Analysing Urban Development Patterns: A Spatio-Temporal Analysis and Predictive Scenarios around Major Railway Stations/Terminals

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DOI: 10.48494/REALCORP2026.5215

1 ABSTRACT

Rapid urbanisation trends in Southeast Asia are primarily influenced by mass transit systems, however the influence of railways on land use dynamics in India remains unique from global patterns. Unlike contemporary Light Rail Transit (LRT) or Metro systems where Transit-Oriented Development (TOD) is often a planned and post-construction intervention, Indian railway nodes typically predate the very concept of TOD, implying urban areas have integrated organically following railway infrastructure rather than being retrofitted. The study investigates this Railway-induced spatial restructuring in the Indian context, specifically the Southern West Bengal region, a rapidly densifying polycentric system, with the primary objective of determining whether railway proximity naturally fosters efficient development or induces chaotic ribbon sprawl. The methodology incorporates a multi-scalar geospatial framework by employing a 25-year temporal gradient (2000-2025) to analyse the relationship between horizontal densification and vertical building density. Data from remote sensing (Landsat 7/8) was utilised to compute fragmentation metrics using FRAGSTATS to quantify horizontal sprawl, while Google Earth Engine (Open Buildings 2.5D) was utilised to derive the average building height. These morphological outputs were further correlated with Space Syntax Integration values to assess functional connectivity. The analysis established four distinct station typologies regarding the urban form efficiency, namely saturated node, stagnant core, benchmark model and developing node. Moving beyond standard computer simulations, the study predicts future growth by analysing these distinct evolutionary categories and utilising passenger footfall data to forecast passenger and train load transfer. The research concludes that without policy intervention, rapid expansion of these urban areas will overburden infrastructure, highlighting the need for specific policy formulation to mitigate these externalities before they become irreversible.

Keywords: Railway-induced Urban Growth, Transit-oriented Development, Spatial Metrics, Urban Sprawl, Urban Morphology

2 INTRODUCTION

2.1 Background and Research Motivation

The relationship between transport infrastructure and urban form is one of the defining characteristics of the 21st century Asian metropolis (Navalkar et al. 2023). A new global paradigm has emerged focusing on smart, sustainable, and inclusive development, yet the practical application of these concepts in Southeast Asia often faces unique challenges. In India, rapid urbanisation is not merely a function of population growth but is intrinsically linked to mass transit availability (Sekar and Gangopadhyay 2017). Southern West Bengal serves as a paradigmatic case of this phenomenon. As a major rail corridor and economic gateway for Eastern India, the region is witnessing a rapid emergence of peri-urban growth clusters centred around the railway stations. Unlike the planned Transit-Oriented Development (TOD) seen in other cities like Singapore or Hong Kong where density is not organic, the urban growth around Southern West Bengal is organic, historical and mostly chaotic (Mandal et al. 2020).

The motivation for this research arises from a critical observation of the surroundings where the Government of India (through the Ministry of Railways) has allocated significant capital of approximately INR 14,000 crores to upgrade railway infrastructure in West Bengal to support micro-enterprises and regional movement. But investment alone does not guarantee urban transformation. With the absence of evidence-based urban planning, capital investment runs the risk of accelerating “ribbon sprawl” rather than fostering efficient and compact transit nodes. This has led to discussions that investment numbers alone are insufficient, and closer attention must be paid to the tangible morphological changes they trigger in cities (Ramachandra et al., 2014).

2.2 Problem Statement

The central planning challenge facing the Kolkata Metropolitan Area (KMA) and its hinterlands is the balancing act between infrastructure expansion and sustainable land management. Current frameworks of urban planning often lack the granular data required to understand how railway stations specifically influence the vertical and horizontal dimensions of growth. There is a clear methodological gap, as most existing studies focus only on 2D land-use patterns and overlook the vertical intensity of development (such as building heights), which is essential for understanding densification (Karmarkar, Jana, and Velaga 2024). Along with this, a significant contextual gap persists because international TOD frameworks are seldom tailored to the complex realities of Indian railway towns, where informal settlements and historically evolved urban layouts resist easy incorporation into conventional planning models (Mehra and Vardhan 2025). In these regions, the presence of informal settlements and historical urban forms resists the ‘clean’ geometry of conventional planning models. While this study establishes a vital baseline for these towns, it also understands that it lacks the socio-economic depth needed to fully capture these physical changes that involve the lives of the people inhabiting them. Consequently, the primary research inquiry stands at “How is railway expansion reshaping patterns of urban development in this dynamic region?” and “Do railway nodes encourage compact, efficient agglomerations, or do they contribute to more fragmented and dispersed urban growth?”

2.3 Aim and Objectives

The primary aim of this study is to investigate the phenomenon of transit-induced spatial restructuring along the Southern West Bengal rail corridor, specifically determining whether railway proximity fosters efficient densification or induces chaotic sprawl. To achieve this, the research examines the spatio-temporal evolution of urban forms around four distinct railway station contexts – Howrah, Shalimar, Santragachi and Uluberia – over a 25-year period (2000 to 2025). This involves a multi-scalar analysis that correlates horizontal fragmentation metrics with vertical building density to establish distinct evolutionary typologies of railway-induced growth. Building upon this morphological classification, the study further seeks to forecast future development trajectories for the active growth nodes by synthesising historical urbanisation trends with passenger ridership shifts.

3 LITERATURE REVIEW

The relationship between rail corridors and urban form has been extensively documented, establishing the fact that mass transit systems are acting as an active agent for densification and spatial restructuring. One of the studies monitored urban growth in Howrah (Mandal et al. 2020). The study used spatial metrics to reveal a distinct pattern of “clumping” in the core city, which is contrasted against rapid outlying growth and high fragmentation at the periphery. This also aligns with the findings of Sekar and Gangopadhyay (Sekar and Gangopadhyay 2017), who analysed land use changes around suburban rail in Chennai using a “concentration index”. This index confirms densification has shifted decisively towards railway corridors, thereby altering the city’s macro-spatial form. All these studies underscore that while rail proximity acts as a catalyst for growth, the resulting urban morphology varies significantly between compact and fragmented based on local constraints.

However, a significant methodological limitation in current research is the heavy reliance on two-dimensional Land Use Land Cover (LULC) analysis, ignoring the vertical intensity that defines the principle of modern urbanisation. While LULC effectively maps the horizontal expansion, it fails to capture the volumetric capacity of transit nodes. Recent work by Karmarkar (Karmarkar et al. 2024) attempts to bridge this gap by modelling “Volumetric Growth” (2D+3D) around new transit stations. Their work demonstrated that high-rise development correlates strongly with station proximity, yet such studies majorly rely on coarse building height classes or limited field data. There remains a gap of more precise and continuous building height assessments to accurately correlate horizontal with vertical densification, which is addressed by this study by using open-source 2.5D datasets.

While Transit-Oriented Development (TOD) frameworks are well established globally, they are rarely adapted to the specific spatial conditions of historical Indian towns. The assessments often utilise the index-based approaches involving density, diversity and accessibility, as demonstrated in a study by Uddin (Uddin et al. 2023) for the Dhaka MRT and Lin (Lin et al. 2023) for Taipei. However, these frameworks are applied to planned systems where the "railway station area" is a designed zone. The study by Mehra and Vardhan (Mehra and Vardhan 2025) emphasises the necessity of defining TOD typologies specific to the corridor context rather than applying generic metrics, arguing that design and density are the most influential factors in Indian suburban rail corridors. In the absence of such contextualisation, standard TOD principles may fail to address the organic, informal and historical nature of urban growth in the context.

Finally, the approach to forecasting future urban growth around these railway nodes requires re-evaluation. Current predictive models, such as those employing Cellular Automata (CA) and Markov chains by Fu (Fu et al. 2024) or SLEUTH models, have successfully predicted land use changes with high accuracy. However, these mathematical simulations often consider very limited variables, which mostly fail to capture the "messy" socio-economic complexities and historical contexts of Indian railway towns. Consequently, this study proposes shifting from purely mathematical simulations to identifying evolutionary typologies based on historical data and passenger footfall, which is a critical demand variable that is often absent in other research, to forecast future development scenarios more accurately.

4 STUDY AREA

The research focuses on the Southern West Bengal Rail corridor, specifically the South Eastern Railway corridor, which acts as the critical economic and trade gateway for Eastern India. This corridor was also selected for its strategic alignment with the urbanisation priorities and economic policies that were established by the Kolkata Metropolitan Development Authority (KMDA), which functions as a polycentric urban system where the selected railway stations act as anchor points for metropolitan area development. The spatial structure of this region is unique, urban growth is heavily constrained by the Hooghly River and existing infrastructure, forcing a linear north-south expansion pattern along the railway network. This geography of the region makes it an ideal laboratory for analysing "transit-induced spatial restructuring", as the railway line effectively dictates the spine of urban densification. To capture the diverse evolutionary stages of transit nodes, four specific railway stations were selected to represent a gradient of urban development maturity (Fig. 1).

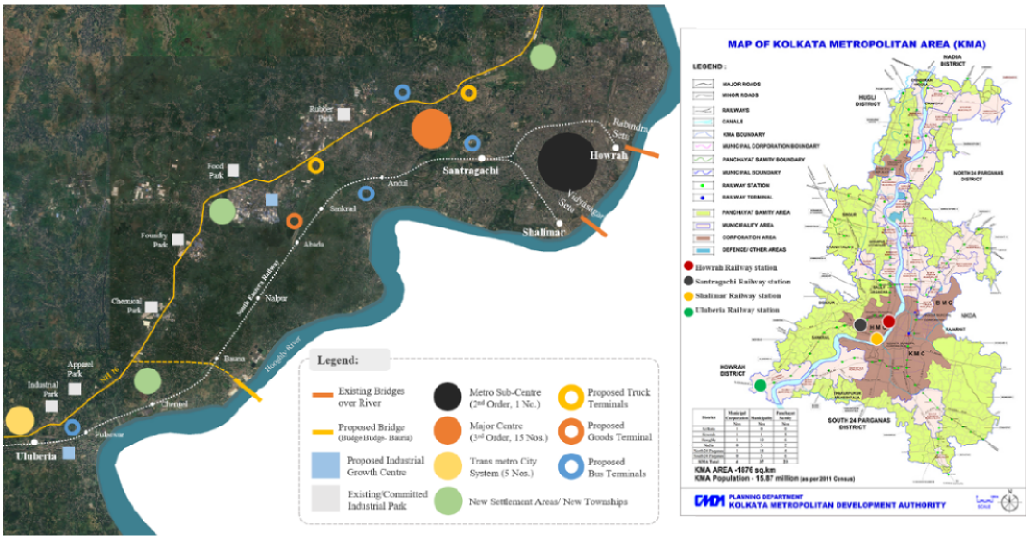


Fig. 1: Map of the Kolkata Metropolitan Area showing the strategic location of Howrah, Santragachi, Shalimar, and Uluberia Railway Stations along the South Eastern Railway Corridor (Source: Adapted from KMDA Comprehensive Mobility Plan, 2008)

- Howrah (The Historic Anchor): Howrah is selected as the primary baseline. It functions as the region's historic terminal and a designated "Metro Sub-Centre", which is providing a fully urbanised and spatially controlled case against which developing nodes can be compared. Currently it serves millions of commuters and also acts as the primary gateway to the Kolkata region .

- Shalimar (The Logistics Hub): Shalimar has a unique spatial dynamic of a specialised logistics and freight-orientated terminal located within the urban core, serving as the case for how heavy freight infrastructure and truck terminals influence immediate neighbourhood development which is distinct from purely passenger-centric hubs.
- Santragachi (The Dual-purpose Node): Santragachi has the strategic role of being a dual-purpose node i.e., functioning simultaneously as a high-volume suburban halt and a major express train terminal with Kona Expressway in close proximity with the railway stations, making it a prime location for analysing the integration of rail infrastructure with the National Highway (NH 16) and its potential as an emerging metropolitan sub-centre.
- Uluberia (The Peri-Urban Periphery): Uluberia represents the metropolitan as well as the corridor's developing edge. This station is designated as a "Trans Metro City" node that acts as a vital intermodal link to the Haldia industrial belt and is also the starting point of the upcoming Varanasi-Ranchi-Kolkata greenfield expressway project, providing a crucial case study for analysing early-stage urbanisation and land-use transformation at the metropolitan fringe.

5 METHODOLOGY

This study adopts an integrated urban development framework that synthesises multi-scalar geospatial analysis with morphological metrics to assess the impact of rail infrastructure on urban form. The methodological approach is subdivided into three distinct phases: urban development analysis, comparative analysis and categorisation, and policy recommendations (Fig. 2).

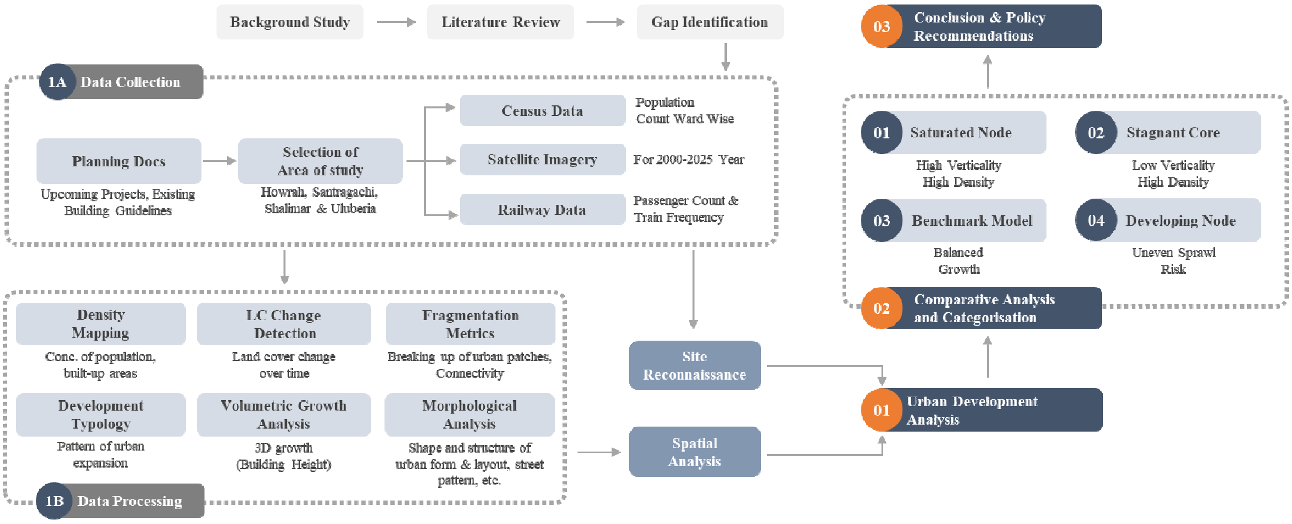


Fig. 2: Methodological Framework Flowchart. (Source: Author)

5.1 Data Collection

For a long-term analysis on transit-induced spatial restructuring, the study integrates diverse secondary sources to create a harmonised dataset spanning 25 years. Land cover changes were monitored using Landsat 7 and 8 satellite imagery (30M resolution) through Google Earth Engine (GEE) for the years 2000 to 2025. To address the critical gap in vertical densification analysis, which is often missed in traditional sprawl studies, building height data was extracted using the "Open Buildings 2.5D" dataset , helping in the calculation of volumetric metrics within the station catchment area. These morphological datasets were complemented by socio-economic layers. These include ward-wise population counts from the Census of India (2001 & 2011) and, crucially, the station-specific passenger footfall and train frequency data sourced from the South Eastern Railway division under Indian Railways. This integration allows for a direct correlation between physical urban form and transit demand.

5.2 Spatial and Morphological Analysis

To quantify the transit-induced spatial restructuring, the study employed a multi-scale buffer analysis. Using the geographic coordinates of each railway station as the geometric centroid, three concentric zones (with radii of 1 km, 3 km and 5 km) were established to capture the influence of railway nodes. The 1 km buffer represents the immediate pedestrian core (TOD Zone), which assesses the walkability of a typical 10–15-minute walking radius. The 3 km buffer captures the intermediate catchment, which is served by non-motorised transport or para-transit feeds. The 5 km buffer shows the peri-urban interface, which analyses the extent to which the station's urbanisation pressure bleeds into the regional rural hinterland. Within these zones, three primary metrics were calculated.

5.2.1 Fragmentation Analysis (Horizontal Growth)

It measures the urban sprawl of the area. Patch Density (PD) was calculated using FRAGSTATS software as used in previous research by (Mandal et al. 2020; Ramachandra et al. 2014). Patch density is defined as the number of separate built-up patches per unit area. It serves as a robust method for classifying fragmentation versus consolidation. As observed in previous studies, high fragmentation at the periphery contrasts with "clumping" in the core. A greater patch density value signifies that the development is spread out, while a lower value indicates successful urbanisation and horizontal consolidation.

5.2.2 Volumetric Analysis

It fills the gap in traditional studies of urban sprawl. The research correlated Average Building Height (Havg) with the Building Density Index (BDI). This volumetric approach draws on methodologies for predicting the growth around the studied stations, which solidifies the fact that building height is a critical indicator of intensity. The Havg was derived using the Google Earth Engine's (GEE) Open Building 2.5D dataset. Comparing the Havg against the percentage of land cover by buildings (BDI), the analysis distinguishes between various categories of development pattern, thus determining the true 3D capacity of the urban core.

5.2.3 Space Syntax (Network Connectivity):

To evaluate the functional efficiency of the road network, Space Syntax Integration values were calculated. These metrics measure how accessible the street in the various buffer regions is, which serves as the unit for measuring walkability and spatial quality. High integration values indicate a movement economy that supports commercial vitality, while low values suggest isolation. This variable helps to identify whether the station node is effectively integrated or functionally disconnected from its regional hinterland.

5.3 Typology Identification and Predictive Scenarios

The final phase of the framework synthesises the quantitative metrics from section 5.2 to establish a qualitative classification of the railway nodes. These classifications form the basis for forecasting future urban growth (Fig. 2).

5.3.1 Station Typology Framework

A comparative typology matrix was established to measure the urban efficiency of each node. The various metrics used were fragmentation, verticality and connectivity. The first category was the "Saturated" node, which is defined by extreme vertical intensity (high Havg) combined with high spatial congestion, this also represents that a node has reached its physical capacity limits. In contrast, the "Stagnant" node is characterised by high horizontal density (high BDI) but has remarkably low vertical growth (low Havg). This indicates a failure to utilise its central location due to poor connectivity or infrastructure bottlenecks. The third category, the "Benchmark Model", represents the ideal Transit-Oriented Development (TOD) outcome. It is also defined by high horizontal consolidation (low PD) paired with sustained vertical growth, highlighting efficiently managed density. Lastly, low vertical density and moderate horizontal saturation indicate the "Emerging node". This designation represents an early-stage node containing large areas of undeveloped land and significant untapped potential for future densification.

6 RESULTS AND DISCUSSION

6.1 Spatio-Temporal Dynamics: Horizontal Fragmentation vs. Consolidation

The temporal analysis of Patch Density (PD) from 2000 to 2025 reveals two divergent urban growth trajectories along the corridor (Fig. 3). In the mature nodes of Howrah and Santragachi, the PD metric demonstrates a distinct consolidation effect. For Howrah, the PD has remained relatively stable over the last decade, implying that the urban fabric is saturated and there are no significant spaces left to fill. This results in a contiguous and congested built-up area. Similarly, Santragachi exhibits a decreasing PD trend despite rapid development. This morphological behaviour, where the number of patches decreases while the total built-up area increases, confirms the successful consolidation of the catchment area. It also suggests that new developments are merging with existing clusters rather than isolated development, proving Santragachi's status as a potentially efficient transit node. In contrast to the previous observations, Shalimar exhibits a volatile spike in PD within the 3 km and 5 km buffers. The analysis shows high fragmentation, though the urban footprint is expanding. The quick growth of isolated industrial and residential areas at the periphery shows "ribbon sprawl" caused by speculative land conversion instead of planned transit-oriented densification. This unusual difference in spatial metrics highlights that while rail corridors drive growth, they don't guarantee morphological efficiency without careful planning interventions. Uluberia, on the other hand shows consolidation with PD decreasing gradually with minor spikes in between.

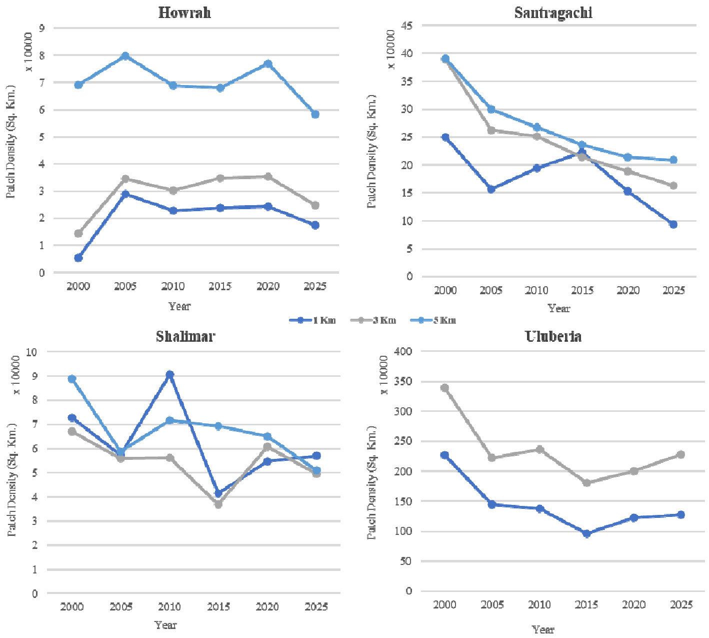


Fig. 3: Temporal variation of Patch Density (Sq.Km.) for Howrah, Santragachi, Shalimar and Uluberia across 1 km, 3 km and 5 km buffers (2000-2025) illustrating the contrast between consolidation (Howrah & Santragachi) and fragmentation (Uluberia). (Source: Author)

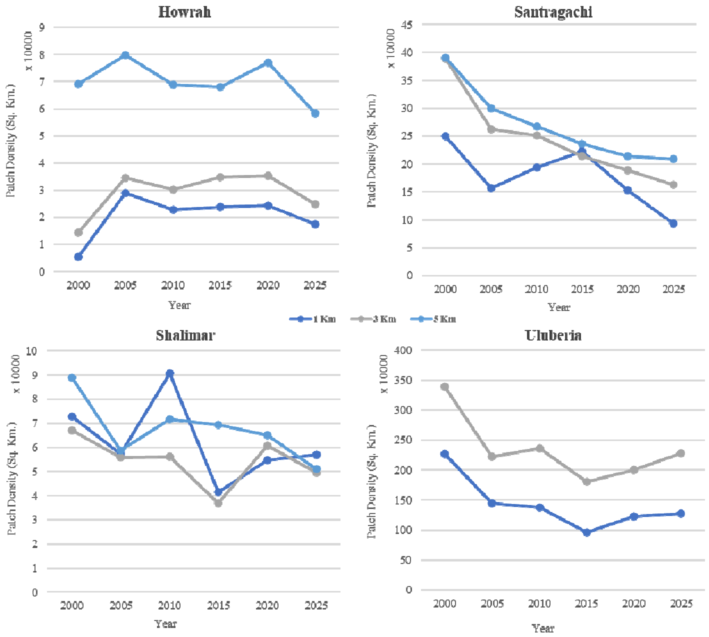


Fig. 4: Spatio-temporal map showing the population density variations for Howrah, Santragachi, Shalimar and Uluberia (2001 & 2011 years), highlighting the demographic shift from the core to the periphery. (Source: Census of India, 2001 & 2011)

6.2 Population Density Gradient and Demographic Shift

The morphological trend is replicated by the demographic pressure on the station areas (Fig. 4). Analysis of ward-wise population density (2001-2011) reveals a clear core-periphery gradient. Howrah exhibits a hyper-dense demographic profile that has stabilised over the last decade, implying that the area has reached its “Carrying capacity”, where further population growth is physically constrained by the lack of developable land.

Santragachi and Uluberia demonstrate a sharp growth in population density, signifying a demographic shift where the functional load is moving away from the saturated core into these peri-urban pockets. This rising density perfectly relates to the Patch Density spike observed in section 6.1, confirming that these nodes are the new active fronts of urbanisation and require immediate infrastructure augmentation to prevent the formation of high-density slums.

6.3 Volumetric Analysis

By relating average building height (Havg) with horizontal saturation (BDI), the study identifies the physical efficiency of each station area (Fig. 5). Combined with saturated horizontal density, Howrah records the highest Havg in the studied area. This reinforces the fact that the node has shifted from horizontal expansion to vertical densification. However, the extreme BDI value suggests that this vertical growth is a reaction to land scarcity rather than a planned outcome. A critical finding is the performance of Shalimar. Despite being located within the high-value urban core and comparable in location to Howrah, it exhibits a (low Havg, high BDI) relation. The data shows that while the ground plane is saturated with logistics and low-rise structures, vertical growth is significantly suppressed compared to its neighbour Howrah. This gap defines the “Stagnant Core” typology i.e., a node where conflicting land uses (freight vs. passenger) have artificially capped development potential. The steady rise in Havg parallels its horizontal consolidation, implying that infrastructure upgrades are successfully inducing real estate investment. In contrast, Santragachi shows a balanced morphology where moderate vertical growth goes with horizontal consolidation. This confirms its status as a sustainable benchmark. Meanwhile, Uluberia records the lowest average vertical height, confirming that its rapid expansion is strictly low-rise and sprawling in nature.

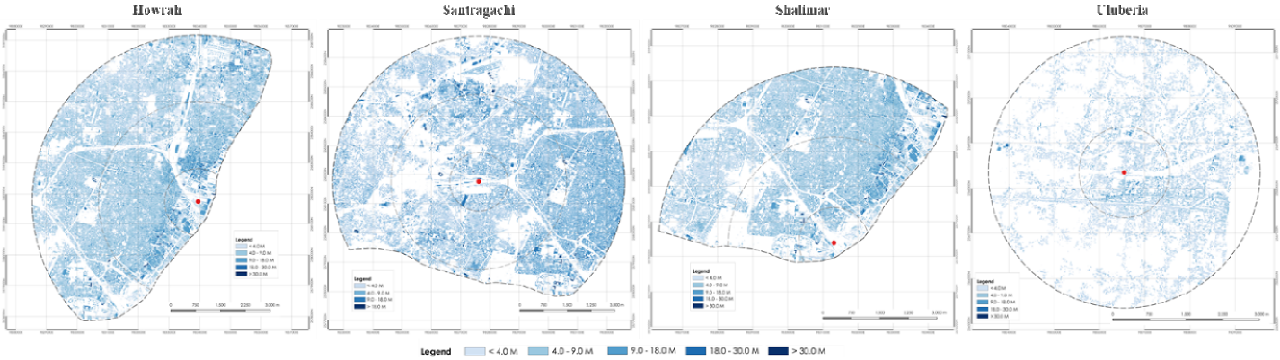


Fig. 5: Building Height Map (2023) visualising the vertical intensity (Havg) across the four station catchment areas (Source: GEE Open Building 2.5D dataset)

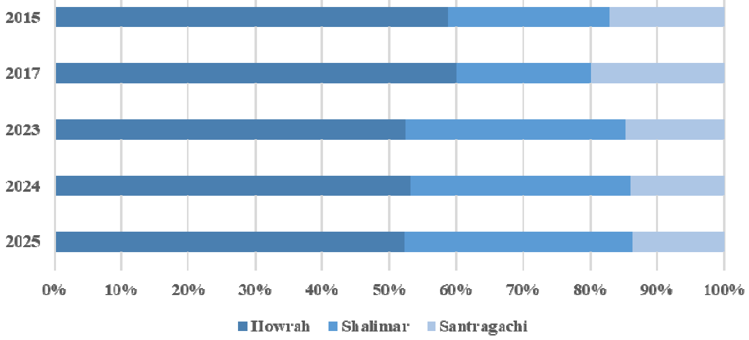


Fig. 6: Year-wise Number of Long-Distance Passenger Trains Originating from Howrah, Shalimar and Santragachi (2015-2025). (Source: South Eastern Railway Division)

6.4 Passenger Ridership Analysis

To support the evidence of urban sprawl, the study analysed station-level passenger footfall data along with express train frequency data for the 2015-2025 period. The data reveal a structural transformation in regional mobility plans, confirming the presence of an active functional load shift from the core to the periphery. In the fiscal year 2017-18, Howrah dominated the corridor with handling 75% of the total passenger volume, while Santragachi and Uluberia accounted for only 10% and 12%, respectively (Fig. 7). However, a sharp break is observed in 2018-19, where Howrah’s share dropped to 50%, while Santragachi and Uluberia surged to 21% and 24% respectively. This drastic redistribution shows that satellite nodes are absorbing the exploding suburban demand that the saturated Howrah terminal can no longer accommodate. This supports the fact that the ridership shift is a distinct operational decentralisation of express train services. Analysis of train frequency data highlights functional roles for each terminal (Fig. 6). Howrah remains the primary hub for Western routes (e.g., Mumbai, Tatanagar) handling a total of 68 long-distance trains. In contrast, Shalimar and Santragachi have been tagged as specialised terminals for southern routes (e.g., Chennai, Hyderabad). This strategic diversion of specific long-distance corridors to satellite terminals is a key driver of the patch density spike observed in their hinterlands. These stations evolve from simple halts to major origins/destinations, they trigger immediate and unplanned residential conversion in the surrounding areas to support the new transit economy.

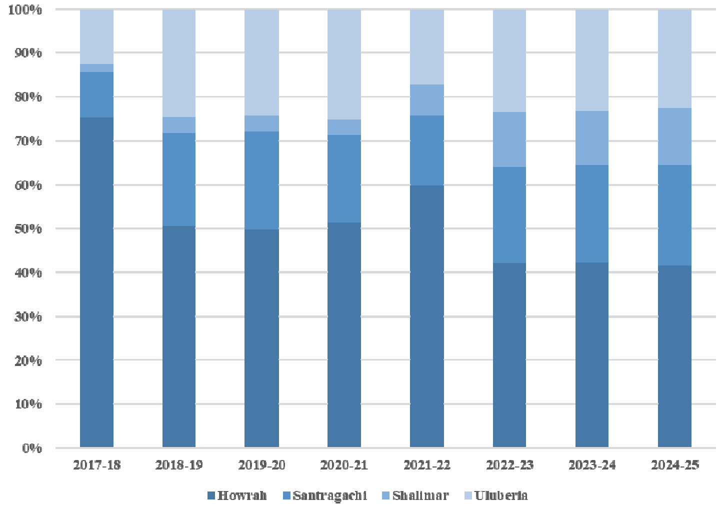


Fig. 7: Year-wise Distribution of Passenger Ridership Share across the Southern West Bengal Rail Corridor (2017-2025), illustrating the functional load shift from Howrah to satellite nodes. (Source: South Eastern Railway Division)

6.5 Operational Efficiency: Traffic Congestion Analysis

To validate the findings from earlier results, the study analysed real-time traffic congestion indices derived from peak-hour movement data (Fig. 8). This analysis serves as a proxy for the functional performance of the street network surrounding the stations. The traffic heatmap reveals that Howrah operates at a severe congestion level, with high indices during peak hours. This confirms the “Saturated Node” typology, where the street network has failed to cope with the vertical densification, resulting in a gridlock pattern that nullifies the benefit of transit proximity. In contrast to this, Santragachi records significantly low congestion indices even during peak windows. This validates its classification as the Benchmark Model. Despite its rising building density, the station area maintains operational fluidity, proving that its urban form (consolidated yet accessible) effectively manages the intermodal transfer of passengers without choking the local road network. This difference provides empirical evidence for the “load shift” strategy i.e., shifting terminal functions to Santragachi is not just a railway capacity decision, but it is an urban relief necessity. Shalimar exhibits a distinct restricted flow pattern. Being a freight terminal, the heavy logistics traffic clashes with passenger movement, effectively cutting the station off from its immediate neighbourhood. Meanwhile, in Uluberia, the outer peripheral roads remain free-flowing. The roads leading directly to the station record a high level of congestion. This specific bottleneck confirms that the unconnected local street network is struggling to cope with the sudden surge in daily commuters.

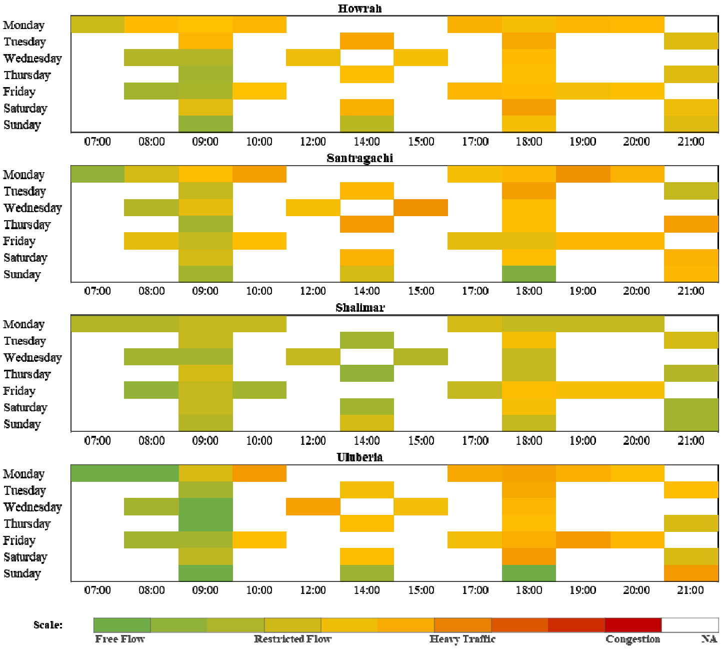


Fig. 8: Comparative Spatio-Temporal Traffic Heatmap (2025) showing congestion indices for peak and off-peak hours across all stations. (Source: Author)

6.6 Morphological Transitional Analysis

The temporal analysis of the spatial footprint across varying building height categories provides a critical indicator for the building transition potential of the station catchment areas (Fig. 9). By correlating the change in low-rise (G+1) versus low-mid-rise (G+4/G+5) built-up shares, the study deduces the probability of organic vertical conversion. In the core area, Howrah demonstrates a “saturation constraint” where the spatial share of the high-rise categories has effectively saturated over the last decade. This suggests the node has reached its morphological limit, and further densification is no longer a function of plot-level upgrading but requires a complex district level development. Conversely, Shalimar shows a stalled conversion trajectory. Despite recording a total built-up coverage comparable to the urban core, the dominance of the low-rise footprint paired with negligible growth in the mid-rise category confirms a deadlock. The functional dominance of freight logistics in this zone appears to suppress the land value aggregation required for residential verticality, effectively trapping the node in a low-rise equilibrium.

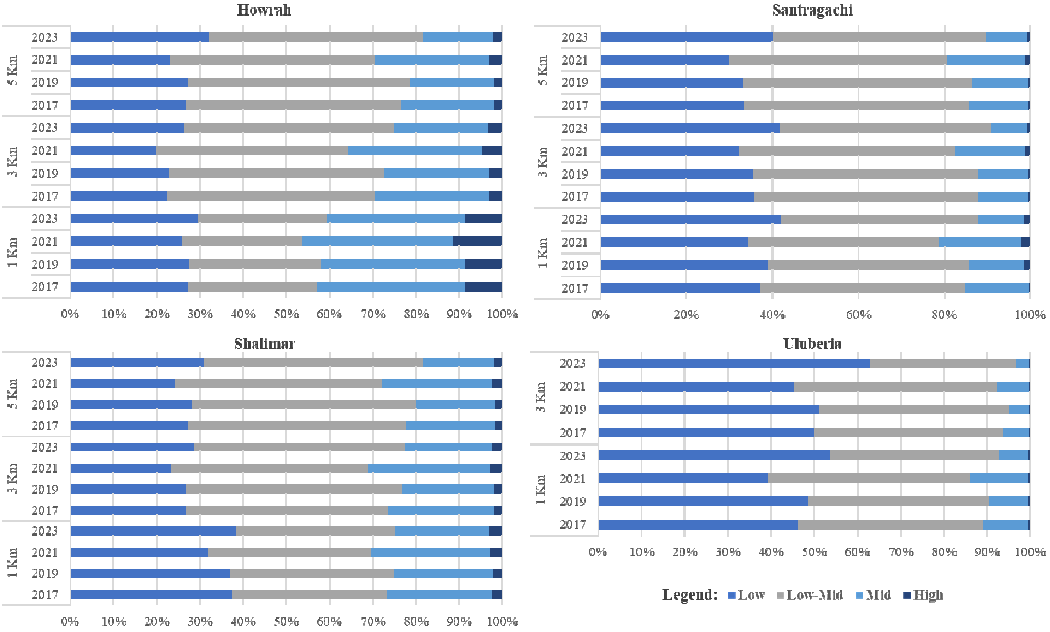
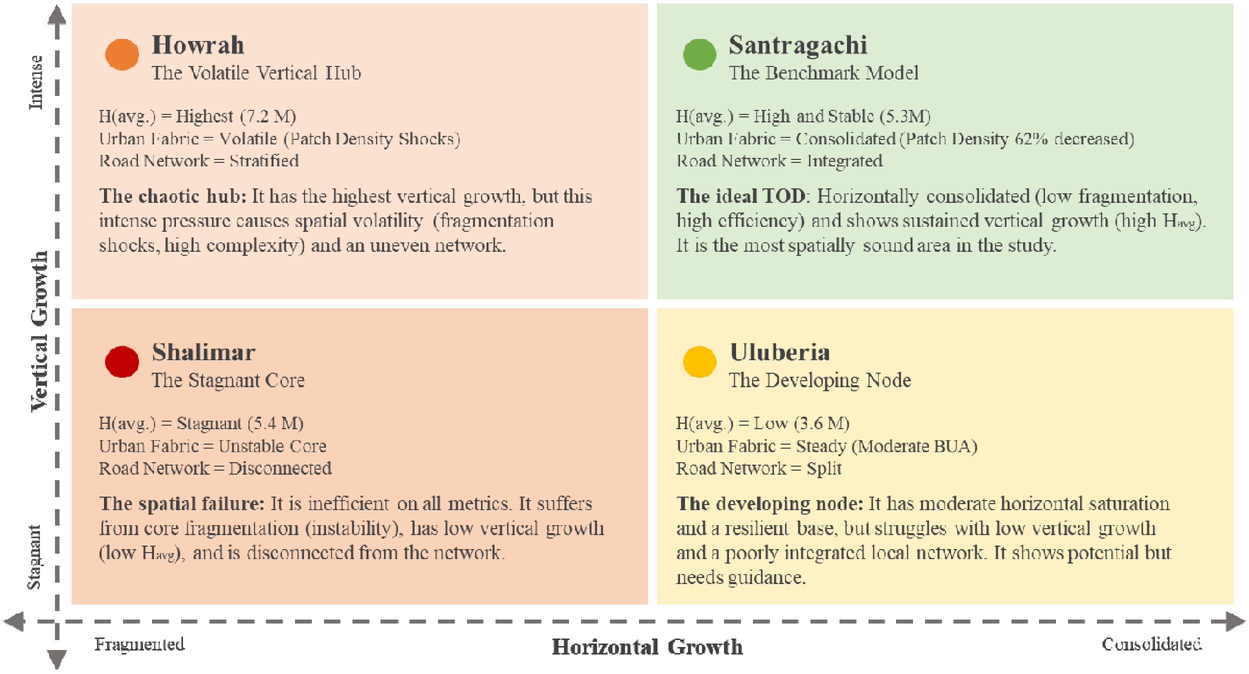


Fig. 9: Temporal Evolution of Building Height Composition (2017-2023) showing the share of low, low-mid, mid, and high-rise structures, indicating the probability of vertical transition. (Source: Google Open Buildings 2.5D Dataset)

Moving towards the periphery, Santragachi emerges as the corridor's active transition zone. The area records a steady increase in the spatial share of low-mid-rise structures relative to the low-rise baseline, which also confirms the high probability of conversion. This indicates that the market is actively responding to the "load shift" by using smaller and fragmented plots to accommodate higher-density housing. In direct contrast, Uluberia displays a probability of diluted conversion. The explosive expansion of the low-rise footprint in this zone far outpaces any transition to mid-rise structures. The data confirms that the market preference here remains skewed toward lateral "ribbon" expansion into the agricultural hinterland rather than vertical densification. As long as the volume of the low-rise construction continues to spike at the periphery, the economic pressure to vertically upgrade the town centre remains minimal. This diverts the growth outwards rather than upwards.

6.7 Comparative Analysis and Categorisation of Station Typologies

Integrating the horizontal, vertical, and other metrics allows for a categorisation of the corridor's urban evolution into four distinct typologies (Fig. 10). Howrah functions as the definitive "Type 1 – Saturated Node", where transit utility is maximised but liveability is compromised by the physical limits of the land. The convergence of peak building height, stabilised patch density and severe traffic congestion metrics indicates that the node has reached a saturation point. The future growth in this area can no longer be accommodated through expansion but is only possible through complex vertical redevelopment. In direct contrast, Shalimar is identified as a "Type 2 – Stagnant Core". Despite its proximity to the urban centre, the low verticality v/s high coverage correlation identifies it as an underperforming asset. The dominance of freight infrastructure and conflicting road networks has created a logistic trap which prevents the station area from transitioning into a modern and mixed-use passenger precinct despite its high land value. Santragachi is confirmed as the "Type 3 – Benchmark Model". The station area demonstrates a rare equilibrium. It absorbs increasing passenger loads and express train traffic while maintaining morphological consolidation (decreasing fragmentation) and low traffic congestion. This balance validates that transit-oriented growth can be sustainable if supported by adequate rail-road integration. Finally, Uluberia is identified as a "Type 4 – Developing Node", which is currently in a critical transition phase. The volatile spike in patch density combined with the massive surge in unreserved ridership indicates that it is rapidly evolving into a town. However, without immediate intervention, its current trajectory of ribbon sprawl suggests it will bypass the efficient "benchmark" stage and degrade directly into a chaotic and low-density agglomeration which mirrors the congestion issues of the core but without its infrastructure capacity.



Howrah
The Volatile Vertical Hub

H(avg.) = Highest (7.2 M)
Urban Fabric = Volatile (Patch Density Shocks)
Road Network = Stratified

The chaotic hub: It has the highest vertical growth, but this intense pressure causes spatial volatility (fragmentation shocks, high complexity) and an uneven network.

Santragachi
The Benchmark Model

H(avg.) = High and Stable (5.3M)
Urban Fabric = Consolidated (Patch Density 62% decreased)
Road Network = Integrated

The ideal TOD: Horizontally consolidated (low fragmentation, high efficiency) and shows sustained vertical growth (high H_{avg}). It is the most spatially sound area in the study.

Shalimar
The Stagnant Core

H(avg.) = Stagnant (5.4 M)
Urban Fabric = Unstable Core
Road Network = Disconnected

The spatial failure: It is inefficient on all metrics. It suffers from core fragmentation (instability), has low vertical growth (low H_{avg}), and is disconnected from the network.

Uluberia
The Developing Node

H(avg.) = Low (3.6 M)
Urban Fabric = Steady (Moderate BUA)
Road Network = Split

The developing node: It has moderate horizontal saturation and a resilient base, but struggles with low vertical growth and a poorly integrated local network. It shows potential but needs guidance.

Fig. 10: Comparative Station Typology Matrix illustrating the classification of Howrah, Shalimar, Santragachi and Uluberia based on vertical growth and horizontal saturation. (Source: Author)

7 CONCLUSION AND WAY FORWARD

The study confirms that while railway proximity acts as the primary driver of spatial development, the resulting urban forms are strictly non-uniform. The study identified four distinct evolutionary typologies by considering demographic, operational and morphological data. The saturated node of Howrah has breached the carrying capacity, which is evidenced by a stabilised hyper-dense population and severe traffic congestion indices that nullify its transit advantage. The stagnant core of Shalimar remains paralysed by a "logistics trap" where conflicting land uses suppress vertical conversion despite having high land value. The Benchmark model of Santragachi demonstrates a rare equilibrium which absorbs the surging number of riders while maintaining its low traffic congestion and morphological consolidation. Conversely, the developing node of Uluberia exhibits a hazardous trajectory where an explosive rise in unreserved ridership is fuelling the fragmented "ribbon sprawl" rather than efficient densification.

7.1 Future Scenarios

Excluding the static baselines of Howrah and Shalimar, the study projects divergent trajectories for the two active nodes based on their current capacity to handle the "load shift". Santragachi is projected to follow an optimised densification path.[1] The node's ability to accommodate a 21% share of corridor ridership while maintaining free flow traffic conditions suggests a robust infrastructural baseline. By 2050, it is predicted to evolve into a fully integrated polycentric anchor, which naturally absorbs the demographic spillover from the core through vertical upgrading without suffering the gridlock associated with rapid growth. In contrast, the "business-as-usual" scenario for Uluberia predicts a systemic functional failure. The convergence of three negative trends, such as a massive surge in unreserved commuters, a volatile spike in horizontal patch density and a disconnected local street network, warns of an impending collapse of accessibility. Without proper intervention, the node is projected to bypass the efficient benchmark stage and degrade directly into a "Congested Sprawl Zone". By 2050, the fragmented settlement pattern will render the limited road network incapable of supporting the high-density commuter flow which replicates the worst aspects of Howrah's congestion.

7.2 Policy Recommendations

To align the future trajectory of the corridor with sustainable principles, the study proposes station-specific micro-plans. For Santragachi, where the road network and urban form are currently efficient, policy must focus on developing and retaining this form i.e., implementing transit-supportive mixed-use zoning (500m radius) to formalise commercial density and prioritising "grade separated pedestrianisation" to separate the growing footfall from vehicular traffic, preserving the node's high operational fluidity. For Uluberia, where natural forces favour chaotic expansion, the strategy must focus on restrictive spatial form. This requires a dual approach: establishing a strict urban growth boundary at the 3 km mark to halt ribbon sprawl while simultaneously executing a grid plan in the immediate vicinity to upgrade the local road network. Furthermore, introducing a differential FAR policy i.e., high FAR strictly within 1 km is essential to economically incentivise vertical redevelopment over horizontal expansion, which will prevent the formation of inaccessible settlements. Looking ahead, the next phase of research will focus on layering this morphological data with deeper socio-economic insights to better understand its impact on transit-induced growth. Additionally, future works must find ways to fully ensure that policies like the proposed micro-plans and FAR adjustments serve the entire community rather than just the formal urban fabric. Bridging these physical and human gaps is essential for creating transit nodes that are not just efficient but truly sustainable.

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[1] The 2050 predictive scenarios assume a linear projection of current ridership growth rates and do not account for unforeseen disruptive events such as new pandemic restrictions or major policy shifts in national rail privatisation.

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