PUBLIC TRANSPORT

Analysis for Urban Transportation Interventions in Vijayawada, Andhra Pradesh

Cost-Benefit Analysis

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ANDHRA PRADESH PRIORITIES — AN INDIA CONSENSUS PRIORITIZATION PROJECT

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This work has been produced as a part of the Andhra Pradesh Priorities project under the larger, India Consensus project.

This project is undertaken in partnership with Tata Trusts.

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Cost Benefit Analysis for Urban Transportation Interventions in Vijayawada

Andhra Pradesh Priorities

An India Consensus Prioritization Project

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Working draft as of May 18, 2018

IL&FS Academy of Applied Development

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List of Abbreviations

- APSRTC: Andhra Pradesh State Road Transport Corporation
- BCR: Benefit-cost ratio
- BOT: Built, Operate & Transfer
- BRT: Bus Rapid Transit
- BRTS: Bus Rapid Transit System
- CRDA: Capital Region Development Authority
- DALY: Disability Adjusted Life Years
- DMRC: Delhi Metro rail Corporation
- DPR: Detailed Project Report
- GHG: Greenhouse Gases
- GoAP: Government of Andhra Pradesh
- EIRR: Economic Internal Rate of Return
- FIRR: Financial Internal Rate of Return
- IL&FS: Infrastructure Leasing and Financial Services Limited
- IPT: Intermediate public transport
- IRR: Internal Rate of Return
- Km/hr: Kilometer per hour
- MoUD: Ministry of Urban Development, Government of India
- MTS: Mass Transit System
- NH: National Highways
- NPV: Net Present Value
- PHPDT: Per Hour Per Direction Of Traffic
- PM: Particulate Matter
- SPM: Suspended Particulate Matter
- SPV: Special Purpose Vehicle
- Sq. Km: Square Kilometer
- ULED: Ultra-Low Emission Discount
- VOC: Vehicle Operating Cost

Academic Abstract

Vijayawada, a city in the Andhra Pradesh Capital Region, has witnessed rapid growth in vehicular traffic and air population in the last few years, especially after the announcement to develop Amaravati as the new capital of Andhra Pradesh. This paper has been developed to test alternative options, in particular, to examine development of comprehensive green urban mass transport network to reduce emphasis on low-capacity private modes, such as cars and motor-cycles, and significantly bring down their share in passenger traffic to 20 percent by 2052. Two options were studied and analyzed:

- **Metro with Feeder Network**: Developing two metro rail elevated routes with total 26 km of length along with sufficient electric feeder bus services and electric intermediate public transport (IPT) to serve 50 percent of the city passenger traffic by metro rail services thereby serving a total 80 percent of passenger traffic by public transport by 2052.
- **Dedicated Bus corridor with Electric Public Transport:** Developing two elevated bus rapid transit (BRT) routes of 26 km, same as proposed metro rail routes, along with sufficient electric feeder bus services and electric IPT to serve 50 percent of the city passenger traffic by BRT thereby serving a total 80 percent of passenger traffic by electric bus and Intermediate Public Transport (IPT) services by 2052.

Benefit-cost ratio (BCR) was estimated for the above two options to quantify their relative merits. The BCR (benefit-cost ratio) for Metro Rail intervention 3.28 and for Elevated BRT was 4.03 at 5 per cent discount rate. Both the interventions are economically viable but benefits are higher in the second case.

Policy Abstract

The Problem

Vijayawada, previously known as Bezawada, is the second largest city of the newly formed state of Andhra Pradesh. As per the census of 2011, the population of Vijayawada Municipal Corporation area was more than 10 lakh with population density of 16,939 per square km. However, population density has increased significantly to 23,700 per sq. km in 2018 .

Being a business and agricultural capital of the state, there is significant floating population as well. The city is well connected with the rest of the country by National Highways (NH). The roads in the city are of moderate width, with only few km of four lane and generally congested. Benz Circle (at the intersection of NH 5 and NH 9) is the busiest area in the city. The average speed of the vehicular traffic in the city is about 25 km per hour (km/hr) .

In recent years, city has witnessed rapid growth in vehicle population following increase in population density. Also, there is an increase in economic activity in Vijayawada due to construction of the new capital Amaravati. The local economy of Vijayawada is expected to reach $17 bn by 2025, a six fold increase over 2010 level . Between FY16 and FY17, the population of motorbikes and car in the city has increased by 73 per cent and 40 per cent respectively. Also, vehicles used for transporting goods have seen a significant increase by 15 per cent during the same period . Most importantly, the air pollution levels (PM_{10}) in the city have increased consistently in the last five years from 90 ug/m3 in 2011 to 110 ug/m3 in 2015, which was almost double compared to the national average of 60 ug/m3 . Thus, growth in number of private vehicles, traffic congestion and mounting city pollution are the major challenges faced by the city.

The city has limited public transport system due to high land cost and reluctance of the public to part with their lands . As a result, widening of roads to accommodate mass transit system (MTS) at road level is difficult. To resolve the issue of traffic problem, solutions can broadly be categorized into two categories:

Change in city planning and infrastructure: Prioritizing buses and other public transport at junctions, 'queue-jumps' and other traffic management measures to ensure that they are not slowed down by congestion and offer a reliable service. Policy enforcement to mandate private off-street parking, developing walking infrastructure for pedestrians and increase in penalties for traffic and parking rule violation can also address the traffic problem.

Change in Traffic Rules: Identifying congestion charge zone, higher vehicle registration tax on the second vehicle, introduction of ultra-low emission discount (ULED) to curb the growing number of diesel and petrol vehicles can help the state government/ transport authority curb traffic congestion and to raise investment funds for developing Vijayawada's transport system.

In this light, this research paper examines development of comprehensive green urban mass transport network to reduce emphasis on low-capacity private modes and significantly bring down their share in passenger traffic to 20 percent by 2052. Two options were studied and analyzed: metro with feeder network and dedicated bus corridor with electric public transport.

Intervention 1: Metro Rail

Overview

Two elevated metro corridors with 25 stations and total length of 26 km were considered to cater 50 percent of the city population by 2052. Additionally, the intervention aims to offer adequate bus services and IPT to bring down the dependency on private mode of transport to 20 percent by 2052. This intervention will address the major challenges such as traffic congestion, mounting pollution, etc. as development of comprehensive green urban mass transport network is crucial considering the rapid population growth of Vijayawada. Further, considering the population growth of the city, a medium capacity metro system with per hour per direction of traffic (PHPDT) of 30,000 to 45,000 is considered as it will help in serving the future traffic needs of the city.

Implementation Considerations

The project will be implemented with funding from Central/State government or multinational funding agencies such as ADB, World Bank, JICA and IMF. The project can be implemented through a Special Purpose Vehicle under the State Government Control or through BOT (Built, Operate & Transfer) model. It is assumed that the construction of the project will start in 2019 and the metro rail will be operational from the beginning of 2023. The project life is considered to be 30 years. Infrastructure projects with long life cycle, are exposed to various kind of risks including economic, financial, social and political. Cost overruns, delays and failed procurement are common in nature.

Quality of Information: The overall quality of information for this intervention is medium to strong. As most of the data are sourced from Vijayawada metro Detailed Project Report and e-mobility report by Niti Aayog, which has been validated with sectorial experts.

Costs and Benefits

Costs

Key cost items include capex and opex cost of metro rail, feeder bus, carbon cost due to energy generation and social cost of disruption during the construction phase. Summary of cost in case of Metro rail Intervention is presented in **Table 1** below.

Table 1: Summary of Cost in Metro Rail Intervention

Items	Costs Incurred (INR Bn)
Direct Cost	
Capex for Metro	64.0
Capex for Metro Feeder and IPT	33.0
Opex for Metro	31.3
Opex for Metro Feeder and IPT	20.5
Indirect Cost	
Carbon cost due to energy generation for metro	2.7
Social cost of disruption due to construction	49.9
Total	**201.5**

Source: Author's calculation; Notes: All figures assume a 5% discount rate

Benefits

The potential direct benefits from the intervention include revenue (ticket and non-ticket) for metro and feeder bus and last-mile connectivity services, fuel cost savings of feeder bus and salvage value. Indirect Benefits include annual time cost saved by both metro passengers and non users, annual vehicle operating cost (VOC) saved by metro passengers, value of DALY avoided due to air pollution emission reduction, savings due to accidents avoided, carbon cost savings of feeder bus and last-mile connectivity services. Summary of benefits in case of Metro rail Intervention is presented in **Table 2** below.

Table 2: Summary of Benefits from Metro Rail Intervention

Items	Benefits Accrued (INR Bn)
Direct Benefits	
Revenue from Metro	180.0
Revenue from Metro Feeder	143.8
Fuel Cost Savings from Metro Feeder	7.6
Salvage Value	12.4
Indirect Benefits	
Annual Time Cost Saved by Metro Passengers	197.9
Annual VOC Saved	24.8
Carbon Cost Savings Metro	0.9
Carbon Cost Savings Metro Feeder	0.3
Accident Cost Savings Metro	9.0
Annual Time Cost Saved by Non-users	44.0
Value of DALY Avoided due to air pollution reduction	41.1
Total	**661.8**

Source: Author's calculation; Notes: All figures assume a 5% discount rate

Thus the BCR for intervention 1 was 3.28 at 5% discount rate.

Intervention 2: Elevated Bus Rapid Transit (BRT)

Overview

In this intervention, two elevated BRT corridors with total length of 26 km, same as proposed metro route, is considered to cater 50 percent of the city population by 2052. Additionally, the intervention aims to offer adequate bus services and IPT to bring down the dependency on private mode of transport to 20 percent by 2052. The requirement of bus services and IPT is estimated based on the LOS 2 (Level of service) benchmark set by Ministry of Housing and Urban Affairs for urban transport for Indian cities. The LOS defines the extent of supply/availability of public transport depending on various factors including city population, accessibility and average trip length among others.

Implementation Considerations

The project will be implemented with funding from Central/State government or multinational funding agencies such as ADB, World Bank, JICA and IMF. The project can be implemented through a Special Purpose Vehicle under the State Government Control or through BOT (Built, Operate & Transfer) model. It is assumed that the construction of the project will start in 2019 and from the beginning of 2023 the metro rail project will be operational by 2023. The project life is considered to be 30 years. Being an infrastructure project with long life cycle, the intervention is exposed to various kind of risks including economic, financial, social and political. Cost overruns, delays and failed procurement are most common.

Quality of Information: The overall quality of information for this intervention is medium to strong. As most of the data are sourced from Vijayawada metro Detailed Project Report, UMTC experience on elevated BRT at Chandigarh and e-mobility report by Niti Aayog, which has been validated with sectorial experts.

Costs and Benefits

Costs

Key cost items include capex and opex cost of BRT structure, e-transport and social cost of disruption during construction phase. Summary of cost in case of Elevated BRT Intervention is presented in **Table 3** below.

Table 3: Summary of Cost in Elevated BRT Intervention

Items	Costs incurred (INR Bn)
Direct Cost	
Capex for BRT infrastructure (excluding buses)	18.4
Capex for E-Transport	93.0
Opex for BRT infrastructure (excluding buses)	18.2
Opex for Feeder and IPT	20.6
Indirect Cost	
Social cost of disruption due to construction	14.4
Total	164.6

Source: Author's calculation; Notes: All figures assume a 5% discount rate

Benefits

The potential direct benefits from the intervention includes revenue (from BRT buses, other buses, and last-mile connectivity services), fuel cost savings from e-public transport and salvage value. Indirect Benefits include annual time cost saved by BRT passengers and non-users, annual VOC saved by BRT passengers, value of DALY avoided due to air pollution reduction, savings due to accidents avoided, and carbon cost savings of e-public transport. Summary of benefits in case of Elevated BRT Intervention is presented in Table 4 below.

Table 4: Summary of Benefits from Elevated BRT Intervention

Items	Benefits accrued (INR Bn)
Direct Benefits	
Revenue from BRT Bus	180.0
Revenue from Other Bus	37.8
Revenue from Electric Rickshaw	59.0
Revenue from Electric Cab	47.0
Fuel Cost Savings from e-public transport	7.6
Salvage Value	19.4
Indirect Benefits	
Annual Time Cost Saved by BRT Passengers	197.9
Annual VOC Saved by BRT Passengers	24.8
Carbon Cost Savings from e-public transport	0.8
Accident Cost Savings BRT	4.5
Annual Time Cost Saved by non users	44.0
Value of DALY Avoided due to air pollution reduction	41.1
Total	**663.8**

Source: Author's calculation; Notes: All figures assume a 5% discount rate

Thus, the BCR for this intervention was 4.03 at 5% discount rate.

BCR Table

The BCR for metro rail intervention at 5 per cent discount rate is 3.28 and for elevated BRT intervention is 4.03 (**Table 5**). Therefore, we can conclude that the intervention to develop metro with feeder network and elevated BRT both are economically viable.

Table 5: Summary of Benefit, Cost and BCR

Interventions	Benefit (INR Bn)	Cost (INR Bn)	BCR	Quality of Evidence
Metro Rail	662	201	3.28	Medium to strong
Elevated BRT	664	165	4.03	Medium to strong

Source: Author's calculation; Notes: All figures assume a 5% discount rate

1. Introduction

Urban areas are the hub of innovations and heart of socio-technical transitions, but are also responsible for 64% of global primary energy use and produced 70% of the planet's carbon dioxide emissions . In India, on-road vehicle movement is one of the major contributors to the challenges of urban air quality. Transportation sector contributes 30 per cent to 50 of total particulate matter (PM) in six cities—Delhi, Kanpur, Bangalore, Pune, Chennai and Mumbai . Additionally, an analysis of State-level Disease Burden listed outdoor air pollution as the 2nd biggest health hazard in 2016 . Hence, there is an urgent need to reduce emissions from the transport sector through introduction of the efficient vehicles and high quality transport system.

Indian cities witnessed fast growth in the ownership of private vehicles, which resulted in increased road congestion, fuel emissions, and pollution. There has been a growing awareness within the government of the need to promote and develop a sustainable transport system. As a result, a number of initiatives were launched, including a national urban transport policy; shift towards mass transit projects to address the infrastructural and environmental issues related to increasing vehicular population and limited road space. Nevertheless, a number of concerns remain in governance of urban transport including the choice of mass transit projects and issues regarding financial viability and inclusiveness.

Absence of one central rule or act to govern the urban transport and nonexistence of an overarching set of rules that govern the functioning of the multiple agencies (e.g. Regional Transport Authority, Traffic Police, State Pollution Control Board, etc.) made the situation more complex. For example, the implementation and monitoring of urban transportation in Andhra Pradesh involves multiple agencies. These agencies can be broadly classified into three groups:

- First, agencies responsible for urban transport that decide the nature of investments in transport projects such as the urban development department (UDD), Andhra Pradesh, Directorate of Town and Country Planning, Andhra Pradesh Capital Region Development Authority (APCRDA) Andhra Pradesh Urban Finance and Infrastructure Development Corporation (APUFIDC), and transport department

- Second, urban local bodies (ULBs) that are responsible for land-use planning and construction, and maintenance of city road infrastructure, that is Vijayawada Municipal Corporation (VMC) and mass transit operators Andhra Pradesh State Road Transport Corporation (APSRTC)
- Third, agencies that are indirectly part of the decision-making process, which includes the Infrastructure Corporation of Andhra Pradesh (INCAP), National Highways Authority of India (NHAI), State Pollution Control Board, traffic police and consultants.

The co-ordination among these institutions remains a major challenge, considering the fact that urban transport itself is a diverse domain, with different ministries in charge of different aspects. Availability of clear, transparent, and timely information also remains a challenge. Further, considering urban transport is largely a state subject, there is little scope for non-state players to be formally part of the decision-making process. As a result, in absence of comprehensive polycentric governance framework (i.e. lack of stakeholder consultation/citizen-participation, nonexistence of comprehensive alternative analysis and absence of autonomous decision-making centres) an apparent favoritism towards “big ticket” was observed.

Private cars and two-wheelers dominate road traffic in Vijayawada city creating congestion on roads. The city has historically been a pioneer in introducing CNG buses in South India and was one of the first to implement the system of Bus Rapid Transit System (BRTS). The city also has fourth largest and busiest bus terminals in India, the Pandit Nehru Bus Station. State run Andhra Pradesh State Road Transport Corporation (APSRTC) buses are operated from this terminal. APSRTC runs more than 450 city buses in the city which include Ordinary, Metro Express and City Sheetal (Air Conditioned Buses). Private bus operators with a large fleet of buses also provide transport services. Motor-driven auto-rickshaws and cycle rickshaws are the other supplementary means of transport. As per Vijayawada Mero rail Detailed Project Report (DPR) prepared in 2015, the total number of vehicles registered in the district is 87,513. There are 9,700 goods vehicles, 1,598 taxi cars, 25,432 private cars, 42,300 two wheelers, 8,765 auto rickshaws and 1,674 buses. Of the above, in each category nearly 80% of vehicles operate within the city.

However, the recent increase in economic activity due to the development of Amaravati as new capital of the state, has increased the air pollution levels. The local economy of Vijayawada is expected to increase from $3 bn in 2010 to $17 bn by 2025 . A study by Pollution Control Board of Andhra Pradesh reveals that pollution levels are increasing due to increasing number of vehicles travelling on the city roads. It is estimated as many as 7.10 lakh vehicles (including floating vehicle population) are moving on city roads daily. . The Suspended Particulate Matter (SPM) level in the city was 115 mg (micron grams) on an average in 2017, higher than the maximum permissible limit of 100 mg per cubic meter. There is a consistent increase in SPM level. In 2011, it was around 90 ug/m3 in 2011 and increased to 97 ug/m3 in 2012. It crossed the 100-mark (104 ug/m3) in 2014 and touched 110 ug/m3 in 2015, which was almost double than the national average of 60 ug/m3 .

Several measures have been initiated by capital region development authority (CRDA) to make the region a green-blue city, including plans for electric city bus services by APSRTC and electric vehicles for garbage disposal, among others. However, there is a need to introduce a comprehensive green mass public transportation plan to address the growing traffic congestion and pollution problem of the city.

The city also has limited public transport system other than bus services due to high land cost and reluctance of the public to part with their lands . As a result, widening of roads to accommodate mass transit system at road level is difficult. Thus, to resolve the issue of traffic problem, an elevated MTS was considered as most appropriate option. The options include the following:

i) Conventional Metro Rail System, either elevated or underground
ii) Mono Rail System
iii) Maglev System
iv) Elevated electric BRT system

The present research paper has not considered Maglev System due to its high cost and technology related challenges. A Mono Rail System was also eliminated due to very high capital and O&M cost, approximately 30 percent to 50 percent more than a conventional metro system . Therefore, the choice of Mass Transit System was narrowed down to a Metro System or elevated electric BRT system. Additionally, in order to make the interventions successful, a holistic approach to improve the existing public transport facilities has been adopted by including provision of energy efficient feeder bus and IPT services as well as adequate charging infrastructure facilities along with above mentioned intervention.

1.1 Theory

To evaluate the potential socio-economic impact of different interventions, study has adopted Cost Benefit Analysis (CBA) approach. This approach is widely used to evaluate and compare various programs in policy discussions around the world. In this approach, incremental benefits are compared with the cost of the investment to determine if the benefits exceed the costs. BCR is measured as ratio of discounted present value of interventions benefits to the discounted present value of interventions costs expressed as:

$$BCR = \frac{\sum_{i=1}^{n} \frac{(B_t)}{(1+r)^t}}{\sum_{i=1}^{n} \frac{(C_t)}{(1+r)^t}}$$

Here, B, C, r and t denote benefit, cost, discount rate and time frame of the project (t = 1,..., n), respectively. The discount rate was used to calculate net present value for costs and benefits.

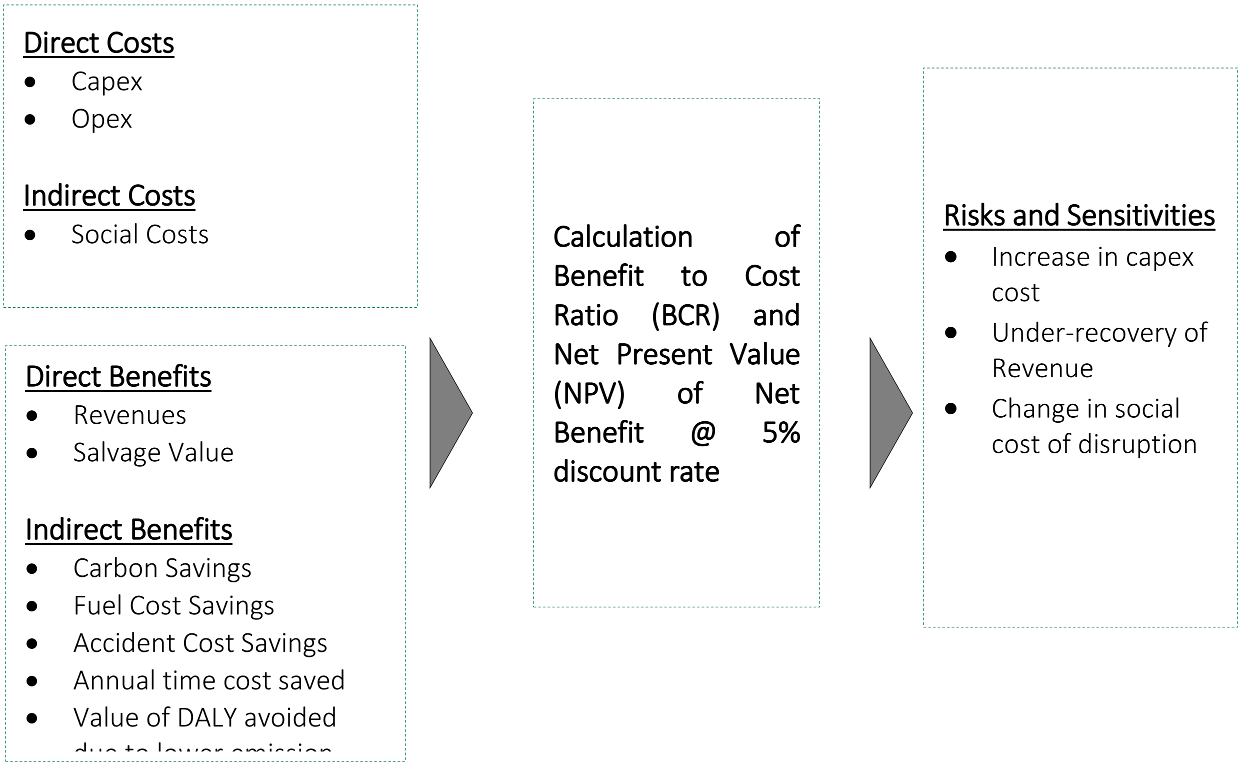
A BCR greater than 1 indicates that benefits exceeds the cost of investment i.e. the program generates net benefits and a BCR less than 1 implies the costs of undertaking the program exceed the benefits generated by it. BCRs enable policymakers to compare and rank alternative policy interventions to prioritize among potential intervention strategies.

CBA Methodology

The present study captures both direct and indirect cost and benefits accruing due to implementation of the two interventions. On the benefit side, there are direct benefits which include ticket and advertising revenue and salvage value. Apart from direct benefits, research captures the diverse range of indirect benefits such as energy savings, fuel savings, time savings and accident cost savings. Similarly on the cost side, in addition to the capex and opex, the study has also considered social cost of disruption.

For the base case scenario, the discount rate of 5 percent was used. Any project is subject to various types of risks during life cycle of the project. The study has identified two types of key risk factors: first, cost variables and second, variables with maximum uncertainty. Sensitivity is performed on cost variables as study has kept all the prices constant. However, if there is an escalation in the prices it could affect the BCR. Similarly, there are some variables with uncertainty such as under recovery of revenue. As a result, sensitivity analysis was performed on these two type of key risk factors to study the impact on BCR. The methodology of CBA is discussed in **Figure 1**. The key assumptions along with the data sources for the study are explained for each interventions in **section 2.3.1** and **3.3.1**.

Figure 1: CBA Methodology



2. Metro Rail

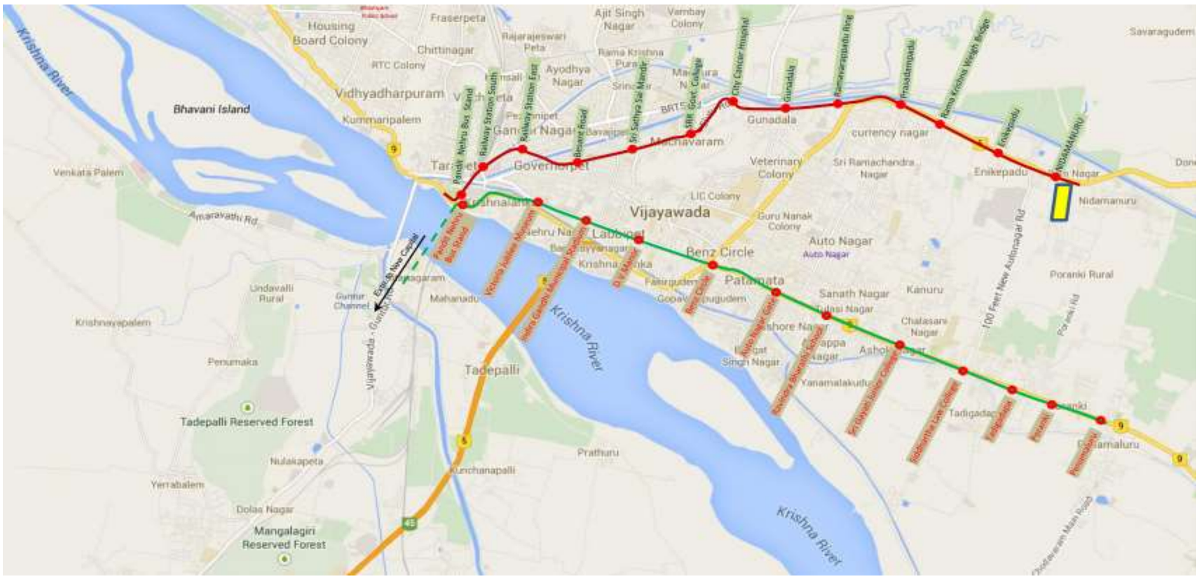
2.1 Description of intervention

In line with the objective of capital region development authority (CRDA) to make the new capital region a green-blue city, a 100 percent city electric public transportation system has been considered. The end objective of this intervention is to serve 50 percent of the city population by 2052 through metro rail services thereby serving a total 80 percent of passenger traffic by public transport by 2052.

This study has considered the two elevated routes as proposed by the detailed project report prepared by Delhi Metro Rail Corporation (DMRC). We believe that since DMRC had identified these routes after an extensive survey of the traffic pattern of the city and consultations with city planners, they represent the optimal solution as in **figure 2**. The proposed metro corridors are

- Line No.1: Pandit Nehru Bus Terminal to Penamaluru with 12 stations, total length of 12.7 Kms
- Line No. 2: Pandit Nehru Bus Terminal to Nidamanuru with 13 stations, total length of 13.3 Kms

Figure 2: Proposed metro corridor for Vijayawada



Source: DMRC, 2015

In order to improve attractiveness of metro rail, complementary feeder network comprising of feeder buses and IPT was considered appropriately based on the LOS 2 (service level 2) established by the Ministry of Housing and Urban Affairs. Worth mentioning, the presence of organized public transport system in 40 percent to 60 percent of the urban area, is considered as standard for LOS 2 service level benchmark.

The study assumed that the intervention will significantly reduce the dependency on low-capacity private modes and will bring down the contribution of private vehicles in traffic composition to 20 percent by 2052, by offering

1) Adequate supply of public transport to ensure easy availability and minimal waiting time for passengers
2) Safety, cleanliness and comfort comparable to private cars
3) Low tariff similar to current prevailing tariff of public transport, mainly buses, which are politically and socially determined tariff and not cost effective tariff.

We believe, by offering adequate supply, superior quality and low tariff, the contribution of public transport (i.e. both metro, bus and IPT services) can enable and lead to 80 percent by 2052.

Building metro route to take away low-capacity private transport off the roads is in effect similar to building more roads. In other words, shifting of commuters to public mass transit may result in more space for private cars. As a result, building metro may not always result in faster speed as more space for private vehicles (post intervention) may attract people to move towards private transport until it reaches to the same pre-intervention equilibrium. Thus in order to achieve the target to transfer 80 percent of the city passenger traffic by public transport, economic instruments may be required as complementary measure to discourage more private cars. The benefit realized through such levy or economic instruments can be used for making future investments in public transport.

2.2 Literature Review

Research by Winston and Langer (2004) indicates that both motorist and truck congestion costs decline in a city as rail transit mileage expands. Garrett and Castelazo (2004) found that traffic congestion growth rates declined in several US cities after light rail service was established. Baum-Snow and Kahn (2005) found significantly lower average commute travel times in areas near rail transit than in otherwise comparable locations that lack rail, due to rail's higher travel speeds compared with automobile or bus under the same conditions. Using a regional traffic model, Nelson et al. (2006) found that Washington DC's Metro rail transit service generates congestion- reduction benefits that exceed subsidies. Litman (2004) shows that per capita congestion delay is significantly lower in cities with high quality rail transit systems than in otherwise comparable cities with little or no rail service.

Table 6 Short Review of Papers on Metro Intervention

Metro Line	Discount Rate	BCR	Comment	Source
Stockholm Metro	4%	8.5	Includes economy wide benefits particular to Stockholm urban planning environment of 1960s	
Madrid Metro	5.4% (backward), 3.3% (forward)	3.1	Generalised cost savings, Diverted Traffic: 75.3% of total benefit Consumer surplus: 8% of total benefit Investment cost: 58.9% of total cost Operating costs: 41.1% of total cost	
Sydney Metro	7%	1.7	Public transport user benefits: 50% Road user benefits: 14% Wider Economic Benefits: 19%	
Dulles Corridor Metro	3%	1	Breakeven (BCR=1) in 2063 after 50 years of operations	
Delhi Metro	8%	2.3	The FIRR was estimated as 17% and EIRR at 24% Reduction of urban air pollutions increased the EIRR by 1.4%	
Chennai Metro	5.2%	1.58	The project is economically viable, including social benefit Pollution reduction- Rs. 2920.80 mn Fuel saving - Rs. 2.2 mn Vehicle opex cost save - Rs. 5,265 bn	
Santo Domingo, Dominican Republic Metro	5%	0.90	Estimated % Reduction in CO2 Because of the Metro: 3.7%	
Jaipur Metro			EIRR: 13.8% FIRR: 3.7%	
Delhi Metro			Health benefit range between $164mn to $469mn due to reduction in PM2.5	
Kochi Metro	12%		EIRR: 14.2%, FIRR: 3.04%	

2.3 Data

2.3.1 Source of Data

Data on benefits and costs of interventions was sourced from secondary literature – published papers and in few cases unpublished documents including Vijayawada Metro Rail Project (Phase I) Detailed Project Report prepared by DMRC, city mobility development plans, and various e-mobility reports by NITI Aayog, Smart Cities Council and IISc. The following table provides an overview of data used.

Table 7 Sources of Data for Metro Intervention

Variable	Data Source	Assumption
Population of Vijayawada	Vijayawada Municipal Corporation	Future population of Vijayawada was projected using the average of annual decadal population growth rate of 2001 and 2011
Project life	30 years	Construction of the project will start in 2019 and the metro rail project will be operational in 2023
Type of Metro		Medium Capacity Metro System, capacity of 90,000 passengers per hour per direction of traffic (PHPDT)
Capital expenditure of metro	for metro rail	Cost estimated at 2017 prices considering 20 percent labor component
Capital expenditure of e-buses and e-cab and E-Rickshaw	for electric vehicles	Battery prices of Electric vehicle will come down 10% annually till 2030 and then after the price will remain constant Contribution of battery price to total capex would be 30 percent, 50 percent and 50 percent respectively for electric buses, electric rickshaw and electric cab
Operating expenditure		Assumed 365 days of operation instead of 340 A labor component of 50 percent is considered for opex. The labor component increased at the real wage growth rate for Andhra Pradesh, provided by CCC. However, the capital component is considered constant over the time.
Estimation of charging infrastructure		Charger requirement for each electric vehicle is assumed at 0.5
Metro rail Fare		Escalation at real wage growth of Andhra Pradesh as projected by CCC.

Table 8: Assumptions related to cost of E-bus

Parameter	Assumption	Source
Bus Price	Rs 2.6 crore	Niti Aayog, Rocky Mountain Institute (RMI), 2017
Battery Charger (AC slow)	Rs 2.0 lacs	Bhubaneswar e-Mobility Plan, 2017
Battery Charger (DC fast)	Rs 25.0 lacs	Bhubaneswar e-Mobility Plan, 2017
Operating cost (E-bus)	Rs17.25/km (other) Rs 10/km (electricity)	Bus Coach India, 2017 Niti Aayog, RMI, 2017

Table 9: Assumption related to cost of E-cab & E-Rickshaw

Parameter	Assumption	Source
E- Rickshaw Price	Rs 1.5 lacs	Niti Aayog, RMI, 2017
Battery Charger (AC slow)	Rs. 48,000	Bhubaneswar e-Mobility Plan, 2017
Battery Charger (DC fast)	Rs 3.6 lacs	Bhubaneswar e-Mobility Plan, 2017
E- Cab Price	Rs 7.0 lacs	Niti Aayog, RMI, 2017
Battery Charger (AC slow)	Rs 1 lacs	Electric Vehicle Charging Station in Nagpur, 2017
Battery Charger (DC fast)	Rs 25 lacs	Electric Vehicle Charging Station in Nagpur, 2017
Electric Rickshaw opex	Rs.0.725/km	Niti Aayog, RMI, 2017
Electric Cab opex	Rs 2/km	Niti Aayog, RMI, 2017
CNG Rickshaw Opex	Rs 1.84/km	Niti Aayog, RMI, 2017
ICE service Vehicle Opex	Rs 3.5/km	Niti Aayog, RMI, 2017

Table 10: Assumption related to benefit from Metro Rail intervention

Parameter	Assumption	Source
Metro rail fare	0-5 KM= Rs 10 5-10 KM = Rs 20 Over 10 KM = Rs 30	DMRC,2015
Metro Non-fare revenue	10 percent of ticket revenue	DMRC,2015
Time-Cost Saved for metro passengers	Rs. 315.41 crore (in 2023) and corresponding yearly numbers	DMRC,2015
Annual VOC Saved for metro passengers	Rs. 84.68 crore (in 2023) and corresponding yearly numbers	DMRC,2015
Diesel Bus Operating cost	Rs 19/km	Niti Aayog, Rocky Mountain Institute, 2017
Average city speed	25 Km/ hour	DMRC,2015
Average Occupancy: Two-Wheeler	1.66	DMRC,2015
Average Occupancy: Car/Jeep/ Van	2.6	DMRC,2015
Average Occupancy: Bus	25.7	DMRC,2015
Average Occupancy: Auto	2.62	DMRC,2015
Average Occupancy: Auto	3.58	DMRC,2015
Daily run for Two-Wheeler	37	CPCB, 2015
Daily run for Car	49	CPCB, 2015
Daily run for electric Bus	183	IISc, BEST, India Smart Grid
Daily run for electric Rickshaw	113	India Smart Grid
Daily run for Electric Cab	200	The Better India Survey
Days per year in operation	365	Own assumption

2.4 Calculation of Costs and Benefits

2.4.1 Costs

Total capital investment and opex requirement for metro rail is estimated based on the detailed project report prepared by DMRC on Vijayawada metro project. The capex and opex information on electric mobility was mainly sourced from Niti Aayog. All costs are at 2017 price levels based on appropriate adjustments. Additionally, the research estimated a service life of electric transport and supporting charging infrastructure as 10 years and necessary replacement capex are considered in the calculation. The requirement for buses and IPT were estimated as per the 2nd highest service level benchmark set by Ministry of Housing and Urban Affairs.

'Social cost of Disruption' is also considered during the construction period, as the construction work will result in traffic disruptions and inconvenience to public. Total capital investment required for the intervention is the sum of these two and estimated to be INR 201.5 bn at 5 per cent discount rate (Table 11).

2.4.2 Benefits

The ticket revenue from metro rail and electric transport services have increased at per real income growth of Andhra Pradesh, as provided by CCC to account for increased WTP. Tariff are based on the prevailing tariff for public transport, mainly buses. Those are politically and socially determined tariff and not cost reflective. Finally, the proposed metro tariff structure as proposed by DMRC in the line with the tariff structure of the metros in other part of the country and fare is attractive enough for people to shift from private to public transport.

Salvage value of the asset at the end of the life of the project was also considered while calculating the benefit. To calculate the salvage value, a depreciation rate of 2.5 percent was considered for metro rail and depreciation rate of 10 percent was considered for electric transportation and supporting infrastructure.

The estimates of carbon emission savings for electric vehicles were sourced from various studies by IISc, World Bank and Smart City Council , , and appropriate adjustment have been made in social cost of carbon.

Fuel cost saving per kilometer information for each electric vehicle categories are sourced from Niti Aayog report. Finally, the average annual run of each vehicle category, were multiplied with the number of operation vehicles in each category and corresponding fuel cost savings figure to arrive at total fuel cost savings due to the intervention.

Saved vehicle operating cost, annual time cost savings and accident cost savings were directly sourced from the DMRC report on Vijayawada metro rail. No adjustment were made for the numbers as this intervention considered same length and ridership in the proposed metro rail services as suggested by DMRC report. Further, as mentioned earlier the metro rail fare considered in the study is largely socio-politically determined tariff and not cost effective tariff, hence the study has considered time savings as additional benefit to give more completeness to the methodology.

Because of reduction in congestion on road, due to the intervention, the average speed of vehicle in the city will go up, which will also benefit the non-users of metro. To calculate the time saved by non-users it was assumed that, the intervention will result in 30 percent increase in average speed on city traffic. It was calculated that the depending on the vehicle type, each vehicle will save in the range of 3 to 5 minutes of time per day. The time value of Vijayawada city was sourced from DMRC report and assumed at Rs 0.75 per minutes in 2015 and increased as per real income growth of Andhra Pradesh, as provided by CCC. Finally, the time saved value of each category were multiplied with corresponding number of vehicles in each year to arrive at the non-user time save benefit.

The study doesn't consider the land value increase due to the intervention as a benefit, though the development of mass transit system can directly benefit the real estate market through increase in land value. The increment in land value can offer better return to property developers or investors. However, the increase in land price can also negatively affect the poor renters in existing housing or businesses in the surrounding areas of mass transit system route – as "the landlord's gain [converts into] the tenant's loses" . As a result, poor tenants are often forced to "drive[n] out to more distant, less-expensive locations" and these outlying areas become concentrations of poverty . Finally, it can be argued that private benefits to land value increase are mainly the transfer of Metro time savings benefits, which have already been considered in the study and adding them to the calculation of total benefit would result in double-counting.

Calculation of value of DALY avoided due to reduced emission: The health damage of a ton of PM2.5, and consequently the health benefit of reducing emissions, depend on how much is inhaled by the population. Apte et al (2012) estimate the so-called intake fraction of distributed ground-level emission sources (e.g. emissions from road vehicles) in over 3,600 cities of the world with a population greater than 100 thousand in year 2000 based on geographic, meteorological, and demographic location specific data. An intake fraction is a measure of how much of a ton of emissions in a geographic area is breathed in by the exposed population. The higher the intake fraction the larger are the health damages and thus the health benefits of emissions reductions. Intake fractions in these cities were found to range from less than 5 to 260 ppm (g/ton of PM2.5). Health benefits per ton of PM2.5 emission reductions in Vijayawada are estimated based on an intake fraction of 60 ppm in 2017, annual ambient PM2.5 of 50 $\mu g/m^3$ (PM10 of 100 $\mu g/m^3$).

In order to estimate the emission, it was assumed that 40 percent of cars in the city run on diesel, 53 percent on petrol and rest 7 percent on Gas (CNG), similar to Hyderabad . Additionally, it was assumed 100 percent of the two wheelers run on petrol. The increase in the ownership of private motorized transport due to the income growth was also factored in the calculation to project the private cars and two wheelers numbers.

An improvement in ambient PM2.5 air pollution is unlikely to instantaneously provide full benefits for health outcomes that develop over long periods of PM2.5 exposure. Annual health benefits of emission reductions are therefore estimated at 78-83% of full benefits at a discount rate of 3-8%.

Finally the health benefits were monetized by valuing a year of life (YLL) and reduced morbidity or a year of disability (YLD) at 3 times GDP per capita of Andhra Pradesh.

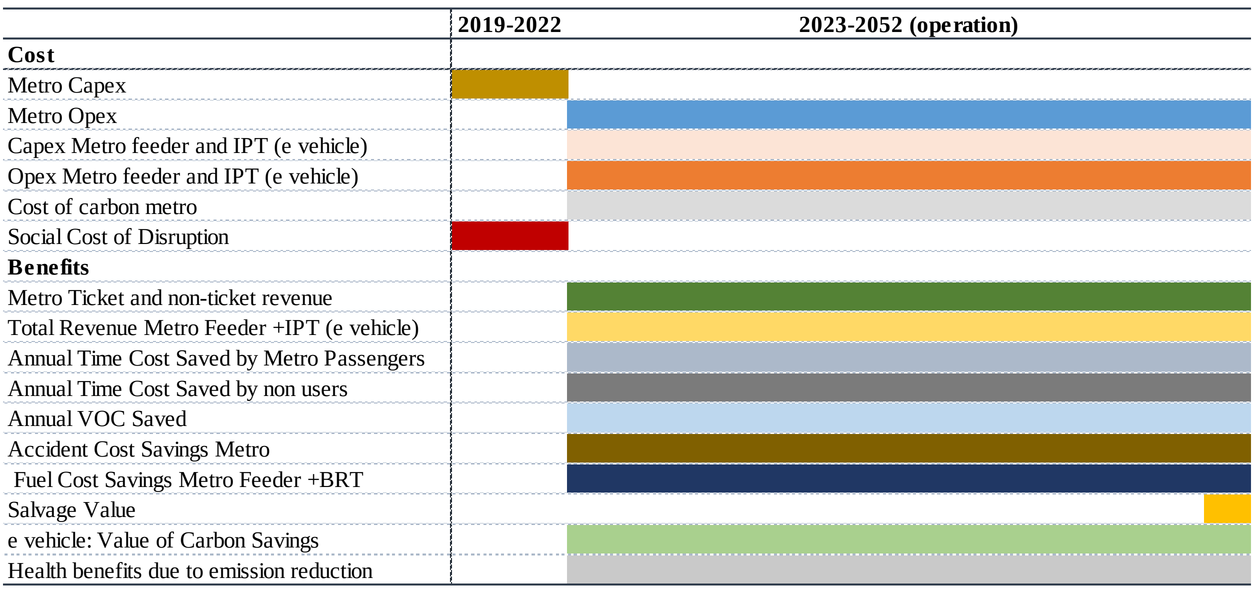
Total Benefits at 5 per cent discount rate were estimated to be INR 661.8 bn (Table 11**)**. The BCR for Metro Rail intervention at 5 per cent discount rate is 3.28. Therefore, we can conclude that the intervention is viable.

Table 11: Cost and Benefits of Metro Rail intervention

Costs	INR Bn	Benefits	INR Bn
Capex Metro Rail	64.0	Total Revenue Metro (ticket and non ticket)	180.0
Capex metro feeder buses and IPT	33.0	Total Revenue Metro Feeder buses and IPT (ticket and non ticket)	143.8
Opex Metro Rail	31.3	Annual VOC Saved by Metro Passengers	24.8
Opex metro feeder buses and IPT	20.5	Accident Cost Savings Metro	9.0
Social Cost of Disruption	49.9	Total Fuel Cost Savings Metro Feeder buses and IPT	7.6
Carbon cost due to energy generation for metro	2.7	Salvage Value	12.4
		Value of Carbon Savings by metro feeder buses and IPT	0.3
		Metro: Value of Carbon Savings	0.9
		Annual Time Cost Saved by Metro Passengers	197.9
		Annual Time Cost Saved by non users	44.0
		Health benefit due to air pollution reduction	41.1
Total Cost	**201.5**	**Total Benefit**	**661.8**

Source: Author's Calculation; Notes: All figures assume a 5% discount rate

Figure 3: Timeline Cost and Benefits



2.5 Assessment of Quality of Evidence

The quality of information on metro rail is medium to strong, as most of the data are collected from the detailed project report prepared by DMRC for Vijayawada metro rail project. However, the quality of evidence for electric mobility can be considered as medium considering it is a relatively new concept and currently the Indian Government is trying to promote electric mobility as one of the key solutions to reduce carbon emissions. However, most of the projects are at the concept stage and availability of specific evidence based data on electric mobility is limited. Additionally, it is expected that technology evolution and mass adoption of electric transport will shape the future of the industry.

2.6 Sensitivity Analysis

All large projects are open to various types of risks during the life cycle. Specially, large infrastructure projects are exposed to high risks in practically all stages of the value chain and throughout the life cycle of a project. .

The purpose of sensitivity analysis is to analyze different outcomes by varying level of cost and benefit estimates. It helps policymaker to observe how valuations move with changes in key variables and to address them in the most acceptable form of mitigation. A number of assumptions are made for each separate cost and benefit assessment. A detailed analysis has been conducted to identify the variables (both cost and benefits) with high level of uncertainty. Additionally, a number of assumptions are made for each separate cost and benefit assessment. Some may have a significant effect on the results, while others will make only a minor difference. Finally, in order to see the effect on the net results if these assumptions are changed we conduct a sensitivity analysis. However, BCR was most sensitive to following three factors (as shown in **Table 12)**.

Table 12: Key risk factors for Sensitivity Analysis

Risk Factors	Case I	Case II
Increase /decrease in capex of Metro rail	10%	(-)10% [(1)]
Under-recovery of ticket revenue	10%	20%
Change in social cost of disruption	50% increase	50% decrease

(1) Decrease in metro rail capex by introducing Light Metro with PHPDT of < 30,000

The result of the sensitivities are presented in

Table 13. It is evident that while changes in capex (10 percent increase or 10 percent decrease in capex) and under recovery of metro rail ticket (10 percent or 30 percent under recovery) do not have much impact on the BCR ratio. However, the change in social cost of disruption (50 percent increase or 50 percent decrease) can significantly impact the BCR ratio. The insignificant sensitivity for under recovery of metro rail ticket on overall BCR is mainly due the reason that metro fare are socio-politically determined tariff and not cost effective tariff. This is applicable for most of the metro rail projects and people use metro rail because they are of good quality, on time and tariff are reasonable. Hence, in general metro projects have very low financial internal rate of return (FIRR) but have high economic internal rate of return (EIRR), as they offer wider social benefits including lesser emission, travel time savings and fuel cost savings. However, considering the low contribution of public transport in Vijayawada in the current traffic composition, the intervention remains economically attractive under all circumstances.

Table 13: Results of Sensitivities under Metro Rail intervention

Sensitivity	Base Case	Case I	Case II
Increase /decrease in capex of Metro rail	3.28	3.11	3.48
Under-recovery of ticket revenue	3.28	3.20	3.04
Change in social cost of disruption	3.28	2.92	3.75
Considering all the negative likelihoods (i.e. under recovery in ticket revenue, cost overrun and higher social cost)	3.28	2.69	2.55

Source: Author's Calculations; Notes: All figures assume a 5% discount rate

3. Elevated Bus Rapid Transit (BRT)

3.1 Description of intervention

Given that the metro DPR by DMRC had already identified the high density corridors for metro rail, we believe that elevated BRT on the same route could be considered as an alternative to metro construction. This approach also enabled a like to like comparison of the two options and provide policy makers with detailed inputs required for making investment decision. The proposed elevated BRT corridors are hence the same as in case of Metro Rail.

- Elevated BRT Corridor No.1: Pandit Nehru Bus Terminal to Penamaluru, with length of 12.7 Kms
- Elevated BRT Corridor No. 2: Pandit Nehru Bus Terminal to Nidamanuru, with length of 13.3 Kms

Similar to metro rail intervention, feeder bus service and IPT have been rationalized to improve last-mile connectivity. Additionally, in order to ensure seamless speedy movement of commuters the requirement of feeder bus services and IPT is estimated based on the LOS 2 (Level of service) benchmark set by Ministry of Housing and Urban Affairs for urban transport for Indian cities. Similar to metro intervention, a 100 percent city electric public transportation system has been considered. The end objective of this intervention is to serve 50 percent of the city population by 2052 through elevated BRT services thereby serving s 80 percent of passenger traffic by public transport by 2052.

We believe, by offering adequate supply, superior quality and low tariff, the contribution of public transport (i.e. both BRT and IPT services) can enable and lead to 80 percent by 2052.

3.2 Literature Review

Bus Rapid Transit (BRT) is growing in popularity throughout the world. The reasons for this phenomenon include its passenger and developer attractiveness, its high performance and quality, and its ability to be built quickly, incrementally, and economically. BRT also provides sufficient transport capacity to meet demands in many corridors even in the largest metropolitan regions. Bus rapid transit systems – largely as a result of faster journey times –

have resulted in lower operating costs, less fuel consumption, greater safety, and land development benefits.

For hybrid and electric city buses, energy storage is one of the most important components in terms of overall energy efficiency, bus lifecycle and costs. During recent years, lithium based batteries have proven to be suitable choice for hybrid and electric passenger vehicles. They offer sufficient power and energy capacity, they are relatively safe, and their calendar and cycle life is long enough at least for hybrid vehicles.

Most of the life cycle costs of city buses come from the capital and operating costs (Nylund and Koponen, 2012; Clark et al., 2008). Even though the capital costs of hybrid and electric city buses are high, the lower energy consumption significantly reduces the operating costs that makes them already potential replacements for the conventional diesel city buses (Feng and Figliozzi, 2013; Hellgren, 2007).

3.3 Data

Several data sources utilized in the Metro intervention are also used for this intervention. The remaining data sources for cost estimation are summarized in the table below.

Table 14: Assumptions Related to cost of Elevated BRT Intervention

Parameter	Source	Assumption
Elevated BRT route Length	(Delhi Metro Rail Corporation (DMRC), 2015)	26.03 km
BRT Capex per KM (without land cost)	UMTC experience with Chandigarh elevated BRT	Rs 55 crore
BRT Opex per KM per annum	UMTC [(1)] experience with Chandigarh elevated BRT	Rs 2.5 crore
Land cost for BRT (same as metro)	Delhi Metro Rail Corporation, 2015	Rs 644 core

(1) UMTC is an urban transport consultancy firm and a partnership between Ministry of Urban Development (MoUD), Government of India, Government of Andhra Pradesh (GoAP), Andhra Pradesh State Road Transport Corporation (APSRTC) and Infrastructure Leasing and Financial Services Limited (IL&FS).

Data sources for benefit estimation are summarized in the table below.

Table 15: Assumptions Related to Benefits from Elevated BRT Intervention

Parameter	Source	Assumption
Efficiency factor metro vs. electric bus		2 (calculated)
Emission saving Cost BRT		The corresponding value for metro rail has been divided by the efficiency factor of metro.
Accident Cost Savings BRT		Considered 50% of the metro
VOC Saved and Annual Time Cost Saved by BRT		Considered same as metro, assuming same number of passenger will travel on the BRT
BRT Ticket Price		Same as metro assuming the willingness to pay for metro and BRT are same
Carbon emission savings for electric Bus per year		25 tons per year per bus
Carbon emission savings per Electric Rickshaw		2 tons per year per Electric Rickshaw
Carbon emission savings per Electric Cab	,	1.2 tons per year per Electric Cab

3.4 Calculation of Costs and Benefits

3.4.1 Cost

The capex and opex information on electric mobility was sourced from Niti Aayog. All costs are at 2017 price levels based on appropriate adjustments. Additionally, the research estimated a service life of electric transport and supporting charging infrastructure as 10 years and necessary replacement capex are considered in the calculation. The requirement for buses and IPT were estimated as per the 2nd highest service level benchmark set by Ministry of Housing and Urban Affairs.

'Social cost of Disruption' is also considered during the construction period, as the construction work will result in traffic disruptions and inconvenience to public. Total capital investment required for the intervention is the sum of these two and along with ongoing opex costs, the total is estimated to be INR 165 bn at 5 per cent discount rate (**Table 16**).

3.4.2 Benefits

The ticket revenue from electric transport services have increased at per real income growth of Andhra Pradesh, as provided by CCC to account for increased WTP. Tariff are based on the prevailing tariff for public transport, mainly buses. Further, as mentioned earlier the elevated BRT fare considered in the study is same like metro rail fare, considering commuters in elevated BRT would enjoy same level of comfort and travel time as the metro rail services. The tariff is socio-politically determined and not cost reflective, hence the study has considered time savings as additional benefit to give more completeness to the methodology.

In order to calculate the emission saving cost for BRT, the corresponding value for metro rail, as mentioned in the Vijayawada metro DPR, was divided by the efficiency factor of metro.

The estimates of carbon emission savings, number of operating electric vehicle in each category was multiplied with the corresponding estimates of carbon emission savings sourced from various studies by IISc, World Bank and Smart City Council , , . Finally appropriate adjustment have been made in social cost of carbon.

Fuel cost saving per kilometer information for electric vehicles are sourced from Niti Aayog report. Finally, the average annual run of each vehicle category, were multiplied with the number of operational vehicles in each category and corresponding cost savings to arrive at total fuel cost savings due to the intervention.

Savings in vehicle operating cost, annual time cost savings and accident cost savings for metro passengers were directly sourced from the DMRC report on Vijayawada metro rail. No adjustment was made for the numbers considering this intervention considered same length and ridership in the proposed metro rail services as suggested by DMRC report. The analysis have also considered that elevated BRT will ensure smooth and disciplined movement of buses, which will significantly bring down the accident rate and assumed 50 percent of corresponding value of metro rail.

In order to calculate the efficiency factor metro over electric bus is calculated based on the IEA Energy Technology network report. The report estimated the energy consumption of 0.4 (MJ/seat-km) for Diesel ICE Bus. The number is multiplied with energy reduction potential (in percent term) of electric buses to reach at the base energy consumption of electric buses. Finally, the base energy consumption of electric buses was compared with Metro Base Energy Consumption to reach at the efficiency factor metro over electric bus.

To calculate the time saved by non-users it was assumed that, the intervention will result in 30 percent increase in average speed on city traffic and depending on the vehicle type, each vehicle will save in the range of 3 to 5 minutes of time per day. The time value of Vijayawada city was sourced from DMRC report and assumed at Rs 0.75 per minutes in 2015 and increased at per real income growth of Andhra Pradesh, as provided by CCC. Finally, the time saved value of each category was multiplied with corresponding numbers of vehicles in each year to arrive at the non-user time save benefit.

The health benefit of avoided DALY due to reduced emission was calculated same like the metro intervention.

Same like metro intervention, elevated BRT intervention doesn't consider the land value increase as a benefit, considering private benefits to land value increase are mainly the transfer of elevated BRT time savings benefits, which have already been considered in the study. Adding them to the calculation of total benefit would result in double-counting.

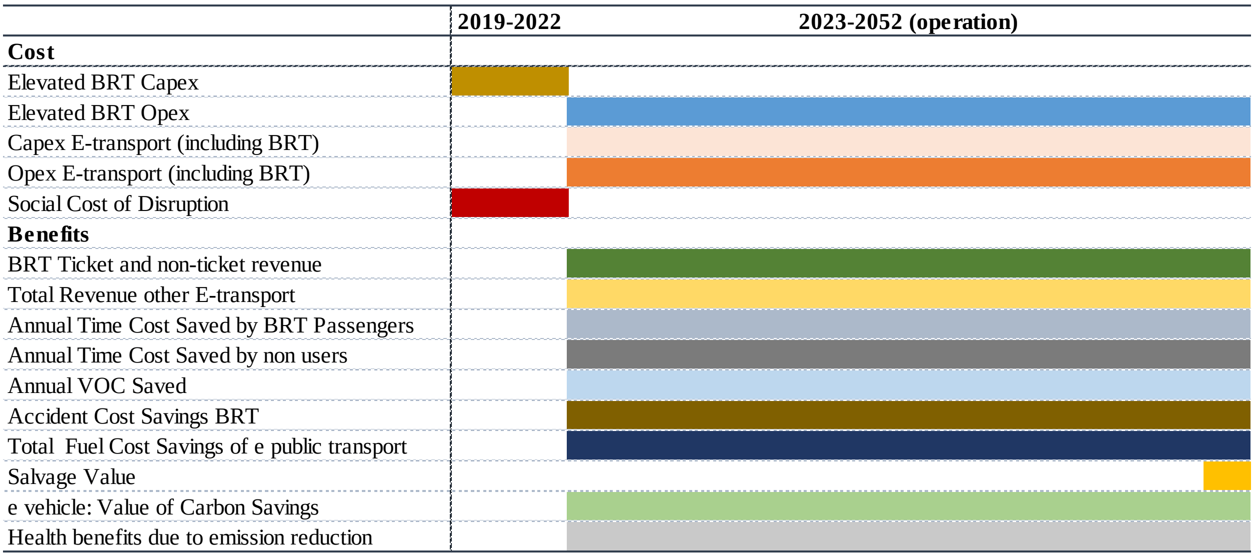
Total Benefits were estimated to be INR 663.8 bn at 5 per cent discount rate (Table 16). The BCR for BRT intervention at 5 per cent discount rate is 4.03 (Table 16). Therefore, we can conclude that the intervention is economically viable.

Table 16: Cost and Benefits of Elevated BRT

Costs	INR Bn	Benefits	INR Bn
Capex for BRT infrastructure (excluding buses)	18.4	Total Revenue : BRT Bus	180.0
Capex E-transport (including BRT)	93.0	Total Revenue : other Bus	37.8
Opex for BRT infrastructure (excluding buses)	18.2	Revenue : Electric Rickshaw	59.0
Opex E-transport (including BRT)	20.6	Revenue : Electric Cab	47.0
Social Cost of Disruption	14.4	Annual Time Cost Saved by BRT Passengers	197.9
		Annual Time Cost Saved by non users	44.0
		Annual VOC Saved by BRT Passengers	24.8
		Accident Cost Savings BRT	4.5
		Total Fuel Cost Savings of e public transport	7.6
		Salvage Value	19.4
		Value of Carbon cost Saving	0.8
		Total health benefits due to air pollution reduction	41.1
Total Cost	**164.6**	**Total Benefit**	**663.8**

Source: Author's Calculation; Notes: All figures assume a 5% discount rate

Figure 4: Timeline Cost and Benefits



3.5 Assessment of Quality of Evidence

The quality of information on elevated BRT is medium to strong. The intervention mainly focuses on increasing the contribution of public transport in Vijayawada through electric mobility. However, the quality of evidence for electric mobility can be considered as medium considering it is a relatively new concept. Currently the Indian Government is trying to promote electric mobility as one of the key solutions to reduce carbon emissions though, most of the projects are at the concept stage and availability of specific evidence based data on electric mobility is limited. Additionally, it is expected that the technology evolution and mass adoption of electric transport will shape the future of the industry.

3.6 Sensitivity Analysis

All projects are exposed to various types of risks during the life cycle. Specially, large infrastructure projects are exposed to high risks practically during the development phase. . Cost overruns, delays, failed procurement, or unavailability of private financing are common.

Hence sensitivity, analysis have been conducted to assess the potential impact of uncertain variables. This sensitivity analysis will provide policymakers an idea of the degree of uncertainty surrounding the interventions and the relative degree of importance .

A number of assumptions were made for each separate cost and benefit assessment. A detailed analysis has been conducted to identify the variables (both cost and benefits) with high level of uncertainty. Additionally, a number of assumptions are made for each separate cost and benefit assessment. Some may have a significant effect on the results, while others will make only a minor difference. Finally, in order to see the effect on the net results sensitivity was performed on the following three factors.

However, BCR was most sensitive to only three factors (as shown in **Table 17**).

Table 17: Key risk factors for Sensitivity Analysis

Risk Factors	Case I	Case II
Increase in elevated BRT capex	10%	20%
Under-recovery of ticket revenue	25%	30%
Change in social cost of disruption	50% increase	50% decrease

The result of the sensitivities are shown in (**Table 18)**. Cost overrun and increase in social value show negative impact on the BCR ratio. Additionally, the under recovery of BRT ticket revenue also pull down the BCR ratio. However, considering the low contribution of public transport in Vijayawada in the current traffic composition, the intervention remains economically attractive even after considering all the negative likelihoods (i.e. under recovery in ticket revenue, cost overrun and higher social cost) together.

Table 18: Results of Sensitivities under Elevated BRT intervention

Sensitivity	Base Case	Case I	Case II
Increase in elevated BRT capex	4.03	3.75	3.50
Under-recovery of ticket revenue	4.03	3.93	3.73
Change in social cost of disruption	4.03	3.86	4.22
Considering all the negative likelihoods (i.e. under recovery in ticket revenue, cost overrun and higher social cost)	4.03	3.50	3.10

Source: Author's Calculation; Notes: All figures assume a 5% discount rate

4. Conclusion

The benefit-cost analysis (in chapter 3.1 and 3.2) emphasized the benefits that could be added for Vijayawada's citizens by giving more emphasis to public transport, and slowing down the growth in low-capacity private transport (particularly cars and motor-cycles). By doing so, Vijayawada would be following the trend in many cities across the globe, especially in developed countries. Additionally, the lessons for this study also apply to other towns and cities in Andhra Pradesh as well as India, whose traffic problems are steadily increasing.

This study ranks intervention 2 (i.e. Elevated BRT with Electric Feeder and Last Mile connectivity Services) over intervention 1 (i.e. Metro Rail with Electric Feeder and Last Mile connectivity Services) as the capex and opex of BRT is lesser than that of the metro. Additionally, BRT can provide more flexibility over metro as the bus fleet estimated for elevated BRT can be used for other flexible routes.

Urban transport planning in Vijayawada has come a long way, and the elements of a polycentric governance already exit in the system. However, there are certain institutional aspects which can be further strength for better transport planning and effective polycentric governance system.

Finally, a measure of success for Vijayawada's future urban transport is that proposed by Gustavo Petro, the former Mayor of Bogota, Colombia who once said — 'A developed country is not a place where the poor have cars. It's where the rich use public transportation'.

Table 19: Summary of Benefits, Cost and BCR at three discount rate

Interventions	Discount	Benefit (INR bn)	Cost (INR bn)	BCR	Quality of Evidence
Metro Rail	3%	₹ 1,049	₹ 252	4.17	Medium to strong
	5%	₹ 662	₹ 201	3.28	
	8%	₹ 354	₹ 158	2.23	
Elevated BRT	3%	₹ 1,054	₹ 225	4.69	Medium to strong
	5%	₹ 664	₹ 165	4.03	
	8%	₹ 354	₹ 112	3.15	

Source: Author's Calculation

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As a new state, Andhra Pradesh faces a bright future, but it is still experiencing many acute social and economic development challenges. It has made great strides in creating a positive environment for business, and was recently ranked 2nd in India for ease of doing business. Yet, progress needs to be much faster if it is to achieve its ambitions of becoming the leading state in India in terms of social development and economic growth. With limited resources and time, it is crucial that focus is informed by what will do the most good for each rupee spent. The Andhra Pradesh Priorities project as part of the larger India Consensus – a partnership between Tata Trusts and the Copenhagen Consensus Center, will work with stakeholders across the state to identify, analyze, rank and disseminate the best solutions for the state. We will engage people and institutions from all parts of society, through newspapers, radio and TV, along with NGOs, decision makers, sector experts and businesses to propose the most relevant solutions to these challenges. We will commission some of the best economists in India, Andhra Pradesh, and the world to calculate the social, environmental and economic costs and benefits of these proposals

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