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THE NEXUS BETWEEN THE QUALITY OF BRT SERVICES AND CUSTOMER ECONOMIC CHOICES: EVIDENCE FROM EMERGING ECONOMY

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ABSTRACT

This study investigates the nexus between the Quality of BRT Services and Customer Economic Choices in Islamic Republic of Pakistan. BRT systems are gaining popularity as a low-cost, environmentally conscious, reliable means of transportation in response to the rising importance of sustainable mobility in cities. However, in the context of BRT, the influence of service quality on customer economic decisions is still controversial. This study employs a mixed-methods approach, combining quantitative surveys and qualitative interviews. Service quality is measured from dependability, accessibility, affordability, and comfort while customer economic choices are measured from travel costs, time savings, and the overall value proposition of BRT services. Preliminary findings indicate a significant relationship between perceived service quality and customer satisfaction. A more nuanced understanding of how specific service attributes influence economic choices sheds light on the factors contributing to BRT systems' attractiveness in urban settings. Furthermore, the study investigates demographic differences in customer preferences and economic decision-making, providing a more comprehensive understanding of the diverse user base of BRT services. The research has implications for city planners, policymakers, and transportation authorities who want to improve BRT systems and promote sustainable urban mobility. This study contributes to the ongoing debate on improving public transport infrastructure and fostering environmentally responsible urban development by identifying the key determinants of service quality that drive positive economic choices.

INTRODUCTION

In Pakistan, the evaluation of public transit (BRT) systems based on accessibility has become an increasingly important topic during the past few years. In the field of public transportation, planners and decision makers are interested in evaluating the performance of transit systems so that they may make key decisions concerning the positioning of stops, the distance between stops, the routings, and other aspects that will increase accessibility. When deciding whether or not to use public transportation, the most essential consideration for most individuals is the amount of walking distance between their starting point and their destination. The expense of and investment in public transportation must be able to be justified in terms of the improvement in accessibility. Therefore, accessibility refers to the ease of access to a transport stop where individuals are eager to walk a specific distance to reach there. This distance varies depending on the location of the stop.

The demand for the transportation system, as well as the predicted demand for the transportation system, needs to be determined in order to provide a realistic estimate of the accessibility of a public transportation system in Pakistan. Researchers have offered a number of different approaches in order to determine the demand for public transportation. Conducting surveys or interviews with people who use the transit system is a tried-and-true method for figuring out how much demand there is for the service. However, the process of conducting a survey is often time-consuming, labor-intensive, and costly. Furthermore, the capacity to generalize the findings may be constrained by factors such as the size of the community that is being studied.

As a result, the implementation of analytical approaches that are founded on data sources that are easily accessible to the public, GIS software packages, and buffers has been a significant step forwards in the assessment of accessibility. Numerous academics have relied on straightforward buffers as a method for estimating the demand for public transit. Measuring the demand for public transportation in a way that is both more efficient and accurate became essential as the number of people who wanted accessibility assessments for public transportation systems continued to rise. The researchers came up with a solution that makes use of networks as well as road networks as buffers. These types of buffers make use of the data from the actual road network to construct a polygon based on a certain minimum distance requirement.

Data on ridership is an additional source of information that is utilized in the process of estimating the demand for public transit in Pakistan. Data on ridership can be gathered to offer information about the demand for public transportation at the station level during specific times of the day, in addition to the demand for a particular geographic region. Evaluations of the accessibility of public transportation systems can be made more precise through the utilization of such data in combination with a simple or network buffer. A precise evaluation of the potential demand for public transportation is necessary in order to achieve the goal of evaluating accessibility in regions that do not already have public transportation. Along with data on ridership, the methodology that has been presented uses variables such as population, employment, income, and land use to produce accurate projections of the amount of demand for public transit. GTFS data, which stands for "General Transit Feed Specification," is a data source that is open to the public and is used for the purpose of acquiring information on the stops and routes in the transit system. The Open Street Map (OSM) project provides the real road-network data that is required to calculate the walking distances between a network and a bus stop or probe/gauge locations.

A case study on the public bus transportation system in Multan and Lahore was conducted, and the proposed technique was used to Analyse the data from the study. For the region, information is gathered from a variety of publicly accessible data sources, including census data (relating to population), employment data, income data, ridership statistics (obtained from the COTA agency), and land use data. The proposed methodology is thought to be applicable in regions that contain a predetermined minimum number of bus stops. In the section of Methodology both the procedure for collecting the data and the validation of the methodology are clarified.

In summary, a comparison of the two situations is reviewed, and a presentation of the potential additional work that may be done to improve upon the proposed technique is made. It is vital to evaluate the effectiveness of BRT systems in Pakistan based on their accessibility in order to ensure that they provide access to all people of the city given the growth of these systems in Pakistan. The deployment of BRT is a cost-effective alternative to expensive train systems that has the potential to stimulate economic revitalization and improve the image of the city in the eyes of both residents and visitors.

Over the course of the past few years, accessibility-focused performance evaluations of public transit systems have received a significant amount of attention and focus. Because public transit designers and decision makers must make fundamental choices to promote accessibility, there has been an increasing interest in analyzing the performance of the system. These decisions include the position of stations, the spacing between stops, the routing, and so on. According to Olszewski and Wibowo (2005), the walking distance is the most important aspect that people take into consideration when deciding whether or not to use public transportation. Therefore, the choices that were made above involve justifying the expense and investment in transit in light of the increase in accessibility.

There has been a lot of study carried out on generating metrics to quantify accessibility through the use of geographic information systems (GIS).

This is because accessibility is a qualitative measure for performance evaluation. It is absolutely necessary to ascertain the demand for the transportation system, as well as the demand that is anticipated for the transportation system, in order to achieve a true evaluation of the accessibility of the public transportation system. Researchers have proposed a number of distinct approaches in order to ascertain the level of interest in the transit system. Conducting surveys or interviews with people who use the transportation system is a conventional method for determining demand (Olszewski & Wibowo, 2005). This can be done in person or over the phone. The execution of a survey is often time-consuming, labor-intensive, and financially burdensome, and one's capacity to generalize the findings may be constrained by considerations such as the size of the population being surveyed.

Numerous scholars have turned to the use of straightforward buffers in order to estimate the demand for public transit (Bertini & El-Geneidy, 2003; Ghanbartehrani, 2015; Yousaf Khan, Ahmad, & Malik, 2021; Zhou et al., 2016). Researchers came up with an approach that makes use of network or road-network buffers as a result of the ever-increasing need for accessibility evaluations of public transportation systems. This demand necessitated more efficient and precise measures of the public transit demand, which led to the development of this methodology.

According to research published by Perveen, Kamruzzaman, and Yigitcanlar (2017), rapid urbanisation has led to an unprecedented expansion of city limits in recent years. As a consequence of this, a multitude of issues connected to the management of the built environment have surfaced. Some of the most obvious problems associated with this management are those that are brought on by an excessive reliance on automobiles, such as climate change, global warming, traffic congestion, air pollution, and socio-economic issues (Bhatnagar et al., 2012). According to Holmgren (2007), Mulalic and Rouwendal (2020) and Y. Khan, Saqib, and Ahmad (2016), one of the necessary countermeasures to address this over-dependence on autos is the installation of public transit. Even if there is a public transit system, most people still choose to drive their own cars since they are more flexible, faster, and comfortable (Mulalic & Rouwendal, 2020). This has been demonstrated in a number of cities around the country. As a result, the installation of public transit should be accompanied with a set of policies designed to encourage more people to use the service. One of the ways in which transit-oriented development (TOD) can be used to encourage people to use public transit is by controlling the land use that is linked with public transit.

According to Kim et al. (2021) TOD is seen as a form of urban development that improves residential and commercial areas that are within a walk able distance of transit stations (Rahman, Yasmin, & Eluru, 2019). Transit-oriented development (TOD) is an approach to urban planning that prioritizes the use of public transportation and walking above the operation of private automobiles. In general, TOD involves the construction of higher-density, mixed-use urban development that is accessible on foot near existing mass transit stations. TOD is created through land use control in order to restrict or guide the urban development and infrastructure development that is carried out by the private sector (Lyu, Bertolini, & Pfeffer, 2016).

This research focuses on the city of Lahore in Pakistan, which has had a BRT system in operation since 2013, but the city does not have a specific land use control and infrastructure development policy with the intention of creating TOD. The primary purpose of this research is to investigate (1) what kind of urban fabric has been developed in regions surrounding BRT stations, and (2) whether or not this urban fabric contains aspects of TOD, which promote the use of public transit and walking rather than the use of private vehicles. In addition to that, the purpose of this study is to propose policy recommendations for encouraging TOD in order to make it viable to implement a BRT system in Lahore. The following is an outline of how this paper is structured: the second section provides an overview of the most recent research on the influence of transit on TOD. Methods and materials are discussed in the third section of the paper. This section also includes a description of the research technique and the scope of the study. The outcomes of the study as well as a discussion of them are presented in the fourth section. The conclusions as well as the recommendations are presented in the final part.

Problem Statement;

In urban centers worldwide, the increasing strain on transportation infrastructure, coupled with growing environmental concerns, has prompted a shift toward sustainable and efficient public transit systems. BRT has emerged as a viable solution, offering a cost-effective and environmentally friendly alternative. However, despite the potential advantages, the nexus between BRT service quality and the economic choices of its customers remains a critical yet underexplored area of research.

Literature Review

Background

"An integrated system of facilities, services, and amenities that collectively improve the speed, reliability, and identity of bus transit," is how the acronym "bus rapid transit system" (BRTS) is written out. It is an integrated system that features buses of a high standard, a distinct infrastructure, and a limited mix of traffic running route. It was developed for increased velocity, dependability, and safety. In comparison to the regular bus routes, the BRTS utilizes a dedicated bus lane and spaces its stops further apart. BRTS is made available because of its high speed, greater capacity, increased reliability, ability to successfully attract ridership, as well as its positive effects on the environment, society, and the economy.

Principal Characteristics of the BRT System

The following is a list of the essential components that make up BRTS, which is a one-of-a-kind, cutting-edge, and standardized modern public transportation service that provides a high-quality public bus service. It includes a multitude of amenities, technologies, and facilities. It was necessary to have efficient, accurate, and easily accessible commuter information technology in order to make the system more user-friendly and appealing to commuters and riders' perceptions of the quality of the service. A commuter is necessary to have scheduled ahead of time prior to starting a trip in order to obtain route advice, and the source of the information may be the telephone or the internet. Real-time bus information, which must include the arrival time of buses, the distance between the current station and the next bus station, the name of the current station, the arrival time of the next station, information regarding location, service alerts, and information on interchange facilities, is necessary in order to increase ridership on the BRTS. All of the aspects of BRTS that were discussed earlier were combined into one system and given the name BRTS. Depending on the pattern of land use, the investment plan, and the environmental considerations, the layout features, design characteristics, operating procedures, and all other features of BRTS may differ from system to system. This is due to the fact that BRTS are modular in nature.

Usage of Available Energy

The amount of fuel and energy that is consumed on a global scale for the transportation industry is growing, and this is one of the most significant problems that is related to energy consumption and the environment. Figure 1 illustrates Pakistan's consumption of transport fuel and makes projections about the country's future needs. In order to find a solution to this issue, energy-efficient approaches are required. Developing nations just do not have the financial resources to afford the high cost of consuming fuel for public transportation, particularly BRTS. If this does not happen, it will drive up the cost of travel due to the fluctuating cost of fuel on the market, and it will put public transportation out of reach for the average traveler's budget.

After the BRTS system was successfully put into place, the primary focus of the study shifted to an evaluation of the system's performance. The development of a public transportation system that is both fuel- and energy-efficient is currently a primary focus of research. In order to investigate these aspects, a concept known as carbon footprint, which makes reference to BRTS, was going to be researched in terms of its influence on the environment. Several different parameters regarding fuel use, such as compressed natural gas (CNG) and Diesel Fuel characteristics, were also discussed. It is vital for BRTS to do an overall analysis on energy-efficient performance in order to create an efficient rapid bus transit system. One of the scenarios that needs to be investigated for an effective transportation system is the amount of fuel and energy that is consumed by the utilization of public transportation.

The use of the Pearson's correlation coefficient allowed for the identification and incorporation into the model of variables that do not share a correlation with one another. In order to develop 16 different models, Generalized Estimating Equations (GEE) were carried out. These equations considered linear, Poisson, Gamma, and negative binomial distributions with log-link. Negative Binomial with log-link distribution was chosen to develop the transit ridership model because it fit the data best and had the lowest values for the Quasi-likelihood criterion under the Independence model (QIC) and the Corrected QIC. Pulugurtha and Agurla estimated bus transit ridership for 2,857 bus stops in Charlotte, North Carolina, using passenger data from the Charlotte Area Transit System (CATS). The ridership model used data. The SPM model had discrepancies of -44% to +40%, while the SWM approach had disparities of -58% to +49%. Comparing their findings to the ridership model revealed several anomalies. The SWM technique based on 1/D2, the best spatial weight parameter compared to 1/D and 1/D3, where D is the buffer width (0.25, 0.50, 0.75, and 1-mile), underestimated ridership for 63% of bus stops, while the SPM model with a 0.25-mile buffer underestimated ridership for 67%. Demographic, socioeconomic, and land-use characteristics can predict bus transit ridership.

Buffer that is Centred on the Route

Instead of focusing on a particular transit stop, route-centered buffers take into account a buffer that surrounds the transit route and has a set threshold value.

In their assessment of what is known as Area Public Transit Accessibility (APTA), Yan et al. (2018) make use of the idea of route-centered buffers as a means of evaluating the accessibility of public transit. According to the findings of this study, the researchers refer the accessibility "convenient degree that passengers travel from one traffic zone to the surrounding zones by public transportation" (Minghai, Khan, Khalil, Khan, & Marwat, 2024) ArcGIS software was utilized in the technique to carry out a number of different spatial analysis tasks in order to offer the accessibility values for the traffic zones that were developed in the Beijing Chaoyang district. The accessibility value of public transit is determined by calculating the ratio of the number of individuals who make use of public transit within a zone to the total number of people who have a need for public transit within that zone. A heat map was utilized to provide a visual representation of the accessibility of each zone in order to highlight the requirement for public transit in the area under investigation.

Horner and Murray (2004) and Y. Khan and Arshad (2023) investigated the differences between the effects of network distances and straight line distances on the population that is anticipated to be served by a given transportation system. As a case study, we looked at Upper Arlington, which is a municipality located in the suburbs of both Multan and Lahore. Before delving into the methodology, the authors provided a number of different scenarios focusing on buffers of varying complexity surrounding distinct stops and routes. According to the results of their mathematical research, simple buffers around stops and routes vary in population coverage. Their approach is comprised of data obtained from the US Census Bureau (2010) as well as the locations of stops and routes obtained from COTA and visualized on a GIS platform by the researchers. In order to determine the population coverage, they used a distance of 0.25 miles (or 400 meres) measured in a straight line between each station. GIS tools helped them calculate Euclidean distance by determining population coverage near stops.

Temporal Accessibility

The time metric is taken into consideration in order to display accessibility trends in temporal accessibility. It offers a fresh perspective on the idea of accessibility and is often determined by the amount of time it takes to walk to the nearest transport station. Gutiérrez and Domènech (2017) investigated Catalonia's central Costa Daurada's residents and tourists' accessibility. Summer holidaymakers flock to this coast. Their conception of accessibility centers on the degree to which one can move freely between locations located within the city limits.

They presented a number of different indicators as a part of their technique in order assesses geographical accessibility. The first indicator is a transport area's (TA) stop-to-population ratio. This indicator provides an assessment of the spatial coverage within the designated transit area. The second indicator is the entire population percentage that is within a 200-meter radius. This indicator takes into account the amount of time it takes a passenger to walk to the station. The third indicator is similar to the second in that it considers the percentage of the population living within 200 meters of bus stops that serve several bus lines. The 4rth indicator, which they call the drift index, is the most important contribution that this research has made. The Drift index takes into account the additional amount of time that must be spent travelling by public transit in order to connect certain transport regions when compared to the quickest route that can be travelled by using personal vehicles. This would be helpful in identifying bus stops and routes that require a longer amount of time to travel between particular starting points and ending points. Their last measure is the percentage of the population that lives within a radius of 500 meters from an intercity bus stop that serves multimodal transportation.

Total Travel Time

When determining the accessibility of bus stops, Tribby and Zandbergen (2012) took into consideration the overall travel time. The total journey time takes into account the amount of time it takes an individual to walk to a stop, the amount of time spent waiting at the stop, the amount of time spent riding the bus, and the amount of time it takes to switch between routes. The 'Spatio-temporal' model that has been presented takes into account both the spatial aspects. The model was implemented in the Albuquerque, located in the state of New Mexico, in order to evaluate the accessibility of two bus lines that had recently been installed. This study utilized a variety of data sources, some of which included income, statistics on individual parcels, the frequency of delivery, and travel times for each route.

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Foda and Osman (2010) were able to make an accurate estimate of the population coverage surrounding a stop by using network buffers. They came up with two indices: one called the Ideal Stop-Accessibility Index (ISAI), and the other was called the ASAI. This ratio is then used to determine the level of accessibility. The use of such a ratio is helpful in determining whether locations have a high density of pedestrian road networks. ASAI considers the real access coverage area, a polygonal area covering the bus stop at the end of each road network. The researchers were able to acquire information regarding the public transit network from Metro Cali. They categorized the neighborhoods that were included in the research project according to their socio-economic standing. It was decided to create six different socioeconomic groupings, ranging from the most impoverished (stratum 1) to the richest (stratum 6) individuals. Not based on people's wealth, but rather on the physical attributes of their housing and the local environment in which they live, the stratification was carried out. For the purpose of determining the network coverage regions surrounding bus stops, the distance travelled by the network from its point of origin to the stops was utilized. The Hansen gravity model was used to estimate how easily one may reach the opportunities offered by urban areas. This model takes into account both the distance between the origin and the destination as well as the attractiveness of the destination itself depending on the amount of time it takes to journey there. In order to determine how far passengers have to travel in order to reach the bus stop, separate models of the pedestrian and MIO route networks were created and used.

The findings indicated that the hospitals are located in the central part of the city, whereas the eastern part of the city, which is more densely populated and has a lower standard of living, does not have any hospitals. The recreational areas were spread out over the city in a more uniform manner, with a greater concentration in the eastern and more disadvantaged neighborhoods. The socio-economic stratum six population has the lowest percentage of people (56%) with a 20-minute walk to the transportation system and 32% with a 15-minute walk. Heat maps showed accessibility.

Comparison of Network Buffer and Straight Line

The contrast between a straight-line and a network buffer is going to be the primary emphasis of this section. When compared to a network buffer, a straight-line buffer results in an overestimation of the population that may be protected by it. This is one of the findings of recent research.

Horner and Murray (2004) investigated the differences between the effects of network distances and straight line distances on the population that is anticipated to be served by a given transportation system. As a case study, we looked at Upper Arlington, which is a municipality located in the suburbs of both Multan and Lahore. Before delving into the methodology, the authors provided a number of different scenarios focusing on buffers of varying complexity surrounding distinct stops and routes. According to the results of their mathematical research, Simple buffer population coverage around stations and routes varies widely. Their approach is comprised of block level population data obtained from the Ratcliffe, Burd, Holder, and Fields (2016) as well as the locations of stops and routes obtained from COTA and visualized on a GIS platform by the researchers. In order to determine the population coverage, they used a distance of 0.25 miles (or 400 meters) measured in a straight line between each station. GIS tools helped them calculate Euclidean distance by determining population coverage near stops.

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According to the findings, the core regions have a higher level of connectedness and accessibility compared to the periphery regions, which have a lower level of accessibility as a result of the high value of the amount of travel time necessary in the peripheral regions. In addition, the intercity links are strong in the middle and eastern regions of the region, but the western region has weaker connectivity and less accessibility to the transportation network.

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When determining the accessibility of bus stops, Tribby and Zandbergen (2012) took into consideration the overall travel time. The total journey time takes into account the amount of time it takes an individual to walk to a stop, the amount of time spent waiting at the stop, the amount of time spent riding the bus, and the amount of time it takes to switch between routes. The 'Spatio-temporal' model that has been presented takes into account both the spatial aspects, such as walking, transit, and journey time. Albuquerque adopted it, located in the state of New Mexico, in order to evaluate the accessibility of two bus8 lines that had recently been installed. This study utilized a variety of data sources, some of which included income, statistics on individual parcels, the frequency of delivery, and travel times for each route.

Methodology

The cities of Lahore and Multan are the primary efforts of this study. According to the statistics provided by the Punjab Bureau of Statistics in 2017, the total population of the city was around 11.12 million, and the land area was 1,772 km2. As a result of the rapid process of urbanisation, the city is expanding in a less regulated manner, and in 2017, it had reached a radius of 38 km. The BRT system was first implemented in Lahore in 2013 in an effort to alleviate the city's worsening traffic congestion. It currently operates 27 stations across a total distance of 27 km (see Figure 1) and is integrated with the

Speedo Bus Service (M. S. Khan, Jamil, & Malik, 2022; Y. Khan, 2022; Y. Khan & Arshad, 2024; Minghai et al., 2024). At the moment, the BRT transports roughly 135,000 commuters each and every day. It has achieved the largest daily ridership of approximately 180,000 persons, as stated by the Punjab Mass transport Authority. However, according to the official who was interviewed, the government has not yet formulated any policies, regulations, norms, or incentives relating BRT-based TOD. These are all things that are expected to happen in the future.

In the research that was conducted, numerous techniques were utilized for the measurement of TOD. Density, diversity, and design are the three aspects of urban architecture that Cervero and Kockelman (1997) identified as having an influence on people's propensity to travel. According toBordoloi, Mote, Sarkar, and Mallikarjuna (2013), these three dimensions are also helpful in describing how travel patterns are influenced by patterns of land use. According toSingh, Sharma, and Nagesh (2017), there are eight factors that can be used to define TODness. These criteria are as follows: density; land use variety; ability to walk and cycle; economic development; user-friendliness of a transit system; accessibility; transit capacity utilizations; and parking at the station. In addition, Su, Du, and Jiang (2021) identified a number of different indicators within the 5Ds framework of TOD. These indicators include design, which includes intersection density and street network connectivity; density, which indicates the population and road density; diversity, which measures the land use proportion and mixture pattern; destination, which represents the accessibility of trip attractions; and demand management, which refers to the travelling services.

A higher population density in the area around the stations may attract more people to use the BRT. A greater variety of things to see and do can encourage more people to ride the BRT and then wander around the station area afterwards. A design that is friendly to people walking can encourage people to walk in the vicinity of BRT. The indicators that are included in each criterion were chosen based on the reasons that are listed below, as well as the availability of data. This study compares the scenario in 2012, before BRT operation, to the situation in 2021, after BRT operation, and analyses the change in the indicators in order to gain a better understanding of the impact of BRT.

Researchers Huang et al. (2020), Ahmad, Khan, Hussain, Khan, and Khan () and Zlot and Schmid (2005) discovered that neighborhoods with a higher number of pedestrian streets also had a greater number of parks. Adams and Simnett (2011) came to a similar conclusion and found that walking for transportation was higher in close proximity to parks. The amount of land devoted to open areas and parks was determined with the help of GIS based on the findings of an observation study conducted in 2021 and the data on land use from 2012.

Analysis and Findings

Population characteristics

Table 1 presents, for the years 2010 to 2016, the average population density within a radius of 800 meters around each of the eight BRT stations that were chosen. From station to station, there is a substantial range in the population density that can be found. The two stations in the city Centre, Bhatti Chowk and Ichra, have the highest population density, and the two stations in the suburban area, Nishtar Colony and Dullu Khurd station, have the lowest population density consistently over time. The population density is highest in the two stations in the city Centre, Bhatti Chowk and Ichra. From 2010 to 2016, there was an overall increase in population density across all eight stations. The most significant increase, 14%, was seen at Kamahan, while the two suburban stations, including Nishtar Colony and Dullu Khurd, saw the least significant increase, 11%. The disparities in population density are more noticeable than the differences in the rate of change. The city of Lahore had an average population density of 45 PPH in 2010 and 51 PPH in 2016, representing an increase of 13% in terms of the percentage change. When compared to the rate of population change that has occurred throughout the entirety of the city, the population density in the area surrounding the eight BRT stations has not greatly increased. The findings of Masoumi and Shaygan (2016) do not concur with the data that we have obtained. They discovered that there was a considerable increase in the population density of Tehran, Iran's monitored metro stations during the period between 2005 and 2015 in that city. In a study that came to a similar conclusion, Bocarejo, Portilla, and Pérez (2013) discovered that the BRT in Bogotá has significantly increased the city's population density in comparison to areas where the system was not in operation. Table 1 presents, for the years 2010 to 2016, the average population density within a radius of 800 meters around each of the eight BRT stations that were chosen. From station to station, there is a substantial range in the population density that can be found. The two stations in the city centre, Bhatti Chowk and Ichra, have the highest population density, and the two stations in the suburban area, Nishtar Colony and Dullu Khurd station, have the lowest population density consistently over time. The population density is highest in the two stations in the city centre, Bhatti Chowk and Ichra. From 2010 to 2016, there was an overall increase in population density across all eight stations. The most significant increase, 14%, was seen at Kamahan, while the two suburban stations, including Nishtar Colony and Dullu Khurd, saw the least significant increase, 11%. The disparities in population density are more noticeable than the differences in the rate of change. The city of Lahore had an average population density of 45 PPH in 2010 and 51 PPH in 2016, representing an increase of 13% in terms of the percentage change. When compared to the rate of population change that has occurred throughout the entirety of the city, the population density in the area surrounding the eight BRT stations has not greatly increased. The findings of Masoumi and Shaygan (2016) do not concur with the data that we have obtained. They discovered that there was a considerable increase in the population density of Tehran, Iran's monitored metro stations during the period between 2005 and 2015 in that city. In a study that came to a similar conclusion, Bocarejo, Portilla, and Pérez (2013) discovered that the BRT in Bogotá has significantly increased the city's population density in comparison to areas where the system was not in operation.

Floor area density

The Floor Area Density (FAD) for each of the eight BRT station regions is presented in Table 2 for the years 2012 and 2021. The changes in land use that occurred between 2012 and 2021 in the research area are depicted station by station in Figure 1. There are significant disparities in FAD between the stations in both 2012 and 2021, despite the fact that FAD was increased across the board (in all stations). The two stations located in the city Centre have the highest FAD in 2021 with values of 2.14 and 1.92, while the Shahdara and Dullu Khurd stations have the lowest FAD with values of about 1.15. The rate of change in FAD is greatest in the station that serves Nishtar Colony. In 2012, the area around the Nishtar Colony station had a significant amount of land that was undeveloped and suitable for agricultural use. This particular type of land use has experienced a significant decline in proportion, whereas other types of land use, such as mixed use and industrial, have experienced increases (see Figure 2). In these regions, the prevalence of the FAD has significantly grown. Additionally, the FAD in the station area in the city centre, which includes the Bhatti Chowk station, climbed dramatically, by 18.5%. Because there is essentially no agricultural land in this station area and only a very tiny percentage of land that is vacant (see Figure 2), it was anticipated that the floor area would need to be extended by either rebuilding or adding more floors. Model Town and Naseerabad, the two regulated regions, both had the lowest rate of FAD change at 6.50% and 2.59%, respectively. This was to be anticipated due to the stringent controls on land use that are imposed by construction and zoning regulations. The results of our study are in line with those found by Deng and Nelson (2013). They came to the conclusion that BRT contributes in a good way to the land development that occurs in the areas surrounding the stations in Lahore.

Diversity

The changes in land use that occurred within the scope of the study are detailed in Table 3, which compares the years 2012 and 2021. The amount of land that is used for residential purposes is projected to drop by 14.6%, from its current level of 613 ha in 2012 to 523 ha in 2021. In Bhatti Chowk, Ichra, and Kamahan stations, the proportion of space devoted to residential usage has drastically shrunk. The percentage of these three stations that are mixed-use has significantly gone up. According to the land use guidelines established by the Lahore Development Authority, the term "land use which enables a range of land use including residential, commercial, and institutional to be co-located in an integrated way" best describes mixed-use development. Because residential land use is included in the category of mixed-use, which experienced a considerable increase of 83.3% growth, it may be concluded that residential land use has not decreased by as much as 14.6%. It is anticipated that the residential floor area in the study region has increased as a result of the rise in population density. This floor space includes both residential usage and the residential component of mixed-use buildings. There has been a noticeable surge in business use, which is up 54.1 percent. As a result of the inclusion of commercial floors in mixed-use properties, it is anticipated that the floor area dedicated to commercial use will be significantly larger than what was estimated in the past. The number of commercial transactions at the stations in Shahdara, Ichra, and Kamahan has greatly increased. Additionally, industrial use has increased by 31.4%, and major changes have been noticed at the stations of Nishtar Colony and Dullu Khurd, both of which had a sizable industrial area in 2012. The revitalisation of economic activity in the study region can be attributed to the shifts in land use that have taken place, as well as the rise in commercial and industrial usage. On the other hand, the amount of open space was reduced by 6.6%, while the amount of land used for vacant and agricultural purposes decreased dramatically by 42.0% and 41.6% respectively. The fraction of land in Nishtar Colony and Dullu Khurd that was unoccupied or used for agriculture in 2012 has drastically shrunk since then. Both of these stations are located in the suburbs. In 2012, both Model Town and Naseerabad were restricted communities with a considerable quantity of open space; however, Model Town has since lost a sizeable portion of its open space. The regulation of land use has contributed to the fact that residential use in these two restricted zones has not fallen to the same extent as it has in other places. In contrast to the findings ofCervero and Dai (2014), which came to the conclusion that the BRT systems in Bogotá (Colombia) and Ahmedabad (India) did not successfully leverage mixed-use development surrounding the station areas, the findings of our analysis are inconsistent with those of Cervero and Dai (2014). Bocarejo, Portilla, and Pérez (2013) and Yousaf Khan et al. (2021) came to the conclusion that important shopping centres had been constructed around the terminals of the Transmilenio BRT in Bogotá. Despite this, they found that the existence of the BRT does not influence a bigger rise in built-up areas for commercial and residential usage. There is some overlap between the results of our investigation and those found by Deng and Nelson (2010). They discovered that BRT has a beneficial impact on the growth of residential and commercial spaces in Beijing. Our research indicates that an investment in BRT does not lead to an increase in the proportion of residential land use.

Table 1. Characteristics of the selected BRT stations in Lahore.

Station	density (persons/ha)	high	medium	low	ridership (Passengers/day)	high	low	controlled	less-controlled	distance (km)	city center	urban	Sub urban	old	new	Land use
Shahdara	350–400	✓			>10,000	✓			✓	4.4		✓		✓		commercial, residential, industrial
Bhatti Chowk	650–750	✓			5,000–10,000	✓			✓	0.5	✓			✓		commercial, residential, public
Ichra	500–600	✓			5,000–10,000	✓			✓	6.1	✓			✓		commercial, residential
Model Town	150–200		✓		< 5,000		✓	✓		10.1		✓			✓	residential
Naseerabad	100–130			✓	< 5,000		✓	✓		11.5		✓			✓	residential
Kamahan	150–200		✓		< 5,000		✓		✓	16.8		✓		✓		commercial, residential
Nishtar Colony	50–60			✓	< 5,000		✓		✓	19.1			✓		✓	industrial, residential
Dullu Khurd	50–60			✓	< 5,000		✓		✓	20.7			✓		✓	industrial, residential

Table 2. Average population density of 2010 and 2016 with the average percentage change in density.

Station	Station's location	Average Population Density (PPH) 2010	Average Population Density (PPH) 2016	Rate of Change (%)
Shahdara	Urban	356	401	13
Bhatti Chowk	city center	650	732	13
Ichra	city center	523	589	13
Model Town	Urban	167	189	13
Naseerabad	Urban	115	129	13
Kamahan	Urban	169	192	14
Nishtar	Suburban	50	56	11

Colony				
Dullu Khurd	Suburban	50	56	11

Table 3. Percentage change in floor area density.

Station	Station's location	FAD 2012	FAD 2021	Rate of Change (%)
Shahdara	Urban	1.07	1.15	7.23
Bhatti Chowk	city center	1.81	2.14	18.50
Ichra	city center	1.70	1.92	12.94
Model Town	Urban	1.13	1.20	6.50
Naseerabad	Urban	1.31	1.35	2.59
Kamahan	Urban	1.38	1.59	15.11
Nishtar Colony	Suburban	1.08	1.45	33.94
Dullu Khurd	Suburban	1.00	1.16	15.71

Entropy index

In the course of our research, the entropy index served as a useful tool for determining how diverse the land uses were that were located in close proximity to BRT stations. An increase in the value of the entropy index indicates an increase in the variety of land uses. The entropy index values that can be found around BRT stations are presented in Table 6. As a result of the tight regulation of land use, the values of the entropy index at the two stations in the controlled regions of Model Town and Naseerabad in both 2012 and 2021 were the lowest they could possibly be. Between the years 2012 and 2021, the entropy index rose at every station, with the exception of Bhatti Chowk and Nishtar Colony, both of which had relatively high index values in 2012.

Design

The pedestrian routes and their respective ratios for each of the eight stations in 2021 are presented in Table 7. We are unable to compute the percentage of pedestrian paths in 2012 due to a lack of data on pedestrian paths from previous years. However, according to interviews conducted with officials from the LDA, the local government, and the transport department, pedestrian walkways were not created in this study area after the BRT system was put into operation. In addition, there were not many significant alterations made to the road network. As a result, the proportion of pedestrian pathways at each station remained the same between the years 2012 and 2021. All of the stations have a relatively low ratio of pedestrian paths, which is a representation of the lack of walkability and accessibility. In older neighbourhoods like Shahdara, Bhatti Chowk, Ichra, and Kamahan, the proportion of pedestrian walkways was extremely low.

Intersection density

The intersection density for 2012 and 2021 is presented in Table 6. In the year 2012, the intersection density ranged from 1.67 to 8.05, and in the year 2021, it will range from 1.74 to 8.05 as well. According to Jacobs (1993), the intersection density in Venice was 5.79 per hectare, whereas the intersection density in downtown Los Angeles was only one-tenth as high as Venice's, and the intersection density in Irvine, California, was only one-tenth as high as downtown Los Angeles. Some station areas in major Western cities have a higher number of intersections than Venice does, making them more walkable than some parts of Venice (Ewing 1999; Jacobs 1993). each Bhatti Chowk and Ichra have a high intersection density, with 8.05 and 7.80, respectively, thanks to the historic built-up region and the numerous public services in each of these areas. There is a connection between the various land uses in these station areas and the roadway network. However, once the BRT investment was made, there was no change in the junction density at either station since there was insufficient capacity for additional construction. Because there is more area available for construction at Shahdara, Model Town, and Kamahan stations, the number of intersections has slightly increased there. This is in comparison to the situation in Naseerabad. Both Nishtar Colony and Dullu Khurd experienced significant increases in the proportion of their population living within walking distance of a crossroads.

Open space ratio

The area of open spaces and parks, measured in hectares, as well as the percentage of open space to total area is presented in Table 9, which compares the eight BRT station areas in 2012 and 2021. Both in 2012 and 2021, the two controlled zones have the biggest amount of available open space. Between the years 2012 and 2021, the total amount of open space declined in four stations while it remained the same in the other four stations. The operation of the BRT has not resulted in an expansion of open space in any of the station sites. The number of people in Model Town has significantly dropped. Very few of the open areas in Shahdara and Bhatti Chowk have been used for residential usage, whereas in Model Town and Naseerabad, the open spaces have been developed into public structures. It is anticipated that the presence of a high number of open spaces and parks within the catchment area will encourage an increase in the number of people walking on the roads that are near to such places.

Table 4. Percentage change in land use area of eight BRT stations for 2012 and 2021

Land use Type	Area (ha) 2012	Area (ha) 2021	Rate of Change (%)
Residential	613.1	523.6	−14.6
Commercial	59.7	92.0	54.1
Mixed-use	104.8	192.1	83.3
Public Building	156.0	167.7	7.5
Open Spaces	75.9	70.9	−6.6
Industry	97.3	128.6	32.2
Graveyard	17.1	17.1	0.00
Vacant	137.5	79.8	−42.0
Agriculture	24.9	14.6	−41.6
Total	1286.4	1286.4	0.00

Table 5. Entropy index in BRT station areas. station areas

Station	Entropy Index Value (2012)	Entropy Index Value (2021)	Rate of Change (%)
Shahdara	0.81	0.84	3.54
Bhatti Chowk	0.72	0.72	0.00
Ichra	0.66	0.69	5.59
Model Town	0.59	0.64	7.60
Naseerabad	0.57	0.61	6.03
Kamahan	0.68	0.78	14.76
Nishtar Colony	0.81	0.79	−2.47
Dullu Khurd	0.75	0.81	9.03

Table 6. Ratio of pedestrian paths in BRT

Station	Intersection Density 2012 (/ha)	Intersection Density 2021 (/ha)	Rate of Change (%)
Shahdara	3.92	3.99	1.78
Bhatti Chowk	8.05	8.05	0.00
Ichra	7.80	7.80	0.00
Model Town	1.88	1.91	1.59
Naseerabad	1.67	1.74	4.11
Kamahan	4.97	5.21	4.70
Nishtar Colony	3.01	3.37	11.90
Dullu Khurd	2.42	2.73	12.53

Table 7. Open space ratio with percentage rate of change for 2012 and 2021.

Station	Area (ha) 2012	Area (ha) 2021	Open Space Ratio (2012)	Open Space Ratio (2021)	Rate of Change (%)
Shahdara	7.02	6.48	3.49	3.22	−7.69
Bhatti Chowk	4.97	4.78	2.47	2.38	−3. 82
Ichra	3.19	3.19	1.59	1.59	0.00
Model Town	26.25	22.33	13.06	11.11	−14.93
Naseerabad	25.50	25.11	14.62	14.39	−1.53
Kamahan	5.43	5.43	2.70	2.70	0.00
Nishtar Colony	3.32	3.32	1.65	1.65	0.00
Dullu Khurd	0.26	0.26	0.13	0.13	0.00

The analysis is the most important aspect of this study, and it is carried out using a number of the factors that are also covered in this section. The BRT system is also investigated. Along with these other variables, the accessibility of the stations of the BRT system for the general public is a very essential component of this analysis. After determining the values of a few factors and carrying out the necessary calculations, the Multan BRT is subjected to an evaluation. The evaluation of the accessibility of the Metro Bus System stations is another extremely significant consideration, as it is necessary for all walkers and residents to have uncomplicated access to the BRT system. Within the realm of transportation projects, residential areas, housing authorities, and various modes of transit for more remote places all fall under the category of the highly significant word "spatial accessibility." The increasing distance between residential neighborhoods and commercial districts is a significant issue that has to be addressed. Therefore, transportation plays a crucial role in order to overcome this segregation of inhabitants to the services in order to overcome this segregation. As a result, some of the rules had been put into place in order to address the issue that creates barriers between residential and commercial sectors of the city. Because of this, it is now much simpler to travel from urban housing authorities to the many services offered by urban areas, taking into account the geographical accessibility of these authorities. The most effective answer was to establish a connection between the people and the social places by utilizing a mode of transportation that allows for a high degree of convenience in establishing such a connection. In addition, more analysis is done through these variables, which are then calculated, and finally, the item itself is evaluated using these variables.

Travel Speed Analysis

When it comes to the overall performance of bus rapid transit, the most important factor is believed to be the trip speed. The graph presents an illustration of the disparity in speed with respect to time in comparison to the BRT systems in Multan. When evaluating the BRT system, the speed of transit is a very significant feature to take into consideration. The Multan BRT system travels at a different speed, which results in different values being displayed for the two of them. The performance of the BRT can be better understood with the help of the graphs that are presented below.

The journey speed of BRT buses operating in the city of Multan is depicted with relation to time in this graph (Figure 6). If we look at the graph, we can see that the average speed of travel on the Multan BRT is between 40 and 55 kilometers per hour, which, when compared to the speeds of other means of transportation, is pretty impressive. The BRT is capable of reaching a top speed of 55 kilometers per hour, which is an excellent value. In addition to this, the time frame is specified in accordance with the stations. Only one minute and one hundred seconds were needed to reach the first stations. This was also observed for additional stations that were covered within sixty to one hundred and ten seconds, which is also extremely astounding

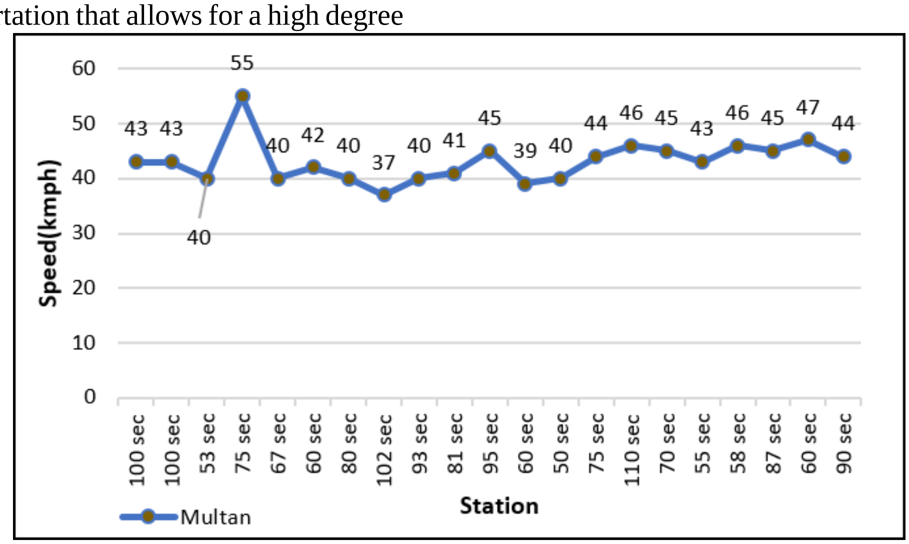

Figure 1. Analysis of Travel Speed of Multan with Respect to Time

Based on the examination of these data, which is presented in Figure 7, it was discovered that the first station could be identified at a distance of 1035 metres. This information was presented. It took around one hundred seconds, which was twice as long as it did in Manzorabad. Both Northern-By-Pass and Shalimar Colony have constant distances of 900 metres, but there is an 8-second variance in the time period between the two. The time length abruptly increased to 110 seconds with a measured distance of 1010 metres at BCG Chowk, and thereafter it varied till the very final station. As a result, the BRT's performance was hindered by the greater distances that existed between the stops.

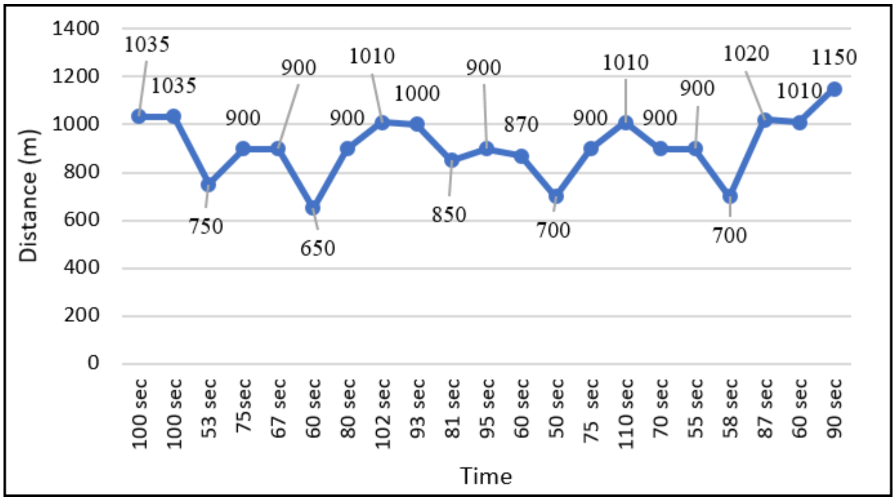

Figure 2. Analysis of Travel Distance of Multan with Respect to Time.

Fuel Consumption and Efficiency Analysis

Bus rapid transit, also known as BRT, is a modern kind of public transportation that offers a number of potential benefits, including increased speed and reduced fuel use. On the other hand, when we contrasted the results with those of the hybrid bus, we found that they were not consistent. The price of fuel accounts for a sizeable portion of the overall budget for public transportation authorities. The use of hybrid technology is not only an appealing alternative for travellers, but it also has the potential to significantly cut down on the operational expenses associated with interventions. There are thousands of normal hybrid buses operating in the city of Multan, however along the BRT line there are only 35 articulated transit buses that are 60 feet long and in operation. The most important advantages of employing a hybrid bus are the savings in fuel and time, as well as the reduction in emissions. In addition, on the same transport route in Multan, three BRT buses and three hybrid buses were investigated. The bus rapid transit system (BRT) has a fuel consumption of 3 kilometers per liter, while the hybrid bus has a fuel consumption of 4.5 kilometers per liter. According to the findings, the gasoline cost for BRT was the highest at the Shah Rukn-e-Alam station, coming in at 20pkr, while the fuel cost for hybrid buses was the lowest at 20pkr at the same terminal. At one particular stop, a hybrid bus reached its highest speed of 54 kilometers per hour, whilst the BRT reached its top speed of 5 kilometers per hour at the Shah Rukn-e-Alam station. The hybrid bus had an average journey time of 73 seconds, whereas the BRT bus had an average trip time of 77 seconds. This demonstrates that hybrid technology is superior to BRT in each of these aspects. The total cost of gasoline for a whole day for a BRT bus is 100pkr. The cost of fuel for a hybrid bus is 70pkr, making the BRT bus more expensive overall. Because of the different passenger capacities, boulevard levels, and road conditions, the BRT and hybrid modes' fuel consumptions

Conclusion and Discussion

A walking-distance accessibility evaluation of a public bus transportation system is offered for locations that currently lack service as part of this body of research. The evaluation is based on predicted demand. In order to get an accurate estimation of the demand for the public transportation, Ridership at bus stops is a measure of demand. Accessibility to public transit stations is an important consideration for transportation planners when making important policy decisions. Bus routes, schedules, frequencies, and stops must be decided. Accessibility to public transit stations is an important consideration because easy access to transit stops can provide passengers with a variety of benefits. Numerous benefits would accrue to a public transportation network that is easily accessible to the general public. To begin, it would validate the need for a transportation system that is designed to assist people in getting to their destinations on time and in a manner that is more convenient for them. Second, it would contribute to an increase in the utilizations of public transit and a reduction in the dependence on alternative ways of transport (Murray, 2003). If this happened, it would justify the public transit agency's investments in building a city's transportation infrastructure. According to Langford (2012), planners can improve policy by assessing public transit networks' accessibility.

Accessibility of space is critical to the growth and development of cities because it enables the provision of simple transportation infrastructure. The bus system serves both as a replacement for the transportation system and as its backbone, making it one of the most efficient and effective ways of transportation. As a result, some of the rules had been put into place in order to address the issue that creates barriers between residential and commercial sectors of the city. Because of this, it is now much simpler to travel from urban housing authorities to the many services offered by urban areas, taking into account the geographical accessibility of these authorities. The most effective answer was to establish a connection between the people and the social places by utilizing a mode of transportation that allows for a high degree of convenience in establishing such a connection. Bus rapid transit, often known as BRT, is becoming an increasingly popular option for urban transit, particularly in cities that are still in the process of developing due to the cost-effectiveness and adaptability of its implementation. Therefore, in order for everyone to take use of this system, it is necessary for the stations of the BRT to be situated in close proximity to the desirable destinations and locations that are in great demand. This advantage appears to be realizable only if the system is supplied with high-quality spatial accessibility to the areas of the society that are being targeted for improvement.

In order to determine the estimated number of riders on a daily basis, ridership forecast estimate model presented by Pulugurtha and Agurla (2012) was used. For the purpose of calculating the typical daily ridership, the model takes into account the population that is within a walking distance of 400 meters, the number of people who are working, the population's income level broken down into various groups, as well as the amount of commercial space per 1000 square feet. A study was carried out on a particular section of the transit system, specifically on BRT Multan and Lahore. The ridership forecast estimation model was validated by comparing it to real daily average ridership data at six of the 178 bus stops in the study area. The stops were chosen at random.

In order to pre-process the data that was input, both simple buffers and network buffers were utilized. Within a radius of 400 meters around each stop, total population, number of individuals employed, and income strata were computed using network buffers. Within a straight-line distance of 400 meters from the bus stops, simple buffers were used to compute the zones surrounding the bus stations.

The ridership forecast approach developed by Y. Khan, Zafar, and Ayaz (2022) makes use of four estimating models. These models include “linear, Poisson log linear, gamma with log-link, and negative binomial with log-link”. This approach that provides the best fit is chosen depends on the quasi-likelihood, which can be found under values for the QIC and the CQL when using the QICC. In our scenario, the Gamma distribution with log-link was used. The estimations provided by the algorithm were compared to the actual ridership data for a total of six different stops that were chosen at random. The absolute estimated and observed ridership values (11 and 7) were similar, but one stop had a huge relative error of -57.14% despite the low average error of -6.77%. The observed discrepancies can be attributed to the reliability of the ridership data, the combination of demographic and census data from 2010 with ridership data from 2019, the significant overlap in service areas for the stops considered in the model, as well as the near proximity to rival stops in the area serving the same route, which based on the person's choice and bus stop characteristics (seating availability, comfort, etc.).

As probes or gauge sites, the centroids of the 26 census block groupings included in the analysis were utilized to determine the number of riders. For the purpose of determining each location's level of accessibility, we used both the anticipated daily ridership average as well as the distance in feet between each probe point and the closest station. To illustrate the improvement in accessibility, a second scenario was evaluated in which there were four additional stops strategically placed at the probe spots. The projected number of passengers using these stops was greater than 10.

In scenario I, the majority of the projected daily ridership (36 persons) were within a walking distance of 2000-2200 meters to their nearest stop. In scenario II, 67 people traveled 0–200 meters to the bus stop that was closest to them. The expected daily ridership with a walking-distance accessibility of 600 grew 31.6%, according to cumulative histograms. Scenario II improved 33.5% at 1,000 meters of walking distance and 19.3% at 2,000 meters. In the second scenario, the average walking distance dropped 18% to 205.60 meters.

In conclusion, the findings indicate that the suggested technique successfully assessed the ridership (transit demand) in regions that are remote from locations that already have bus transportation service, but the validation results reveal that there is a tolerable amount of inaccuracy. The relevance of the position of the bus stop in terms of accessibility is brought out by comparison of the two scenarios for determining the accessibility via walking distance. The method that has been proposed can be utilized by transit agencies in order for them to evaluate transit accessibility in regions that have limited or no access to public transportation, and as a result, Analyse the demand for their public transportation system.

In addition to this, it can provide assistance in the process of establishing new bus stops or repositioning existing bus stops in order to service regions that are now unserved. The proposed method makes use of data sources that are open to the public and ridership data that is not difficult to obtain, making it suitable for replication by departments of transportation as well as public transit agencies.

Future studies can include vehicle ownership and transit service frequency data to increase ridership predictions. In addition to this, it is anticipated that the utilizations of data from the upcoming census in 2020 would significantly enhance the precision of the estimates. The median approach can be utilized to identify extra transit stops or re-position present stations depend on transit demand. Y. Khan, Shad, and Irfan (2022) developed a scalable median algorithm for real road networks and then exercised it to the issue of where bus stops should be placed. The facility location model has been included in the proposed

The methodology produces a workable framework that may be used for the evaluation and enhancement of metropolitan public transportation services. These techniques would be of use in finding less-than-optimal solutions for the positioning of such probe points.

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