Enhancing Efficiency and Societal Impact of Ahmedabad's BRTS: Interventions and Innovations

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UG Thesis

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Contents

Abstract

The research focuses on the examination of the utilization and travel behavior of the Bus Rapid Transit System (BRTS), with the objective of modeling and comprehending the effects of BRTS on travel time, duration, and emissions. A survey was carried out at Ahmedabad University to evaluate BRTS usage patterns and identify the factors contributing to the underutilization of BRTS services. Using SUMO (Simulation of Urban Mobility), a comparative analysis was conducted to assess travel performance and emissions across Ahmedabad Municipal Transport Service (AMTS), private vehicles, and BRTS. Furthermore, a forward-looking strategy involving the integration of electric AMTS into the simulation was implemented, resulting in significant outcomes. Various policies were proposed, such as increasing parking fees, offering discounts at restaurants, introducing carts for enhanced connectivity, and encouraging a shift from private transportation to public transportation.

Keywords: BRTS, AMTS, public transportation, SUMO, emission, sustainability, carbon emission

Rationale

As of the year 2024, the estimated population of Ahmedabad stands at 8.85 million. Data analysis reveals that approximately 250,000 residents are currently residing in slum areas, constituting approximately 4.49% of the total population of the city [1]. The accessibility of transportation services to this demographic segment is identified as a critical and dominant challenge in promoting their utilization of public transportation systems. The primary objective of this study is to investigate the factors involved in delivering public transportation services to residents and assess its effectiveness in meeting the specified objectives. The case study of New Delhi, where a comparable strategy was implemented by the government, resulting in an increase in electoral support for the ruling party and a rise in female workforce participation. The goal is to analyze how a similar situation unfolded in Ahmedabad.

Introduction

Each year, 127 million Indians use the BRTS. The Ahmedabad BRTS dominates this ridership, accounting for approximately 31% of total daily passengers. The BRTS system in Ahmedabad is designed to carry approximately 349,000 passengers daily with a fleet of around 275 buses. This translates to an average passenger capacity of about 1,286 passengers per bus per day [2]. BRTS buses in Ahmedabad operate at an average speed of around 20 km/h (12 mph). This is faster than traditional buses due to dedicated lanes and signal priority at intersections. The BRTS system in Ahmedabad experiences an average delay per junction of around 30 seconds. This is significantly less than traditional bus services due to priority at intersections and dedicated lanes [3]. There are two types of BRTS corridors: open corridors, which are used by buses from other routes, and closed corridors, which prevent buses from other routes or buses from entering the bus lanes designated for them. New Delhi is an example of an open corridor, while Ahmedabad is an example of a closed corridor.

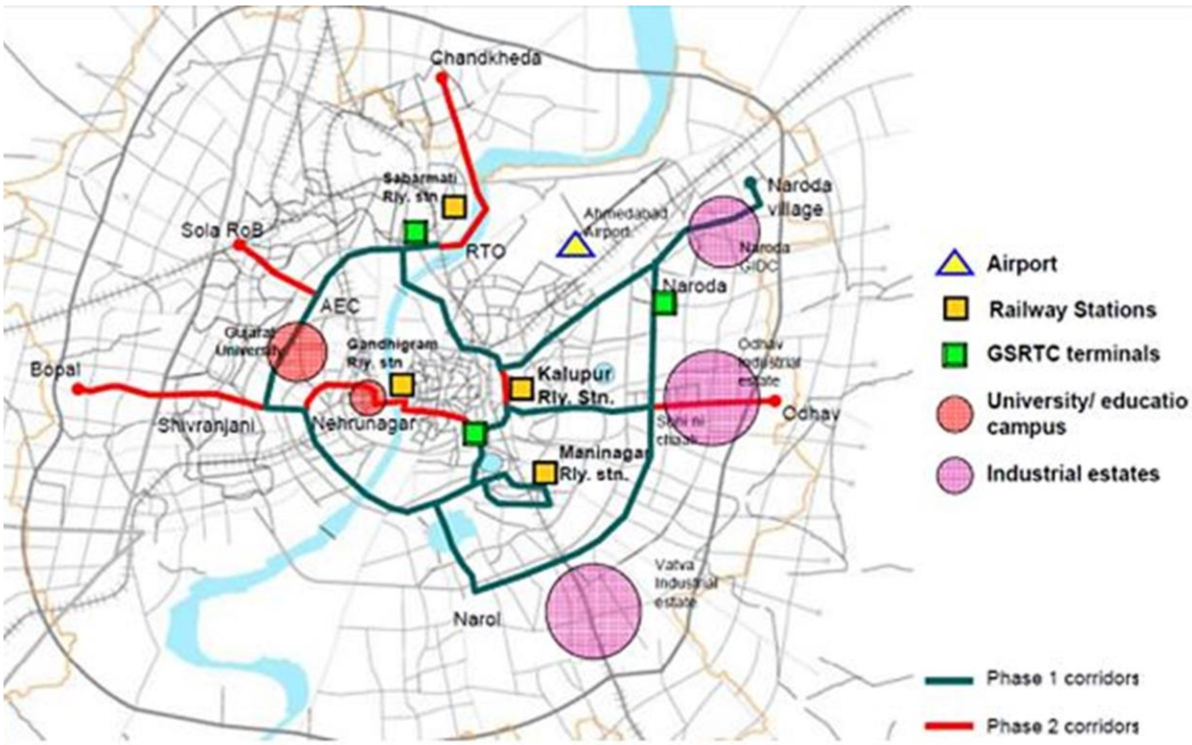


Figure 1: BRTS routes [5]

Transportation equity pertains to transportation systems that enable diverse transportation modes that are economical, eco-friendly, dependable, efficient, safe, and easy to use. When independent travel is required, it also includes first-rate transportation services that are available to all demographic groups. Furthermore, as part of the Minnesota Department of Transportation's Advancing Transportation Equity project, transportation equity entails inclusive public participation in decision-making processes related to transportation planning in order to lessen the persistent socioeconomic disparities that marginalized and underrepresented communities must contend with [4]. In the context of Ahmedabad, as shown in Figure 1, a sizable chunk of the region at the lower left corner is Juhapura, Ahmedabad, predominantly inhabited by Muslim residents where the Bus Rapid Transit System (BRTS) is not accessible. People who live in Juhapura cannot use the BRTS since they have to travel around 9 kilometers to Bopal in order to access the service. This makes them less likely to use this transit option.

A comprehensive perspective on a Bus Rapid Transit System (BRTS) would encompass its alignment with the urban land use strategy and residential policy of a municipality to ensure fair access and diminish travel distances, consequently leading to a decrease in carbon emissions [6].

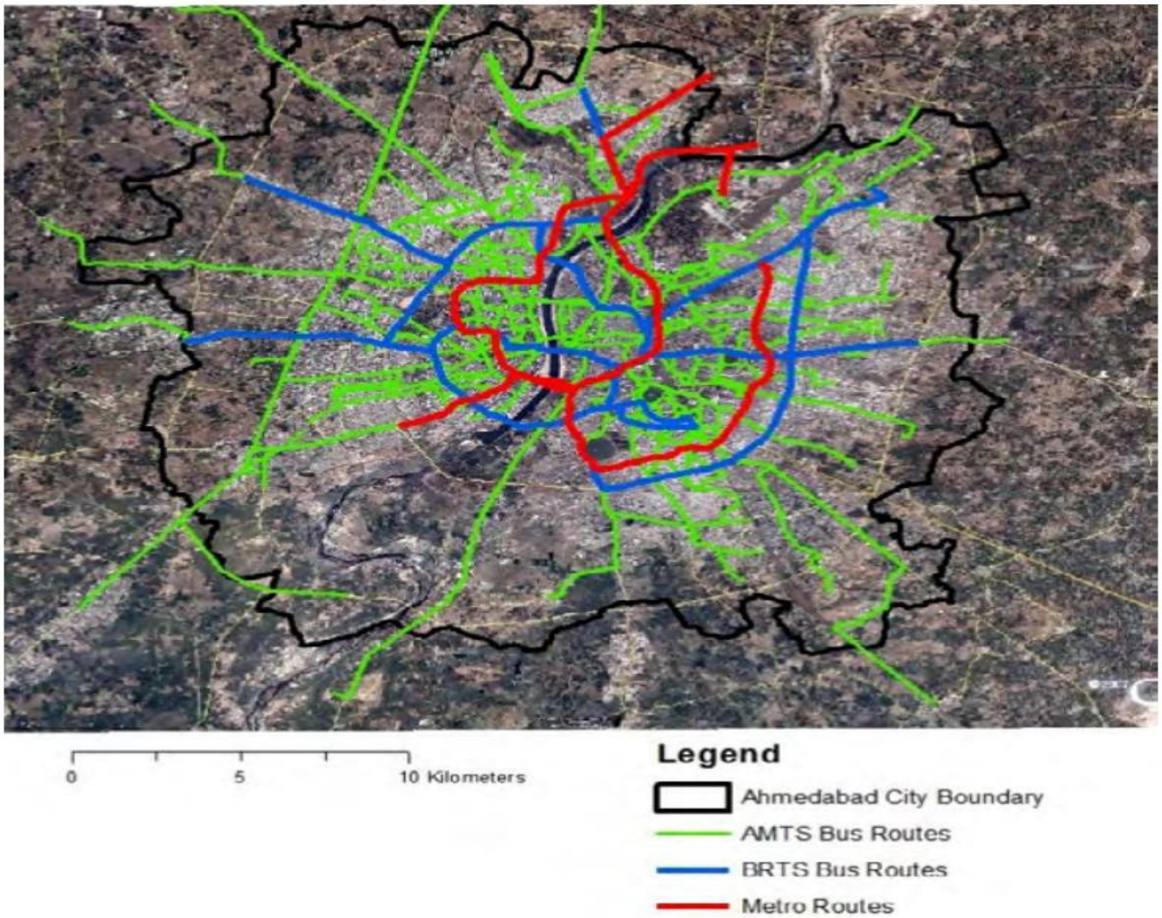


Figure 2: AMTS, BRTS and metro routes [7]

As depicted in the picture, BRTS routes have significantly lower accessibility than AMTS routes. Despite being electric and environmentally friendly, BRTS has limited accessibility.

Figure 3: Accessibility chain [7]

Non-motorized transport (NMT) is the primary mode of first and last-mile access to public transportation. If the accessibility chain,links 1 and 7 in Figure 3 is broken, the journey cannot be completed. Improved pedestrian facilities are crucial for improving first and last mile connectivity in public transportation accessibility. Door-to-door travel time refers to the time it takes a passenger to go from their starting point to their ultimate destination using the BRT system. This includes time spent walking, waiting for buses, and any additional walking or transfer periods. Minimizing this is critical to attracting more passengers.

The BRTS' efficacy is primarily reliant on its ability to connect to key destinations such as residential neighborhoods, business centers, educational institutions, and transit hubs. If the network of BRTS lines does not give quick access to these areas, people may prefer other means of transportation that provide better connectivity. Last mile connectivity is the most important and influential factor for enhancing the ridership of BRTS in Pune City [1]Lack of Last mile connectivity (LMC) also makes the overall journey expensive, tiring, unsafe and unpleasant for the transit users [8[.

It is quite difficult to switch to public transit when you own a private vehicle. The study used a Stated Preference (SP) exercise and a psychological questionnaire to assess TPB variables and private car use patterns among 600 participants. It discovered that participants had favorable

[1] Integrating BRTS with other forms of public transportation, like local buses, suburban trains, and shared auto rickshaws, has been identified as an important technique for improving last-mile connectivity in Pune. Pune is promoting the use of non-motorized transportation infrastructure, such as pedestrian paths, cycle lanes, and sidewalks, as a last mile connectivity strategy, promoting active transportation alternatives like walking and cycling, which are environmentally friendly, cost-effective, and healthy.

perspectives on BRT as a new method of transportation, but also had a strong preference for private automobiles due to the availability and ease of motorcycles [9].

The primary focus of this research paper is to investigate the effectiveness of Bus Rapid Transit Systems (BRTs) and the influence of policies on public transportation users' behavior. By prioritizing efficient public transportation options and implementing supportive policies, urban areas can significantly improve their transportation networks, reduce environmental impact, increase accessibility, and create more sustainable urban environments. This study seeks to understand how various policy interventions affect ridership patterns, encourage the transition from private vehicles to public transit, and contribute to achieving broader sustainability objectives.

There is also a connection between the research paper and the Sustainable Development Goals, specifically with reference to Goals 11 and 13. Sustainable Cities and Communities is the eleventh Sustainable Development Goal. By encouraging everyone to have access to safe, reasonably priced, accessible, and sustainable transportation networks, it primarily addresses sustainable urban development. In order to meet the demands of vulnerable groups, it highlights the extension of public transportation networks. When it comes to lowering carbon emissions from private automobiles and enhancing urban air quality, public transportation is essential. Investing in the infrastructure of public transportation, such as electric buses, is consistent with Goal 11.

Sustainable Development Goal 13 pertains to Climate Action.The primary objective of this goal is to combat climate change and its effects as soon as possible. It highlights the necessity for nations to increase their ability for adaptation and resilience to risks associated with climate change and natural disasters. Making the switch to electric buses can help mitigate climate change by lowering greenhouse gas emissions from the transportation sector.The utilization of sustainable energy sources in public transportation systems is crucial in accomplishing the emission reduction objectives outlined in Goal 13. Improving the accessibility of public transportation can result in a reduction of overall car use, which will aid in the fight against global warming.

Methodology

The research focuses on two aspects:

1. the utilization of Bus Rapid Transit Systems (BRTS) and the considerations for not utilizing BRTS
2. The impact of incentives on the performance of Bus Rapid Transit Systems (BRTS) and on the subsequent shift of individuals towards utilizing public transportation services.

Primary data is collected in the form of questionnaires, which are initially emailed to Ahmedabad University students. For the first stage, the plan is to send it to either L.D. College of Arts or Gujarat University to investigate student income groups and associated transport choices in order to draw a comparison to the case at Ahmedabad University, where 50% of students use private vehicles. The surveys conducted by L.D. College of Arts and Gujarat University were not feasible. Consequently, the attention was redirected towards transitioning 50% of private vehicle users to utilizing public transportation.The survey was analyzed by SPSS (Statistical Package for the Social Sciences).

The second stage of the process involves the analysis of data concerning the transition of individuals from private modes of transportation to public transportation utilizing Simulation for Urban Mobility (SUMO) software. The goal of this research project is to advance a simulation model intended to forecast the effect on waiting times, emissions, and duration times. A project like this has a lot of potential to improve our comprehension of the intricate interactions between these factors in different cases.

Literature Review

Efficient, comfortable, safe, fast, and affordable urban transport systems are necessary to enhance the advantage offered by cities in economic growth. In addition, the benefits of effective public transport systems also permeate to improve the quality of life and make cities more livable and sustainable (Planning Commission of India 2011). Accessibility to the public transport system is the key to improving the level of service in line with rising demand. To improve accessibility, it is important to be able to measure it as accurately as possible. Better understanding of accessibility levels of the public transport systems will not only be necessary to improve the level of service but also to plan and budget for resources (capital costs, operations & maintenance costs, etc.) [7].

Merely 18% of the city's overall population use public transportation [10]. Using public transit more often is necessary. BRTS is recognized as one of the most promising high-performance, competitively priced solutions that provide users with high-quality services. Each year, 127 million Indians use the BRTS. The Ahmedabad BRTS dominates this ridership, accounting for approximately 31% of total daily passengers. Feeder service, sluggish speeds, network coverage, land use, station spacing, and accessibility are the main factors influencing ridership [11]. It was discovered that respondents in Ahmedabad with higher educational qualifications were more likely to feel comfortable riding public buses [12]. Three things could happen as a result of transportation: women's ideas on gender changing at home and in local businesses; women's access to non-farm employment opportunities expanding; and women's time freed up from family obligations [13].

According to study results, system energy per passenger trip values ranged from 1.7 MegaJoules to 7.6 MJ, with a strong concentration around 3 MJ per passenger trip for a ridership of 30,000 or fewer per day. This is a significant energy reduction when compared to motorized excursions, which in Europe have an average energy consumption of 4.7 MJ/km. The emission calculations show that BRT can save a large amount of money when compared to individual motorized transportation such as private passenger automobiles [14]. According to a study, more than half of BRTS users are eager to switch to non-motorized modes of transportation for their last mile connectivity in order to create a pollution-free environment [15]. The analysis revealed that, as compared to a Euro III diesel baseline vehicle, utilizing any of the advanced BRT technology choices, such as plug-in hybrid buses and trolleybuses, would dramatically cut emissions at a low additional cost [16]. Although low-carbon buses frequently result in large reductions in greenhouse gas and air pollution emissions, they typically require higher initial capital expenditures and additional infrastructure. However, because they have fewer moving parts and less structural vibration, they frequently have longer lifespans and lower energy and maintenance costs, particularly battery electric buses [17]. Subsidies for electric vehicles (EVs), paired with a cap-and-trade policy that applies to the entire economy, have the potential to improve overall economic performance while mitigating the environmentally damaging rebound impact [18]. To address environmental issues, there is a growing trend of electrifying road transportation with various electric cars. Electric vehicles (EVs) offer benefits such as reduced noise pollution, lower operating costs (including energy and maintenance), and improved driving performance [19].

This study investigates the implementation of electric Bus Rapid Transit System (BRTS) in Mexico City, with a specific focus on the operational, environmental, and economic dimensions of the shift from privately operated to publicly managed bus services. The researchers found that the installation of electric BRTS significantly increased passenger demand, as shown by a daily average ridership increase of about 35%. This gain was ascribed to up to 20% shorter travel times made possible by the availability of priority signaling at junctions and exclusive lanes. Additionally, the deployment of electric BRTS led to notable decreases in particulate matter (up to 95%) and greenhouse gas emissions (up to 67%). Electric BRTS serves as a cost-effective strategy for enhancing urban mobility while concurrently mitigating environmental impacts [20].

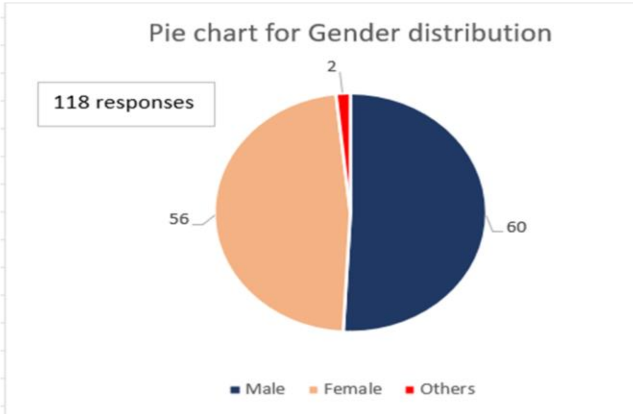
In order to find ways to improve last-mile connection, a comprehensive analysis of the existing Bus Rapid Transit System (BRTS) corridor includes a close look at its operations, infrastructure, and connectivity. The evaluation of last-mile connectivity aims to address the problem of providing passengers with practical and efficient means of transportation from BRTS stations or stops to their final destinations. The procedure may entail assessing the feasibility of integrating feeder services, such as bicycles, pedestrian walkways, or shuttles, to close the distance between the BRTS route and important sites, such as neighborhoods, shopping malls, transit hubs, and educational institutions [21].

The Bus Rapid Transit System (BRTS) utilization and travel habits study conducted at Ahmedabad University stands out from previous research because it focuses on pinpointing the causes of the system's underutilization. This study goes beyond a simple examination of usage patterns to gain a better understanding of the underlying causes of the BRTS system's underutilization in a given context. This research stands out in part because of the creative comparison analysis that was done using the Simulation of Urban MObility (SUMO) program. The study provides insightful information about the most cost-effective and environmentally friendly transportation choices available in the area by contrasting the performance of the electric Bus Rapid Transit System (BRTS) with that of other forms of transportation, including automobiles and the Ahmedabad Municipal Transport Service (AMTS). In order to determine the effectiveness of electric AMTS in the area, it also compares electric BRTS, electric AMTS, and automobiles.

Results

Survey

A survey was conducted among the students, staff, and faculty of Ahmedabad University, resulting in 118 responses [22].



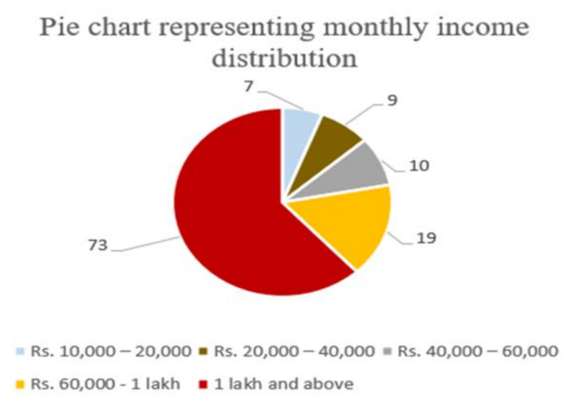


Figure 4: Pie chart showing the gender distribution

Figure 5: Pie chart showing the monthly Income distribution

The above graph depicts the demographics of the survey. The distribution of the gender is mostly equal for both male and female with 56 females, 60 males and 2 others. As for the income distribution, approximately 78% of the respondents were of the rich population i.e.Rs 60,000 or more.

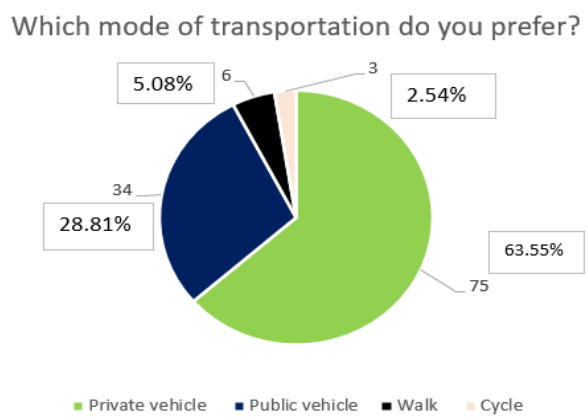


Figure 6: Pie chart showing which mode of transportation do the respondents prefer?

As depicted in the above pie chart, 64% of the respondents prefer private transportation while only approximately 29% of the respondents prefer public transportation.

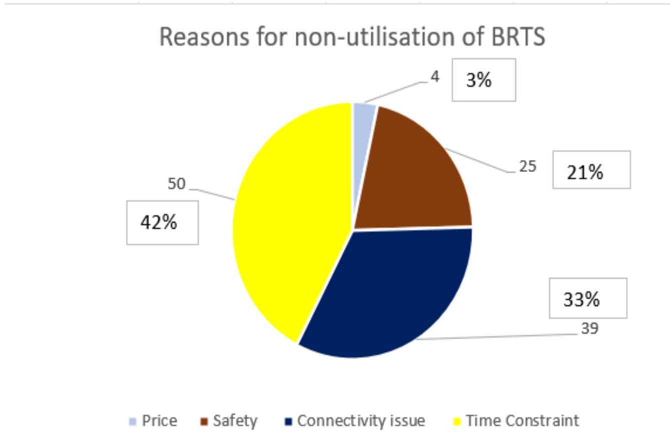


Figure 7: Pie chart showing the reasons for non-utilisation of the BRTS

The major findings that came into light were that if a respondent owns a private vehicle the chances of that individual to shift to BRTS are nil or extremely low due to factors like time constraints and connectivity issues.

From the pie chart above, 42% and 33% of respondents have to say that the main reason why they do not use BRTS is time constraint and connectivity respectively. On the basis of the responses, it can be stated that Individuals may choose other modes of transportation, such as private vehicles or taxis, because they feel that BRTS is more time taking when it comes to commuting or less efficient. In regards to that, these perspectives can be influenced by factors such as bus stop wait times, bus frequency, and overall travel duration when compared to other means of transportation.

It is quite difficult to switch to public transit when you own a private vehicle. The study used a Stated Preference (SP) exercise and a psychological questionnaire to assess TPB variables and private car use patterns among 600 participants. It discovered that participants had favorable perspectives on BRT as a new method of transportation, but also had a strong preference for private automobiles due to the availability and ease of motorcycles [23].

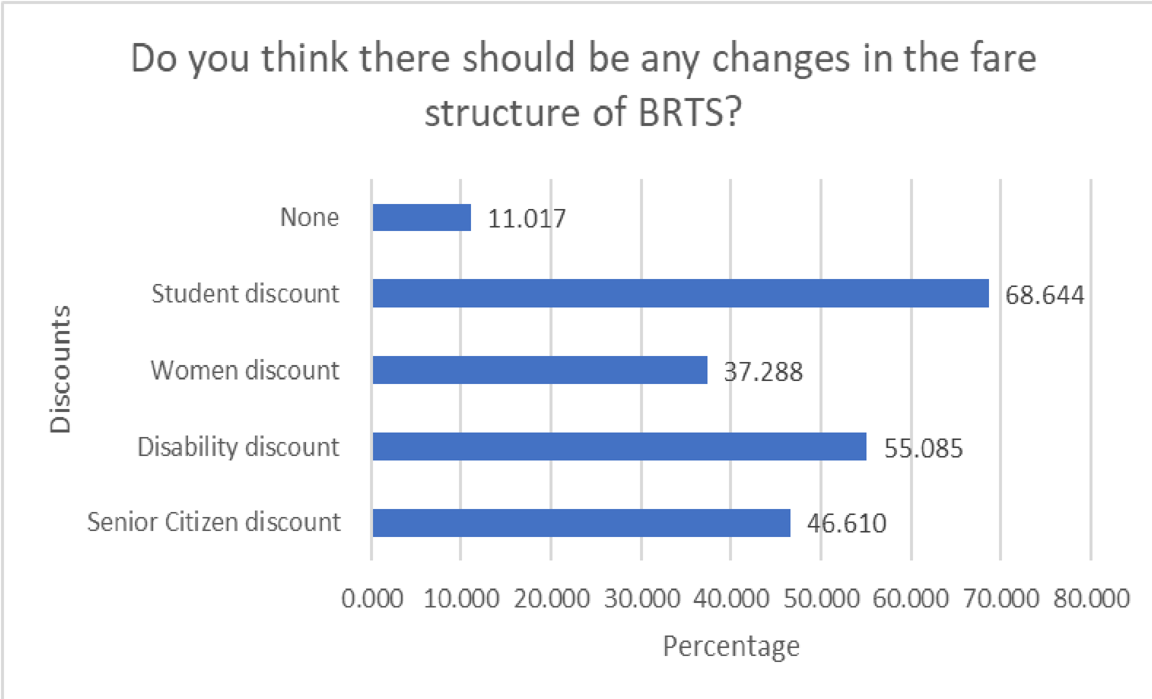


Figure 8: Graph showing the percentage change in the fare structure of BRTS

11% of respondents don't want a change in the fare structure of BRTS. So, 89% of respondents had a point of view towards a tweaked and changed fare structure of BRTS. This indicates that they were looking forward to discount introductions like (student, women, senior citizen and disability).

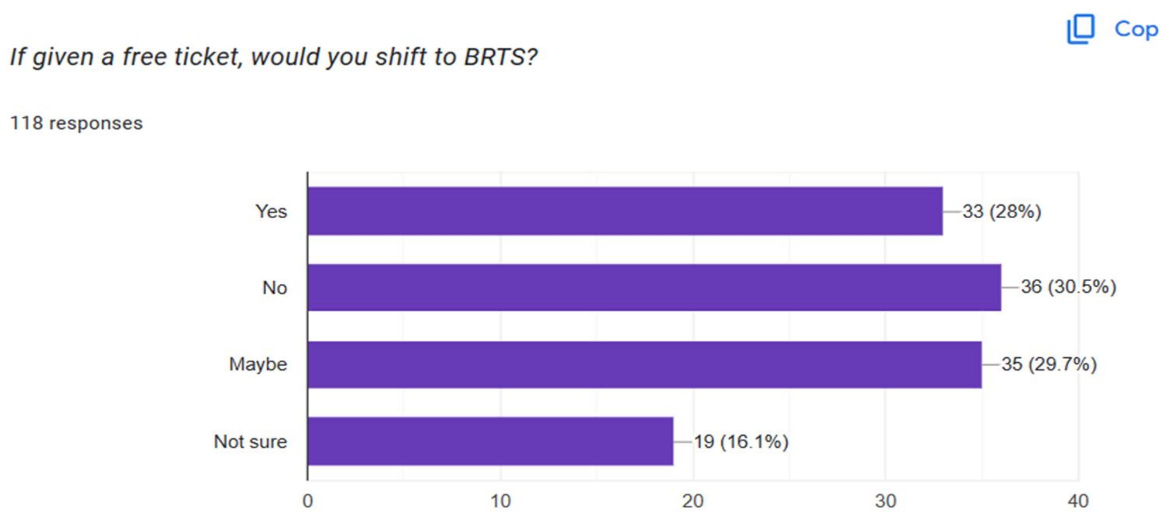


Figure 9: Graph showing If given a free ticket, would a respondent shift to BRTS?

The graph above suggests that only 28% of the respondents would shift to BRTS if provided a free ticket. The survey population includes respondents from high income class who would not want to shift to BRTS if given a chance because for them, price is not the major reason to shift but factors like connectivity and time constraint are.

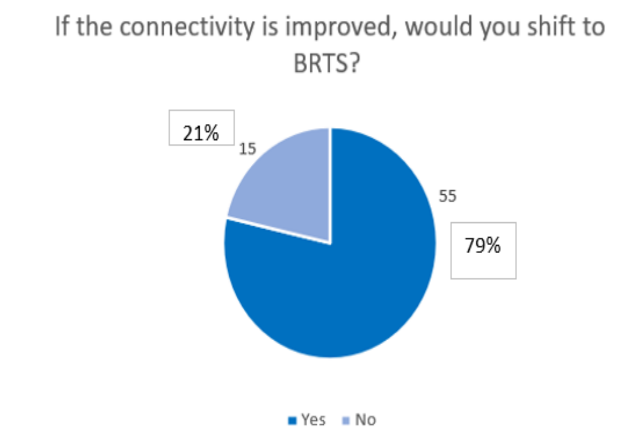


Figure 10: Pie chart showing if the connectivity is improved, would you shift to BRTS?

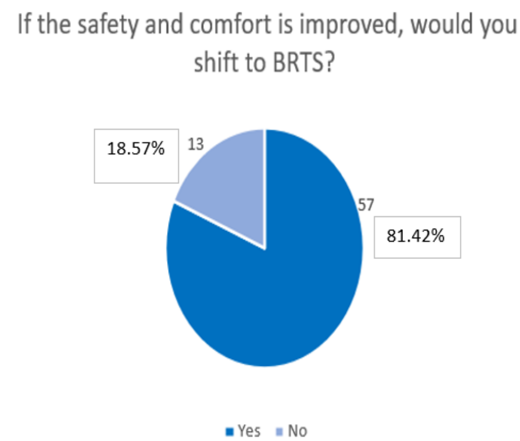


Figure 11: Pie chart showing if the safety and comfort is improved, would you shift to BRTS?

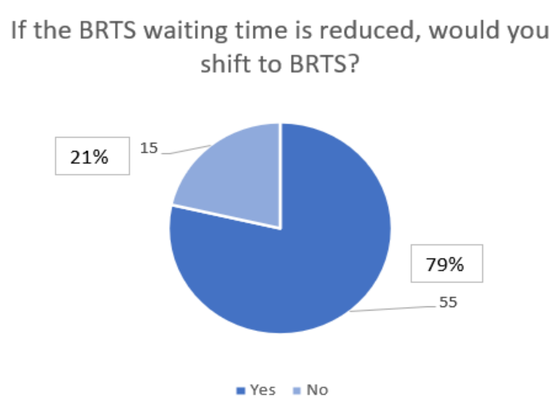


Figure 12: Pie chart showing If the BRTS waiting time is reduced, would you shift to BRTS?

As depicted in the above graphs, if connectivity is improved, safety and comfort is improved and waiting time is reduced then 79%, 81.4% and 79% respectively would shift to BRTS. Only 40.67% of the respondents would shift to BRTS if all the three conditions are satisfied.

Simulation

SUMO

A simulation model abstracts an actual system, allowing one to focus on fascinating phenomena. Simulated study results are only meaningful if they accurately reflect real-world scenarios. There are numerous traffic simulators that allow for microscopic traffic simulation in the literature (SUMO, VISSIM, VanetMobiSim, PARAMICS, etc. to name a few).

The Simulation of Urban Mobility (SUMO) represents an open-source traffic simulation package specifically engineered to manage extensive networks. The primary characteristics of the Simulation of Urban Mobility (SUMO) software encompass a variety of features, notably the integration of multimodal traffic. This entails the amalgamation of diverse modes of transportation such as automobiles, buses, trains, bicycles, and pedestrian movement. Additionally, SUMO facilitates network importation and enables the simulation of traffic dynamics by modeling signalized intersections and regulating traffic flow through these junctions.

The diverse traffic landscape in India presents distinctive challenges owing to the simultaneous presence of various categories of vehicles such as automobiles, motorcycles, bicycles, pedestrians, and even livestock on the roadways. This heterogeneity in the composition of traffic necessitates the application of specialized modeling methodologies to accurately depict the intricate interactions among different road users.

Through the utilization of simulation software known as SUMO, scholars at the Indian Institute of Technology Bombay successfully constructed virtual environments that closely mirrored the actual traffic scenarios observed in urban areas across India. This approach enabled them to investigate how variables like road infrastructure, traffic signal timings, driver conduct, and vehicle classifications impacted both the efficiency and safety of traffic flow. The outcomes derived from this research endeavor yielded valuable insights for devising more efficient traffic management strategies tailored specifically to address the unique requirements of Indian metropolitan regions.

Methodology

Given that the Ahmedabad urban agglomeration area is about 1866 km2, it was necessary to limit the geographical extent of the study area. Since, it was necessary to cover the L.D. college bus stop in our study area, so hence took the study area from Nehru Nagar char rasta to Vijay char rasta, approximately 4 km. Within the study area are about 6 AMTS bus stops and 3 BRTS bus stops.

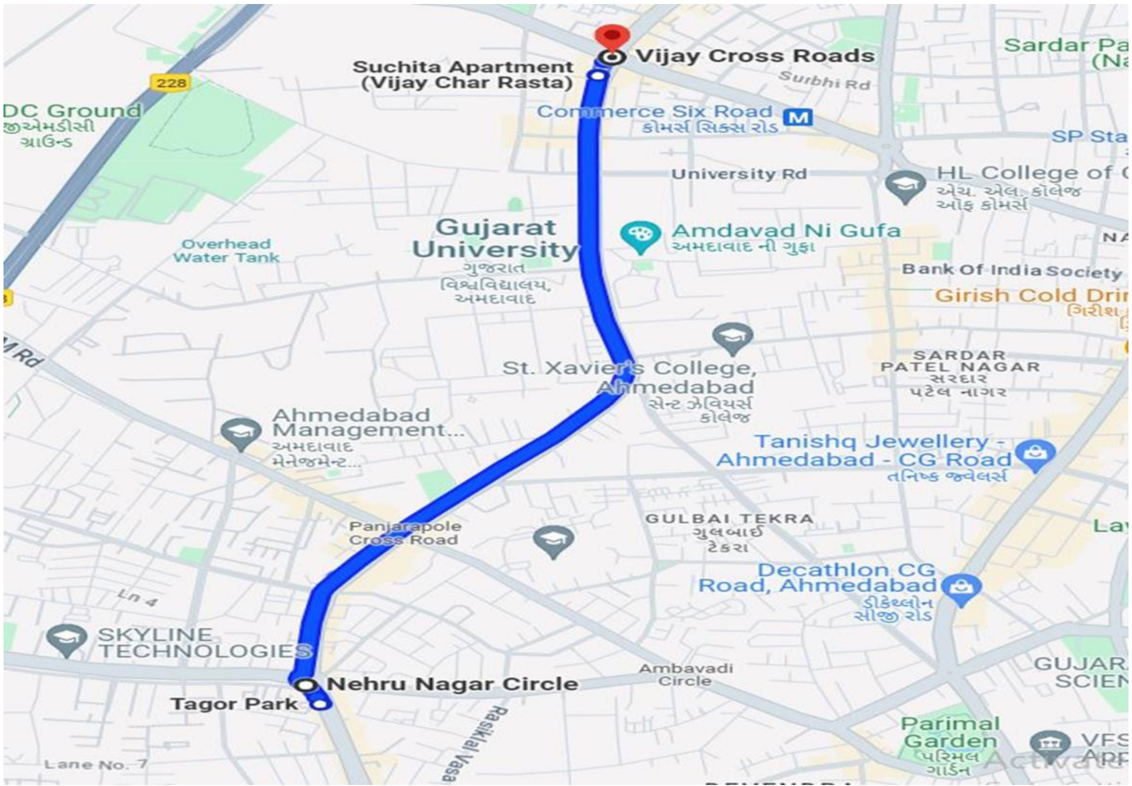


Figure 13: Map of the study area [24]

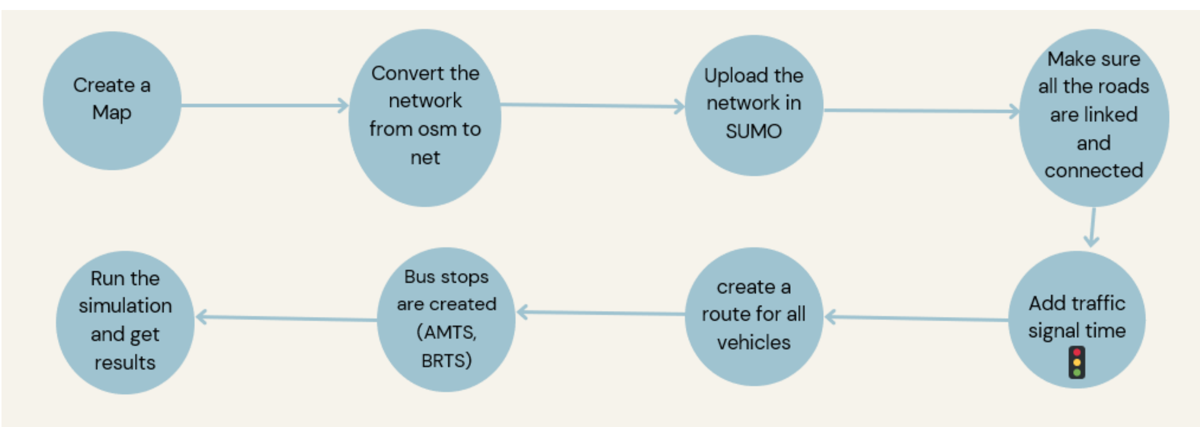


Figure 14: Flow chart of the process of the simulation

As seen in the flowchart above, OpenStreetMap was used to create a map connecting Nehru Nagar Char Rasta with Vijay Char Rasta. The next step involved converting the network from OSM to XML to upload it to SUMO. For editing in SUMO, we utilized Netedit, a graphical network editor that allows users to design and modify traffic networks. It is built on top of Net Convert, providing equivalent functionality within a visual interface. While editing in Netedit, the roads needed to be linked and connected if necessary. Subsequently, traffic lights were non-functional wherever they existed in reality, each with a total signal cycle of 90 seconds. Traffic was generated from Nehru Nagar Char Rasta to Vijay Char Rasta for exactly 40 cars, as around 35 to 40 cars were present at the L.D. College Char Rasta signal during peak hours, from 5:30 p.m. to 7:30 p.m. A specific route has been established for AMTS and BRTS from Vijay Char Rasta to Nehru Nagar Char Rasta. To enhance practicality, BRTS buses were designed to achieve 90% zero carbon emissions, charging stations for BRTS were installed, and bus stops for both the AMTS and the BRTS were maintained.

To obtain reliable results and facilitate comparison, it is divided into four cases:

Case No.	Description	No. of Cars	No. of AMTS	No. of BRTS
Case 1	Present Scenario	40	3	3
Case 2	Converting AMTS transportation to BRTS transportation	40	-	6
Case 3	Converting private transportation to public transportation	18	3	6
Case 4	A slight punishment for private vehicles and AMTS	18	3	6

In the table provided, it is evident that the number of cars decreases significantly from 40 to 18 in both Case 3 and Case 4. This reduction is directly linked to the findings of the Google survey mentioned earlier. The survey involved a total of 118 respondents, out of which 75 individuals rely on private transportation. Among these respondents, 27 expressed their willingness to switch to Bus Rapid Transit System (BRTS) if certain improvements are made, such as enhanced safety measures, increased comfort, better connectivity, and reduced waiting times for BRTS. However, when offered a complimentary ticket, only 15 respondents indicated they would consider shifting to BRTS under the same conditions.

In total, 34 respondents are inclined to transition to BRTS if all the specified criteria are met. Notably, upon recalculating based on an initial assumption of 40 cars being considered for potential shifters, the final count reduces to 18 individuals who would opt for BRTS.

Variable of interest

1. Signal time

Case No.	Cars (secs)	AMTS (secs)	BRTS (secs)
Case 1	90 30	90 30	30 10
Case 2	90 30	—	20 40
Case 3	90 30	90 30	20 40
Case 4	120 40	120 40	20 40

In cases 2, 3, and 4, the signal duration for the Bus Rapid Transit System (BRTS) has been extended due to the increase in the number of BRTS vehicles. Additionally, in case 4, a minor penalty was imposed on cars and Ahmedabad Municipal Transport Service (AMTS) vehicles by increasing the signal duration.

2. Speed

Case No.	Cars (m/s)	AMTS (m/s)	BRTS (m/s)
Case 1	12.5	11.1	14.4
Case 2	13.8	—	14.4
Case 3	13.8	11.1	14.4
Case 4	12.5	11.1	14.4

In the context of automobiles, the speed of cars varies under different cases. In Case 1, the speed is recorded at 12.5 meters per second. This speed sees an increase in both Case 2 and Case 3, reaching 13.8 meters per second. This increase can be attributed to the absence of Automated Manual Transmission Systems (AMTS) on the road and a decrease in the number of cars from 40 to 18 respectively. However, in Case 4, the speed experiences a decline due to longer signal times leading to increased traffic congestion. Consequently, the speed of cars decreases under these circumstances.

It is noteworthy that for Automated Manual Transmission Systems (AMTS) and Bus Rapid Transit Systems (BRTS), the speed remains constant across all cases regardless of the specific case being considered.

Results

This research paper provides an analysis of the simulation outcomes concerning the travel duration, waiting time, and emissions of all vehicles. The primary objective of the simulation was to assess the prospective environmental and operational advantages associated with the deployment of electric Bus Rapid Transits (BRTs) within an urban environment.

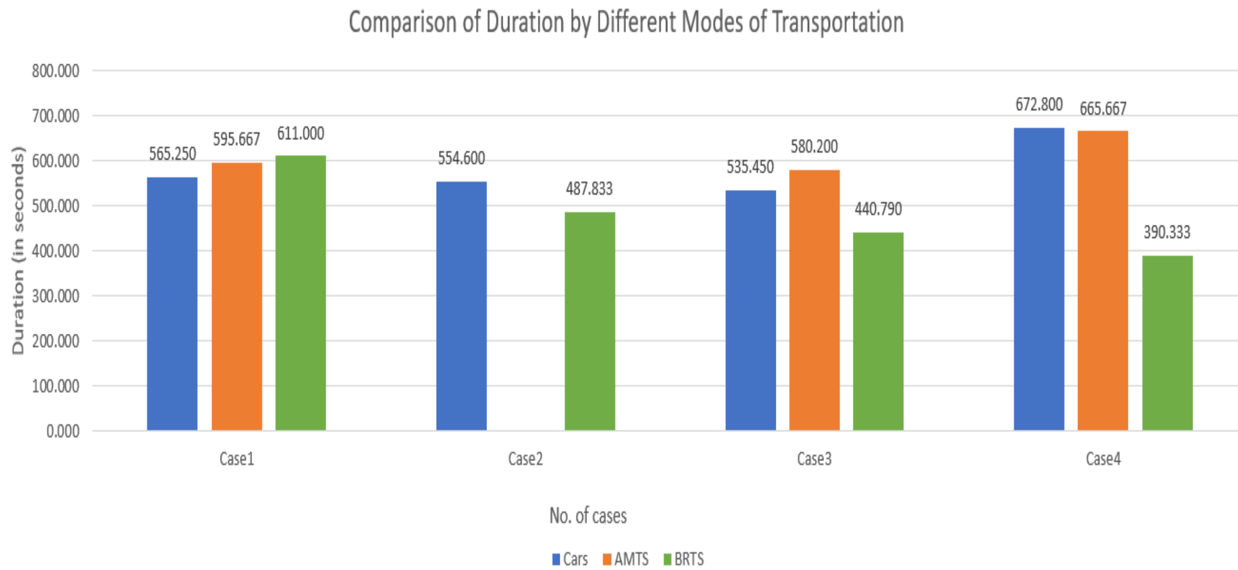


Figure 15: Graph showing the comparison of the duration time by different mode of transport

In the Simulation of Urban Mobility (SUMO), the term "duration time of a vehicle" pertains to the period it requires for a vehicle to traverse from its initial point to its final destination or until it exits the simulation area. This duration is subject to influence by various factors that includes the speed of the vehicle, length of the route, prevailing traffic conditions, as well as any halts or delays encountered during the journey. [2]

In Case 1, the duration time is significantly longer compared to Case 2 and Case 3. In the context of cars, the duration time decreased in Case 2 and Case 3 due to the absence of AMTS on the road and a reduction in the number of cars from 40 to 18 respectively. Concerning AMTS, in Case 3, there was a reduction of 15 seconds in the duration time attributed to the decrease in the number of cars. In Case 4, an increase in signal time for both cars and AMTS led to a notable increase in the duration time. In contrast, for BRTS, there was a consistent decrease in duration across all cases. BRTS, being a rapid transport system with a dedicated corridor and optimized signal times, exhibited lower duration times compared to other modes of transportation.

The research conducted on the travel time characteristics of the Hubli-Dharwad Bus Rapid Transit System (BRTS) in comparison with heterogeneous traffic lanes aimed to examine and contrast the travel times of buses operating within the BRTS system with those operating in conventional traffic lanes. The study revealed that buses within the BRTS system encountered shorter travel times, decreased delays at intersections, and more consistent journey durations compared to buses navigating through regular traffic. Passengers utilizing the BRTS system benefited from quicker and more predictable travel times [25].

[2] Details regarding the definition, outcomes, and codes associated with the results obtained from the simulation of urban mobility (SUMO) https://sumo.dlr.de/docs/Simulation/Output/index.html

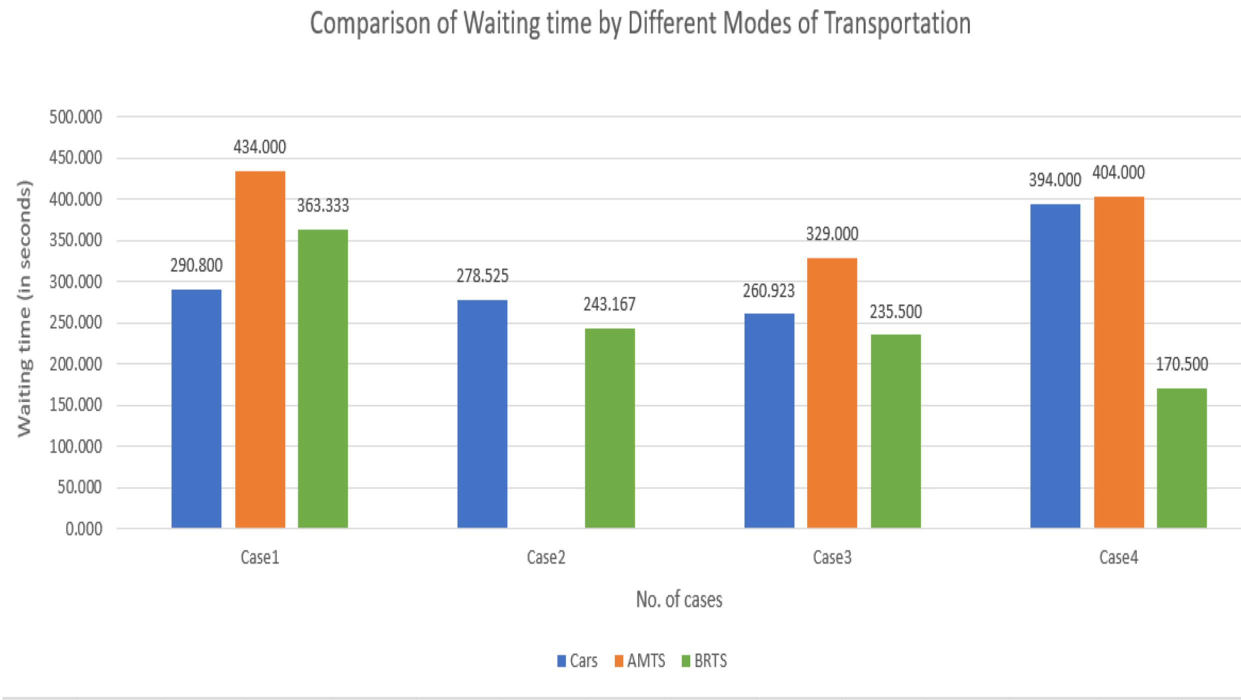


Figure 16: Graph showing the comparison of the waiting time by different mode of transport

In the Simulation of Urban Mobility (SUMO) framework, the term "waiting time" pertains to the period during which a vehicle stays stationary or moves at a significantly reduced speed while awaiting clearance at traffic signals, intersections, or other designated points along its designated path. [3]

The image above illustrates a trend in the reduction of waiting times for cars as we progress through different cases. In Case 2, the waiting time decreased by 13 seconds due to the absence of AMTS, resulting in slightly lower traffic on the road. Moving on to Case 3, there was a further reduction in waiting time of approximately 30 seconds, attributed to a decrease in the number of cars from 40 to 18. However, in Case 4, waiting times increased significantly as a result of an extension in signal time. Specifically concerning AMTS, there was a notable shift in waiting times with a reduction of 50 seconds observed in Case 3. Although waiting times increased in Case 4 compared to Case 3, the increase was less pronounced than that seen in Case 1. In the context of BRTS, waiting times were highest in Case 1 due to longer signal times; however, subsequent cases demonstrated a decrease in waiting times.

In the academic research titled "A SUMO Based Simulation Framework for Intelligent Traffic Management System," the correlation between traffic signal lights and waiting time in the Simulation of Urban Mobility (SUMO) software was explored. At intersections, traffic signal lights play a crucial role in directing vehicle traffic. The length of the green, yellow, and red phases directly affects how cars move through the transportation system. Prolonged green signals can diminish waiting times for vehicles approaching an intersection, whereas abbreviated green signals might result in heightened congestion and

[3] Details regarding the definition and outcomes associated with the results obtained from the simulation of urban mobility (SUMO) https://sumo.dlr.de/docs/TraCI/Vehicle_Value_Retrieval.html

extended delays [26].

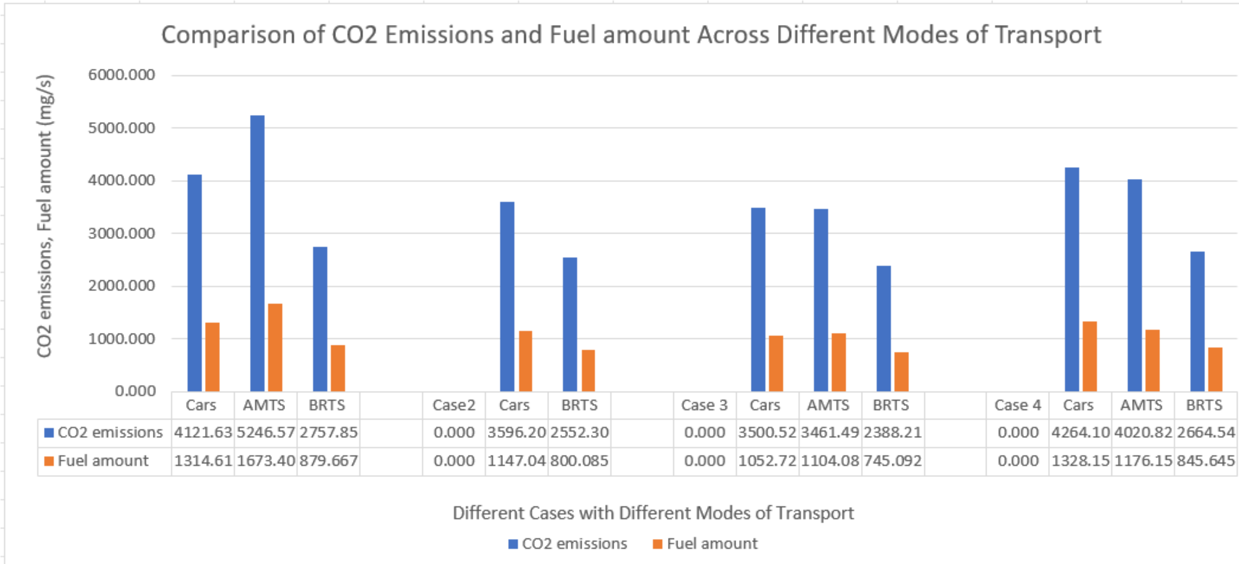


Figure 17: Graph showing the comparison of the CO2 emissions and fuel amount by different mode of transport

Carbon dioxide (CO2) emissions are defined as the release of carbon dioxide gas into the Earth's atmosphere due to human activities, including the combustion of fossil fuels for energy generation, transportation, and industrial operations. In the context of simulation modeling, CO2 emissions are measured by figuring out how much fuel is used by machinery or cars during the simulation. This calculation considers factors such as the type and volume of fuel utilized, as well as the efficiency of the vehicle or machinery in converting fuel into usable energy. The standard unit for measuring CO2 emissions in the simulation is milligrams per second (mg/s).[4]

In the graph presented, it is evident that the carbon dioxide (CO2) emissions and fuel consumption of vehicles exhibit a reduction in both case 2 and case 3 when compared to case 1. This phenomenon can be attributed to the absence of Automated Manual Transmission System (AMTS) in case 2, leading to more efficient traffic flow due to increased road capacity for vehicles. Similarly, in case 3, the decrease in the number of cars results in lower CO2 emissions and fuel consumption. The implementation of AMTS demonstrates a significant decrease in both CO2 emissions and fuel consumption from case 1 to case 3. Conversely, in Case 4, there is a notable increase in CO2 emissions and fuel consumption for vehicles with AMTS due to prolonged signal times resulting in extended waiting periods at traffic signals, consequently leading to higher emissions.In the realm of Bus Rapid Transit System (BRTS), it has been noted that carbon dioxide (CO2) emissions and fuel consumption exhibit a slight increase in case 4 when contrasted with cases 2 and 3; nevertheless, they persistently remain notably lower than those witnessed in case 1. This disparity can be attributed to the utilization of electric buses within the BRTS infrastructure.

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[4] Details regarding the definition, units and outcomes associated with the emissions obtained from the simulation of urban mobility (SUMO) https://sumo.dlr.de/docs/Tools/Emissions.html#output

The scholarly article titled "The Influence of Electric Vehicles on Carbon Emissions" delves into an examination of the impact that electric vehicles (EVs) have on carbon emissions in contrast to conventional internal combustion engine vehicles. The findings of this study reveal that the integration of electric vehicles can result in a substantial decrease in carbon emissions when juxtaposed with gasoline or diesel-fueled vehicles. The primary cause of this drop is the reduced carbon intensity of electricity generation when compared to the use of fossil fuels. In essence, the research paper underscores the potential of electric vehicles as a sustainable mode of transportation that holds promise for aiding in the mitigation of climate change by diminishing greenhouse gas emissions linked to traditional vehicles [27].

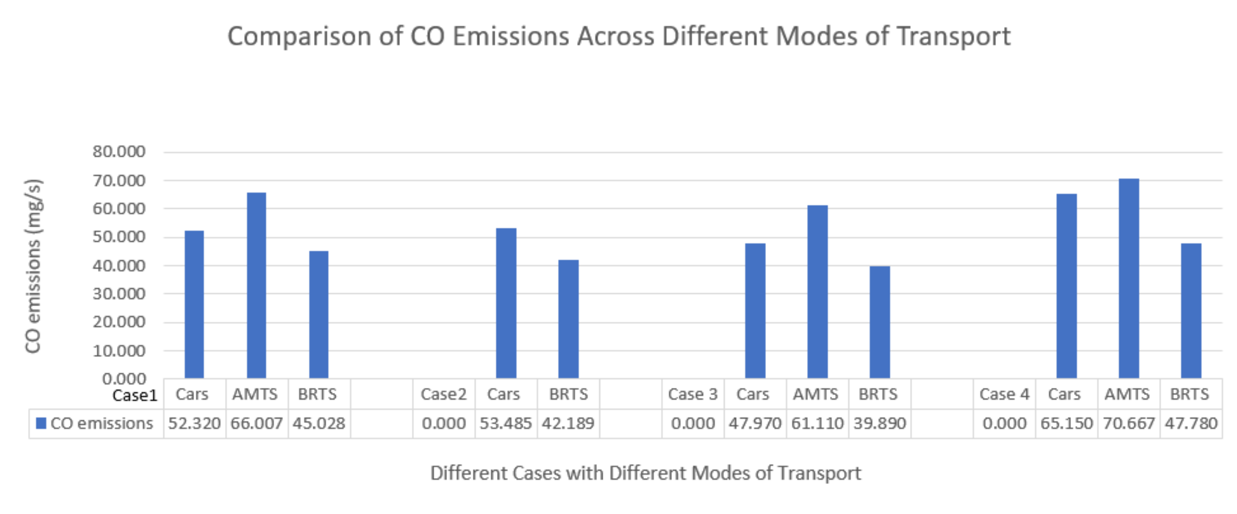


Figure 18: Graph showing the comparison of the CO emission by different mode of transport

Carbon monoxide (CO) emissions represent a form of air pollution that arises from the incomplete combustion of carbon-containing fuels like gasoline, diesel, and natural gas. In contrast, electric vehicles (EVs) exhibit significantly reduced levels of CO emissions in comparison to conventional vehicles due to their lack of direct fossil fuel combustion. Instead of relying on internal combustion engines, EVs utilize electric motors powered by batteries or fuel cells for propulsion. Consequently, the primary source of emissions associated with EVs stems from electricity generation required for charging their batteries [28].

In the case of automobiles, the carbon monoxide (CO) emissions in case 3 are significantly lower compared to cases 1 and 2. This disparity can be attributed to the fact that there are fewer cars present in case 3, less than half the number in the other cases. Conversely, in case 4, CO emissions increase due to longer signal times leading to extended waiting periods and subsequently higher CO emissions. The findings for the Ahmedabad Municipal Transport Service (AMTS) mirror those of the cars, with emissions being notably lower in case 3 than in case1, but significantly higher in case 4. Regarding the Bus Rapid Transit System (BRTS), there is a reduction in emissions for cases 2 and 3 compared to case 1; however, emissions slightly increase in case 4. Notably, since BRTS vehicles are electrically powered, their CO emissions are substantially lower than those of motorized vehicles such as cars and AMTS buses.

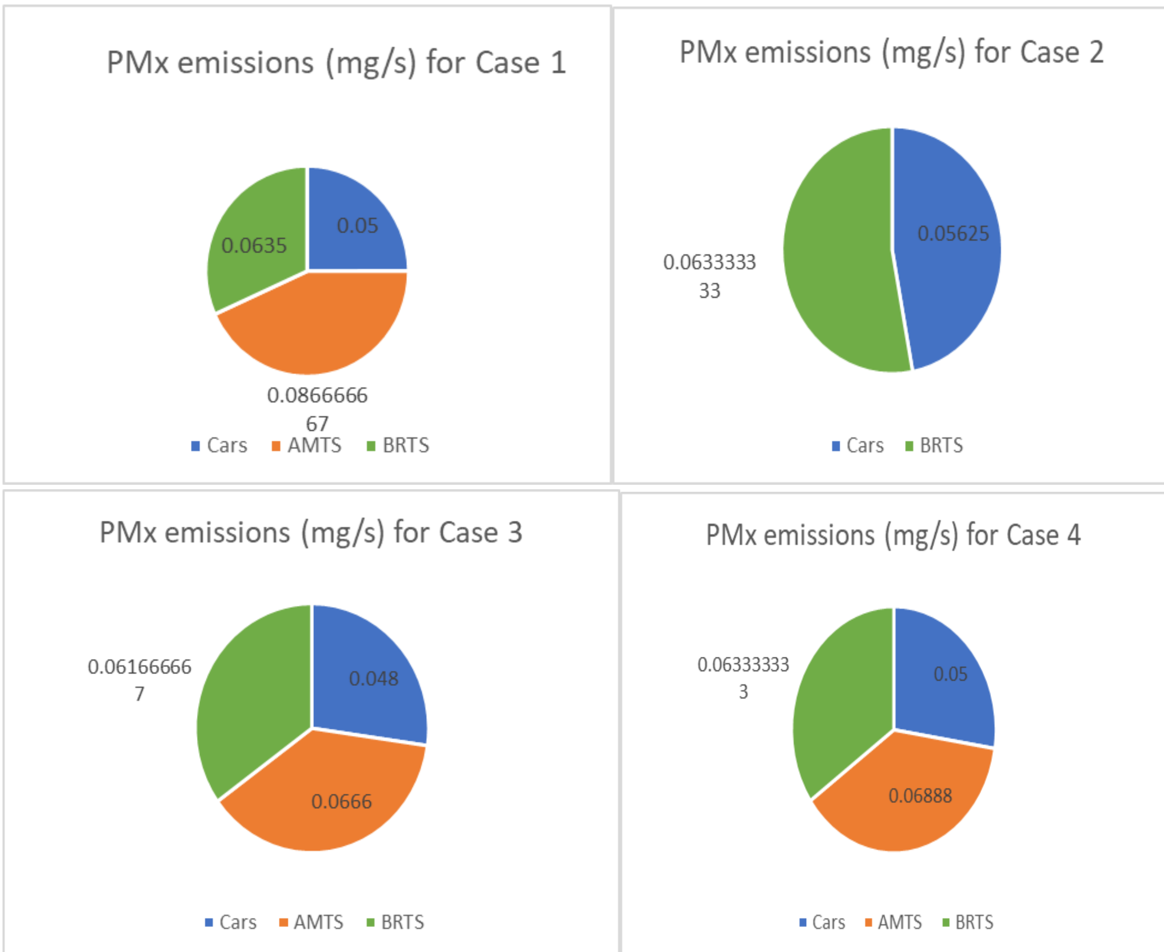


Figure 19: Pie charts showing the PMx emissions by different mode of transport

Particulate matter emissions, or PMx emissions, are described as microscopic solid or liquid particles suspended in the atmosphere. PM emissions are significantly influenced by the length of vehicles. Larger surface surfaces of longer vehicles can lead to more friction with the surrounding air when they are moving. Because of this increased friction, PM emissions can be higher than in shorter vehicles. Longer cars may also have bigger engines or be carrying higher loads, which can both add to the overall rise in PM emissions [29].

As seen above, the PMx emissions in cars is way less than the PMx emissions in AMTS and BRTS. The reason behind it is the length of the vehicle. In the simulation, the length of the car is taken as 5 meters whereas the length of AMTS and BRTS is 11 meters and 9 meters respectively.[5]

[5] Length of the BRTS - https://www.buses.tatamotors.com/products/brands/starbus/tata-ultra-9-9m-ac-electric-bus/
Length of the AMTS - https://www.buses.tatamotors.com/products/brands/starbus-ultra/ultra-prime-44-d-lpo-11-6-54/

Futuristic Plan

Ahmedabad, India, was founded in AD 1411 and is the largest city in Gujarat and the seventh largest in India, with a population of 8.85 million in 2024 [30]. Ahmedabad has two public transportation systems: the Ahmedabad Municipal Transport Service (AMTS), a bus service that operates in mixed traffic, and the Ahmedabad Janmarg Ltd (AJL), which operates on dedicated corridors (except intersections and a few linkages). AMTS and BRTS are wholly-owned subsidiaries of the Ahmedabad Municipal Corporation [7].

Bus Rapid Transit System (BRTS) is a bus-based transit system that allows for faster travel, more capacity, and improved bus safety by separating buses from other vehicle traffic. A closed system refers to bus operations in which only one route uses the corridor from end to finish and no other route or bus enters the designated bus lanes. Ahmedabad has implemented a closed bus operation style that includes high floor island stations as well as high-floor buses. In the case of Ahmedabad, performance versus all passengers improves if the current architecture is modified to provide an open system that allows AMTS to enter [31].

Battery electric vehicles (BEVs) are becoming more popular due to lower prices and more charging stations. Affordable BEVs may have limited range, leading to range anxiety (fear of being stranded due to low battery power). To reduce range anxiety, vehicles should have an accurate range assessment feature that informs customers (BRTS driver) if the remaining battery charge is sufficient to reach their destination [32].

The Ahmedabad Municipal Transport Service (AMTS) is indeed moving towards electric transportation. A brand-new fleet of air-conditioned double-decker electric buses was just launched by AMTS. These buses were first introduced as a trial service between Vasna and Chandkheda [33].

In order to address this issue, two additional cases are also being considered.

Case No.	Description	No. of Cars	No. of electric AMTS	No. of BRTS
Case 5	Conversion of AMTS to electric AMTS	40	3	3
Case 6	Converting BRTS transportation to AMTS transportation	40	6	-

Variable of Interest

1. Signal time

Case No.	Cars (secs)	AMTS (secs)	BRTS (secs)
Case 5	90 30	90 30	30 10
Case 6	90 30	90 30	—

2. Speed

Case No.	Cars (m/s)	AMTS (m/s)	BRTS (m/s)
Case 5	12.5	11.1	14.4
Case 6	12.5	11.1	—

Results

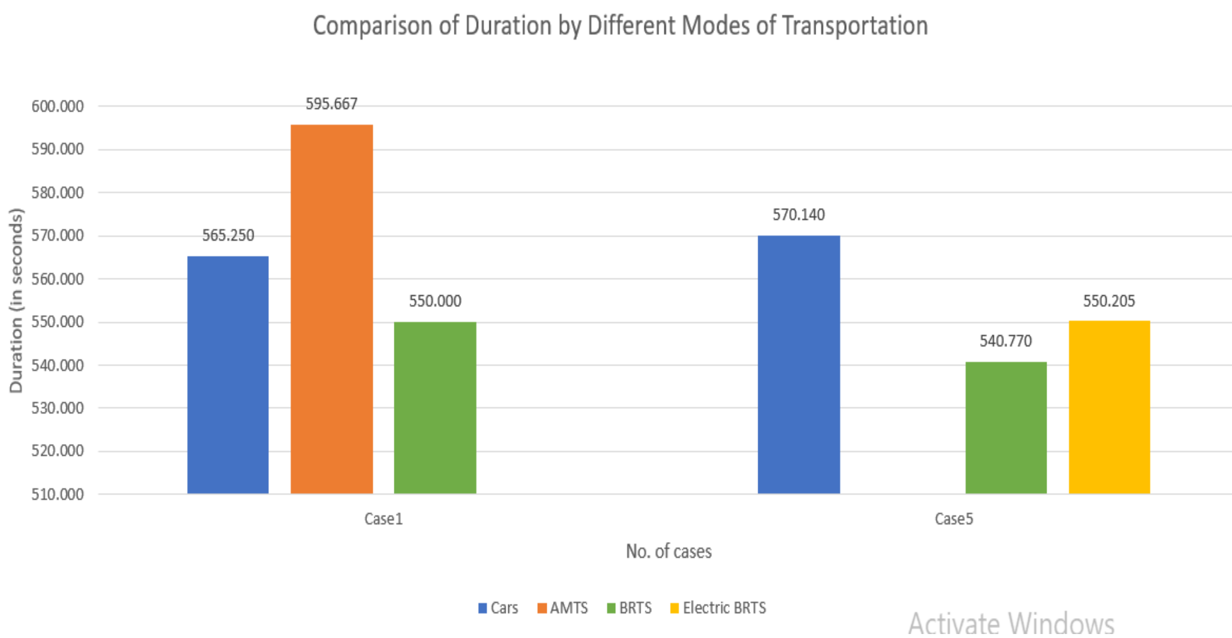


Figure 20: Graph showing the comparison of the duration time by different mode of transport for Case 1 and 5

Following the transition from automated manual transmission systems (AMTS) to electric AMTS, a significant reduction in duration time is observed. Shifting to electric AMTS results in an approximate 45-second decrease in shifting time.

The focus of this research study lies in the advancements of automotive technology that integrate electric drive systems with automated manual transmissions (AMTs). A key finding of this investigation is that electric AMTs, when compared to traditional manual gearboxes, notably diminish the time required for gear shifts. The seamless fusion of automated manual transmission systems with electric motors enables quicker and smoother gear changes, thereby enhancing acceleration, responsiveness, and overall driving dynamics [34].

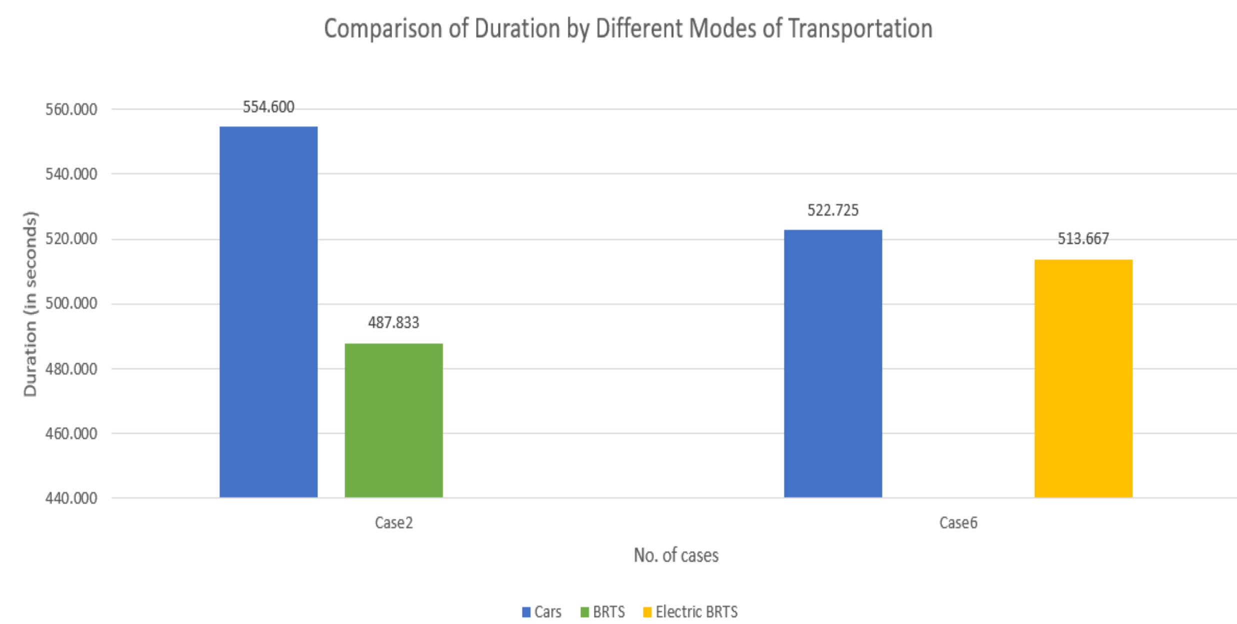


Figure 21: Graph showing the comparison of the duration time by different mode of transport for Case 2 and 6

The graph illustrates a comparison between cars equipped with electric Bus Rapid Transit System (BRTS) and those with electric Automated Multimodal Transit System (AMTS). It is evident that the duration of travel for electric BRTS vehicles is shorter in comparison to electric AMTS vehicles. This difference can be attributed to the specific corridor design, which allows BRTS vehicles to operate at higher speeds, making them more efficient and rapid in their transportation capabilities.

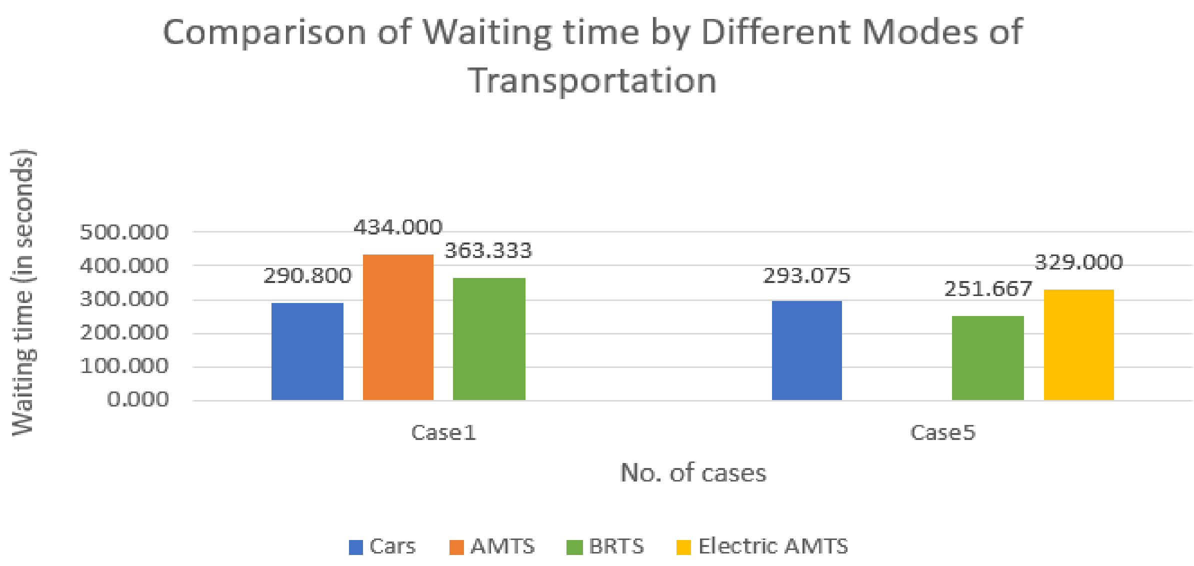


Figure 22: Graph showing the comparison of the waiting time by different mode of transport for Case 1 and 5

The graph shows that in both cases, the wait time for the car is essentially the same. However, there is a significant reduction in wait times when switching from AMTS to electric BRTS. Additionally, there has been a decrease in the BRTS waiting time. Because of the difference in signal times between the BRTS and the electric AMTS in case 5, BRTS requires less waiting time than electric AMTS.

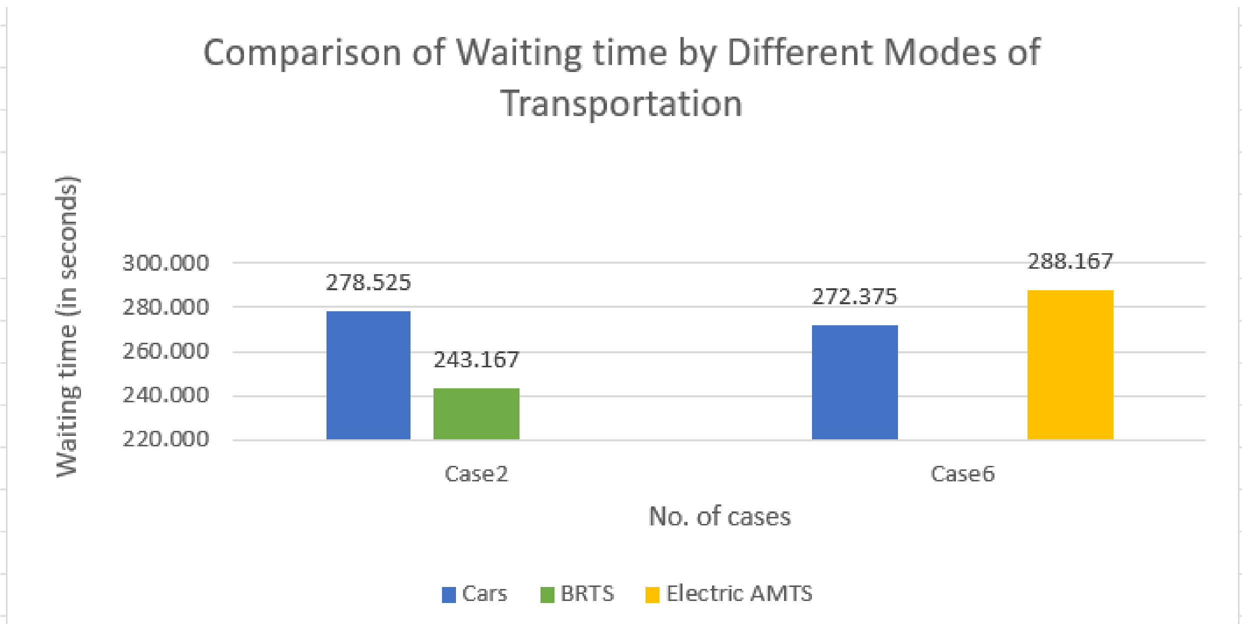


Figure 23: Graph showing the comparison of the waiting time by different mode of transport for Case 2 and 6

The graph shows a comparison between automobiles equipped with the electric Automated Multimodal Transit System (AMTS) and those with the electric Bus Rapid Transit System (BRTS). The main cause of the roughly 40-second difference in waiting periods between the electric BRTS and the electric AMTS is changes in signal timing. More specifically, the BRTS signal lasts shorter than the AMTS signal.

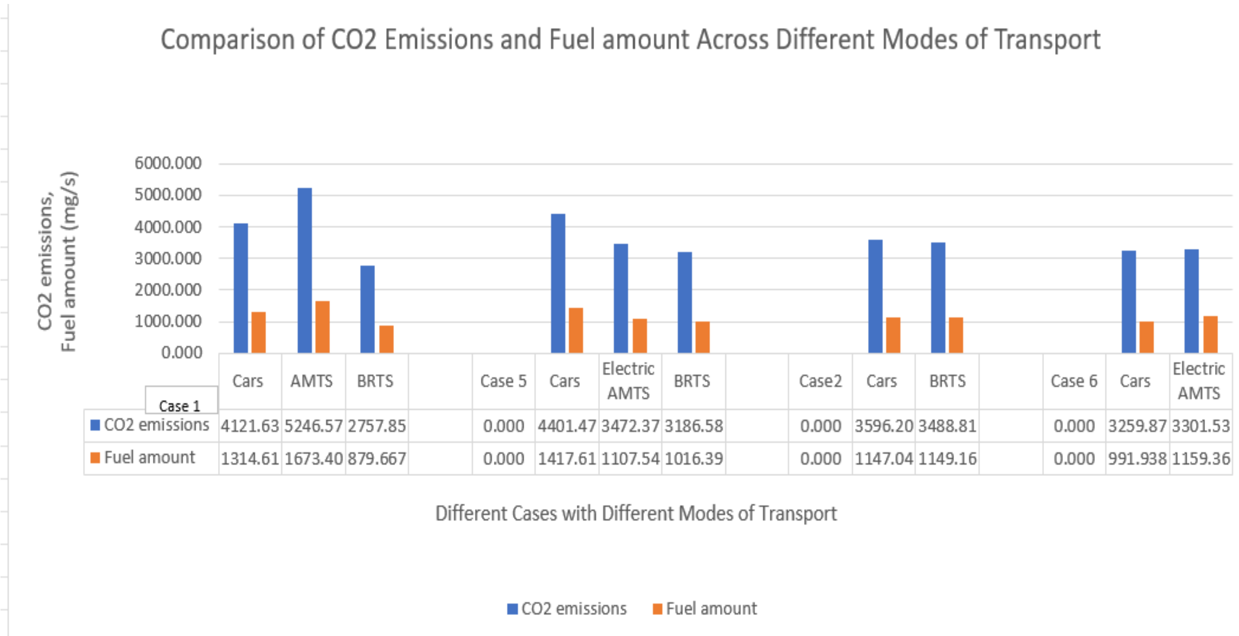


Figure 24: Graph showing the comparison of the CO2 emissions and fuel amount by different mode of transport

In the graph presented, a comparison between case 1 and case 5 reveals that the emissions from cars remain relatively stable. However, a significant increase in emissions is observed in Bus Rapid Transit System (BRTS), while a decline in emissions occurs during the transition from Ahmedabad Municipal Transport Service (AMTS) to electric AMTS.

Upon examining case 2 and case 6, it is evident that the levels of CO2 emissions and fuel consumption are notably lower in case 6 as opposed to case 2. This indicates that electric AMTS offers advantages in terms of reduced CO2 emissions and fuel consumption.

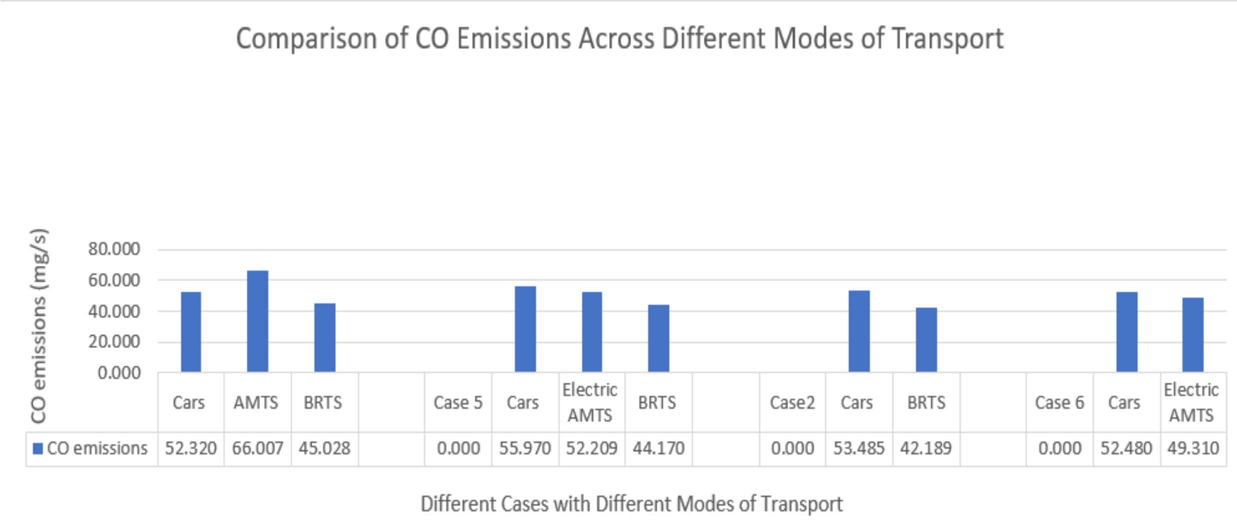
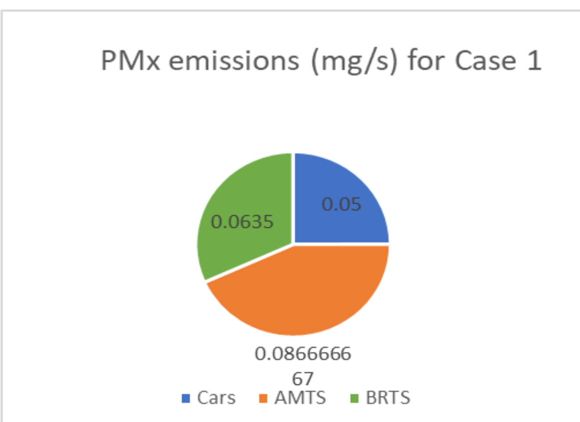
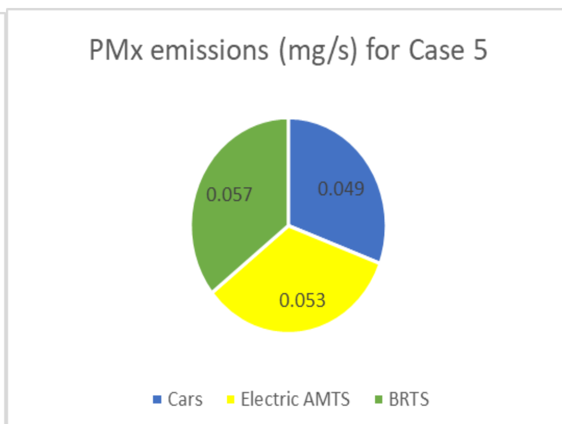


Figure 25: Graph showing the comparison of the CO emission by different mode of transport

Carbon monoxide (CO) emissions are shown to have significantly decreased in Case 5 of the graph after switching from an automated manual transmission system (AMTS) to an electric AMT. This decrease is explained by the fact that CO emissions for electric vehicles only include emissions from the battery. To be precise, the CO emissions for AMTS and the Bus Rapid Transit System (BRTS) are 49 mg/sec and 42 mg/sec, respectively, with a slight disparity between the two.





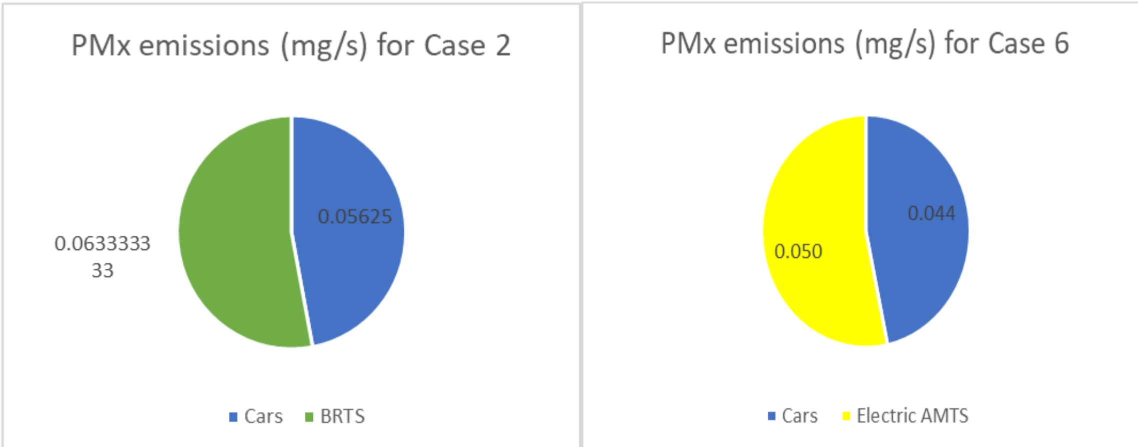


Figure 26: Pie charts showing the PMx emissions by different mode of transport

As seen above, the PMx emissions in cars is way less than the PMx emissions in AMTS, electric AMTS and BRTS. The reason behind it is the length of the vehicle. In the simulation, the length of the car is taken as 5 meters whereas the length of AMTS, electric AMTS and BRTS is 11 meters, 9 meters and 9 meters respectively. [6]Additionally, while both electric AMTS and BRTS have the same length, their PMx emissions are almost the same.

[6] Length of the electric AMTS (double decker electric bus) - 9 meters - https://www.autocarpro.in/news/us-climate-secretary-john-kerry-meets-mhi-minister-to-further-the-electric-buses-securitisation-programme-116171

Overall Emissions

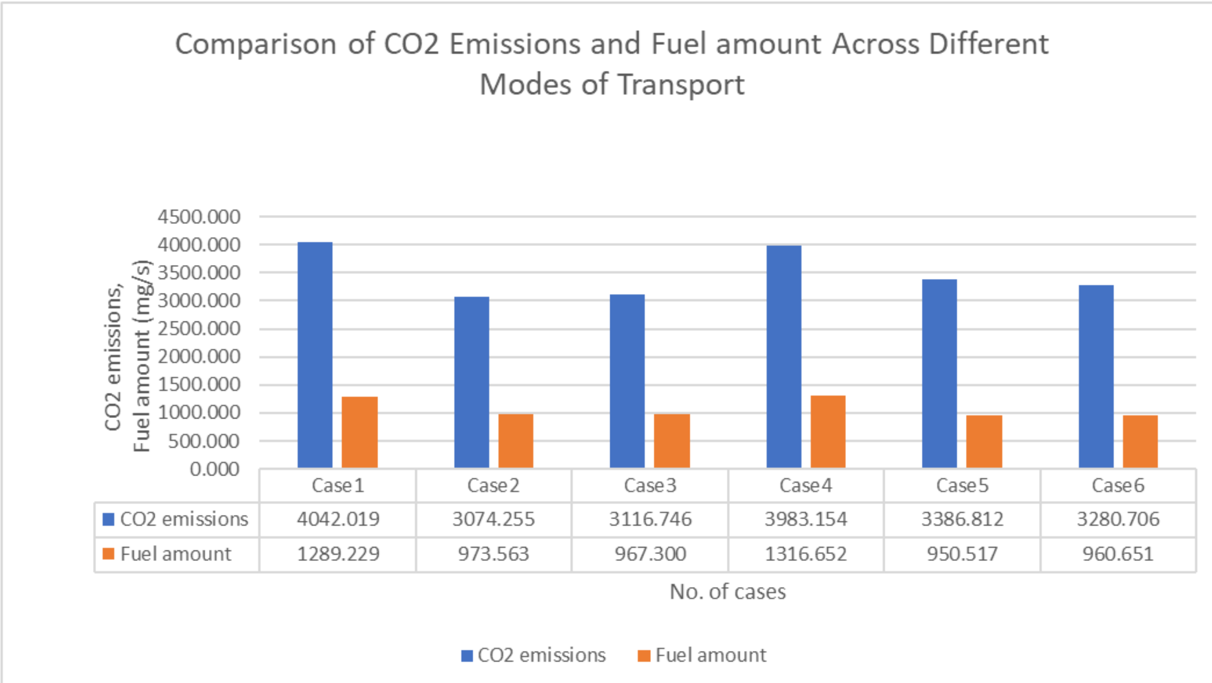


Figure 27: Graph showing the overall emissions by different mode of transport

As depicted in the graph, the highest level of emissions is observed in Case 1, while the second-highest level of emissions is found in Case 4 due to an increase in signal time. Conversely, the lowest CO2 emissions are recorded in Case 2, and the least amount of fuel is consumed in Case 6. Consequently, it can be inferred that Case 2 and Case 6 represent the optimal solutions for minimizing emissions output.

Conclusion

Case 2 represents the optimal choice among all the presented cases. The reasons are cost saving, environmental benefits and societal benefits. Having only one public transportation at one road would decrease the cost, emissions have also reduced because of the electric BRTS yielding to an environmental benefit. Electric BRTS can also enhance public health by reducing air pollution and traffic congestion leading to many societal benefits also.

Implementing a modest penalty on private vehicles could serve as an incentive for individuals to transition towards utilizing public transportation. The ongoing transition of the Ahmedabad Municipal Transport Service (AMTS) to electric vehicles suggests that amalgamating AMTS with the Bus Rapid Transit System (BRTS) could yield significant positive impacts on both the environment and society. The implementation of electric Automated Metro Transit Systems (AMTS) in areas lacking access to electric Bus Rapid Transit Systems (BRTS) would result in enhanced accessibility, cost savings, and environmental benefits.

Discussion

Impacts of BRTS in society

BRTS covers a smaller region in Ahmedabad compared to AMTS, which operates on 173 routes. This may explain why it has less job accessibility than AMTS. BRTS station catchments only provide access to 0.52 million of Ahmedabad's 1.67 million employment. This variable has minimal predictive value for BRTS ridership. BRTS does not offer service in many job-rich areas of Ahmedabad.BRTS covers a smaller region in Ahmedabad compared to AMTS, which operates on 173 routes. This may explain why it has less job accessibility than AMTS. Access to work is the most influential factor in choosing a mode of transportation, leading to increased ridership. People are more likely to opt for other forms of transportation rather than BRTS, which cover the majority of job sites. BRTS accounts for barely 1% of the total travel demand of 30 billion passenger kilometers. Only a small number of people use this service. BRTS is losing popularity among commuters due to expensive fares and limited-service areas. As per the findings, time constraint and connectivity are also a main issue which is driving people away from BRTS. The restricted number of BRTS riders from each region (station catchment) cannot develop an explicit relationship with built-form. Income and other socio-economic factors, such as car ownership, may impact BRTS ridership. Increased two-wheeler ownership in Ahmedabad may impact BRTS ridership at individual stations [35].

The social benefit-cost ratio (SBCR) was used to assess the electric bus transportation system in Ahmedabad, India. According to the SBCR, such a project can be positively justified in terms of both societal benefits obtained and long-term financial returns and value addition from infrastructure investment. A 25-year social benefit-cost analysis study for the e-BRTS network in Ahmedabad found a benefit-to-cost ratio greater than unity, indicating a potential positive investment for the city if socio-economic factors are considered. The case is expected to yield 50% environmental benefits and a 29% reduction in fossil fuel use. Developing this infrastructure comes at a significant cost of 51%. The transaction system operation and maintenance cost is 24% of the overall cost. The BRTS has numerous benefits, including money generation, reduced traffic congestion, time savings, and accident reduction. These benefits will continue to apply to e-BRTS. The bus, charging stations, and battery replacement are expected to account for 15-20% of the entire life cycle cost. When weighing current and future expectations, e-BRTS provides 86% of the benefits (INR 28,520 million or USD 365.64 million) and only 20% of the costs (INR 4,515 million or USD 57.88 million) [36].

Policy implementation

As emissions decrease, societal costs are reduced, leading to an increase in societal benefits. The cost to individuals may fluctuate upon the implementation of an electric Bus Rapid Transit System (BRTS). The introduction of electric BRT systems can result in decreased healthcare expenses for individuals. Electric buses emit fewer pollutants than diesel buses, thereby enhancing air quality and reducing health risks associated with pollution. Consequently, this reduction in pollution-related health issues can lead to decreased healthcare costs for residents residing in areas serviced by electric BRT. Furthermore, the adoption of electric BRT systems could positively impact individual living costs through various means such as job creation, heightened productivity, and bolstered economic development within regions where these systems are established.

On the other hand, electric BRTS could increase the economic cost. This can include initial infrastructure investment (charging stations and maintenance facilities), land acquisition cost, electricity cost and training cost. BRTS corridor can enable an increase in urban and property values around that area. The study titled “The Impact of Bus Rapid Transit System (BRTS) on Urban Land/Property Value in Pune City” sought to examine the influence of the Bus Rapid Transit System (BRTS) on urban land and property values in Pune, India. Properties situated near BRTS corridors exhibited a rise in value in comparison to similar properties located in non-BRTS areas. This escalation in property values was ascribed to the enhanced accessibility, decreased travel times, and improved connectivity facilitated by the BRTS infrastructure [37].

There is a trade-off between societal advantages and time efficiency with the Electric Bus Rapid Transit System (BRTS). Human psychology dictates that people give priority to time-saving strategies. Giving out discount vouchers is a good way to encourage people to use BRTS services. These coupons might be distributed for use at cafes, restaurants, or various events. Additionally, the introduction of electric rickshaws or carts is suggested to address the problem of last-mile connection by facilitating easy pick-up and drop-off locations. This program could be used, especially in areas close to colleges and other educational establishments, to encourage students to use BRTS more frequently.

An area for free parking should be made near a BRTS stop to facilitate more people to use the BRTS. Another way to encourage people is to get an incentive with free tickets to travel in BRTS. Also, increasing the parking fee would demotivate them to use private vehicles and shift to public transportation. Parking near the university should be charged highly; this would urge the students to shift to public transportation.

The implementation of policies, such as raising parking fees or providing discounts for Bus Rapid Transit System (BRTS) utilization, has the potential to impact travel behavior significantly. Insights from behavioral studies indicate that individuals are responsive to economic incentives, which can lead to a transition in their choice of transportation mode from private vehicles to public transport. This shift has the capacity to decrease emissions and alleviate traffic congestion in urban areas [38].

A significant societal concern associated with the utilization of Bus Rapid Transit Systems (BRTS) is the reluctance of individuals from higher socioeconomic classes to travel alongside those from lower socioeconomic classes. The discomfort and perceived lack of prestige associated with BRTS make it undesirable for high-class individuals. Unlike airplanes and trains that offer separate classes such as business class and first class for those willing to pay more for enhanced comfort and amenities, BRTS lacks such differentiation. Implementing a class-based system within BRTS would likely exacerbate the existing divide between the rich and the poor. As the younger generation increasingly prioritizes comfort and convenience, their unwillingness to compromise on these aspects may further underscore this issue in the future.

Conclusion

Understanding the factors influencing individuals' decisions to not utilize the Bus Rapid Transit System (BRTS) can be facilitated by considering elements such as connectivity and time constraints. This study can open the door for specific system improvements that are intended to make the system more operationally and user-friendly. The adoption of electric BRTS vehicles has resulted in notable reductions in travel duration, waiting times, and emissions output. This sustainable alternative proves beneficial for both the environment and society at large. The ongoing shift of the Ahmedabad Municipal Transport Service (AMTS) towards electric transportation signifies a potential integration of AMTS services with the BRTS, promising substantial positive outcomes for environmental conservation and societal welfare.

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