	Metro	BRT	Skytrain
Metro	1	5	1/3
BRT	1/5	1	1/7
Skytrain	3	7	1

Expert 6			
EE	Metro	BRT	Skytrain
Metro	1	2	2
BRT	1/2	1	1/2
Skytrain	1/2	2	1

Expert 7			
EE	Metro	BRT	Skytrain
Metro	1	4	5
BRT	1/4	1	1/3
Skytrain	1/5	3	1

Expert 8			
EE	Metro	BRT	Skytrain
Metro	1	1/5	3
BRT	5	1	5
Skytrain	1/3	1/5	1

[Low Cost ALTERNATIVES]

Expert 1			
EE	Bus. C	Car. C	W/C
Bus. C	1	6	4
Car. C	1/6	1	1/3
W/C	1/4	3	1

Expert 2			
EE	Bus. C	Car. C	W/C
Bus. C	1	8	5
Car. C	1/8	1	1/7
W/C	1/5	7	1

Expert 3			
EE	Bus. C	Car. C	W/C
Bus. C	1	7	1/9
Car. C	1/7	1	1/9
W/C	9	9	1

Expert 4			
EE	Bus. C	Car. C	W/C
Bus. C	1	9	2
Car. C	1/9	1	1/9
W/C	1/2	9	1

Expert 5			
EE	Bus. C	Car. C	W/C
Bus. C	1	5	1/3
Car. C	1/5	1	1/7
W/C	3	7	1

Expert 6			
EE	Bus. C	Car. C	W/C
Bus. C	1	2	1/2
Car. C	1/2	1	1/4
W/C	2	4	1

Expert 7			
EE	Bus. C	Car. C	W/C
Bus. C	1	5	1/7
Car. C	1/5	1	1/9
W/C	7	9	1

Expert 8			
EE	Bus. C	Car. C	W/C
Bus. C	1	7	1
Car. C	1/7	1	1/8
W/C	1	8	1

Opinion – 3:

Which alternative is more important regarding the criteria **Emission Reduction Potential?**

[High Cost ALTERNATIVES]

Expert 1			
EE	Metro	BRT	Skytrain
Metro	1	4	1/3
BRT	1/4	1	1/3
Skytrain	3	3	1

Expert 2			
EE	Metro	BRT	Skytrain
Metro	1	5	5
BRT	1/5	1	1/5
Skytrain	1/5	5	1

Expert 3			
EE	Metro	BRT	Skytrain
Metro	1	7	1/4
BRT	1/7	1	1/6
Skytrain	4	6	1

Expert 4			
EE	Metro	BRT	Skytrain
Metro	1	1	3
BRT	1	1	2
Skytrain	1/3	1/2	1

Expert 5			
EE	Metro	BRT	Skytrain
Metro	1	9	1
BRT	1/9	1	1/5
Skytrain	1	5	1

Expert 6			
EE	Metro	BRT	Skytrain
Metro	1	3	2
BRT	1/3	1	1/3
Skytrain	1/2	3	1

Expert 7			
EE	Metro	BRT	Skytrain
Metro	1	6	1/3
BRT	1/6	1	1/6
Skytrain	3	6	1

Expert 8			
EE	Metro	BRT	Skytrain
Metro	1	3	4
BRT	1/3	1	5
Skytrain	1/4	1/5	1

[Low Cost ALTERNATIVES]

Expert 1			
EE	Bus. C	Car. C	W/C
Bus. C	1	3	1/4
Car. C	1/3	1	1/5
W/C	4	5	1

Expert 2			
EE	Bus. C	Car. C	W/C
Bus. C	1	3	1/5
Car. C	1/3	1	1/6
W/C	5	6	1

Expert 3			
EE	Bus. C	Car. C	W/C
Bus. C	1	3	1/5
Car. C	1/3	1	1/6
W/C	5	6	1

Expert 4			
EE	Bus. C	Car. C	W/C
Bus. C	1	3	1/5
Car. C	1/3	1	1/7
W/C	5	7	1

Expert 5			
EE	Bus. C	Car. C	W/C
Bus. C	1	2	1/4
Car. C	1/2	1	1/5
W/C	4	5	1

Expert 6			
EE	Bus. C	Car. C	W/C
Bus. C	1	2	1/4
Car. C	1/2	1	1/4
W/C	4	4	1

Expert 7			
EE	Bus. C	Car. C	W/C
Bus. C	1	3	1/5
Car. C	1/3	1	1/7
W/C	5	7	1

Expert 8			
EE	Bus. C	Car. C	W/C
Bus. C	1	3	1
Car. C	1/3	1	1/9
W/C	1	9	1

Opinion – 4:
Which alternative is more important regarding the criteria **Economic Feasibility**?

[High Cost ALTERNATIVES]

Expert 1			
EE	Metro	BRT	Skytrain
Metro	1	4	1/3
BRT	1/4	1	1/4
Skytrain	3	4	1

Expert 2			
EE	Metro	BRT	Skytrain
Metro	1	1/5	5
BRT	5	1	5
Skytrain	1/5	1/5	1

Expert 3			
EE	Metro	BRT	Skytrain
Metro	1	1/9	1/5
BRT	9	1	8
Skytrain	5	1/8	1

Expert 4			
EE	Metro	BRT	Skytrain
Metro	1	1/8	5
BRT	8	1	9
Skytrain	1/5	1/9	1

Expert 5			
EE	Metro	BRT	Skytrain
Metro	1	1/3	3
BRT	3	1	7
Skytrain	1/3	1/7	1

Expert 6			
EE	Metro	BRT	Skytrain
Metro	1	2	1
BRT	1/2	1	1/2
Skytrain	1	2	1

Expert 7			
EE	Metro	BRT	Skytrain
Metro	1	1/7	1/5
BRT	7	1	8
Skytrain	5	1/8	1

Expert 8			
EE	Metro	BRT	Skytrain
Metro	1	1/9	1/5
BRT	9	1	9
Skytrain	5	1/9	1

[Low Cost ALTERNATIVES]

Expert 1			
EE	Bus. C	Car. C	W/C
Bus. C	1	5	3
Car. C	1/5	1	1/4
W/C	1/3	4	1

Expert 2			
EE	Bus. C	Car. C	W/C
Bus. C	1	5	4
Car. C	1/5	1	1/4
W/C	1/4	4	1

Expert 3			
EE	Bus. C	Car. C	W/C
Bus. C	1	7	1/7
Car. C	1/7	1	1/7
W/C	7	7	1

Expert 4			
EE	Bus. C	Car. C	W/C
Bus. C	1	9	1
Car. C	1/9	1	1/7
W/C	1	7	1

Expert 5			
EE	Bus. C	Car. C	W/C
Bus. C	1	5	1/9
Car. C	1/5	1	1/9
W/C	9	9	1

Expert 6			
EE	Bus. C	Car. C	W/C
Bus. C	1	3	1/4
Car. C	1/3	1	1/4
W/C	4	4	1

Expert 7			
EE	Bus. C	Car. C	W/C
Bus. C	1	7	1/7
Car. C	1/7	1	1/8
W/C	7	8	1

Expert 8			
EE	Bus. C	Car. C	W/C
Bus. C	1	8	1
Car. C	1/8	1	1/9
W/C	1	9	1

Opinion – 5:
Which alternative is more important regarding the criteria **Technological Availability**?

[High Cost ALTERNATIVES]

Expert 1			
EE	Metro	BRT	Skytrain
Metro	1	1/3	1/4
BRT	3	1	2
Skytrain	4	1/2	1

Expert 2			
EE	Metro	BRT	Skytrain
Metro	1	1/4	5
BRT	4	1	5
Skytrain	1/5	1/5	1

Expert 3			
EE	Metro	BRT	Skytrain
Metro	1	1/7	1
BRT	7	1	6
Skytrain	1	1/6	1

Expert 4			
EE	Metro	BRT	Skytrain
Metro	1	1/7	6
BRT	7	1	9
Skytrain	1/6	1/9	1

Expert 5			
EE	Metro	BRT	Skytrain
Metro	1	1/3	3
BRT	3	1	3
Skytrain	1/3	1/3	1

Expert 6			
EE	Metro	BRT	Skytrain
Metro	1	1/2	1
BRT	2	1	2
Skytrain	1	1/2	1

Expert 7			
EE	Metro	BRT	Skytrain
Metro	1	1/7	1
BRT	7	1	5
Skytrain	1	1/5	1

Expert 8			
EE	Metro	BRT	Skytrain
Metro	1	1/9	1
BRT	9	1	9
Skytrain	1	1/9	1

[Low Cost ALTERNATIVES]

Expert 1			
EE	Bus. C	Car. C	W/C
Bus. C	1	2	1/8
Car. C	1/2	1	1/8
W/C	8	8	1

Expert 2			
EE	Bus. C	Car. C	W/C
Bus. C	1	5	1
Car. C	1/5	1	1/5
W/C	1	5	1

Expert 3			
EE	Bus. C	Car. C	W/C
Bus. C	1	2	1/9
Car. C	1/2	1	1/9
W/C	9	9	1

Expert 4			
EE	Bus. C	Car. C	W/C
Bus. C	1	8	1/3
Car. C	1/8	1	1/8
W/C	3	8	1

Expert 5			
EE	Bus. C	Car. C	W/C
Bus. C	1	1/3	1/5
Car. C	3	1	1/5
W/C	5	5	1

Expert 6			
EE	Bus. C	Car. C	W/C
Bus. C	1	3	1/4
Car. C	1/3	1	1/4
W/C	4	4	1

Expert 7			
EE	Bus. C	Car. C	W/C
Bus. C	1	2	1/9
Car. C	1/2	1	1/9
W/C	9	9	1

Expert 8			
EE	Bus. C	Car. C	W/C
Bus. C	1	9	1/7
Car. C	1/9	1	1/9
W/C	7	9	1

Opinion – 6:
Which alternative is more important regarding the criteria **Implementability**?
[High Cost ALTERNATIVES]

Expert 1			
EE	Metro	BRT	Skytrain
Metro	1	1/8	1/3
BRT	8	1	4
Skytrain	3	1/4	1

Expert 2			
EE	Metro	BRT	Skytrain
Metro	1	1/5	1
BRT	5	1	5
Skytrain	1	1/5	1

Expert 3			
EE	Metro	BRT	Skytrain
Metro	1	1/9	1/3
BRT	9	1	8
Skytrain	3	1/8	1

Expert 4			
EE	Metro	BRT	Skytrain
Metro	1	1/7	6
BRT	7	1	9
Skytrain	1/6	1/9	1

Expert 5			
EE	Metro	BRT	Skytrain
Metro	1	1/3	3
BRT	3	1	5
Skytrain	1/3	1/5	1

Expert 6			
EE	Metro	BRT	Skytrain
Metro	1	1/2	1
BRT	2	1	1/2
Skytrain	1	2	1

Expert 7			
EE	Metro	BRT	Skytrain
Metro	1	1/7	1/3
BRT	7	1	4
Skytrain	3	1/4	1

Expert 8			
EE	Metro	BRT	Skytrain
Metro	1	1/9	1
BRT	9	1	9
Skytrain	1	1/9	1

Expert 1			
EE	Bus. C	Car. C	W/C
Bus. C	1	2	1/4
Car. C	1/2	1	1/5
W/C	4	5	1

Expert 2			
EE	Bus. C	Car. C	W/C
Bus. C	1	5	1
Car. C	1/5	1	1
W/C	1	1	1

Expert 3			
EE	Bus. C	Car. C	W/C
Bus. C	1	2	1/5
Car. C	1/2	1	1/5
W/C	5	5	1

Expert 4			
EE	Bus. C	Car. C	W/C
Bus. C	1	6	4
Car. C	1/6	1	1
W/C	1/4	1	1

Expert 5			
EE	Bus. C	Car. C	W/C
Bus. C	1	1	1
Car. C	1	1	1/3
W/C	1	3	1

Expert 6			
EE	Bus. C	Car. C	W/C
Bus. C	1	2	1/4
Car. C	1/3	1	1/4
W/C	4	4	1

Expert 7			
EE	Bus. C	Car. C	W/C
Bus. C	1	2	1/4
Car. C	1/2	1	1/5
W/C	4	5	1

Expert 8			
EE	Bus. C	Car. C	W/C
Bus. C	1	7	1
Car. C	1/7	1	1/9
W/C	1	9	1

Appendix C: Data, processed for Fuzzy TOPSIS analysis

<u>Opinion – 1:</u>
Please assign the following sustainability criteria in linguistic terms according to their weight preferences for selection of any sustainable transport options.

Criteria	Experts							
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**
Operating costs (C1)	M	L	M	H	M	VH	M	L
Safety (C2)	H	L	H	H	M	H	H	H
Security (C3)	M	L	L	M	M	H	M	M
Reliability (C4)	M	M	L	L	M	VH	L	H
Air Pollutants (C5)	L	M	L	VH	VL	M	L	L
Noise (C6)	L	M	L	H	L	M	L	L
Travel costs (C7)	H	L	H	VH	L	VH	H	L
Energy consumption (C8)	M	M	VH	VH	L	H	H	VL
Land Usage (C9)	H	H	H	M	VH	H	H	L
Accessibility (C10)	H	H	H	VH	M	VH	H	VH
Benefits to economy (C11)	M	H	M	H	VH	H	M	VH
Competency (C12)	M	M	L	M	M	M	M	M
Equity (C13)	H	H	H	VH	M	M	H	VH
Possibility of expansion (C14)	H	H	M	L	H	M	M	H
Mobility (C15)	M	H	M	H	M	H	M	H
Productivity (C16)	M	H	M	L	H	M	M	VH
Occupancy rate (C17)	L	H	VL	M	VH	H	L	H
Share in public transit (C18)	H	H	H	H	H	M	M	VH
Convenience to use (C19)	H	M	M	M	L	M	M	H
Quality of service (C20)	H	M	M	M	M	H	H	M
Tangibles (C21)	L	M	VL	L	M	H	L	M

Opinion – 2:
Please assign the performance (linguistic rating) of the following alternatives (high cost) with respect to the selected criteria.

Criteria	Alternative Options Rating							
	Metro							
	E1	E2	E3	E4	E5	E6	E7	E8
C1	VP	P	P	P	P	F	P	F
C2	G	F	VG	VG	G	VG	G	VG
C3	G	F	F	VG	F	F	F	G
C4	VG	F	VG	VG	G	VG	G	VG
C5	G	G	VG	G	G	VG	G	VG
C6	VG	G	VG	G	G	F	VG	VG
C7	VP	F	F	VP	F	P	F	F
C8	P	F	F	VP	F	P	P	F
C9	VG	G	G	F	VG	VG	VG	VG
C10	P	F	F	G	G	F	F	F
C11	G	F	VG	G	VG	G	VG	F
C12	VP	F	P	F	VP	F	P	F
C13	G	F	G	F	G	F	G	G
C14	P	F	F	P	P	F	F	F
C15	G	G	VG	VG	G	VG	G	F
C16	F	F	VG	G	F	G	G	G
C17	VG	G	VG	VG	VG	G	VG	VG
C18	VG	G	VG	G	VG	VG	VG	G
C19	F	G	VG	G	G	VG	F	G
C20	G	G	VG	G	VG	VG	G	VG
C21	F	G	G	G	F	G	G	G

Criteria	Alternative Options Rating							
	BRT							
	E1	E2	E3	E4	E5	E6	E7	E8
C1	G	G	G	VG	F	G	G	VG
C2	F	F	G	VG	F	G	G	G
C3	G	F	G	VG	VG	G	G	VG
C4	G	G	G	VG	G	G	VG	G
C5	P	F	F	G	P	F	P	G
C6	G	F	G	VG	P	G	F	G
C7	G	G	VG	G	F	G	G	VG
C8	F	G	P	G	F	F	P	G
C9	P	F	G	G	F	F	P	G

C10	G	G	G	G	VG	G	G	VG
C11	G	G	F	VG	F	VG	G	VG
C12	F	G	F	VG	F	G	F	G
C13	G	G	G	VG	F	G	G	VG
C14	G	G	VG	G	VG	VG	VG	VG
C15	F	G	F	G	G	G	F	VG
C16	G	G	F	G	F	F	F	VG
C17	G	G	G	VG	F	VG	F	VG
C18	F	G	F	VG	F	G	F	VG
C19	G	F	G	VG	VG	G	G	VG
C20	F	G	G	VG	F	G	G	F
C21	VG	G	G	VG	F	G	G	G

Criteria	**Alternative Options Rating**							
	Skytrain							
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**
C1	P	F	F	VP	P	P	F	F
C2	VG	G	G	VG	VG	VG	VG	G
C3	VG	G	F	G	G	G	G	G
C4	VG	F	G	G	VG	VG	G	VG
C5	VG	G	G	VG	F	VG	G	VG
C6	F	G	G	F	F	F	G	F
C7	P	F	G	P	G	G	F	F
C8	F	F	G	P	G	G	F	G
C9	G	G	F	F	VG	G	F	VG
C10	F	F	G	P	F	G	G	F
C11	F	F	G	P	G	G	F	F
C12	VP	F	P	F	F	F	P	F
C13	F	F	G	P	G	F	G	G
C14	P	P	F	VP	P	F	F	F
C15	F	F	G	G	G	VG	F	F
C16	G	P	F	P	G	G	F	G
C17	F	F	G	G	VG	VG	G	VG
C18	G	F	G	F	VG	VG	G	G
C19	F	G	VG	F	G	VG	G	F
C20	VG	G	VG	G	VG	VG	VG	G
C21	F	G	G	F	F	G	G	G

Opinion – 3:
Please assign the performance (linguistic rating) of the following alternatives (high cost) with respect to the selected criteria.

Criteria	Alternative Options Rating							
	Bus (CNG Conversion)							
	E1	E2	E3	E4	E5	E6	E7	E8
C1	F	VG	G	VG	G	G	F	G
C2	G	F	F	VG	F	G	G	VG
C3	G	F	F	G	P	G	G	VG
C4	VG	G	F	F	F	G	G	G
C5	G	G	F	VG	G	F	G	F
C6	G	F	F	G	F	F	F	P
C7	P	G	F	G	F	G	G	G
C8	P	F	G	F	F	G	G	F
C9	F	G	G	VG	G	F	G	G
C10	VP	P	F	F	P	F	F	F
C11	F	G	F	VG	F	VG	G	VG
C12	P	G	F	G	F	G	F	G
C13	F	G	F	VG	F	G	F	VG
C14	F	G	VG	VG	F	G	G	G
C15	P	G	G	G	P	F	G	G
C16	G	G	F	G	G	VG	F	VG
C17	F	F	F	VG	F	G	G	VG
C18	G	G	G	VG	F	VG	G	VG
C19	F	G	G	F	F	G	G	G
C20	VG	F	G	F	F	G	G	G
C21	F	G	F	G	F	G	F	G

Criteria	Alternative Options Rating							
	Car (CNG Conversion)							
	E1	E2	E3	E4	E5	E6	E7	E8
C1	P	G	P	F	P	F	P	P
C2	F	F	P	G	F	G	F	F
C3	P	F	F	G	G	G	F	G
C4	G	F	VG	G	G	VG	G	G
C5	F	G	VP	F	P	F	F	VP
C6	G	F	P	F	G	F	P	P
C7	F	G	G	P	G	F	F	P
C8	G	F	G	F	P	F	P	P
C9	F	F	F	P	G	F	F	P

C10	F	G	VG	G	VG	VG	G	G
C11	G	G	F	F	P	F	F	P
C12	P	G	F	F	G	G	F	P
C13	P	F	P	VP	F	F	VP	VP
C14	P	F	F	G	P	G	G	G
C15	G	G	VG	G	F	G	VG	VG
C16	G	G	G	F	F	G	VP	P
C17	P	P	VP	P	VP	F	F	P
C18	F	P	VP	P	VP	F	VP	VP
C19	G	G	F	G	F	VG	VG	VG
C20	G	F	G	G	G	VG	G	VG
C21	F	G	F	F	F	G	F	F

Criteria	**Alternative Options Rating**							
	Walking/ Cycling							
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**
C1	G	G	F	VG	F	VG	G	VG
C2	VG	VG	VG	VG	VG	VG	VG	VG
C3	VG	VG	VG	VG	G	G	G	G
C4	VG	VG	VG	VG	VG	VG	VG	VG
C5	G	F	F	VG	P	VG	VG	G
C6	G	G	P	G	P	F	G	G
C7	F	G	G	G	G	G	VG	VG
C8	F	G	F	G	G	VG	VG	VG
C9	G	F	P	G	P	F	G	F
C10	G	VG	VG	VG	G	VG	G	VG
C11	G	VG	VG	G	G	VG	G	VG
C12	VG	VG	F	G	G	VG	F	G
C13	VG	VG	VG	VG	VG	G	G	VG
C14	G	G	G	G	G	VG	G	VG
C15	G	G	F	G	F	G	VG	VG
C16	G	G	G	F	F	F	G	VG
C17	G	G	G	G	G	VG	F	VG
C18	F	F	G	G	F	G	F	F
C19	G	G	G	G	VG	VG	G	G
C20	VG	G	G	VG	G	VG	G	F
C21	G	G	G	G	G	VG	F	VG

Appendix D: Random Consistency Index (R.I)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Source: Analytic Hierarchy Process (AHP) Tutorial. Web: http://people.revoledu.com/kardi/tutorial/AHP/