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Behavioural Friction in Urban Mobility: A Spatial–Psychological Analysis of Low Metro Ridership in Indian Cities- A Case Study of Ahmedabad Metro

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Abstract

Metro rail systems are increasingly promoted as sustainable solutions for managing congestion, reducing pollution, and improving urban mobility efficiency in Indian cities. Despite extensive public investment and technically advanced infrastructure, many newly operational metro systems continue to experience ridership levels that are significantly lower than initial projections. This persistent gap highlights the limitations of infrastructure-led planning approaches that overlook behavioural, spatial, and environmental dimensions of everyday travel.

This research examines low metro ridership in Indian cities through the concept of behavioural friction, defined as the cumulative spatial, psychological, climatic, and social resistance encountered by commuters during daily mobility. The study moves beyond traditional transport performance metrics by focusing on lived commuter experience, particularly during first- and last-mile access to metro stations. A mixed-method approach combining commuter perception surveys, spatial accessibility analysis, walkability audits, and qualitative behavioural assessment is adopted.

A Behavioural Friction Index (BFI) is developed to evaluate station-level resistance to metro usage by integrating walkability quality, climatic comfort, safety perception, last-mile reliability, and surrounding land-use activity. Findings indicate that extreme thermal stress, fragmented pedestrian infrastructure, safety concerns, unreliable last-mile services, and entrenched two- wheeler dependence significantly reduce the effective catchment area of metro stations. The paper concludes that metro performance in Indian cities depends less on engineering capacity and more on access comfort, behavioural acceptance, and spatial quality, advocating a shift toward behaviour-led, climate-responsive, and human-centric urban mobility planning.

Keywords: Behavioural friction, metro ridership, urban mobility, walkability, climate stress, Indian cities

1. Introduction

Indian cities are experiencing rapid demographic growth, spatial expansion, and economic transformation. These processes have resulted in escalating travel demand and increasing reliance on private motorised transport, particularly two-wheelers. Rising motorisation has contributed to traffic congestion, air pollution, road safety concerns, and declining urban liveability. In response, metro rail systems have been introduced as high-capacity, energy-efficient, and environmentally sustainable transport solutions capable of restructuring urban mobility patterns.

Over the past two decades, metro systems have been implemented in more than twenty Indian cities. While older networks such as the Delhi Metro have achieved substantial ridership and behavioural acceptance, many newer systems continue to experience underutilisation. Cities such as Ahmedabad, Jaipur, Nagpur, Kochi, and Lucknow present a recurring pattern: modern metro infrastructure exists, yet daily ridership remains significantly below projected levels.

Conventional explanations for low metro usage often focus on incomplete networks, insufficient feeder services, or low population density around stations. Although these factors are relevant, they fail to fully explain why commuters continue to prefer private vehicles even when metro services are affordable, reliable, and geographically accessible. This discrepancy suggests that deeper behavioural, spatial, and experiential factors shape mobility decisions.

Urban travel choices are rarely driven solely by travel time and cost considerations. Comfort, habit, safety perception, perceived effort, and environmental exposure strongly influence everyday decisions. In Indian cities— particularly those experiencing extreme climatic conditions—the effort required to reach a metro station often outweighs the perceived benefits of metro travel. Consequently, the access journey becomes a critical determinant of ridership.

This paper introduces the concept of behavioural friction to explain low metro adoption in Indian cities. By examining the spatial and psychological barriers embedded in daily mobility environments, the study seeks to provide a more nuanced understanding of metro underperformance.

2. Conceptual Framework of Behavioural Friction

Behavioural friction refers to the cumulative resistance experienced by commuters while interacting with a transport system. Unlike conventional measures of accessibility that focus primarily on distance or travel time, behavioural friction captures a broader set of deterrents that operate simultaneously and often subconsciously.

In the context of metro systems, behavioural friction manifests through multiple interrelated dimensions. Spatial friction arises from discontinuous footpaths, unsafe pedestrian crossings, long blocks, and poorly designed station access points. Climatic friction results from heat stress, lack of shade, high surface temperatures, and exposure to air pollution. Psychological friction includes uncertainty, perceived complexity, discomfort with crowds, and the
cognitive effort required to navigate unfamiliar systems.

Social friction encompasses safety concerns, particularly among women, elderly users, and other vulnerable groups, as well as cultural norms that favour private vehicle use. Habitual friction reflects long-established dependence on two-wheelers and cars, which discourages experimentation with alternative modes of transport. These dimensions do not operate independently; instead, they accumulate along the journey, progressively increasing resistance to metro usage.

Even when individual barriers appear minor, their combined effect can significantly discourage adoption. The concept of behavioural friction therefore provides a comprehensive lens through which to understand why metro systems with adequate engineering performance may still struggle to attract users.

3. Review of Literature

Research on urban mobility increasingly challenges the assumption that commuters make purely rational decisions based on travel time and cost. Behavioural studies demonstrate that habitual behaviour, comfort, perceived safety, and emotional responses frequently outweigh objective efficiency. Modes that require additional physical or cognitive effort—such as walking through uncomfortable or unsafe environments—are often avoided.

Walkability and station accessibility studies consistently show that access quality is a critical predictor of metro ridership. Poor pedestrian infrastructure, encroachments, missing links, and unsafe crossings reduce the effective catchment area of stations. In many Indian cities, footpaths are fragmented or absent, forcing pedestrians to share space with fast-moving vehicular traffic.

Climatic research highlights the strong influence of thermal comfort on walking behaviour. In hot environments, walking tolerance declines sharply as temperatures exceed comfort thresholds.
Lack of shade, tree cover, and
microclimatic mitigation discourages walking even over short distances, directly affecting metro accessibility.

Comparative analyses of Indian metro systems reveal that ridership success depends on more than network length or train frequency. Systems that integrate pedestrian comfort, structured feeder services, safety measures, and supportive land-use planning perform significantly better than those that prioritise corridor construction alone.

4. Research Methodology

A mixed-method research design was adopted to capture both quantitative and qualitative
dimensions of metro usage in Indian cities. Primary data collection included structured commuter perception surveys, informal interviews near selected metro stations, and systematic field observations of pedestrian routes and last-mile activity.

Secondary data sources included metro ridership statistics, census information, land-use data, and satellite imagery. Spatial analysis was conducted using buffer-based techniques, typically 500 m and 1000 m radii around metro stations, to examine walkability, access continuity, and environmental conditions.

Walkability audits assessed footpath quality, crossing safety, shade availability, and levels of encroachment. To synthesise findings, a Behavioural Friction Index (BFI) was formulated by integrating walkability quality, climatic comfort, safety perception, last-mile reliability, and land- use activity intensity.

4.1 Case Study Context: Ahmedabad Metro

The city of Ahmedabad represents a unique urban mobility context within India, characterised by rapid spatial expansion, strong two-wheeler dependency, and extreme climatic conditions. As one of western India's major economic and cultural centres, Ahmedabad has experienced sustained population growth and outward urban sprawl over the past two decades.

The Ahmedabad Metro was conceptualised to address rising congestion, improve regional connectivity, and promote sustainable urban transport. Despite modern rolling stock, elevated corridors, and affordable fares, the metro has struggled to attract consistent daily ridership comparable to initial projections.

Ahmedabad's urban form plays a significant role in shaping metro accessibility. Wide arterial roads, large institutional plots, industrial areas, and low-density residential zones dominate several metro corridors. These characteristics increase walking distances and reduce pedestrian comfort around stations. Furthermore, the city's strong two-wheeler culture—supported by wide roads and ample parking—reinforces habitual preference for private modes.

Climatically, Ahmedabad experiences prolonged periods This condition significantly affects walking behaviour, particularly during daytime hours. The absence of shaded pedestrian infrastructure around many metro stations further amplifies thermal discomfort, reducing the effective station catchment area.

This combination of urban form, climate, and travel behaviour makes Ahmedabad a relevant and representative case for examining behavioural friction in Indian metro systems.

5. Findings and Analysis

Analysis across multiple Indian cities reveals consistent patterns in station-area environments. Pedestrian networks are frequently fragmented, with discontinuous footpaths, encroachments, and unsafe crossings. Such conditions increase perceived risk and physical discomfort, discouraging walking to metro stations.

Climatic stress emerged as one of the strongest deterrents to metro usage. In cities experiencing extreme summer temperatures, lack of shade and high surface temperatures significantly reduce walking tolerance. As a result, effective station catchments shrink during hotter months, limiting metro accessibility.

Last-mile connectivity remains dominated by informal and unregulated transport modes. Unpredictable fares, waiting times, and service quality increase cognitive effort and uncertainty, discouraging habitual metro use. Behavioural analysis further indicates strong habitual reliance on two-wheelers, reinforced by perceptions of convenience, control, and social acceptability.

5.2 Behavioural Friction Characteristics in Ahmedabad Metro

Field observations and survey responses around Ahmedabad Metro stations reveal a consistent pattern of high behavioural friction during first- and last-mile access. Pedestrian infrastructure around several stations is fragmented, with discontinuous footpaths, insufficient crossings, and frequent encroachments by parking and informal activities. These conditions force commuters to walk on carriageways, increasing perceived risk and discomfort.

Thermal stress emerges as a dominant deterrent in Ahmedabad. Due to the city's hot semi-arid climate, walking even short distances becomes physically taxing during much of the year.

Stations located along wide, exposed roads without tree cover or shading experience particularly low pedestrian activity. As a result, the effective walking catchment of many stations is significantly lower than the conventional 500 m planning standard.

Last-mile connectivity further contributes to behavioural friction. While auto-rickshaws and e- rickshaws are available near stations, services are largely informal and fare negotiation is common. This uncertainty increases cognitive effort and discourages routine metro usage, especially among women, elderly commuters, and first-time users.

Survey responses indicate that many commuters perceive the metro as suitable for occasional trips but inconvenient for daily travel. This perception reflects accumulated behavioural friction rather than dissatisfaction with metro services themselves.

6. Ahmedabad Metro: Station-Level Behavioural Friction Index Interpretation

Applying the Behavioural Friction Index to selected Ahmedabad Metro stations highlights substantial variation in access quality across the network. Stations located near mixed-use areas with active street frontage exhibit comparatively lower behavioural friction due to higher pedestrian presence and perceived safety. However, a majority of stations located along arterial corridors and low-activity zones register high BFI scores.

High BFI values in Ahmedabad are primarily driven by climatic discomfort and walkability constraints rather than safety inside stations. This finding suggests that improving train operations alone will not significantly enhance ridership unless station-area environments are redesigned to reduce access-related resistance.

The BFI framework demonstrates practical value for Ahmedabad Metro by enabling planners to identify priority intervention zones. Instead of uniform network-wide improvements, targeted station-area strategies—such as shaded walkways, pedestrian crossings, and organised last-mile services—can deliver more effective ridership outcomes.

Factor	**Ahmedabad Context**	**Impact on Ridership**
Walkability	Discontinuous footpaths, wide roads	High
Climate	Extreme summer heat, low shade	Very High

Factor	**Ahmedabad Context**	**Impact on Ridership**
Last-mile access	Informal, unregulated	High
Land use	Low activity near stations	Moderate
Travel culture	Strong two-wheeler dependency	High

7. Discussion

The findings demonstrate that low metro ridership in Indian cities is primarily driven by access- related discomfort rather than operational deficiencies. Behavioural friction accumulates across multiple stages of the journey, making metro travel appear inconvenient relative to private vehicles. Improving train frequency or extending corridors alone is unlikely to significantly increase ridership unless access environments are addressed. Comfort during access emerges as more influential than comfort during the metro journey itself, challenging prevailing infrastructure-centric planning paradigms.

7.1 Integrating Behavioural Friction into Urban Transport Planning

Current transport planning practices in Indian cities remain heavily infrastructure-oriented, with limited emphasis on commuter experience. Behavioural friction provides a useful framework for bridging this gap by translating lived experience into measurable planning parameters.

Incorporating behavioural friction into planning requires a shift from corridor-based evaluation to station-area and access-based assessment. Metrics such as walking comfort, thermal exposure, perceived safety, and last-mile reliability should be systematically evaluated alongside traditional indicators like ridership and service frequency.

Planning agencies can use tools such as the Behavioural Friction Index to identify high- resistance zones and prioritise targeted interventions. Rather than uniform city-wide solutions, this approach supports context-sensitive design responses tailored to local conditions.

Institutional coordination between transport authorities, municipal bodies, and urban development agencies is essential for implementing such an approach. Behaviour-led planning also requires long-term commitment, as changes in commuter behaviour occur gradually through consistent improvement in everyday travel environments.

8. Planning and Policy Implications

Reducing behavioural friction requires a shift toward people-centric and climate-responsive planning approaches. Priority interventions include continuous shaded pedestrian infrastructure within station influence zones, climate-responsive street design, regulated and reliable last-mile services, enhanced lighting and surveillance, and integration of land-use planning with metro accessibility.

Behavioural change should be supported through awareness campaigns, incentives, and institutional coordination across transport agencies and urban local bodies.

9. Conclusion

This research establishes that behavioural friction plays a decisive role in shaping metro ridership outcomes in Indian cities. Low ridership reflects uncomfortable, uncertain, and psychologically discouraging access environments rather than failures of engineering design. Addressing behavioural, spatial, and climatic barriers through human-centric planning is essential for achieving sustainable metro adoption across Indian cities.

10. Limitations and Scope for Future Research

While this study provides Valuable insights into the role of behavioural friction in shaping metro ridership, certain limitations must be acknowledged. The research relies on perception-based surveys and observational analysis, which may be influenced by subjective biases. Climatic impacts were assessed qualitatively rather than through detailed microclimate modelling.

Future research can expand this framework by incorporating high-resolution thermal mapping, GPS-based travel behaviour data, and longitudinal studies to track behavioural change over time. Comparative analysis across a larger number of cities and metro systems would further strengthen the applicability of the Behavioural Friction Index.

Additionally, future studies may explore the role of digital tools, fare integration, and smart mobility services in reducing psychological and habitual friction. Such extensions would contribute to more comprehensive and actionable urban mobility planning strategies.

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