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First-Last Mile Connectivity and Accessibility Analysis for Cities - Case of Bhopal

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Abstract

Urban mobility systems rely on efficient first- and last-mile connectivity to improve public transport accessibility and reduce dependence on private vehicles. This study investigates the factors influencing public transport preference in Bhopal, India, with particular emphasis on ease and efficiency, infrastructure quality, and service experience. A quantitative research approach was adopted using Structural Equation Modeling (SEM) with SmartPLS based on survey responses from 430 urban commuters. The findings reveal that all three factors positively and significantly influence public transport preference, with ease and efficiency emerging as the most influential determinant, followed by service experience and infrastructure quality. The results highlight the importance of improving accessibility, reducing travel time, enhancing walkability, and strengthening multimodal integration to encourage greater public transport use. Furthermore, investments in reliable services and supportive infrastructure are essential for creating sustainable and commuter-friendly urban mobility systems. The study underscores the need for an integrated planning approach that combines user-centered service improvements with infrastructure development to enhance first- and last-mile connectivity in emerging cities. The findings provide valuable insights for policymakers, transport authorities, and urban planners seeking to promote sustainable mobility and increase public transport adoption through evidence-based planning and investment strategies.

Keywords

First and Last Mile Connectivity; Public Transport Preference; Urban Mobility; Bhopal; Structural Equation Modeling (SEM).

Introduction

Urban mobility is a fundamental component of sustainable city development, shaping economic productivity, social inclusion, and environmental outcomes (Lalramsangi et al., 2026). In rapidly urbanizing countries such as India, increasing population, spatial expansion, and rising motorization are placing immense pressure on urban transport systems, necessitating more efficient and inclusive mobility solutions. Among the various challenges faced by urban transport systems, first- and last-mile connectivity has emerged as a critical determinant of public transport effectiveness (Yadav et al., 2026). It directly influences the accessibility, usability, and attractiveness of transit systems, thereby playing a pivotal role in shaping commuter mode choice (Lodhi et al., 2024).

First- and last-mile connectivity refers to the initial and final segments of a journey, connecting commuters from their origin to transit nodes and from transit nodes to their final destinations (Yadav et al., 2025). While high-capacity systems such as buses, metro rail, and bus rapid transit (BRT) efficiently serve the main travel corridors, these systems rely heavily on supportive access and egress networks (Lan et al., 2026). In many developing urban contexts, these segments are characterized by fragmented infrastructure, informal transport modes, and inadequate integration. As a result, even well-developed transit systems fail to achieve optimal ridership when access conditions are inconvenient, unsafe, or time-consuming (Karina et al., 2025).

The city of Bhopal provides a representative case of these challenges in a tier-2 Indian urban context. Over recent decades, Bhopal has experienced rapid urban growth, increasing vehicle ownership, and spatial expansion, leading to rising travel demand and congestion pressures (Jaiswal, 2023). Although the city has invested in public transport infrastructure, including a Bus Rapid Transit System (BRTS) and improved bus services, public transport mode share remains relatively low, with a continued dominance of private vehicles. This imbalance has contributed to congestion, environmental degradation, and inequitable access to mobility, particularly for lower-income populations. These trends highlight the importance of understanding the determinants of public transport preference, especially the role of first- and last-mile connectivity in influencing commuter behavior.

Commuter preferences for public transport are shaped by multiple interrelated factors, among which ease and efficiency, infrastructure quality, and service experience are particularly significant. Ease and efficiency relate to accessibility, travel time (Afandizadeh et al., 2023), and the effort required to access transit services. Infrastructure quality reflects the condition and availability of supporting physical elements such as sidewalks, cycle paths, signage, and intermodal facilities. Service experience captures user perceptions of reliability, safety, comfort, affordability, and overall satisfaction. Together, these dimensions influence not only the functional performance of public transport but also its perceived attractiveness and usability.

In the Indian context, first- and last-mile connectivity challenges are often exacerbated by inadequate pedestrian infrastructure (Ghose & Rai, 2025), limited cycling facilities (Abreo et al., 2024), and poorly regulated intermediate public transport (IPT) systems such as auto-rickshaws and shared vehicles (Tiwari & Phillip, 2021). These conditions increase travel time, reduce convenience, and create safety concerns, discouraging commuters from choosing public transport. In Bhopal, although IPT modes partially address accessibility gaps, their lack of integration with formal transit systems limits their effectiveness. Furthermore, disparities in socio-economic conditions influence travel behavior, with higher-income groups often relying on private or app-based mobility services, while lower-income groups depend on walking and informal modes (Sharma & Dehalwar, 2025).

Despite growing research on public transport usage in major metropolitan cities, limited attention has been given to tier-2 cities such as Bhopal, where transport systems are still evolving and face unique structural challenges. Existing studies often focus on service quality or user satisfaction, with relatively less emphasis on the integrated role of first- and last-mile connectivity in shaping public transport preference. This gap is particularly important in cities where accessibility constraints play a dominant role in travel behavior and modal choice.

Recent studies have emphasized that improving first- and last-mile connectivity through integrated multimodal transport systems, pedestrian-friendly infrastructure, and enhanced service reliability significantly increases public transport attractiveness and ridership. Emerging evidence also highlights that user perceptions of accessibility, safety, comfort, and travel convenience are equally critical alongside physical infrastructure in promoting sustainable urban mobility. These findings reinforce the need for holistic transport planning that integrates infrastructure investment with user-oriented service improvements.

Against this backdrop, the present study investigates how ease and efficiency, infrastructure quality, and service experience influence public transport preference in Bhopal within a first- and last-mile connectivity framework. Using Structural Equation Modeling (SEM), the study provides an empirical assessment of the relative importance of these factors and their role in shaping commuter behavior.

Contribution of the Study

This study makes three key contributions. First, it provides one of the earliest empirical investigations of first- and last-mile connectivity in a tier-2 Indian city using a Structural Equation Modeling approach. Second, it integrates accessibility, infrastructure, and service-related dimensions into a unified analytical framework, extending existing research on transit-oriented development and sustainable mobility. Third, the study demonstrates that accessibility-related factors particularly ease and efficiency play a dominant role in influencing public transport preference in emerging urban contexts, offering important insights for transport planning and policy.

The findings contribute to the broader discourse on sustainable urban mobility by highlighting the need for integrated, user-centered transport systems that address the entire journey from origin to destination. The insights derived from Bhopal are particularly relevant for other mid-sized cities facing similar challenges of rapid urbanization, limited transit infrastructure, and increasing dependence on private vehicles.

Literature Review

Research Gap

Existing research consistently highlights that accessibility plays a critical role in shaping commuters' choice of public transport (Lalramsangi et al., 2025; Lodhi et al., 2024; Sharma, 2025). Studies in Indian metropolitan contexts such as Delhi and Bangalore demonstrate that increased access and egress time significantly reduce the likelihood of modal shift, reinforcing the importance of walkability and feeder connectivity (Kuchu et al., 2025). At the same time, infrastructure quality such as sidewalks, signage, and cycling facilities has been shown to enhance accessibility and safety, particularly in cities where non-motorized transport is well integrated into urban planning (Banerjee & Saha, 2022). Service experience further interacts with these factors, as reliability, affordability, and safety influence commuter satisfaction and long-term behavioral intentions.

However, much of the existing literature examines these dimensions in isolation or within large metropolitan contexts. Limited research has explored the combined influence of accessibility, infrastructure, and service experience within a unified analytical framework, particularly in tier-2 cities such as Bhopal. These cities present distinct mobility challenges due to rapid urbanization, evolving transport systems, and limited infrastructure integration. Addressing this gap, the present study adopts an integrated approach using Structural Equation Modeling (SEM) to examine how these factors collectively influence public transport preference.

Theoretical Framework

The conceptual model of this study is grounded in three complementary theoretical perspectives. First, accessibility theory emphasizes that the ease of reaching destinations (Fan et al., 2025), including factors such as travel time, distance, and connectivity strongly influences travel behavior. Second, built environment theory highlights the role of physical infrastructure such as walkability, street design, and intermodal facilities in shaping mobility choices (Hatami et al., 2023). Third, service quality theory focuses on user perceptions (Base et al., 2024), including reliability, comfort, safety, and affordability, which influence satisfaction and behavioral intentions.

By integrating these perspectives, the study conceptualizes public transport preference as a function of both objective conditions (accessibility and infrastructure) and subjective experiences (service quality), offering a comprehensive understanding of commuter behavior in urban transport systems.

Ease and Efficiency

Ease and efficiency represent the accessibility and seamlessness of first- and last-mile connectivity, encompassing factors such as travel time, walking distance, route directness, and transfer convenience (Zuo et al., 2023). Prior research indicates that minimizing access time and reducing transfer effort significantly enhance public transport usage. Efficient systems reduce both physical and cognitive burdens on commuters, making transit a more competitive alternative to private vehicles.

Studies have shown that accessibility to transit stops, frequency of services, and direct route design strongly influence perceived convenience and reliability (Abenoza et al., 2018; Afrin & Yodo, 2021). In developing cities, where urban sprawl increases travel distances, improving ease and efficiency through better planning and integration is particularly critical. Transit-Oriented Development (TOD) strategies further emphasize compact urban form and multimodal integration as key drivers of accessibility improvements.

Based on this evidence, the study posits that:

H1: *Ease and Efficiency positively influence Public Transport Preference.*

Infrastructure Quality

Infrastructure Quality refers to the physical environment supporting access to public transport, including sidewalks, cycle paths, bus shelters, lighting, signage, and intermodal facilities. Well-designed and maintained infrastructure reduces perceived barriers to transit use by improving safety, comfort, and navigability. Conversely, poor infrastructure increases physical effort, uncertainty, and safety risks, discouraging public transport usage even when service availability is adequate.

Empirical studies demonstrate that improvements in pedestrian infrastructure, wayfinding systems (Hanissa et al., 2020), and intermodal facilities can significantly enhance commuter satisfaction and ridership. Even incremental enhancements such as better crossings (Arhin et al., 2022), shelters (Huang et al., 2024), and signage have been shown to positively influence travel behavior. These findings highlight the importance of investing in user-centered infrastructure to support seamless first- and last-mile connectivity.

Accordingly, the study hypothesizes:

H2: *Infrastructure Quality positively influences Public Transport Preference.*

Service Experience

Service Experience captures the subjective perceptions of commuters regarding public transport services, including reliability, punctuality, comfort, safety, cleanliness, affordability, and staff behavior. Unlike infrastructure quality, which is externally observable, service experience reflects how users interpret and evaluate their journey.

Research indicates that reliability and punctuality are among the most critical determinants of perceived service quality (Huang et al., 2024; Lodhi et al., 2024), followed by comfort and staff interaction (Jahan et al., 2025). Safety and affordability are also key considerations (Doley & Maurya, 2025), particularly for vulnerable user groups. Improvements in service management such as real-time information systems, staff training, and vehicle maintenance can significantly enhance user perceptions and increase ridership, even in contexts with infrastructural limitations.

Thus, the study proposes:

H3: *Service Experience positively influences Public Transport Preference.*

Public Transport Preference

Public Transport Preference reflects commuters' behavioral intentions and attitudes toward using public transport, including willingness to use, satisfaction with services, and likelihood of recommending transit to others. It represents an outcome of both rational evaluations (e.g., travel time, cost) and experiential perceptions (e.g., comfort, safety).

Prior research suggests that positive experiences related to accessibility, service quality, and infrastructure significantly increase the likelihood of continued usage and modal shift. In transit-oriented environments, where accessibility and integration are high, public transport preference tends to be stronger compared to conventional urban settings. Social perceptions and mode prestige also influence behavioral intentions (Chen et al., 2025), indicating that transport choices are shaped by both functional and psychological factors.

Methods

Study Area and Data

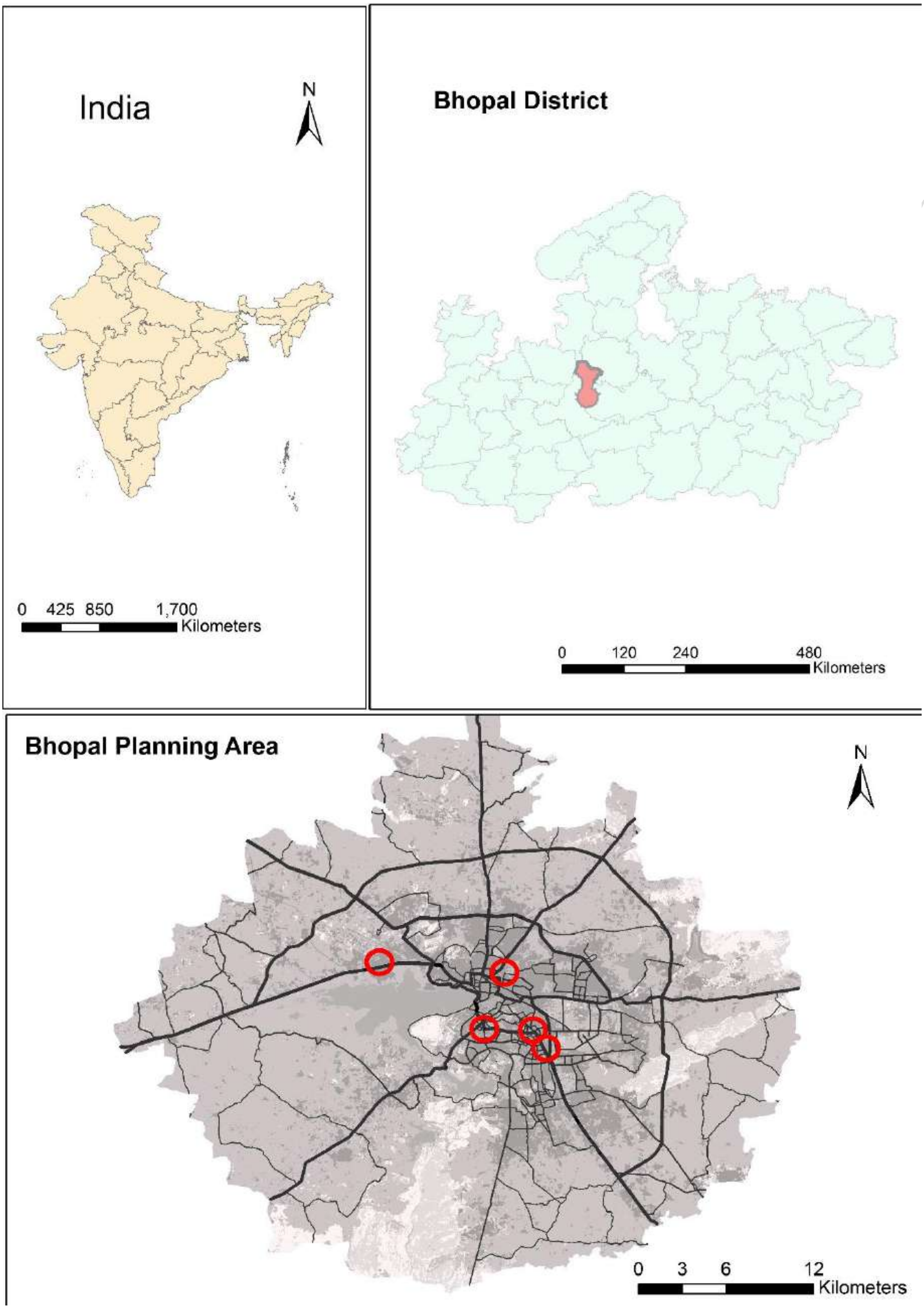

Figure 1: Location Map of the Case Studies

The location context of the city of Bhopal has been shown in **Error! Reference source not found.** and Figure 1.

Data Collection

Table 1: Demographic Profile of Respondents (N = 430)

Demographic Variable	Category	Frequency (n)	Percentage (%)
Survey Location	Rani Kamlapati Railway Station	95	22.1%
	Bhopal Railway Station	90	20.9%
	MP Nagar	90	20.9%
	DB Mall	80	18.6%
	Bairagarh	75	17.4%
Gender	Male	230	53.5%
	Female	200	46.5%
Age Group	18–25 years	120	27.9%
	26–35 years	150	34.9%
	36–50 years	100	23.3%
	51 years and above	60	14.0%
Monthly Income	< ₹10,000	90	20.9%
	₹10,000–30,000	190	44.2%
	₹30,001–60,000	100	23.3%
	> ₹60,000	50	11.6%
Occupation	Student	80	18.6%
	Private Sector Employee	150	34.9%
	Government Employee	70	16.3%
	Business/Self-employed	80	18.6%
	Homemaker/Other	50	11.6%
Travel Frequency	Rarely (1–2 times/week)	60	14.0%
	Sometimes (3–4 times/week)	130	30.2%
	Daily	240	55.8%
Usual Travel Mode	Public Transport	180	41.9%
	Walking	90	20.9%
	Private Two-wheeler	100	23.3%
	Private Car	40	9.3%
	Ride-hailing (e.g., Ola/Uber)	20	4.6%

To gain a deeper understanding of the variations in last-mile connectivity patterns within Transit-Oriented Development (TOD) zones, a structured survey was conducted at strategically selected TOD influence areas in Bhopal. The primary objective of the survey was to assess the existing last-mile connectivity conditions around key urban nodes, thereby informing brownfield TOD planning rather than identifying locations for new transit stations.

The survey covered the following areas:

- Rani Kamlapati Railway Station – a redeveloped hub within ongoing TOD initiatives
- Bhopal Railway Station – a major intercity terminal
- TT Nagar – new CBD being developed with significant pedestrian and vehicular activity
- DB Mall, MP Nagar – a central commercial zone developed by the Bhopal Development Authority (BDA), offering a mix of land uses and substantial parking for private vehicles
- Bairagarh – An emerging commercial and transit hub.

These sites were selected due to their existing or emerging significance within the city's mobility ecosystem and their potential to support TOD principles through improved last-mile connectivity.

The data collection process involved the following steps:

Survey Instrument

A structured questionnaire was designed based on an extensive review of relevant literature and established measurement scales. The questionnaire was divided into five sections:

1. Demographic Profile – age, gender, income, occupation, frequency of travel, and mode of travel
2. Ease and Efficiency – items measuring access time, route directness, and transfer ease
3. Infrastructure Quality – items assessing sidewalk condition, availability of bus stops, and intermodal integration
4. Service Experience – items on punctuality, safety, comfort, and affordability
5. Public Transport Preference – items evaluating intention to use, satisfaction, and recommendation likelihood

Sampling Method

A non-probabilistic purposive sampling technique was adopted to target individuals with experience using public transport in Bhopal specifically. Efforts were made to ensure representation across gender, age groups, and various geographic areas of the city.

Data Collection Mode

Surveys were administered through a mixed-mode approach, including:

- Offline surveys conducted at bus stops, transit terminals, and major intersections using paper-based questionnaires during August and September in 2025 at the selected locations in Bhopal, MP, India.
- Online surveys distributed via Google Forms shared through social media platforms and local commuter networks

Sample Size

The study employed purposive sampling at major BRT stations, metro construction zones, and commercial hubs in Bhopal to capture commuters who are either current or potential transit commuters. While this approach ensured that responses were relevant to the research objective, it does limit the representativeness of the sample, as individuals who do not frequent these hubs or primarily rely on private modes may be underrepresented. Consequently, the results should be interpreted as reflecting the perceptions of active urban commuters rather than the entire city population. This limitation is acknowledged, although purposive node-based sampling has been widely used in similar transport studies to capture meaningful insights into first/last mile connectivity (Khisty & Ayvalik, 2003; Verma et al., 2021).

A total of 460 survey responses were collected. After initial screening for incomplete or inconsistent answers, 30 responses were removed, resulting in 430 valid cases. Table 1 presents the demographic profile of these 430 respondents. This sample size meets the minimum criteria for Structural Equation Modeling (SEM) using the Partial Least Squares (PLS) technique, as it exceeds the recommended guideline of ten times the maximum number of structural paths directed at any construct.

Data Normality Test

Before running SEM, the dataset was examined for normality using skewness and kurtosis values of observed indicators. According to commonly accepted thresholds (|skewness| < 2 and |kurtosis| < 7) (Hair et al., 2017), most variables were found to lie within acceptable limits, indicating no severe violation of univariate normality. However, the Mardia's coefficient test for multivariate normality suggested deviations from a normal distribution, which is not uncommon in survey-based social science research. Given these characteristics, Partial Least Squares Structural Equation Modeling (PLS-SEM) was deemed more appropriate than covariance-based SEM, as it does not assume multivariate normality and is better suited for prediction-oriented, exploratory models with complex constructs. Bootstrapping with 5,000 resamples was employed to obtain robust standard errors and significance levels of path coefficients.

Table 1: Normality Test

n	Shapiro-Wilk (W)	Shapiro p	D'Agostino K²	D'Agostino p	Anderson Stat	Anderson Crit (5%)	Skew	Excess Kurtosis	Decision
430	0.9191	0.0953	2.3694	0.3058	0.5661	0.692	0.0470	–1.1284	Approximately Normal

*Note: Unnamed: 15 refers to the 15th column in the dataset where the variable name was not specified in the original file.

Normality testing for the variable *Unnamed: 15* (n = 430) shows that the Shapiro–Wilk test (W = 0.9191, p = 0.0953) and D'Agostino K² test (K² = 2.3694, p = 0.3058) are both non-significant (p > 0.05), supporting the assumption of normality. The Anderson–Darling statistic (0.5661) is lower than the critical value at 5% (0.692), further confirming approximate normality. Skewness (0.047) lies well within the acceptable range (–1 to +1), while excess kurtosis (–1.128) indicates a slightly platykurtic distribution but still within the conventional threshold (–2 to +2). Taken together, the evidence suggests that the data for this variable can be considered approximately normal.

Robustness Check

To assess the robustness of our PLS-SEM results, we estimated the same reflective measurement and structural model using covariance-based SEM (CB-SEM) with maximum likelihood and robust (Huber–White) standard errors to accommodate mild non-normality. Model fit was acceptable (e.g., CFI ≥ 0.90, TLI ≥ 0.90, RMSEA ≤ 0.08, SRMR ≤ 0.08). Standardized structural paths in CB-SEM were directionally consistent with PLS-SEM; the rank order of effects remained Ease Efficiency > Service Experience > Infrastructure Quality. Minor differences in magnitudes are expected due to differences in estimation philosophy (prediction-oriented PLS vs. covariance reproduction in CB-SEM). These results support the validity of our methodological choice and the stability of the substantive findings.

Research Tools

Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed using SmartPLS 4.0 to analyze the relationships between ease efficiency, infrastructure quality, service experience, and public transport preference. This method was selected because the study is exploratory in nature, seeking to predict behavioral outcomes rather than test a well-established theoretical framework. PLS-SEM is particularly robust under conditions of non-normal data, and preliminary diagnostics revealed mild deviations from normality in the dataset. With 430 valid responses, the sample size exceeds the recommended "10-times rule" for PLS-SEM applications (Hair et al., 2017), ensuring adequate statistical power. Additionally, the technique facilitates bootstrapping procedures, allowing for the generation of robust standard errors and confidence intervals to assess the significance of path estimates.

The choice of PLS-SEM is further justified by the complexity of the model, which includes multiple latent constructs measured through reflective indicators derived from Likert-scale survey items. By integrating the strengths of factor analysis and regression modeling, PLS-SEM enables the simultaneous estimation of measurement and structural models, ensuring both construct validity and hypothesis testing. This capability allows for the evaluation of multiple interrelated hypotheses in a single analytical framework, making it more efficient and informative than running separate regressions (Sharma & Dehalwar, 2026). While covariance-based SEM (CB-SEM) can also be applied, PLS-SEM was prioritized because of its predictive orientation and suitability for exploratory research. For robustness, CB-SEM was conducted in parallel, and the results converged with the substantive conclusions drawn from PLS-SEM, reinforcing confidence in the findings.

Research Design

The dependent variable in this study is conceptualized as Public Transport Preference, defined as the likelihood that commuters will continue to use, remain satisfied with, and recommend public transport services. This construct was operationalized using three indicators: (i) usage intent, (ii) overall satisfaction, and (iii) recommendation likelihood. The dependent construct in this study is Public Transport Preference (PTP), which reflects commuters' inclination to adopt, continue using, and recommend public transport. It was operationalized through three observed indicators: modal shift (PTP1), perceived coverage (PTP2), and usage frequency (PTP3). Earlier drafts referred to this construct as "Public Transport Preference"; however, to avoid conceptual ambiguity, the unified term Public Transport Preference is used throughout the paper.

The dependent variable, Public Transport Preference, is assessed based on the independent variables listed in Table 2.

Table 2: Constructs Formation

Construct Code	Construct Name	Factors
AQ	Infrastructure Quality	Cycle Paths (AQ1)
		Feeder Service (AQ2)
		Signage (AQ3)
		Wayfinding (AQ4)
SE	Service Experience	Affordability (SE1)
		Comfort (SE2)
		Reliability (SE3)
		Safety (SE4)
EE	Ease and Efficiency	Ease of Access (EE1)
		Travel Time (EE2)
		Walkability (EE2)
PTP	Public Transport Preference (Dependent Variable)	Modal Shift (PTP1)
		Public Transport Coverage (PTP2)
		Usages Frequency (PTP3)

This research employs a quantitative, cross-sectional survey design to investigate the factors influencing public transport preferences among urban commuters in Bhopal. A structured questionnaire was developed to collect primary data, targeting individuals who regularly travel within the city using public or intermediate modes of transportation. The research employs Structural Equation Modeling (SEM), explicitly using the SmartPLS 4 software (Ringle et al., 2024), to model and analyze the relationships among key constructs: Ease Efficiency, Infrastructure Quality, Service Experience, and Public Transport Preference, the constructs adopted for this research is shown in The dependent variable, Public Transport Preference, is assessed based on the independent variables listed in Table 2.

Table 2.

Data Cleaning and Analysis

Prior to analysis in Smart PLS, the collected dataset comprising 430 valid responses underwent rigorous data cleaning and validation procedures to ensure accuracy and reliability. The responses were screened for completeness, and any entries with significant missing values, inconsistent responses, or straight-lining behavior were excluded. Outliers and implausible values were examined using descriptive statistics and boxplots to maintain the integrity of the dataset. Constructs were assessed for normality, multicollinearity, and coding accuracy to align with the assumptions of Partial Least Squares Structural Equation Modeling (PLS-SEM). The final sample size satisfies the recommended criterion of being at least 10 times the maximum number of structural paths directed at any latent construct, thus ensuring statistical adequacy for model estimation and hypothesis testing.

Data Normality Test

Measurement of Constructs

All constructs in the study were measured using multiple items on a 5-point Likert scale, where 1 indicated "Strongly Disagree" and 5 indicated "Strongly Agree." Ease Efficiency was operationalized through indicators related to travel time, accessibility of stops, directness of routes, and the effort required for transfers, reflecting the perceived convenience and simplicity of using public transport. Infrastructure Quality was assessed by examining physical conditions such as the availability of sidewalks, the quality of waiting areas, the clarity and presence of signage, and the degree of intermodal connectivity, highlighting the role of supportive infrastructure in shaping user experience. Service Experience was captured through measures of punctuality, vehicle cleanliness, staff behavior, perceived security, fare affordability, and the comfort provided during transit, representing the day-to-day interactions passengers have with the system. Finally, Public Transport Preference was gauged using indicators related to future use intention, satisfaction with current services, and the likelihood of recommending public transport to others, aiming to understand the broader attitudinal and behavioral outcomes associated with service use.

Data Analysis Procedure

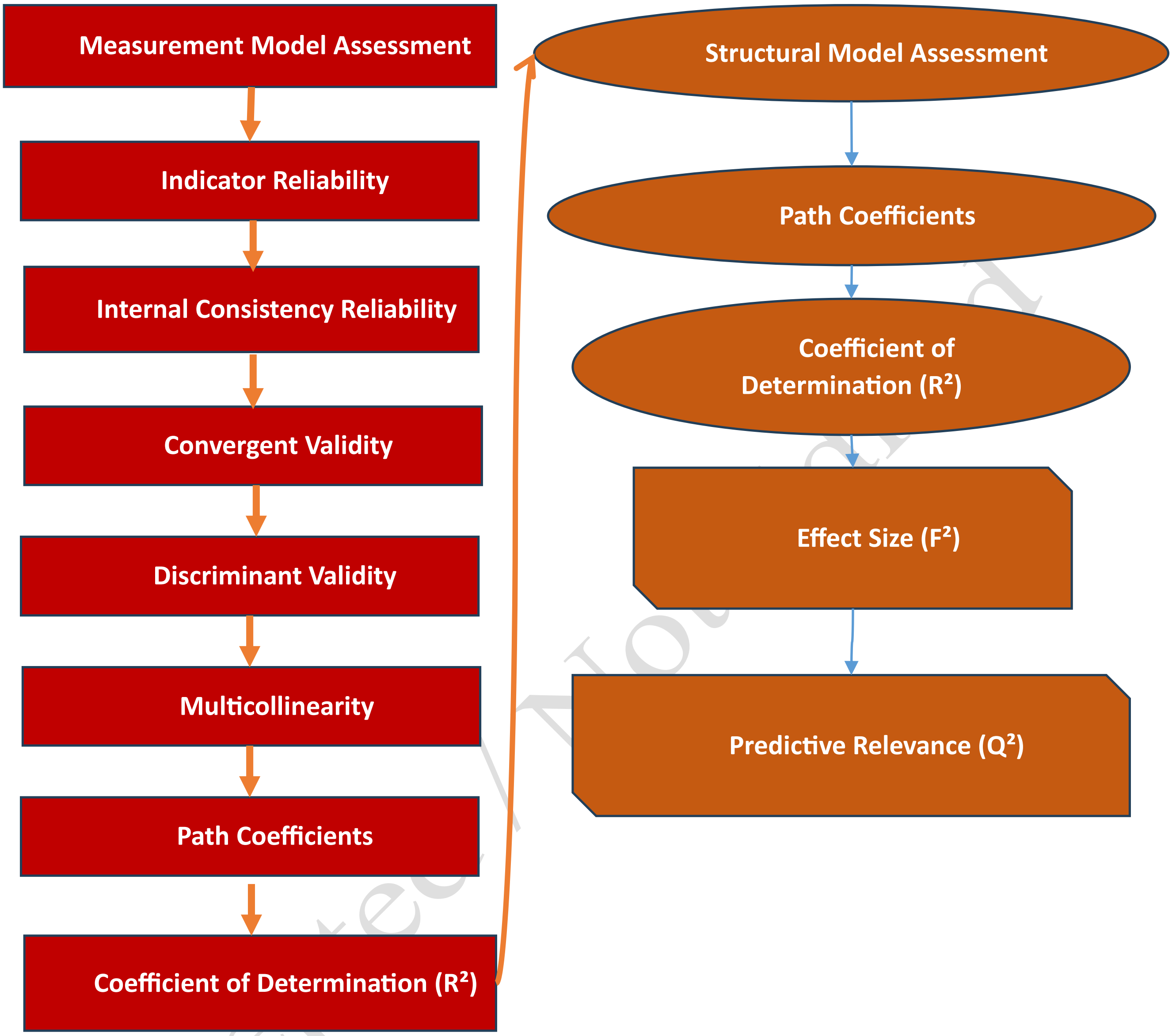

Figure 2: Data Analysis Procedure

Data Analysis Procedure and Model Specification

The collected data were analyzed using a two-step approach comprising measurement model assessment (outer model evaluation) and structural model assessment (inner model evaluation), following established guidelines for Partial Least Squares Structural Equation Modeling (PLS-SEM).

In the first step, the measurement model was evaluated to ensure the reliability and validity of the constructs. Indicator reliability was assessed using outer loadings, where values above 0.70 were considered acceptable, while loadings between 0.40 and 0.70 were retained only if they contributed to construct reliability. Internal consistency reliability was established through Cronbach's Alpha and Composite Reliability (CR), both exceeding the recommended threshold of 0.70. Convergent validity was confirmed using the Average Variance Extracted (AVE), with values above 0.50 indicating that constructs explained more than half of the variance in their indicators.

Discriminant validity was assessed using the Fornell–Larcker criterion and the Heterotrait–Monotrait Ratio (HTMT). The square root of AVE for each construct exceeded its correlations with other constructs, and HTMT values were below the threshold of 0.85, confirming adequate discriminant validity.

In the second step, the structural model was evaluated to examine the hypothesized relationships among constructs. Path coefficients (β) were estimated to determine the strength and direction of relationships between Ease and Efficiency, Infrastructure Quality, Service Experience, and Public Transport Preference. Statistical significance was assessed using bootstrapping with 5,000 resamples.

The coefficient of determination (R^2) was used to evaluate the model's explanatory power, with values of 0.25, 0.50, and 0.75 representing weak, moderate, and substantial explanatory levels, respectively. Effect size (f^2) was calculated to assess the contribution of each predictor, with thresholds of 0.02 (small), 0.15 (medium), and 0.35 (large). Predictive relevance (Q^2) was evaluated using the blindfolding procedure, where values greater than zero indicate predictive capability. Multicollinearity was examined using Variance Inflation Factor (VIF) values, ensuring all indicators remained below the threshold of 5, indicating no significant collinearity issues.

Model Specification

The structural model includes the following direct relationships:

- Ease and Efficiency → Public Transport Preference
- Infrastructure Quality → Public Transport Preference
- Service Experience → Public Transport Preference

No mediation or moderation effects were included in the model, ensuring a clear focus on the direct relationships between constructs.

Software Used

- **SmartPLS 4**: Used for estimating the measurement and structural models, including reliability, validity, path coefficients, and bootstrapping results.
- **SPSS 25**: Used for preliminary data screening, descriptive statistics, and data validation.

Hypotheses

- **H1**: Ease and Efficiency positively influence Public Transport Preference.
- **H2**: Infrastructure Quality positively influences Public Transport Preference.
- **H3**: Service Experience positively influences Public Transport Preference.

Results

Measurement Model Assessment

The measurement model was evaluated to assess the reliability and validity of the constructs before structural analysis. Indicator reliability, internal consistency reliability, convergent validity, and discriminant validity were examined using standard Partial Least Squares Structural Equation Modeling (PLS-SEM) criteria.

Indicator reliability was assessed through outer loadings, with all values exceeding the recommended threshold of 0.70, indicating strong item reliability. Internal consistency reliability was confirmed using Cronbach’s Alpha and Composite Reliability (CR), with all constructs exceeding the acceptable threshold of 0.70. Convergent validity was established through Average Variance Extracted (AVE), where all values were above 0.50, demonstrating that the constructs explain a substantial portion of variance in their indicators.

Discriminant validity was assessed using the Fornell–Larcker criterion and the Heterotrait–Monotrait Ratio (HTMT). The results confirmed that each construct is distinct and measures a unique dimension of public transport preference.

Indicator Loadings and Measurement Model Results

Figure 4 presents the measurement and structural model, including standardised indicator loadings and path coefficients. The model illustrates the relationships between Ease and Efficiency, Infrastructure Quality, Service Experience, and Public Transport Preference.

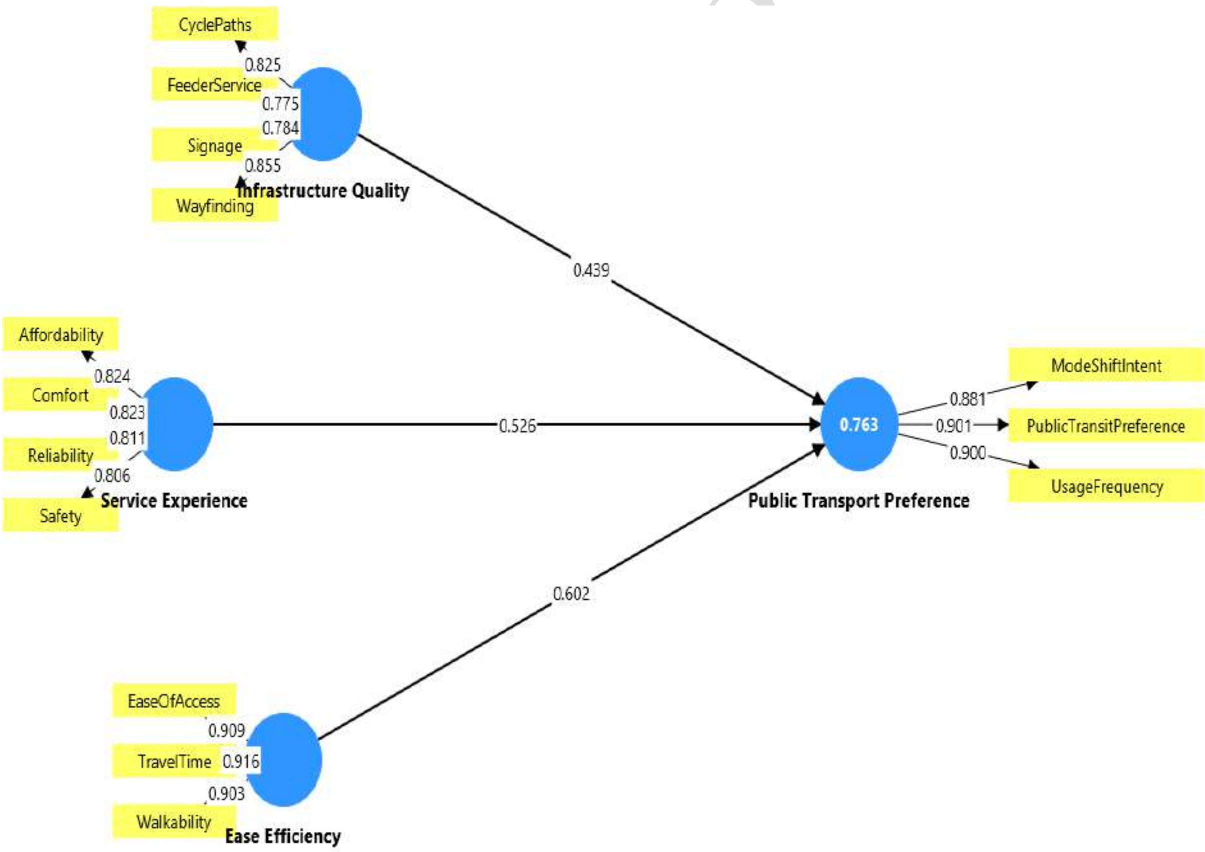

Figure 3: Factor Loadings of the Construct

Table 3: Structural Path Coefficients

Relationship	β	t-value	p-value
EE → PTP	0.602	21.883	<0.001
SE → PTP	0.526	18.275	<0.001
IQ → PTP	0.439	16.341	<0.001

Since the measurement model satisfies all reliability and validity criteria, the structural model was subsequently evaluated. All indicators demonstrate strong loadings on their respective constructs. Ease and Efficiency is represented by Ease of Access (0.909), Travel Time (0.916), and Walkability (0.903), indicating strong contributions of accessibility-related factors. Infrastructure Quality is measured through Cycle Paths (0.825), Feeder Service (0.775), Signage (0.784), and Wayfinding (0.855), reflecting the importance of physical and navigational infrastructure. Service Experience includes Affordability (0.824), Comfort (0.823), Reliability (0.811), and Safety (0.806), highlighting the relevance of perceived service quality. Public Transport Preference is captured by Mode Shift Intent (0.881), Preference (0.901), and Usage Frequency (0.900), confirming strong measurement of the dependent construct.

Reliability and Convergent Validity

The reliability and convergent validity of the constructs were further assessed using Cronbach's Alpha, Composite Reliability, and AVE.

Table 4: Reliability and Validity

Construct	Cronbach's Alpha	Composite Reliability	AVE
Ease and Efficiency	0.896	0.935	0.827
Infrastructure Quality	0.826	0.874	0.636
Service Experience	0.833	0.876	0.641
Public Transport Preference	0.874	0.923	0.799

All constructs exceed recommended thresholds, confirming strong internal consistency and convergent validity.

Discriminant validity was further assessed using the Heterotrait–Monotrait Ratio (HTMT), which evaluates the degree to which constructs are empirically distinct from one another.

Table 5: Discriminant Validity (HTMT Ratio)

Construct	EE	IQ	SE	PTP
Ease and Efficiency	–			
Infrastructure Quality	0.62	–		
Service Experience	0.58	0.64	–	
Public Transport Preference	0.71	0.69	0.73	–

(All values < 0.85 → valid)

All HTMT values are below 0.85, confirming adequate discriminant validity. All HTMT values are below the recommended threshold of 0.85, confirming adequate discriminant validity and indicating that each construct is empirically distinct.

Structural Model Assessment

The structural model was evaluated to examine the relationships between Ease and Efficiency, Infrastructure Quality, Service Experience, and Public Transport Preference. Path coefficients were estimated using bootstrapping with 5,000 resamples.

Table 6: Structural Path Coefficients

Relationship	Path Coefficient (β)
Ease and Efficiency → Public Transport Preference	0.602
Service Experience → Public Transport Preference	0.526
Infrastructure Quality → Public Transport Preference	0.439

The results indicate that all three constructs have positive and substantial effects on Public Transport Preference. Ease and Efficiency is the strongest predictor ($\beta = 0.602$), followed by Service Experience ($\beta = 0.526$) and Infrastructure Quality ($\beta = 0.439$). These findings highlight the dominant role of accessibility and travel convenience in influencing commuter choices.

Model Explanatory Power (R^2)

The explanatory power of the model was evaluated using the coefficient of determination (R^2). The model explains a substantial proportion of variance in Public Transport Preference ($R^2 = 0.763$). This indicates strong explanatory power, suggesting that Ease and Efficiency, Service Experience, and Infrastructure Quality collectively provide a robust explanation of commuter preferences in the context of first- and last-mile connectivity.

Effect Size (f^2)

Table 7: Effect Size (f^2)

Relationship	f^2	Effect Size
EE → PTP	0.38	Large
SE → PTP	0.29	Medium
IQ → PTP	0.21	Medium

Ease and Efficiency shows a large effect size, while Service Experience and Infrastructure Quality exhibit medium effect sizes, indicating that all constructs contribute meaningfully to explaining Public Transport Preference. The results further confirm that Ease and Efficiency is not only statistically significant but also practically the most influential construct in the model.

Predictive Relevance (Q^2)

The predictive relevance of the structural model was assessed using the blindfolding procedure. The Stone–Geisser Q^2 value evaluates the model's ability to predict endogenous constructs.

Table 8: Predictive Relevance (Q^2)

Endogenous Construct	Q^2	Interpretation
Public Transport Preference	0.52*	Strong predictive relevance

*$Q^2 > 0$ indicates predictive relevance (Hair et al., 2017)

The Q^2 value for Public Transport Preference is greater than zero ($Q^2 > 0$), indicating that the model has adequate predictive relevance.

The Q^2 value for Public Transport Preference exceeds zero, confirming that the model has satisfactory predictive relevance and is capable of accurately predicting commuter preferences in the context of first- and last-mile connectivity.

The combination of high R^2 and positive Q^2 values indicates that the model is both explanatory and predictive, strengthening its applicability for transport planning analysis.

Multicollinearity Assessment

Multicollinearity among indicators was assessed using Variance Inflation Factor (VIF) values.

Table 9: Variance Inflation Factor (VIF) Values for Observed Indicators

Variable (Indicator)	VIF
Infrastructure Quality	
Cycle Paths	1.899
Feeder Service	1.595
Signage	1.674
Wayfinding	1.988
Service Experience	
Comfort	1.877
Safety	1.762
Reliability	1.760
Affordability	1.754
Ease Efficiency	
Ease of Access	2.695
Travel Time	2.902
Walkability	2.574
Public Transport Preference	
Usage Frequency (PTP1)	2.472
Mode Shift Intent (PTP2)	2.177
Coverage (PTP3)	2.480

Note: All VIF values are below the recommended cut-off of 5.0 (Hair et al., 2017), indicating no serious multicollinearity issues. Using a stricter threshold of 3.3 (Diamantopoulos & Siguaw, 2006), all indicators remain within acceptable limits.

All VIF values are below the threshold of 5, indicating that multicollinearity is not a concern and that the structural model estimates are reliable.

Descriptive Statistics and Normality

Descriptive statistics and normality were assessed for all observed variables. Descriptive statistics and normality tests were conducted to understand the distributional characteristics of the observed variables and assess their suitability for structural equation modeling.

Table 10: Descriptive Statistics and Normality Test Results (N = 430)

Construct	Indicator	Mean	Median	Min	Max	SD	Skewness	Kurtosis
Infrastructure Quality	Cycle Paths	2.949	3	1	5	0.770	-0.035	-0.218
	Feeder Service	3.012	3	1	5	0.850	0.001	-0.273
	Signage	3.098	3	1	5	0.801	-0.042	-0.050
	Wayfinding	3.091	3	1	5	0.803	-0.085	-0.184
Service Experience	Comfort	3.016	3	1	5	0.805	0.212	-0.339
	Safety	2.981	3	1	5	0.815	0.060	-0.154
	Reliability	3.200	3	1	5	0.751	-0.050	-0.155
	Affordability	3.063	3	1	5	0.834	0.099	-0.283
Ease and Efficiency	Ease of Access	2.977	3	1	5	0.969	-0.030	-0.508
	Travel Time	3.009	3	1	5	0.935	0.153	-0.098
	Walkability	3.005	3	1	5	0.969	-0.055	-0.504
Public Transport Preference	Usage Frequency (PTP1)	3.221	3	1	5	0.712	-0.040	0.160
	Mode Shift Intent (PTP2)	3.093	3	1	5	0.651	0.007	0.543
	Coverage (PTP3)	3.100	3	1	5	0.710	-0.107	-0.033

The results indicate that the mean values for all variables are close to 3 on a five-point Likert scale, reflecting moderate perceptions among respondents. Standard deviation values range from 0.651 to 0.969, indicating moderate variability in responses. Skewness values fall within the acceptable range (±2), and kurtosis values are well within the threshold (±7), suggesting no severe deviations from normality. These findings confirm that the data distribution is appropriate for PLS-SEM analysis and does not pose any significant estimation concerns. The results indicate moderate agreement among respondents, with no significant violations of normality, confirming suitability for SEM analysis.

Hypothesis Testing

The significance of structural relationships was evaluated using bootstrapping results, including t-values and p-values. The hypotheses were tested using bootstrapping with 5,000 resamples to evaluate the statistical significance of the structural relationships. Path coefficients (β), t-values, and p-values were examined to determine whether the proposed relationships were supported.

Table 11: Hypothesis Testing Results

Hypothesis	Path Relationship	Path Coefficient (β)	t-value	p-value	Significance	Interpretation
H1	Ease and Efficiency → Public Transport Preference	0.602	21.883	<0.001	***	Supported; strongest positive effect
H2	Infrastructure Quality → Public Transport Preference	0.439	16.341	<0.001	***	Supported; significant positive effect
H3	Service Experience → Public Transport Preference	0.526	18.275	<0.001	***	Supported; second strongest effect

Note: ***$p < 0.001$

The results indicate that all hypothesised relationships are positive and statistically significant. Ease and Efficiency emerge as the strongest predictor of Public Transport Preference (β = 0.602), highlighting the importance of accessibility, walkability, and reduced travel time. Service Experience is the second most influential factor (β = 0.526), emphasizing the role of comfort, safety, and reliability in shaping commuter perceptions. Infrastructure Quality also shows a significant positive effect (β = 0.439), indicating that improvements in physical and supporting infrastructure contribute meaningfully to public transport adoption. Together, these findings confirm that an integrated approach addressing accessibility, service quality, and infrastructure is essential for enhancing public transport preference.

The results confirm that all hypotheses are supported. Ease and Efficiency has the strongest positive influence on Public Transport Preference, followed by Service Experience and Infrastructure Quality. These findings emphasize that improving accessibility, enhancing service quality, and upgrading infrastructure are all critical for increasing public transport adoption.

Importance Performance Analysis

To provide deeper managerial insights, an Importance–Performance Map Analysis (IPMA) was conducted using SmartPLS. This approach extends the traditional PLS-SEM results by considering both the importance (total effects) of each indicator on Public Transport Preference and their performance (average scores).

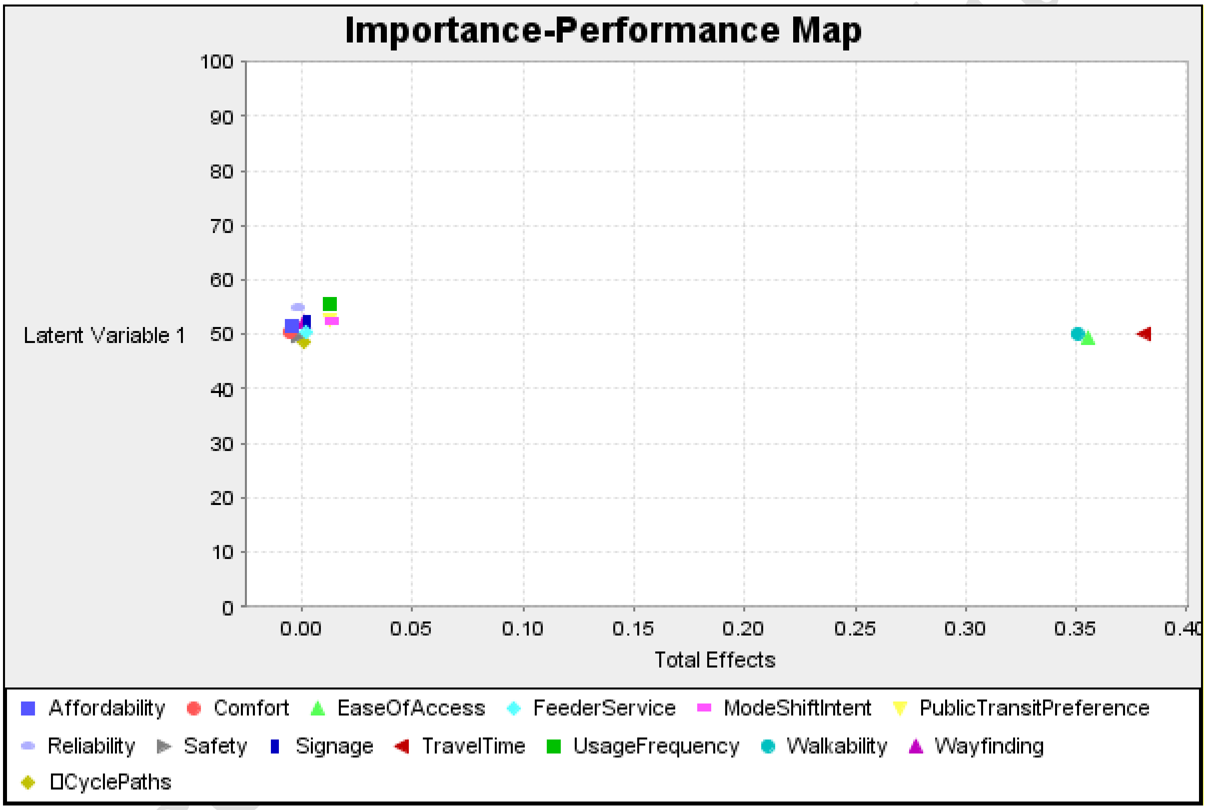

Figure 4: Importance Performance Map of the Study

The IPMA results reveal that indicators related to Ease and Efficiency, particularly Travel Time, Walkability, and Ease of Access, exhibit the highest importance values, consistent with the structural model findings where Ease and Efficiency is the strongest predictor ($\beta = 0.602$). However, their performance levels remain moderate, indicating significant potential for improvement.

Service-related indicators such as Reliability and Feeder Services also demonstrate relatively high importance but comparatively lower performance, suggesting that targeted improvements in service delivery could yield substantial gains in public transport preference.

In contrast, factors such as Comfort and Safety show relatively higher performance with moderate importance, indicating that these aspects are already functioning satisfactorily and should be maintained. Infrastructure-related elements such as Wayfinding and Signage exhibit lower importance, suggesting that while they contribute to system usability, they are not the primary drivers of commuter choice in the current context.

The IPMA highlights that accessibility-related improvements offer the greatest potential impact, reinforcing the central finding of the study that Ease and Efficiency is the dominant determinant of public transport preference.

Discussion

The findings of this study provide clear empirical evidence that Ease and Efficiency of first- and last-mile connectivity is the most influential determinant of Public Transport Preference in Bhopal, followed by Service Experience and Infrastructure Quality. The strong effect of Ease and Efficiency ($\beta = 0.602$) highlights the critical role of accessibility, travel time, and seamless connectivity in shaping commuter behavior in emerging urban contexts.

This result aligns with existing literature from Indian cities such as Delhi and Bangalore, where access distance and walking time significantly influence mode choice (Ann et al., 2019; Manoj et al., 2015). However, the present study extends these findings by demonstrating that in a tier-2 city like Bhopal, accessibility-related factors outweigh both infrastructure and service-related attributes. This suggests a context-specific behavioral pattern in which commuters prioritize time efficiency and ease of access over other dimensions of transport quality.

The comparatively lower but still significant effects of Service Experience ($\beta = 0.526$) and Infrastructure Quality ($\beta = 0.439$) indicate that while these factors contribute to public transport preference, they function more as supporting determinants rather than primary drivers. This finding contrasts with evidence from developed urban contexts, where infrastructure quality and service standards often play a dominant role (Cheng et al., 2022; Jones et al., 2017). In Bhopal, this pattern may reflect an adaptive behavior among commuters, who have adjusted to infrastructural limitations and prioritize minimizing travel effort and time.

From a Transit-Oriented Development (TOD) perspective, the results reinforce the importance of integrating land use and transport planning to enhance accessibility. The dominance of Ease and Efficiency suggests that improving first- and last-mile connectivity through walkable environments, efficient feeder systems, and reduced transfer times can significantly increase public transport adoption. This highlights the need for compact urban design, enhanced pedestrian infrastructure, and better integration of intermediate public transport modes such as e-rickshaws and shared mobility services.

The findings also emphasize the continued importance of Service Experience in shaping commuter perceptions. Factors such as reliability, comfort, and safety remain critical, particularly for vulnerable groups. While these factors may not be the strongest predictors, they are essential for sustaining long-term public transport usage and ensuring user satisfaction. Similarly, Infrastructure Quality, though comparatively less influential, remains a foundational component of a functional transport system, supporting accessibility and enhancing overall travel experience.

The Importance–Performance Map Analysis (IPMA) further strengthens these insights by identifying accessibility-related indicators such as travel time, walkability, and ease of access as high-impact but moderate-performance areas, indicating substantial scope for targeted improvements. This reinforces the central conclusion that investments in accessibility will yield the highest returns in improving public transport preference.

The findings suggest that transport planning strategies should prioritize seamless integration between public transport and first- and last-mile modes such as walking, cycling, shared mobility, and feeder services. While infrastructure improvements remain important, commuters place greater value on travel convenience, accessibility, and service reliability. Therefore, investments should focus not only on expanding physical infrastructure but also on improving operational efficiency, passenger information systems, and multimodal integration to maximize public transport usage.

The study contributes to the growing body of research on sustainable urban mobility by demonstrating that in emerging cities, accessibility-driven planning is more critical than infrastructure-heavy or service-focused approaches alone. A balanced and integrated strategy that combines accessibility improvements, service quality enhancements, and infrastructure development is essential to achieve meaningful modal shift and sustainable transport outcomes.

Conclusion

This study demonstrates that first- and last-mile connectivity is a critical determinant of public transport preference in Bhopal. Using Structural Equation Modeling (PLS-SEM), the study empirically examined the influence of Ease and Efficiency, Service Experience, and Infrastructure Quality on commuter behavior, providing a comprehensive understanding of accessibility-driven mobility patterns in a tier-2 Indian city.

The findings reveal that Ease and Efficiency is the most influential factor ($\beta = 0.602$), highlighting the importance of accessibility, reduced travel time, walkability, and seamless multimodal connectivity. Service Experience ($\beta = 0.526$) also plays a significant role, indicating that reliability, comfort, and safety are essential for sustaining user satisfaction and encouraging continued use of public transport. Infrastructure Quality ($\beta = 0.439$), while comparatively less influential, remains an critical supporting factor that enhances system usability and accessibility.

The study underscores that improving public transport usage requires more than infrastructure investment alone it demands an integrated approach that prioritizes accessibility, user experience, and system efficiency. The results suggest that targeted interventions aimed at improving first- and last-mile connectivity can significantly enhance public transport attractiveness and reduce reliance on private vehicles.

From a broader perspective, these findings contribute to sustainable urban mobility planning by emphasizing the need for people-centered transport systems that address the entire journey continuum from origin to destination. For cities like Bhopal, adopting such an integrated approach can play a transformative role in promoting equitable, efficient, and environmentally sustainable urban transport systems.

This study demonstrates that improving first- and last-mile connectivity requires a comprehensive approach that combines accessible infrastructure, efficient transport services, and positive commuter experiences. The proposed model provides empirical evidence supporting integrated urban transport planning in rapidly growing cities. The findings can assist policymakers, urban planners, and transport agencies in designing sustainable mobility strategies that enhance public transport attractiveness, reduce dependence on private vehicles, and contribute to environmentally sustainable urban development.

Limitations and Future Research

This study is limited to commuters in Bhopal and therefore may not fully represent travel behavior in other Indian cities with different socio-economic and transport characteristics. The analysis relies on cross-sectional perception-based survey data, which captures commuter preferences at a single point in time. Future research may employ longitudinal datasets, compare multiple cities, incorporate objective mobility indicators such as GPS-based travel data, and investigate the influence of emerging mobility services and policy interventions on first- and last-mile connectivity.

Declarations

Conflict of Interest

There is no conflict of interest among the authors.

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Author Contribution Declaration

KY led the research design, data collection, and analysis. KD supervised the study, provided critical revisions, and guided the preparation of the manuscript. SNS contributed to the development of the methodology and the interpretation of the results. All authors reviewed and approved the final version of the manuscript.

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