# Stepping towards a sustainable future with TOD: Evaluating the Potential of the Lahore city for a Regional Policy Reform

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**Abstract**

This study investigates the potential of Transit-Oriented Development (TOD) in Lahore, Pakistan, a developing city in South Asia, to address its pressing transport and environmental challenges. Recognized as the world's most polluted city in 2022, Lahore confronts urgent issues exacerbated by urban sprawl and automobile dependency. Despite the introduction of a mass transit system, the city lacks robust urban planning strategies to effectively utilize these services. Our research seeks to bridge this gap by evaluating the TOD potential at 95 transit stations across four transit lines, using Geographic Information Systems (GIS) and Spatial Multicriteria Analysis (SMCA). The findings contribute to a sustainable urban planning framework, aiming to assist planners in making informed decisions for the development, funding, and implementation of TOD strategies, as outlined in the Master Plan for Lahore Division (MPLD-2050). This comprehensive approach will act as game changer, rejuvenating Lahore's urban center and promoting sustainable urban growth in emerging economies.

*Keywords:* Developing City, Game Changer, Sustainable Urban Planning, South Asia Transit-Oriented Development (TOD)

## 1. Background

According to the United Nations (UN, 2018), 55 percent (55%) of the global population currently resides in urban areas, a figure expected to double by 2050. This urban expansion is driven by population growth and migration to cities. Urban centers, as economic powerhouses, generate over 80 percent (80%) of the world's Gross Domestic Product (GDP), as reported by the World bank (2020). However, cities also consume approximately 70 percent (70%) of the world's resources, positioning them as major consumers of energy and significant contributors to greenhouse gas (GHG) emissions. The trends of urban sprawl and increased reliance on automobiles exacerbate these issues. Consequently, there is a growing advocacy for investment in public transport as a means to counteract low density development and rejuvenate urban environments. Such investments promote sustainability by enhancing convenience, encouraging active travel, improving air quality, reducing congestion, and mitigating climate shifts.

In this context, cities in developing countries encounter significant difficulties in maximizing prospects foe eco-friendly urban planning. These challenges stem from immediate transportation needs, disjointed organizational structures, problems with interdepartmental coordination, and stringent administrative environments. Many major cities in Asia are currently making significant investments in public transport networks, oscillating between transit-oriented models and auto-centric, traffic-congested urban forms. Moreover, transforming city structures and strengthening teamwork within the transportation sector consistently pose considerable challenges. This is particularly evident in Lahore, the cultural capital of Pakistan, which has recently initiated a mass transit system as a step towards sustainability. However, there is an urgent need for effective planning approaches to utilize these services effectively as tools for urban revitalization.

Transit-Oriented Development (TOD) has garnered increasing recognition among scholars and professionals for integrating transportation with urban development, spatial planning, and design to provide comprehensive solutions to contemporary urban challenges globally. TOD encourages walking, cycling, and the use of public transit over cars by fostering the development of multifunctional communities near transport nodes, characterized by average to high density levels and walker-friendly zones. While much of the research demonstrating TOD's practical implementation comes from developed countries (Singh *et al.*, 2017; Hamid and Saadi, 2018; Li *et al.*, 2019; Teklemariam and Shen, 2020), there remains a notable gap in its applicability and evidence for developing nations, which compel the formulation of bespoke action plans.

This research seeks to bridge existing gap by conducting focused research on the potential for TOD in Lahore, Pakistan—a developing city in South Asia facing significant challenges related to its transportation sector and associated environmental and urban issues. Lahore, often in the global spotlight as the 'World's most polluted city,' has endured years of severe smog conditions(IQAir, 2022). Moreover, the new Master Plan for Lahore Division (MPLD-2050) proposes TOD principles for major transit corridors, but falls short on proactive implementation steps. This research aims to evaluate the TOD's potential in Lahore as a sustainable strategy that could revolutionize its comprehensive issues, thus marking a progressive step towards a sustainable future. Additionally, it seeks to develop a framework for sustainable urban planning that enhances emerging economies through the effective utilization of transit services like BRT and LRT.

## 2. Literature Review

Achieving sustainable urban growth is a primary goal of transportation-linked urban strategies, despite their inherent contradictions. Throughout the 20th century, as cities expanded, transportation systems both supported urban development and posed challenges to economic, social, and environmental sustainability (Banister, 2005). Sustainability is commonly interpreted through the concept of sustainable development, defined by the World Commission on Environment and Development (WCED, 1987) as meeting the needs of the present without compromising the ability of future generations to meet their own. Understanding 'sustainable urban development' is critical when exploring the interplay between cities and sustainability (Dizdaroglu and Yigitcanlar, 2016). This involves a continuous alignment of resource use, investment, technological progress, and institutional change with the needs of both present and future populations.

This narrative is especially pertinent in Asia, where bustling cities and robust economic growth are marred by significant sustainability challenges. According to the Asian Development Bank (ADB, 2017), 80 percent (80%) of new economic growth in Asia will stem from urban areas, leading to urban sprawl and an increased reliance on vehicles (Jenks, Kozak and Takkanon, 2008). These dynamics contribute to traffic congestion, environmental pollution, and unequal access to services, exacerbated by inadequate urban planning and limited transportation alternatives. To address these issues, many Asian cities have escalated their investment in mass rapid transit systems. From 2001 to 2010, the majority of these systems were constructed in Asia, with half being built in China alone. This trend is expected to continue, with approximately 30 cities in China, including Beijing and Shanghai, and nearly 20 in India, such as Delhi and Mumbai, alongside several in Southeast Asia like Bangkok and Jakarta, actively expanding their transit infrastructures. According to ADB projections (2017), emerging Asia will require $26 trillion in infrastructure investments from 2016 to 2030 to sustain growth and address climate change, with $8.4 trillion earmarked for the transport sector (Abiad, Farrin and Hale, 2019).

In South Asia, however, the trajectory of urban transport development has diverged significantly from other regions. Major cities here have followed a delayed development path compared to global cities such as Tokyo, Paris, and London, which had established extensive rapid transit networks before the advent of mass motorization (Barter, 2018). South Asian countries initially prioritized increasing road capacity to alleviate traffic congestion, fostering auto-oriented urban planning standards. Consequently, air quality in South Asia remains critically poor, with countries like Bangladesh, Pakistan, and India featuring among the top five most polluted nations as per the 2019 World Air Quality Report by IQAir (IQAir, 2019). Furthermore, a study of 114 countries worldwide indicates that economic and population growth have been significant drivers of increasing global $CO_2$ emissions over recent decades, with urban centers at the heart of this trend (Pani and Mukhopadhyay, 2010).

Dense urban planning is essential for managing energy consumption and reducing carbon emissions, achievable through strategies like TOD and mixed land-use. Research indicates a strong correlation between urban development density and $CO_2$ emissions: areas with low-density expansion tend to have higher emissions compared to those with compact urban growth (Glaeser and Kahn, 2010). Moreover, implementing TOD strategies can significantly lessen Vehicle Miles Traveled (VMT) and related greenhouse gas (GHG) emissions (Haas and Miknaitis, 2010). Additionally, mixed-use designs can lower carbon emissions by minimizing travel distances and reducing reliance on automobiles (Fong *et al.*, 2008).

(Calthorpe, 1993) outlined best practices for smart city planning through eight design principles, including enhancing walkability and bicycle systems, developing dense networks of streets and pathways, promoting mass transit, zoning for mixed land-use, aligning density with transit capacity, fostering compact regions with short travel distances, and optimizing mobility by managing parking and road space. These principles align well with the features of TOD, emphasizing compact growth, pedestrian and bicycle friendliness, and the integration of public spaces around transit stations, which are designed as community hubs (Thomas *et al.*, 2018). TOD's success in promoting urban and transportation sustainability is notable. Originating in the 1980s to address urban issues in U.S. cities, the approach has gained global recognition, particularly in developing countries grappling with rapid urbanization and increasing traffic congestion. This concept resonates with the challenges described in South Asia, where there is a critical need for sustainable infrastructure to accommodate burgeoning urban populations and mitigate environmental impacts.

Since the 1990s, TOD has become a key term among urban planning circles worldwide. It has gained recognition from scholars and professionals for its approach to integrating the transport sector with urban development, spatial planning, and design to address contemporary urban challenges comprehensively. Although TOD initiatives have been implemented globally, it has become apparent that their outcomes can vary significantly. This variability underscores that the results of any given plan depend on a complex array of factors, methods, and interactions. Consequently, after practical applications, global literature has offered various critiques of TODs, particularly from American, European, and Australian contexts. These critiques often highlight how many projects have evolved into Transit Adjacent Developments (TAD) without the necessary supportive conditions.

Integrating TOD planning across various levels is essential to effectively address transportation challenges. The TOD approach can be viewed from two perspectives: one at the station level, involving prescriptive guidelines for development, and another at the regional level, which allows for a more flexible approach to urban growth (Hrelja *et al.*, 2020). First, TOD requires high-quality rail transit services that connect municipalities and must be planned, managed, and financed at the metropolitan or regional level. Second, station areas along transit lines can differ significantly in their current development status and potential for growth, as well as their balance between being a node and a place. Regional planning is crucial in evaluating the specific role each station plays within a broader territorial framework, thereby guiding local decision-making to align with larger-scale objectives.

A substantial body of literature on TOD assessment incorporates both quantitative and qualitative analyses. Various scholars have proposed numerous indicators to establish empirical or theoretical foundations within specific contexts. Calthorpe (1993) introduced the '3D' approach to TOD, encompassing Density—with a high concentration of housing, population, workplaces, and recreational sites; Diversity—featuring mixed land uses; and Design—promoting compact urban forms and pedestrian-friendly environments. Building on this foundation, Cervero and Kockelman (1997); Ewing and Cervero (2010) and Renne (2016) expanded the definition by adding three additional dimensions: Distance to transit stations, Terminus Accessibility, and Demand Management of urban car traffic. Furthermore, Knowles (Knowles, 2012; D. Knowles and Ferbrache, 2016) identified High-frequency transit service as another critical requirement for successful TOD.

Researchers have employed various methodologies to analyze transit station areas, utilizing spatial analysis, spatial statistics, and simulation techniques. Notably, Evans and Pratt (2007) and Singh *et al.* (2014) developed a TOD index to quantify existing levels at transit stations. Higgins and Kanaroglou (2016) used the latent class method to classify 372 stations in Toronto into distinct TOD typologies, while Shirke *et al.* (2017) applied a discrete choice model to assess the impacts of TOD along Mumbai's Metro Line-1. Further advancing TOD assessment, Mirzahossein *et al.* (2022) utilized the Analytic Hierarchy Process (AHP) to devise an interactive transit system in and Iranian city. The integration of both qualitative and quantitative methods has been prevalent, enhancing TOD evaluation(Nagari, Suryan and Pratiwi, 2020; Millard-Ball, 2021; Mohamad, Fahmy-Abdullah and Masrom, 2021; Liu *et al.*, 2022; Maheshwari, Grigolon and Brussel, 2022). The evaluation of a TOD involves integrating factors related to Transportation, Orientation and Urban Growth, which may differ in scope and can be spatial or non-spatial, often demanding Multiple Criteria Analysis (MCA) for an inclusive valuation. Spatial Multi Criteria Analysis (SMCA) is particularly favored for identifying priority interference areas, thus deepening insights into regional TOD levels. In a recent example, Ibrahim *et al.* (2023) used SMCA to evaluate TOD potential in Alexandria, Egypt . This interconnected approach highlights the evolving complexity and precision in TOD research, emphasizing the importance of multifaceted assessment techniques to inform urban planning and development strategies.

Although the aforementioned studies have made significant contributions to evaluating TOD in various contexts, most TOD research and implementation examples are derived from developed countries. This has resulted in a noticeable gap in knowledge and practical application for developing cities. Consequently, we have chosen to employ the 3D criteria to assess the extent to which TOD supportive characteristics exist in Lahore and identify areas that require improvement to steer the city towards sustainable growth. The selection of criteria and relevant indicators is grounded in a thorough review of pertinent literature and the availability of data within the context of developing countries. This approach ensures that our methodology is both informed and adaptable to the specific challenges and resources of these regions.

## 3. Research Approach and Case Study Background

### 3.1 Research Approach

We worked on 3Ds criteria established by Cervero and Kockelman (1997) which includes density, diversity and design. Higher density around stations promotes public transit usage, while greater diversity attracts visitors to use BRT/LRT services and explore the area on foot. Pedestrian-friendly designs further encourage walking near these transit stations. The selection of indicators for each criterion is guided by specific reasons and the availability of data. The detailed methodology is illustrated in the Figure.1, and the Table.1 outlines the final selected variables, providing descriptions and the data sources utilized for this study.

Before evaluating TOD, it is crucial to delineate the "TOD area" around each transit node, usually defined by a walking distance of 400m to 800m. In Lahore, the typical walking distance to access public transport is around 600m(JICA, 2012). Stations along transit lines are strategically placed about 1km apart, supporting an optimal walking distance of 500-600m. For this study, we have considered a 500m radius (equivalent to a 5-minute walk) as the basis for measuring indicators within the areas surrounding the four transit lines (Figure 2).

Population density is calculated as the ratio of population to land area, as shown in Equation (1). For this analysis, the WorldPop open population repository (WOPR) provided population data set for Pakistan in 2020, with a resolution of 100 meters. This dataset, in Geotiff format, was processed more using ArcGIS to compute the population density within each demarcated zone.

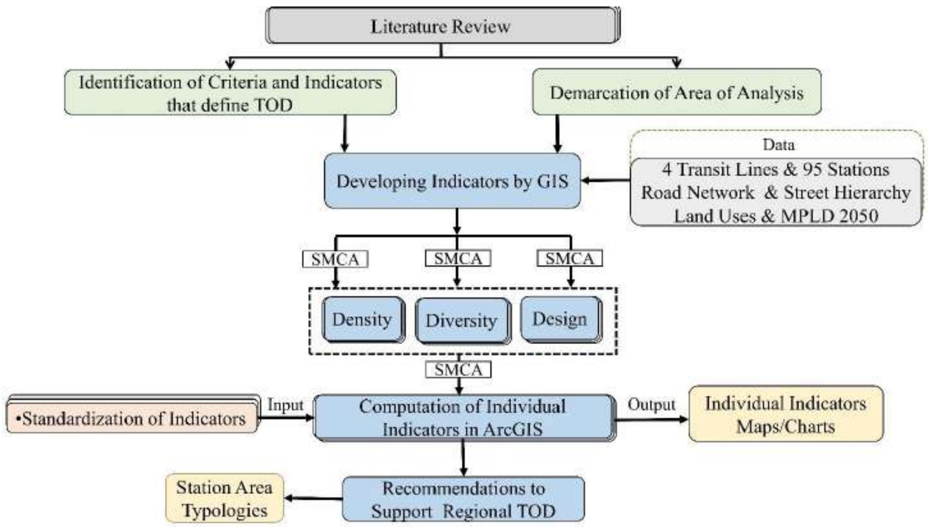


Figure 1. Research Framework

Table 1 Criteria and indicators

| Criteria | Indicators | Description | Data Source |
|---|---|---|---|
| Density | Population Density | Number of people/sqkm | WorldPop |
| Diversity | Land use Diversity | Entropy index | Computed with ArcGIS |
| Design | Open Space Ratio | Area of open spaces and parks | Computed with ArcGIS |
| | Landuse Mixedness | Ratio of residential land use with non-residential land uses | Computed with ArcGIS |
| | Intersection Density | Number of intersections per km2 | Computed with ArcGIS |
| | Walkable/Cyclable paths | Aggregate length in meters of walkable and cyclable routes | Computed with ArcGIS |

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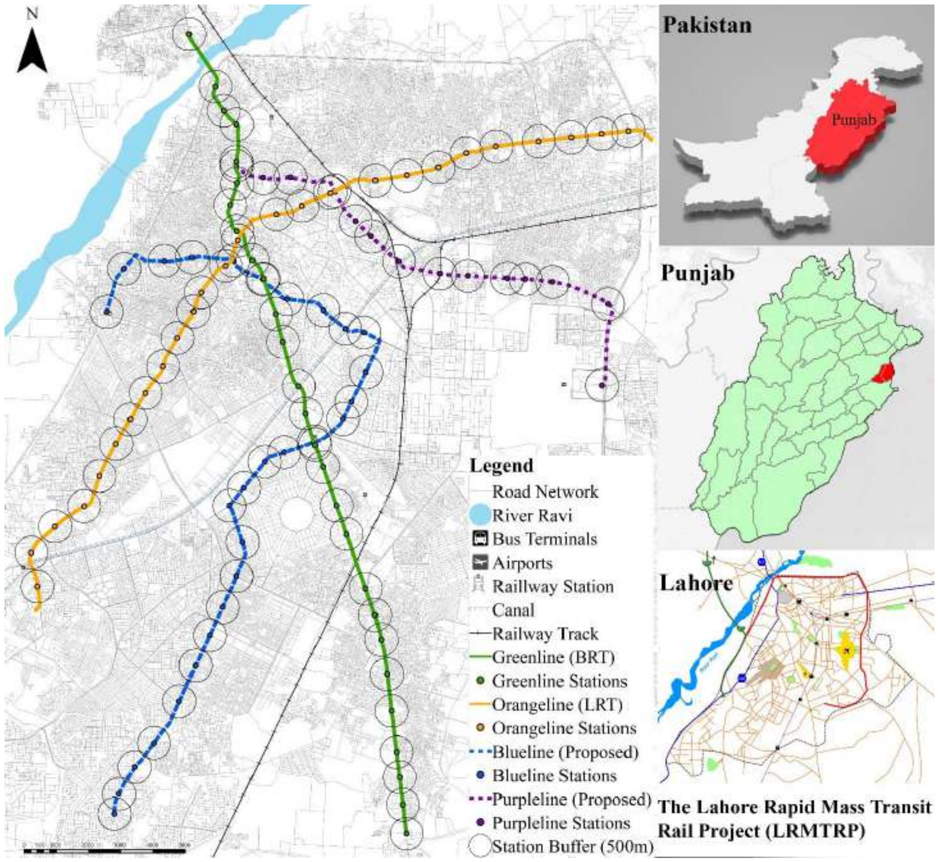


Figure 2. Transit lines in LRMTRP with demarcated TOD Area

$$Population\ Density = \frac{\text{No. of People}}{\text{Buffer Area}} \quad (1)$$

Building on the analysis of population density, the study also examined land use diversity, which evaluates the spatial variety of various land use categories in accessible proximity. This diversity in land usage addresses various needs of residents, thereby encouraging the use of transportation services during off-peak times and on holidays. Among several methods considered, the entropy method was chosen to quantify land use diversity. The specific formula employed is detailed below.

$$Entropy\ Index = \frac{-\sum_i Q_{lu_t} \times \ln(Q_{lu_t})}{\ln(n)} \quad (2)$$

where

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$lu_t = land\ use\ class\ (1{,}2, \ldots\ldots, n)\ within\ analysis\ area\ t$

$Q_{lu_t}$ = Propotion of particular land use within area of analysis t

$S_{lu_t}$ = Overall spatial extent of the designaed landuse in area t

$S_t$ = Total area of analysis t

Design plays a crucial role in creating accessible environments that promote walking, an essential component for TOD. Moreover, design is not merely linked to travel choices; it also forms a vital connection in the spatial layout between residents and stations, facilitating the development of high-quality open spaces. Under this criterion, indicators such as land use mixedness, walkable and cyclable pathways, intersection density, and the ratio of open spaces have been selected.

The objective of assessing land use mixedness is to determine how well-suited an area is for walking and cycling. This concept is distinct from diversity index as it explicitly measures the integration of residential areas with other land uses. A good blend of residential and other land uses supports a higher number of non-work-related trips that can be made by walking or cycling, as indicated by various studies (Jacobs, 1961; Evans and Pratt, 2007). Therefore, we calculated mixedness using a formula developed by Zhang and Guindon (2006):

$$\text{Land use Mixedness} = \frac{\sum_{nt} S_c}{\sum_{nt}(S_{c+}S_r)}\ \forall t\ \text{a} \quad (3)$$

$S_c$ = Aggregate area of non − residential urban land uses

$S_r$ = Total area of residential landuse within (t)

The length of walkable and cyclable paths is computed in meters. Data related to roads network is employed in ArcGIS (version 10.8) to compute intersection density, depicted as the number of intersections per square kilometer within each station buffer area. Furthermore, this study utilizes the open space ratio as an indicator of walkability. Research by McCormack et al. (2010) demonstrated that high-quality green spaces and parks encourage walking within neighborhoods. Koohsari et al. (2013) also found that the size and quality of these areas positively influence pedestrian activity. Further supporting this, studies by Zhang et al. (2020) and Zlot and Schmid (2005) indicated that neighborhoods with abundant parks are generally more walkable. In this study, we employ the following formula to calculate the open space ratio.

$$Open\ Space\ Ratio = \frac{Area\ of\ open\ spaces\ and\ parks\ (sqm)}{Total\ catchment\ area\ of\ a\ station\ (sqm)} \quad (4)$$

After developing individual indicators in ArcGIS, further step is spatial multi-criteria analysis (SMCA). It involves standardizing values reflecting indicators to compare and aggregate. This standardization is crucial due to the diverse units of measurement used in computing these indicators. In this study, among the various methods available, we employ the "maximum" method. Under this approach, the highest attained indicator value is assigned a value of "1". All other values are then proportionally assigned a value between 0 and 1, based on their ratio to this maximum value.

**3.2 The Case Study Background**

Lahore, Pakistan's cultural capital and one of the top thirty most populated cities globally, is a key center for economic, political, transportation, entertainment, and education. According to the 2017 census, its population stands at 11 million with an annual growth rate of 4.07 percent (4.07%) since 1998 (PBS, 2018). Contributing 13.2 percent (13.2%) to Pakistan's GDP, Lahore ranks 122nd worldwide in economic output (Ali et al., 2020).With a history that spans over two millennia, the city is celebrated for its significant architectural heritage and vibrant cultural scene.

Once governed by the Mughal Empire and later under British colonial rule, Lahore became the Islamic Republic of Pakistan following its freedom in 1947. Known for its historical architecture, including mosques, temples, churches, tombs, and parks, Lahore is a vibrant destination for tourists. Its urban landscape is characterized by a densely populated walled city and more expansive urban and outlying regions to the south and southeast (NESPAK, 2004). As a major metropolitan center, Lahore offers a variety of commercial and trade opportunities and is becoming a key player in the technology sector. Historically referred to as the "Mughal city of gardens" (Naz and Anjum, 2007)and the "Paris of the East," the region has seen significant transformations over the past few years through urban rejuvenation, heritage conservation, renovation initiatives, and extensive infrastructure improvements. Transitioning from the "City of Gardens" to the "City of Concrete," Lahore faces ongoing challenges such as urban decay, escalating land prices, and infrastructural concerns (Abubakar, 2016).

A significant undertaking is the Lahore Rapid Mass Transit Rail Project (LRMTRP), encompassing 97 kilometers of rail lines to deliver sustainable transport in Lahore. The project is divided into two stages: Phase I features the Greenline (MBS), operational since 10 February, 2013, and the Orangeline, operational since October 2020. Phase II proposes two additional lines: the blue and purple lines. However, a noted issue with these infrastructure projects is their isolated development, often disregarding the city's character(Rana, Bhatti and e Saqib, 2017).A research on Greenline by Anwar et al. (2020) also noted that transport infrastructure dominance alters the city's overall character. Further confirmation was found regarding the neglect of social considerations during the design and construction phases. Attention was exclusively directed towards physical infrastructure, neglecting softer elements such as community development, socio-cultural values, and people-centric design (Anwar, Leng and Ahmad, 2024).

Numerous urban green spaces in Lahore have been converted into pavement for infrastructure projects such as flyovers, underpasses, and road expansions, often at the expense of the city's green belts. Furthermore, the construction of the Greenline and Orange Line has negatively impacted the city's environment and cultural identity. While Lahore has made significant strides in infrastructure, it continues to face numerous challenges. Many of these major projects are executed in isolation, without an integrated plan or strategic framework (Alam, 2015).

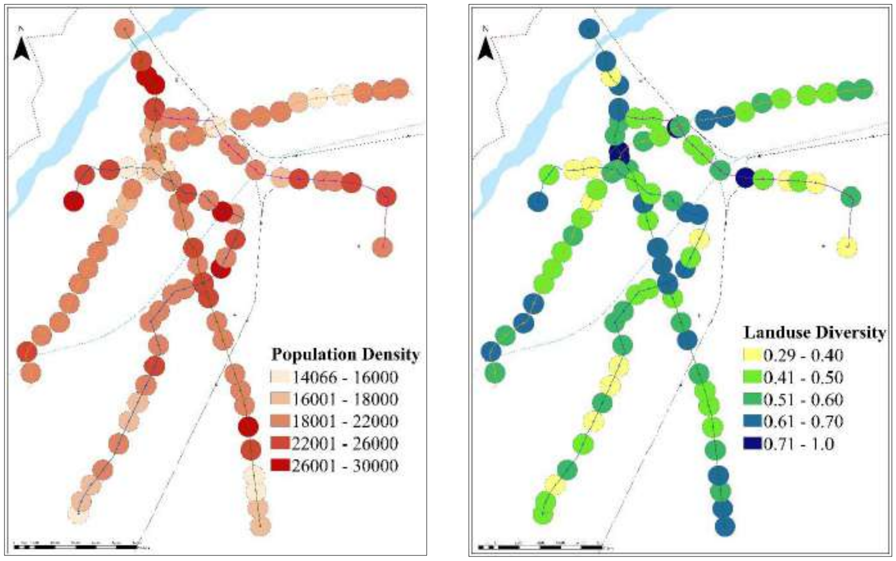
Despite these issues, Lahore has taken a step towards sustainability by implementing a mass transit system. However, the city still struggles to find effective planning approaches that can transform these services into tools for urban renewal. Once known as a garden city, Lahore is now in a phase of urban transformation, and is eagerly awaiting sustainable initiatives to bridge these developmental gaps.

**4. Results and Discussion**

Utilizing population density as a benchmark is pivotal for assessing transit areas, as regions around transit stations with high population densities typically see increased public transit ridership and spur urban development. Thus, areas of high-density development not only suggest substantial travel demand but also indicate a strong alignment with TOD principles. Figure 3a visually represents the population density within specific zones around each transit station. Notably, the highest population densities occur near Azaadi Chowk Station and Timber Market Station, due to the tightly packed and densely populated residential parcels. In contrast, the areas near Canal and Liberty Station exhibit higher densities due to multistory building structures. This variation underscores the influence of residential patterns and architectural styles on the population density surrounding transit stations.

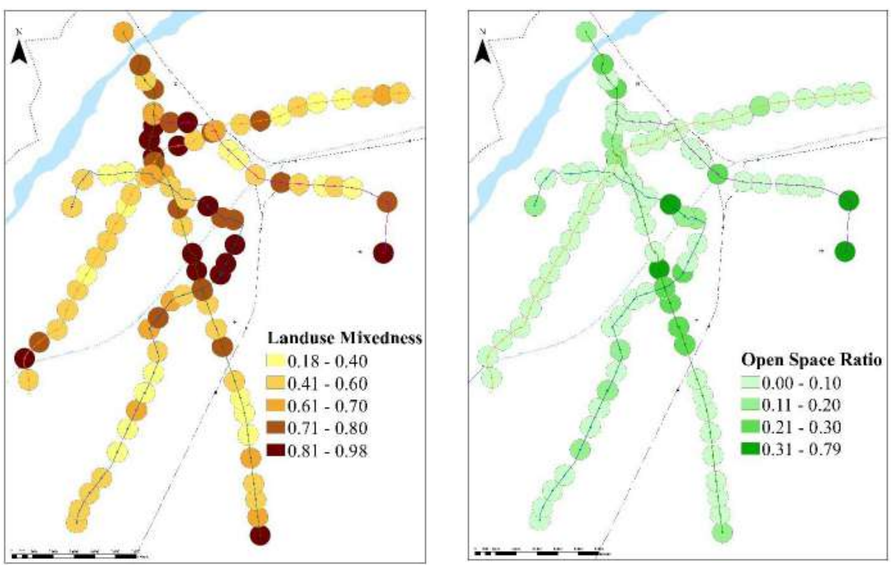
The entropy method was adopted to evaluate land use diversity, and parcel-level land use data was compiled in vector format using ArcGIS 10.8. This dataset includes a 500-meter radius around each station and incorporates data from surveys, Google Earth, OpenStreetMap, and extensive field trips. The analysis covered diverse types of land uses including commercial, educational, healthcare, institutional, industrial, religious, parks and green spaces, leisure zones, graveyards, underutilized or vacant plots, residential areas, utilities, and transportation facilities. Figure 3b illustrates the land use diversity surrounding each node. The calculated measure ranges between 0 and 1, with higher values indicating increased land use diversity and improved TOD effectiveness. Notably, the highest levels of land use diversity are observed near Railway Station, Dharampura Station, Lake Road, MAO College Station, and Shama Station. These locations serve as central hubs for a variety of businesses that cater to the entire city. Conversely, the lowest diversity values are found at Samanabad Station, Shamnagar Station, NFC Society Station, Askari IX Station, and Airport Station, predominantly due to the prevalence of residential neighborhoods. This comprehensive approach underscores the complex nature of urban development and its potential to support TOD.

In the same context, figure 4a displays the land use mixedness for all 95 stations in the area. This mixedness also spans from 0 to 1, where 0 indicates no residential usage and 1 denotes exclusively residential areas. A mixedness value of 0.5 represents a balanced mix of residential and other land usage, suggesting a harmonious blend. Subsequently, the open space ratio is calculated and presented in Figure 4b.




(a) (b)

Figure 3. (a) Population density (b) Land use diversity




(a) (b)

Figure 4. (a) Landuse Mixedness (b) Open Space Ratio

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Intersections significantly enhance walkability and cyclability by reducing travel distances. A higher density of intersections provides more route options for pedestrians and cyclists, effectively shortening their travel paths. This phenomenon is demonstrated across 95 stations of the LRMTRP, as illustrated in Figure 5. The highest intersection density is observed around Bhaati Chowk Station, Janazgah Station, Lakshmi Chowk Station, Samanabad, and Ichra Station. These areas benefit from old, organic development in the city core, characterized by small land parcels. In contrast, the lowest densities are observed around Liberty Chowk Station, Canal Station, and Gulberg College Station—areas of newer planned development—as well as Airport Station and NFC Society Station, which are characterized by vacant land parcels.

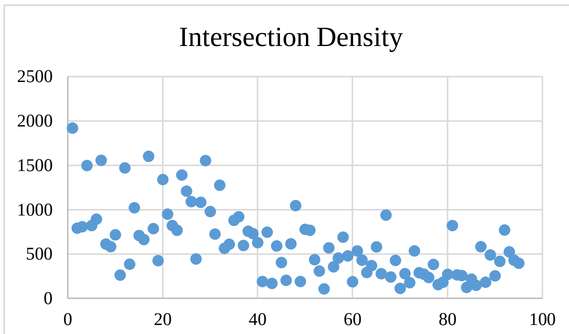


Figure 5. Intersection density around 95 stations of LRMTRP

Similarly, the total length of pathways, measured in meters using ArcGIS, varies significantly, as depicted in Figure 6. Pathway lengths range from 0 to 36,573 meters. Stations such as Samanabad, Bhaati Chowk, Timber Market, Lakshmi Chowk, and Chungi Amra Sidhu report the highest measurements, corresponding to their locations in the dense, inner core of the city. Conversely, stations like Liberty Chowk, NFC Society, Marrian Stop, and Gulberg College, situated in newly developed areas, report the shortest pathways. Additionally, Boharwala Chowk Station exhibits lower values due to its proximity to railway infrastructure. This distribution highlights how urban planning influences pedestrian and cyclist accessibility.

After computing all indicators, their results are standardized for spatial multi-criteria analysis (SMCA). The standardized results for all indicators around the 95 stations of the LRMTRP are displayed in Table 2. Using these values, stations can be compared to identify which criteria require improvements based on the context and location of each station within the region. For instance, a standardized value of 1 for intersection density at Bhaati Station shows that this area has the highest intersection density among all stations. There is a necessity to focus on individual stations by enhancing their low-scoring criteria to contribute to TOD for a sustainable future. Radar charts have been created for three sample stations located in varied city zones—urban, suburban, and greenfield—to highlight areas for improvement based on their standardized values (Figure7).

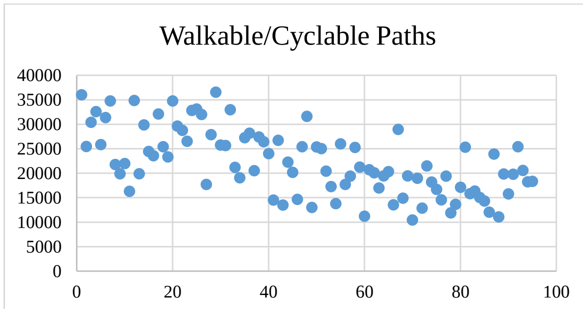


Figure 6. Walkable/cyclable paths

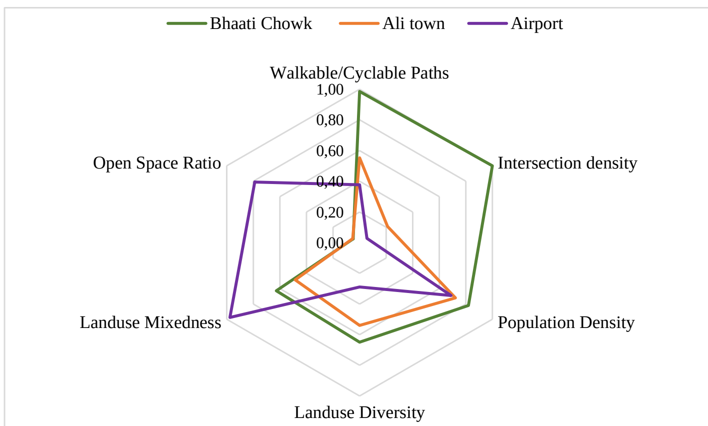


Figure 7. Radar Charts for 3 Sample Stations

## 5. Conclusion and Recommendations

Research on practical TOD implementation has traditionally been conducted in developed countries, leaving a gap in evidence and experience regarding its applicability in developing cities. To address this gap, this study focuses on TOD application in Pakistan, specifically examining planning parameters critical for implementing TOD as a sustainable transport strategy in mega cities. The case study of Lahore is particularly highlighted to provide context-specific insights.

The results indicate that TOD is feasible in Lahore. It suggests that each node, whether existing or proposed, must be tailored stemming from its unique features and difficulties to effectively implement TOD. The recent master plan for the Lahore Division (MPLD 2050) recommends densification along the existing public transport corridors of the orange and green lines, as well as along major structural plan roads (Figure 8).

Table 2 Standardized values of all Indicators around 95 stations of LRMTRP

| Sr. No. | Station Name | Population Density | Landuse Diversity | Open Space Ratio | Landuse Mixedness | Intersection Density | Walkable/ Cyclable |
|---|---|---|---|---|---|---|---|
| 1 | Bhaati Chowk (Greenline) | 0.82 | 0.65 | 0.05 | 0.63 | 1.00 | 0.99 |
| 2 | Azaadi Chowk | 1.00 | 0.67 | 0.25 | 0.75 | 0.41 | 0.70 |
| 3 | MAO College | 0.66 | 0.72 | 0.19 | 0.81 | 0.42 | 0.83 |
| 4 | Ichra Station | 0.72 | 0.49 | 0.02 | 0.56 | 0.78 | 0.89 |
| 5 | GPO | 0.69 | 0.56 | 0.03 | 0.92 | 0.43 | 0.71 |
| 6 | Lake Road | 0.64 | 0.73 | 0.15 | 0.71 | 0.46 | 0.86 |
| 7 | Lakshami Chowk | 0.63 | 0.47 | 0.00 | 0.56 | 0.81 | 0.95 |
| 8 | Shahdara | 0.76 | 0.67 | 0.11 | 0.66 | 0.32 | 0.60 |
| 9 | Railway Station | 0.58 | 0.76 | 0.07 | 0.71 | 0.30 | 0.54 |
| 10 | Katchehry | 0.68 | 0.59 | 0.08 | 0.92 | 0.37 | 0.60 |
| 11 | Thokar Niaz Baig | 0.81 | 0.68 | 0.05 | 0.88 | 0.14 | 0.45 |
| 12 | Timber Market | 0.96 | 0.38 | 0.03 | 0.46 | 0.77 | 0.95 |
| 13 | Kalma Chowk (Greenline) | 0.87 | 0.67 | 0.13 | 0.73 | 0.20 | 0.54 |
| 14 | Bund Road | 0.62 | 0.49 | 0.01 | 0.49 | 0.53 | 0.82 |
| 15 | Niazi Chowk | 0.83 | 0.64 | 0.25 | 0.77 | 0.37 | 0.67 |
| 16 | Shama Station | 0.74 | 0.70 | 0.03 | 0.76 | 0.35 | 0.64 |
| 17 | Janazgah | 0.55 | 0.51 | 0.00 | 0.64 | 0.83 | 0.88 |
| 18 | Qartaba Chowk | 0.64 | 0.52 | 0.01 | 0.62 | 0.41 | 0.69 |
| 19 | Canal Station (Greenline) | 0.80 | 0.65 | 0.09 | 0.83 | 0.22 | 0.64 |
| 20 | Chungi Amar Sidhu | 0.76 | 0.43 | 0.04 | 0.38 | 0.70 | 0.95 |
| 21 | Qainchi Station | 0.77 | 0.54 | 0.02 | 0.53 | 0.49 | 0.81 |
| 22 | Salahudin road | 0.72 | 0.52 | 0.06 | 0.53 | 0.43 | 0.79 |
| 23 | Wahdat Road | 0.73 | 0.62 | 0.04 | 0.52 | 0.40 | 0.73 |
| 24 | Baghbanpura | 0.74 | 0.46 | 0.01 | 0.35 | 0.72 | 0.90 |
| 25 | Ghulshan-e-Ravi | 0.68 | 0.46 | 0.07 | 0.41 | 0.63 | 0.91 |
| 26 | Kamahan | 0.95 | 0.41 | 0.03 | 0.32 | 0.57 | 0.88 |
| 27 | Civil Secretariate | 0.63 | 0.58 | 0.16 | 0.94 | 0.23 | 0.48 |
| 28 | Shalimar Gardens | 0.56 | 0.57 | 0.18 | 0.48 | 0.56 | 0.76 |
| 29 | Samanabad | 0.59 | 0.33 | 0.01 | 0.29 | 0.81 | 1.00 |
| 30 | Sultanpura | 0.76 | 0.65 | 0.05 | 0.50 | 0.51 | 0.70 |
| 31 | Awan town | 0.72 | 0.5 | 0.07 | 0.43 | 0.38 | 0.70 |
| 32 | Ghazi Chowk | 0.67 | 0.42 | 0.00 | 0.37 | 0.66 | 0.90 |
| 33 | Atari Saroba | 0.79 | 0.54 | 0.00 | 0.62 | 0.29 | 0.58 |
| 34 | UET | 0.69 | 0.67 | 0.06 | 0.75 | 0.32 | 0.52 |
| 35 | Chauburji (Orangeline) | 0.55 | 0.59 | 0.04 | 0.54 | 0.46 | 0.75 |
| 36 | Khatm-e-Nabooat | 0.74 | 0.48 | 0.03 | 0.42 | 0.48 | 0.77 |
| 37 | Hanjarwal | 0.68 | 0.65 | 0.01 | 0.58 | 0.31 | 0.56 |
| 38 | Sabzazar | 0.74 | 0.42 | 0.03 | 0.35 | 0.39 | 0.75 |
| 39 | Salamtpura | 0.70 | 0.49 | 0.00 | 0.57 | 0.38 | 0.72 |
| 40 | Islam Park | 0.69 | 0.53 | 0.00 | 0.63 | 0.33 | 0.66 |
| 41 | Gajjumata | 0.62 | 0.69 | 0.11 | 0.98 | 0.10 | 0.40 |
| 42 | Nishter Colony | 0.49 | 0.67 | 0.03 | 0.59 | 0.39 | 0.73 |
| 43 | Ittefaq Hospital | 0.74 | 0.67 | 0.26 | 0.78 | 0.09 | 0.37 |
| 44 | Dulu Khurd | 0.59 | 0.62 | 0.00 | 0.66 | 0.31 | 0.61 |
| 45 | Ali town | 0.72 | 0.54 | 0.05 | 0.48 | 0.21 | 0.55 |
| 46 | Qaddafi Stadium | 0.71 | 0.65 | 0.39 | 0.80 | 0.11 | 0.40 |
| 47 | Dera Gujran | 0.75 | 0.58 | 0.07 | 0.54 | 0.32 | 0.70 |

| Sr. No. | Station Name | Population Density | Landuse Diversity | Open Space Ratio | Landuse Mixedness | Intersection Density | Walkable/ Cyclable |
|---|---|---|---|---|---|---|---|
| 48 | Mahmood Booti | 0.55 | 0.43 | 0.00 | 0.37 | 0.54 | 0.86 |
| 49 | Canal View | 0.74 | 0.6 | 0.01 | 0.70 | 0.10 | 0.36 |
| 50 | Pakistan Mint | 0.54 | 0.48 | 0.08 | 0.37 | 0.40 | 0.69 |
| 51 | Youhanabad | 0.50 | 0.59 | 0.00 | 0.56 | 0.40 | 0.69 |
| 52 | Model Town | 0.81 | 0.48 | 0.29 | 0.54 | 0.23 | 0.56 |
| 53 | Naseerabad | 0.66 | 0.55 | 0.29 | 0.50 | 0.16 | 0.47 |
| 54 | Airport | 0.69 | 0.29 | 0.79 | 0.98 | 0.06 | 0.38 |
| 55 | Akbar chowk | 0.77 | 0.40 | 0.06 | 0.37 | 0.30 | 0.71 |
| 56 | Ameer Chowk | 0.75 | 0.44 | 0.12 | 0.36 | 0.19 | 0.48 |
| 57 | Askari IX | 0.77 | 0.29 | 0.05 | 0.18 | 0.24 | 0.53 |
| 58 | Babu Sabo | 0.91 | 0.61 | 0.19 | 0.59 | 0.36 | 0.69 |
| 59 | Bhaati Chowk (Purpleline) | 0.80 | 0.65 | 0.05 | 0.63 | 0.25 | 0.58 |
| 60 | Boharwala Chowk | 0.55 | 0.59 | 0.07 | 0.69 | 0.10 | 0.31 |
| 61 | Brandreth Road | 0.64 | 0.42 | 0.05 | 0.89 | 0.28 | 0.57 |
| 62 | Butt Chowk | 0.62 | 0.39 | 0.09 | 0.32 | 0.22 | 0.55 |
| 63 | Canal purple | 0.76 | 0.53 | 0.27 | 0.52 | 0.15 | 0.46 |
| 64 | Central flats | 0.69 | 0.53 | 0.18 | 0.49 | 0.19 | 0.53 |
| 65 | Chauburji (Blueline) | 0.58 | 0.53 | 0.03 | 0.70 | 0.30 | 0.56 |
| 66 | Dharampura | 0.63 | 0.74 | 0.04 | 0.75 | 0.14 | 0.37 |
| 67 | Double Sarkan | 0.83 | 0.46 | 0.01 | 0.42 | 0.49 | 0.79 |
| 68 | Faisal Town | 0.70 | 0.53 | 0.06 | 0.65 | 0.12 | 0.41 |
| 69 | Garhi Shahu | 0.73 | 0.43 | 0.01 | 0.36 | 0.22 | 0.53 |
| 70 | Gulberg College | 0.71 | 0.67 | 0.18 | 0.72 | 0.06 | 0.29 |
| 71 | Guldasht Colony | 0.83 | 0.52 | 0.40 | 0.71 | 0.14 | 0.52 |
| 72 | Hafeez Centre | 0.69 | 0.43 | 0.01 | 0.86 | 0.09 | 0.35 |
| 73 | Jora Pull | 0.79 | 0.35 | 0.02 | 0.36 | 0.28 | 0.59 |
| 74 | Kalma chowk (Blueline) | 0.89 | 0.65 | 0.23 | 0.72 | 0.15 | 0.50 |
| 75 | Lahore College | 0.78 | 0.47 | 0.02 | 0.42 | 0.14 | 0.46 |
| 76 | Lajhna Chowk | 0.62 | 0.55 | 0.08 | 0.65 | 0.12 | 0.40 |
| 77 | Mini Market | 0.90 | 0.35 | 0.03 | 0.88 | 0.20 | 0.53 |
| 78 | NFC Society | 0.56 | 0.31 | 0.01 | 0.60 | 0.08 | 0.33 |
| 79 | Punjab University | 0.77 | 0.49 | 0.03 | 0.66 | 0.09 | 0.37 |
| 80 | Services Hospital | 0.65 | 0.60 | 0.43 | 0.90 | 0.14 | 0.47 |
| 81 | Shamnagar | 0.54 | 0.32 | 0.09 | 0.23 | 0.43 | 0.69 |
| 82 | Valencia | 0.50 | 0.44 | 0.06 | 0.48 | 0.14 | 0.43 |
| 83 | Barkat Market | 0.75 | 0.50 | 0.04 | 0.49 | 0.13 | 0.45 |
| 84 | Canal (Blueline) | 0.98 | 0.64 | 0.11 | 0.76 | 0.06 | 0.41 |
| 85 | Engineering Society | 0.57 | 0.41 | 0.08 | 0.47 | 0.11 | 0.39 |
| 86 | Liberty | 0.95 | 0.65 | 0.24 | 0.88 | 0.08 | 0.33 |
| 87 | M Ali Chaudhry Chowk | 0.77 | 0.39 | 0.11 | 0.33 | 0.30 | 0.65 |
| 88 | Marrian Stop | 0.69 | 0.53 | 0.05 | 0.76 | 0.09 | 0.30 |
| 89 | Mayo Gardens | 0.73 | 0.48 | 0.03 | 0.40 | 0.25 | 0.54 |
| 90 | Military Accounts Society | 0.66 | 0.53 | 0.09 | 0.47 | 0.13 | 0.43 |
| 91 | Qartaba Chowk (Blueline) | 0.66 | 0.46 | 0.01 | 0.44 | 0.22 | 0.54 |
| 92 | Rajgarh | 0.79 | 0.37 | 0.05 | 0.26 | 0.40 | 0.70 |
| 93 | Saddat Chowk | 0.86 | 0.50 | 0.01 | 0.41 | 0.27 | 0.56 |
| 94 | Shah Alam Chowk | 0.72 | 0.44 | 0.04 | 0.78 | 0.22 | 0.50 |
| 95 | Zarrar Shaheed | 0.67 | 0.47 | 0.02 | 0.45 | 0.21 | 0.50 |

These lines currently operate at nearly 40% below their projected capacity, surrounded by low-density areas near major stations. To combat this, a 500-meter radius around each station has been designated for regeneration and densification. This approach aims to enhance accessibility and walkability, fostering an urban environment conducive to TOD. The typical building height in these areas is currently 2 to 3 floors. There is a proposal to increase the permitted building height between 8 and 12 stories within this 500-meter radius around the main transit stations, which is expected to increase the population density to approximately 350 to 400 persons per hectare. This adjustment highlights Lahore's potential to adopt TOD as a sustainable strategy.

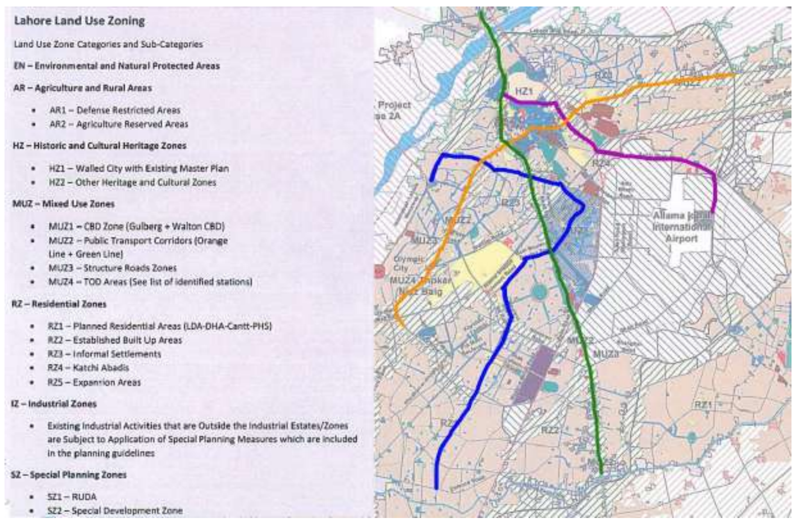


Figure 8. Transit lines of Lahore in Master Plan of Lahore Division (MPLD-2050)

This study assessed the existing characteristics of Lahore's urban landscape around transit nodes to evaluate the potential for adopting TOD. Our findings reveal that variations in different indicators across various transit nodes are due to their distinct contexts within the region. A significant issue in implementing TOD is the application of uniform Floor Space Index (FSI) or Floor Area Ratio (FAR) across the city, which overlooks local nuances such as existing infrastructure. The cornerstone of effective TOD is context-specific design, which considers factors like transit capabilities, lot dimensions, street sizes, and infrastructure capabilities.

To pave the way for urban redevelopment, a gradual and necessary process through democratic means is essential. Instead of granting higher FSI universally, it should be market-responsive, awarded selectively to those contributing to urban development. This approach prevents "Transit Adjacent Development" (TAD), which merely accumulates floor space near transit stations without necessarily increasing public transit ridership. Moreover, challenges such as lengthy timelines for urban development, uncertain demographic shifts, and difficulties in achieving a jobs-housing balance pose substantial obstacles.

As Lahore continues on its urban development path, addressing these challenges and opportunities will be vital in shaping a sustainable and inclusive urban future. Based on the results from various indicators, all 95 stations across four mass transit lines have been categorized into three types, reflecting their development context as illustrated in Figure 9. Additionally, associated possibilities, challenges, and representative stations have been compiled in Table 3. These outcomes offer a valuable diagnostic tool for planners, policymakers, and governmental authorities, enabling them to assess and compare the efficacy of TOD attributes in both existing and proposed neighborhoods. Moreover, incorporating TOD principles into urban planning frameworks, such as the MPLD 2050, can guide future transit projects and promote sustainable urban growth in Lahore, other cities in Pakistan, and other emerging nations aspiring to implement public transport networks. This comprehensive approach will act as game changer, rejuvenating Lahore's urban center and promoting sustainable urban growth in emerging economies.

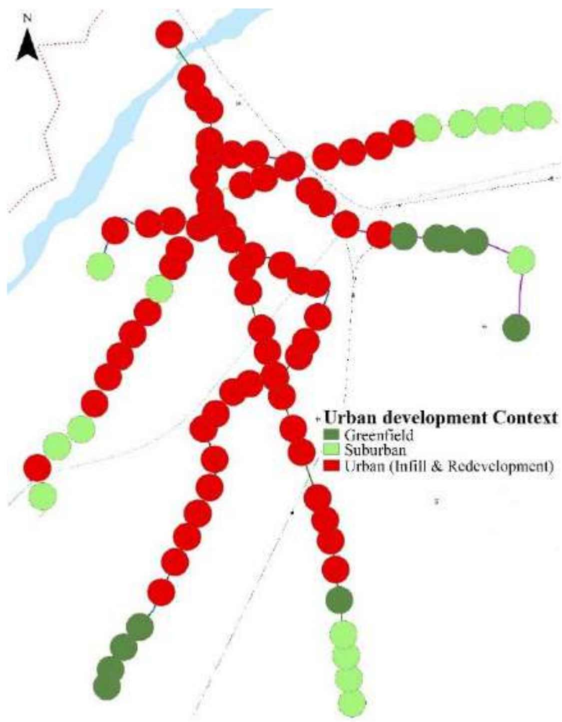


Figure 9. Development Context of all Stations

Table 3. Urban Development Context of all Stations of LRMTS

| Urban Development Context | Opportunities | Challenges | Representative Case |
|---|---|---|---|
|  **Greenfield** | Abundance of government lands<br>New communities can be master planned around transit<br>Lower land costs<br>Increased financial resources available<br>Construction of higher capacity infrastructure is feasible<br>Strong political backing<br>Minimal regulatory barriers<br>Road safety is emphasized through systematic concepts | Long timeline for city development.<br>Uncertain population composition.<br>Challenges in achieving jobs-housing balance initially.<br>Weak public transport connectivity promotes sprawl.<br>Developers may lack risk appetite. | Askari IX, Zarrar Shaheed, Jora Pull, Saddat Chowk, Valencia Town, Engineers Society, NFC Society, Military Accounts Society, Atari Saroba, Airport |
|  **Suburban** | More spots are at hand for transformation.<br>Chance to enhance transit access in low-density areas.<br>Lower land costs. | Sprawled lower density growth pattern.<br>Singular land uses.<br>Poor mobility connections, prioritizing automobiles over pedestrians, public transport, and non-motorized options like walking and cycling. | Ali Town, Canal View, Hanjarwal, Dulu Khurd, Gajjumata, Guldasht colony, Dera Gujran, Islam Park, Babu Sabu, Bund Road |
|  **Urban** | Proximity to major transit routes and business hubs.<br>Greater utilization of active travel modes, especially in low and middle-income areas.<br>Potential for enhancing transit accessibility.<br>Chances for redevelopment of aging buildings. | Multiple ownership complicates land assembly.<br>Varying property dimensions and layouts.<br>Current land uses are often not transit-friendly.<br>Large block sizes hinder accessibility.<br>Inadequate and risky pedestrian and bicycle infrastructure.<br>Narrow or limited pathways. | Chungi Amar Sidhu, Canal (Green), Canal (Blue), Niazi Chowk, Garhi Shahu, Mayo Gardens, Barkat Market, Baghbanpura, Sultanpura, Janazgah, Shama, GPO, Lakshami Chowk, Brandreth Road, Shah Alam Chowk, Katchehry, Civil Secretariate, MAO College, Lake Road, Railway Station, Kalma Chowk (Green), Kalma Chowk (Blue), Bhaati Chowk (Green), Bhaati Chowk (Purple), |

Qartaba Chowk (Green), Qartaba Chowk (Blue), Chauburjii (Blue), Chauburjii (Orange), Boharwala Chowk, Ittefaq Hospital, Ghazi Chowk, Ichra, UET, Qaddafi Stadium, Azaadi Chowk, Lajhna Chowk, Faisal Town, Marrian Stop, Punjab University, Gulberg College, Services Hospital, Lahore College, Shalimar Gardens, Pakistan Mint, Dharampura, Shahdara, Thokar Niaz Baig, Qainchi Station, Liberty, Hafeez Center, Main Market, Salamatpura, Mahmood Booti, Ameer Chowk, Butt Chowk, M Ali Chaudhry Chowk, Akbar Chowk, Central Flats, Rajgarh, Shamnagar, Double Sarkan, Youhanabad, Naseerabad, Kamahan, Model Town, Nishter Colony, Timber Market, Awan Town, Gulshan-e-Ravi, Khatam-e-Nabooat, Salahuddin Road, Samanabad, Sabzazar, Wahdat Road

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