DOCTORAL DISSERTATION

The effect of bus rapid transit on enhancing transit-oriented development and its impact on travel behavior: A case study of Lahore, Pakistan

(BRTの公共交通指向型開発促進への効果とその交通行動への影響ーパキスタン・ラホールのケーススタディ)

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ABSTRACT

Transit-oriented Development (TOD) stimulates high dense, mixed-use, and walkable environments, encourages sustainable travel behavior, and reduces vehicle kilometers traveled (VKT). Most previous studies have explored the interaction between transit and TOD, and the impact of built environment characteristics on travel behavior in developed nations, and little is known about developing economies, particularly in Asian regions such as Pakistan. Whether Bus Rapid Transit (BRT) shaped TOD has not been well examined, though rail transit has been widely studied in the literature. Our study fills these research gaps and investigates what kind of urban fabric has been created by BRT's shaping of the TOD within 800 meters between 2012 and 2021 in Lahore using three TOD criteria: density, diversity, and design. It also examines the impact of TOD attributes on residents' travel behavior around selected BRT stations using 426 respondents in Lahore. This study develops TOD models around BRT stations. In addition, this study identifies the causes of not implementing land use and transport strategies of Integrated Master Plan for Lahore (IMPL) 2021 and understands the challenges and opportunities to enhancing TOD with BRT in Lahore using structured interviews of nine professionals working in various departments of land use and transport planning in Lahore. This study conducted observation surveys and interviews with the officials of departments to evaluate the aforementioned TOD criteria, and the collected data were analyzed using ArcMap. We employed descriptive statistics and a multilevel mixed-effect regression model to understand the resident's travel characteristics and the impact of TOD attributes on VKT in TOD and Transit-adjacent Development (TAD) areas, respectively, using SPSS. The structured interview data was analyzed using word frequency analysis in NVivo 14. This study concluded that population density, development volume, and land use for economic activities increased after the BRT operation. Pedestrian paths were not improved or remained the same, signifying that the walkability and open space either remained the same or declined in the station areas. However, intersection density increased in some station areas. The evidence in this study indicates that density and diversity improved, but design criteria remained the same or declined. This study also concluded that TOD residents are more likely to use BRT, walking, and motorcycles and drive less than TAD residents. Almost 81% and 82% of the respondents agreed with the travel mode to work and shopping trips, respectively. The model results demonstrate that population density, residential density, and land-use diversity were not significantly associated with VKT. Our study proposed two BRT-based TOD models for urban and suburban areas to enhance TOD in Lahore. The previous master plan strategies were not implemented due to multiple causes, such as functional overlapping, path dependencies, bureaucratic and project–centric approach, and weak land use and building control, to mention just a few. Our study concluded that the absence of planning and implementation framework and mechanism, lack of institutional coordination, less government priority and political will, absence of incentives for developers, absence of clear rules and regulations, lack of specific TOD plan, and absence of professional capacity and leadership were the foremost challenges for not implementing land use and transport strategies of IMPL and enhancing TOD with BRT. Therefore, to achieve TOD, the government should give priority to improving the walking environment, for instance, by creating more pedestrian paths and open spaces. Our results suggest that high-density mixed-use development strategies reduce VKT and encourage transit and non-motorized use for sustainable travel behavior. Moreover, our study indicated that clear planning and implementation framework, rules, regulations, TOD plan, local plans, coordination, strong political will, professional capacity and visionary leadership, and incentives are crucial to promote TOD with BRT. Moreover, a separate TOD department or TOD team within departments is also essential to enhance TOD with BRT in Lahore.

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DEDICATION

Dedicated to my beloved parents

Mr. and Mrs. Rao Muhammad Yousaf

And

My siblings, teachers, and family for their unconditional love, endless support, and encouragement.

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LIST OF ABBREVIATIONS

AMPLD	Amended Master Plan of Lahore Division
BRT	Bus Rapid Transit
CBD	Central Business District
CBDA	Central Business Development Authority
CUTA	Canadian Urban Transit Association
DCRP	Department of City and Regional Planning
DHA	Defense Housing Authority
FAD	Floor Area Density
FAR	Floor Area Ratio
GIS	Geographic Information System
HRT	Heavy Rail Transit
HUD&PHD	Housing, Urban Development, and Public Health Department
IMPL	Integrated Master Plan for Lahore
ITDP	Institute for Transportation and Development Policy
IPPUC	Institute for Research and Urban Planning of Curitiba
JICA	Japan International Cooperation Agency
LCBDDA	Lahore Central Business District Development Authority
LDA	Lahore Development Authority
LG	Local Government
LG&CDD	Local Government and Community Development Department
LRMTS	Lahore Rapid Mass Transit System
LRR	Lahore Ring Road
LRT	Light Rail Transit
MPLD	Master Plan of Lahore Division
MC	Metropolitan Corporation
MRT	Mass Rapid Transit
NESPAK	National Engineering Services Pakistan
ODP	Outline Development Plan
OLT	Orange Line Train

PHATA	Punjab Housing and Town Planning Agency
PKR	Pakistani Rupee
PMA	Punjab Mass Transit Authority
PPH	Persons per Hectare
PPTA	Punjab Provincial Transport Authority
PTC	Punjab Transport Company
RIT	Integrated Transit Network
RUDA	Ravi Urban Development Authority
TAD	Transit Adjacent Development
TDM	Transportation Demand Management
TEPA	Traffic Engineering and Transportation Planning Agency
TOD	Transit-Oriented Development
TPU	Transport Planning Unit
SPSS	Statistical Package for the Social Sciences
UC	Union Council
UET	University of Engineering and Technology
UPZ	Zonal Planning Unit
USA	United States of America
USD	United States Dollar
USGS	United States Geological Survey
VKT	Vehicle Kilometer Traveled
VMT	Vehicle Miles Traveled
WCLA	Walled City for Lahore Authority

CHAPTER 1: INTRODUCTION

1.1. Research Background

Recently, cities have been expanding unprecedentedly due to rapid urbanization (Perveen et al., 2017). Consequently, many problems associated with managing the built environment have emerged; some of the most visible issues are caused by over-dependence on automobiles, such as climate change, global warming, traffic congestion, air pollution, and socioeconomic issues (Sharma & Kumar, 2012). Introducing public transit is one of the essential countermeasures to overcome this over-dependence on automobiles (Holmgren, 2007; Kanthavel, Sangeetha, & Keerthana, 2021; Mulalic & Rouwendal, 2020). However, many cities have revealed that introducing public transit is not enough because even with a public transit system, people prefer to use automobiles as they are more flexible, fast, and comfortable (Bergstad et al., 2011; Redman et al., 2013). Hence, some measures to encourage public transit use need to accompany the introduction of public transit. Controlling land use associated with public transit can encourage public transit usage, and one of the ways is transit-oriented development (TOD).

The concept of TOD was first developed in 1993 by Peter Calthorpe in "The Next American Metropolis." He defined TOD as a "mixed-use community within average 2000-feet (600m) walking distance of a transit stop and core commercial area. TODs mix residential, retail, office, open space, and public uses in a walkable environment, making it convenient for residents and employees to travel by transit, bicycle, foot, or car" (Calthorpe, 1993). Recently, TOD has been described as "land-use and transport planning that makes sustainable transport modes convenient and desirable, and that maximizes the efficiency of transport services by concentrating urban development around transit stations" (Ibraeva et al., 2020). Moreover, TOD has gained a reputation worldwide for mitigating several urban issues, such as traffic congestion, long commuting distances, and air pollution (Ewing & Cervero, 2010; Thomas & Bertolini, 2015).

TOD is considered a form of urban development that enhances residential and commercial places within walkable distances from transit stations (Chen et al., 2021; Lamour et al., 2019). Generally, TOD offers higher density, mixed-use, walkable urban development near mass transit stations and encourages public transit and walking rather than automobiles (Nasri & Zhang, 2014; Rahman et al., 2019). As TOD consists of various aspects, such as urban development and infrastructure in the station area, it is created through land use control to restrict/guide urban development and infrastructure development by the private sector (Lyu et al., 2016; Pojani & Stead, 2014; Renne, 2017). To consider how land uses control and infrastructure development promote TOD, understanding what urban fabric is created and what aspects of TOD are lacking in the station area without these factors is essential.

Moreover, big cities worldwide are affected by unplanned growth, traffic congestion, and environmental problems, particularly in developing economies (Nguyen et al., 2020). The most efficient way to overcome these issues is to take advantage of mass transit to reduce the number of automobiles and promote public transit, cycling, and walking (Abenoza et al., 2017; Wu & Hong, 2017). One of the most effective ways to encourage public transit is to harmonize the relationship between the built environment and travel behaviors (Yu et al., 2019). Furthermore, previous studies have advocated that more mixed-use and compact urban forms can encourage transit and non-motorized use, resulting in less automobile use (Chatman, 2008; Zhang et al., 2012). The abovementioned issues can be lessened through land use and transport integration, particularly in developing countries (Cervero, 2013). Transit-oriented Development (TOD) establishes the integration between land use and transport to produce more sustainable communities (Singh et al., 2012). It has reduced vehicle kilometers traveled (VKT), car ownership, and traffic congestion and encouraged transit use for sustainable travel behavior (Kumar et al., 2018; Nasri & Zhang, 2019). Most previous studies confirm that TOD is adopted as a strategy to enhance a neighborhood's sustainable travel behavior, mainly by encouraging transit and non-motorized use while reducing the use of cars (Kamruzzaman et al., 2016; Kwoka et al., 2015; Nasri & Zhang, 2014; Noland & Dipetrillo, 2015; Venigalla & Faghri, 2015; Zamir et al., 2014).

Nevertheless, TOD impacts on travel behavior are usually diluted due to Transit-adjacent Development (TAD), where residents' travel characteristics can vary (Kamruzzaman et al., 2014; Renne, 2009). TAD is located around transit stations with low densities, mostly homogeneous land uses, and poorly connected streets (Duncan, 2011). Regrettably, most studies have considered TAD as TOD, even though almost 60% of the rail stations at the neighborhood and regional level in the United States do not meet the criteria for TOD and are more like TAD (Nasri & Zhang, 2019). However, little empirical evidence exists on how residents' travel behavior differs in TOD and TAD areas (Kamruzzaman et al., 2015).

Though, TOD is not dependent only on the heavy rail transit (HRT) system but also depends on light rail transit (LRT) and bus rapid transit (BRT) (Knowles, Ferbrache, & Nikitas, 2020). Many cities worldwide encourage BRT as a cost-effective solution to overcome traffic congestion and increase mobility choices for the urban poor (Cervero & Kang, 2011). The past literature has examined the impact of the HRT system on the development of station areas. Notwithstanding the rising reputation of the BRT system, little is known about its influence on land development (Cervero & Kang, 2011; Rodriguez et al., 2016). Moreover, the effect of BRT on land development is context-dependent (Mullins et al., 1990; Rodriguez et al., 2016). Most studies on the interaction between rail transit and TOD have been conducted in cities in developed countries; there is little evidence of TOD, particularly in developing nations. However, several unanswered questions remain about whether BRT can stimulate TOD (Cervero & Dai, 2014; Lindau et al., 2010; Macedo, 2013; Vergel-Tovar & Rodriguez, 2022).

Understanding the existing urban fabric and travel behavior in the BRT station's proximity is crucial for TOD planning. Our study fills the abovementioned research gaps and aims to investigate the existing urban fabric and residents' travel behavior of different BRT station areas within a catchment of 800 m in Lahore. Moreover, this study develops BRT-based TOD models and understands the causes of not implementing land use and transport strategies in previous master plans specific to Integrated Master Plan for Lahore (IMPL) 2021. Additionally, our study focuses on understanding the challenges and opportunities for enhancing TOD with BRT in Lahore. The results of this study can be directly helpful in formulating TOD strategies that promote sustainable development and travel behavior near the BRT stations in Lahore.

1.2. Problem Statement

Globally, 55% of the world's population lives in urban settlements. Just 30% of the world's population was in urban areas in 1950, but it will account for 68% by the end of 2050 (United Nations, 2018). The cities in the developing economies have become the center of global urban debates owing to swift urbanization and expected that 96% of urban growth would happen in less developed areas of South Asia, East Asia, and Africa. Between 2018 and 2050, three countries, including China, India, and Nigeria, will account for 35% of the world's urban population (United Nations Human Settlements Programme, 2020). Moreover, cities accommodate 2.3 billion people; Asia comprises the world's most significant number of urban inhabitants; 50.1% urbanized and attributed to 54% of the global urban population growth. The growing concentration of dwellers has been perceived in highly urbanized cities, particularly megacities (at least 10 million population). In 2018, 33 megacities accommodated 13% of the world's urban population growth (United Nations Human Settlements Programme, 2020). There are 20 megacities out of 33 in Asia region in 2018; Lahore city is one of them (United Nations, 2018).

One of the threats is that a limited number of fast-growing cities that sprawled out at the urban fringe, most of them have been motorized, may prevent years of top world endeavors from limiting adverse environmental effects of urban development (Cervero, 2013). It is linked to the increase in automobiles, which is much higher in developing economies as compared to the developed nations (Jadaan et al., 2018; Pojani & Stead, 2017; Susilo et al., 2007) that caused 93% of the road deaths in developing countries (World Health Organization, 2023). Moreover, this growing trend in urban growth and motorization caused several issues in urban areas, such as overcrowded urban centers, urban sprawl, traffic congestion, air pollution, and poor road networks (Bernardo & Bhat, 2013; Cervero, 2013; Curtis & Scheurer, 2017; Nguyen et al., 2020; Pojani & Stead, 2017). Land use and transport integration can overcome the abovementioned issues, particularly in developing countries (Cervero, 2013). Transit-oriented Development (TOD) establishes the integration between land use and transport to produce more sustainable communities (Singh et al., 2012) and encourages transit use for sustainable travel behavior (Kumar et al., 2018; Nasri & Zhang, 2019).

Pakistan is the fifth most populated country in the world, with a population of 241.49 million in 2023 (Pakistan Bureau of Statistics, 2023). Lahore is the 2nd largest city in Pakistan. The city is spread over an area of 1772 km^2. The city's population is about 13 million as per census 2017, which was 11.12 and 6.32 million in 2017 and 1998, respectively (Punjab Bureau of Statistics, 2017). The city will reach the size of a megacity before 2030, as projected by United Nations (United Nations Human Settlements Programme, 2020). Rapid urban growth increased urbanization from central to suburban areas (Lahore Development Authority, 2004; Riaz et al., 2014). Due to rapid urbanization, the city has sprawled in an unplanned manner and crossed a radius of 38 km in 2017 (Nadeem et al., 2021) due to weak land use and building control from various local government authorities. Moreover, many housing scheme projects have been initiated in suburban areas, considerably altering the travel pattern in recent years. This unplanned growth has caused a rapid increase in private vehicles (Shah, 2021).

Nevertheless, the public transport supply is insufficient for Lahore residents (Malik, 2013). The lack of public transportation infrastructure resulted in private vehicles. The number of automobiles per 1000 inhabitants increased from 95 to 230 from 2001 to 2008 in Lahore (ALMEC Corporation, 2012). In 2020, the total number of registered vehicles was 6.3 million, which was 5.7 million in 2019. The annual increase in registered vehicles is more than 10%, primarily private vehicles (more than 95% share of total vehicles), with a negligible percentage of public transport (less than 5%). Consequently, the rise in motorization causes traffic congestion, accidents, and longer travel times in Lahore. To overcome these problems, the city invested in a BRT infrastructure in 2013.

Moreover, Lahore City has become a center of many opportunities. It is surrounded by industries that are primary employment homes in the locality, so more people are moving from regional areas to the city for better living opportunities (Javid et al., 2021). Most of these people cannot afford to reside in urban areas, so they choose to live in suburban areas due to the availability of cheap property and low rental prices, where public transport and other services are very poor. Since public transit is the foremost travel mode for people, their accessibility and service coverage is limited (Aziz et al., 2018). So, there is a need for comprehensive urban and infrastructure planning to increase the socio-economic conditions of the people. Transit infrastructure can improve access to the opportunities integrated with land use planning to attain sustainable development and travel behavior. Recently, the city has invested in a BRT system serving 27 km; however, this infrastructure is not ample. So, it is crucial to integrate transit with land use (TOD) because it has been documented at the global level as a way to obtain sustainable urban development and travel behavior. Further, TOD is regarded as one of the most important means of avoiding or reducing car dependence and urban sprawl (Zhou et al., 2016).

In Lahore, no policy, regulations, rules, or incentives regarding BRT-based TOD have yet been prepared by the government to promote sustainable urban development and travel behavior. So, this study investigated whether BRT created urban fabric and what aspects of TOD are lacking in the station areas of Lahore. This study also examines the residents' travel behavior and the impact of TOD attributes on residents’ travel behavior in Lahore. This study also develops BRT-based TOD models to enhance sustainable urban development. In addition, this study understands the causes of not implementing land use and transport strategies of IMPL 2021 and the challenges and opportunities for encouraging TOD with BRT in Lahore. Thus, this study offers some recommendations for urban planning/policy in Lahore to enhance TOD around BRT stations to make Lahore a sustainable city.

1.3. Research Objectives and Questions

The main aim of this study is to develop BRT-based TOD models and suggest policy recommendations and strategies for enhancing TOD and sustainable travel behavior close to the BRT station areas in Lahore. The following research objectives and questions are addressed in this study;

1. To study the influence of BRT investment in shaping TOD in the proximity of the station areas.

- What kind of urban fabric has been created in BRT station areas?
- Whether the urban fabric has elements of TOD, which encourage public transit use and walking rather than private vehicle use?

2. To study the resident's travel behavior in TOD and TAD areas using the proximity of BRT stations.

- What are the travel characteristics of residents in the TOD and TAD areas around BRT stations?
- Can TOD reduce the VKT of residents living around BRT station areas?

3. To propose BRT-based TOD models for urban and suburban areas in Lahore.

- What are the BRT-based TOD models for urban and suburban areas in Lahore?

4. To understand the causes of not implementing TOD strategies in previous master plans specific to IMPL 2021 and challenges and opportunities for enhancing TOD with BRT

- Why TOD strategies in the previous master plans were not implemented, specific to Integrated Master Plan for Lahore (IMPL) 2021?
- What are the challenges and opportunities for enhancing TOD with BRT around stations?

1.4. Significance and Contribution to the Knowledge

This study is expected to contribute to the knowledge in the following ways. First, it contributes to urban fabric knowledge of TOD in different contexts. Researchers are growingly investigating the rail transit proximity for TOD, but there has been little evidence of how BRT proximity contributes to TOD. Our study can offer a helpful dimension for evaluating what kind of urban fabric has been created by BRT's shaping of the TOD and whether the urban fabric has elements of TOD using a case study from a developing country, i.e., Lahore. Second, this study fills an empirical gap in travel behavior. Notwithstanding, several studies have investigated travel behavior, but most are from developed countries, little has concentrated on residents' travel behavior in developing economies, and even fewer on BRT proximity. Third, our study develops BRT-based TOD models for urban and suburban areas, which will help to encourage TOD to make Lahore a sustainable city. Fourth, our study adds to the current research by offering a robust examination that deals with not implementing land use and transport strategies of IMPL 2021. Fifth, understanding the association between professionals working for TOD and its features around BRT station areas gets to be more crucial, in line with the planning and implementation of various rules, regulations, and plans enforced with the involvement of several actors in the formation of the urban fabric and transit investments. Therefore, our study focuses on understanding the challenges and opportunities for enhancing TOD with BRT.

The significance of our study includes; urban planners and local government in Lahore by offering them the current evidence of urban fabric around BRT stations, empirical evidence of resident's travel behavior, BRT-based TOD models for urban and suburban areas, understanding the causes of not implementing land use and transport strategies of IMPL 2021, and studying the challenges and opportunities for encouraging TOD with BRT which will help to develop the TOD strategies around BRT stations towards sustainable development and travel behavior. The findings are expected to provide the foundation from which land use rules, regulations, policies, and master plans be revisited to promote the TOD. This study provides valuable insights that will help to reduce the use of private vehicles and encourage the use of BRT and non-motorized modes, boosting BRT ridership. Our study will contribute to achieving sustainable development goals 7, 11, and 13.

1.5. Scope and Limitations

This research focuses on the urban fabric within a catchment of 800 m around eight selected BRT station areas in Lahore. Moreover, the resident's travel behavior is also investigated for the same BRT stations within 800 m for 426 samples classified into TOD and TAD areas. In addition, this study proposed two BRT-based TOD models for urban and suburban areas. This study determined the root causes of not implementing land use and transport strategies of IMPL 2021. This study also understands the challenges and opportunities for promoting TOD with BRT using structured interviews of nine professionals working in different land use and transport departments in Lahore. However, the results and recommendations of this study would serve as TOD strategies for the BRT stations but depending on the characteristics of each BRT station.

This study has limitations; we only compared station areas and the whole city by population density. However, we have density data for 2010 and 2016, which was close to the opening year of the BRT. This study revealed that FAD and land use diversity increased in the station areas, but we were unable to determine whether this was a particular tendency in the station areas or not. Further, the number of 3D criteria is smaller than in other studies because of data availability. We only classified the selected BRT stations into TOD and TAD areas to examine the travel behavior rather than taking the entire BRT route to understand the residents' travel behavior better. Further, this study classified planned station areas, such as Model Town and Naseerabad, into TAD owing to their characteristics. Nevertheless, the travel behaviors of planned and unplanned areas can differ; therefore, the planned station areas need to be dealt with separately to understand the differences in travel behavior clearly. Furthermore, the number of respondents was small in this study, which impacts the overall significance of the model. We have just considered the professionals to understand the challenges and opportunities to encourage TOD with BRT with small samples.

1.6. Organization of the Thesis

This thesis is organized into ten chapters;

Chapter 1 summarizes the background of the research. It emphasizes the research importance and develops links with evident challenges to evaluate the research gaps. It presents the problem statement of the study. Moreover, it focuses on the research objectives and questions that this study needs to address. The scope and limitations are discussed in this chapter. It highlights the overall contribution and significance of the study. The thesis organization is offered in the last section of this chapter.

Chapter 2 provides a basic understanding of BRT and TOD. This chapter also discusses the evolution of BRT and TOD. It offers valuable insights into successful practices of BRT implementation and BRT-based TOD.

Chapter 3 offers a discussion on relevant previous research. This chapter is divided into three parts; the impacts of transit on urban development/TOD and the impacts of transit on travel behavior in TOD and TAD areas, and challenges and opportunities for TOD with the transit system.

Chapter 4 is about the case study. It briefly describes Lahore with urbanization, urban growth dynamics, and vehicle ownership. It gives valuable insights into the BRT system in Lahore. It also explains the selection of BRT stations used for this research.

Chapter 5 describes the methodology used to conduct this research. It provides the criteria and indicators of TOD used in this study and their description. It offers the classification of the BRT stations into TOD and TAD areas to investigate travel behavior. The survey, sampling technique, and data analysis method are discussed. The review of master plans and interviews conducted with various departments was also described.

Chapter 6 provides the results and findings of the impact of BRT on shaping TOD using 3D's criteria of TOD, including density, diversity, and design. It also compares the findings of this study with the previous studies.

Chapter 7 evidences the impact of TOD of BRT station areas on residents' travel behavior. It provides the classification of TOD and TAD areas and compares the respondents' socio-economic and travel characteristics. It also studies the impact of TOD attributes on VKT in the study area. It offers the reasons for choosing the address in TOD and TAD areas. Further, it compares this study's findings with previous studies findings.

Chapter 8 briefly compared the indicators of 3Ds (density, diversity, and design) and travel characteristics of the respondents (n = 426) in TOD and TAD areas. Calthorpe's TOD concept was discussed. Two BRT-based TOD models were proposed for urban and suburban areas to encourage TOD in Lahore.

Chapter 9 understands the causes of not implementing TOD strategies in previous master plans in Lahore. This chapter highlights the transportation and urban planning system of Lahore. The previous master plans, ordinances, and acts prepared and implemented in Lahore were reviewed under this chapter. Moreover, this chapter presents the word frequency analysis to understand the causes of not implementing land use and transport strategies of IMPL 2021 and the challenges and opportunities that stand in the way of TOD with BRT.

Chapter 10 summarizes this study's major findings and suggests recommendations for urban planning and enhancing TOD with BRT in Lahore. This chapter ends with future research directions as they came from the limitations of this research.

The systematic flow chart of the thesis organization is shown in **Figure 1.1**.

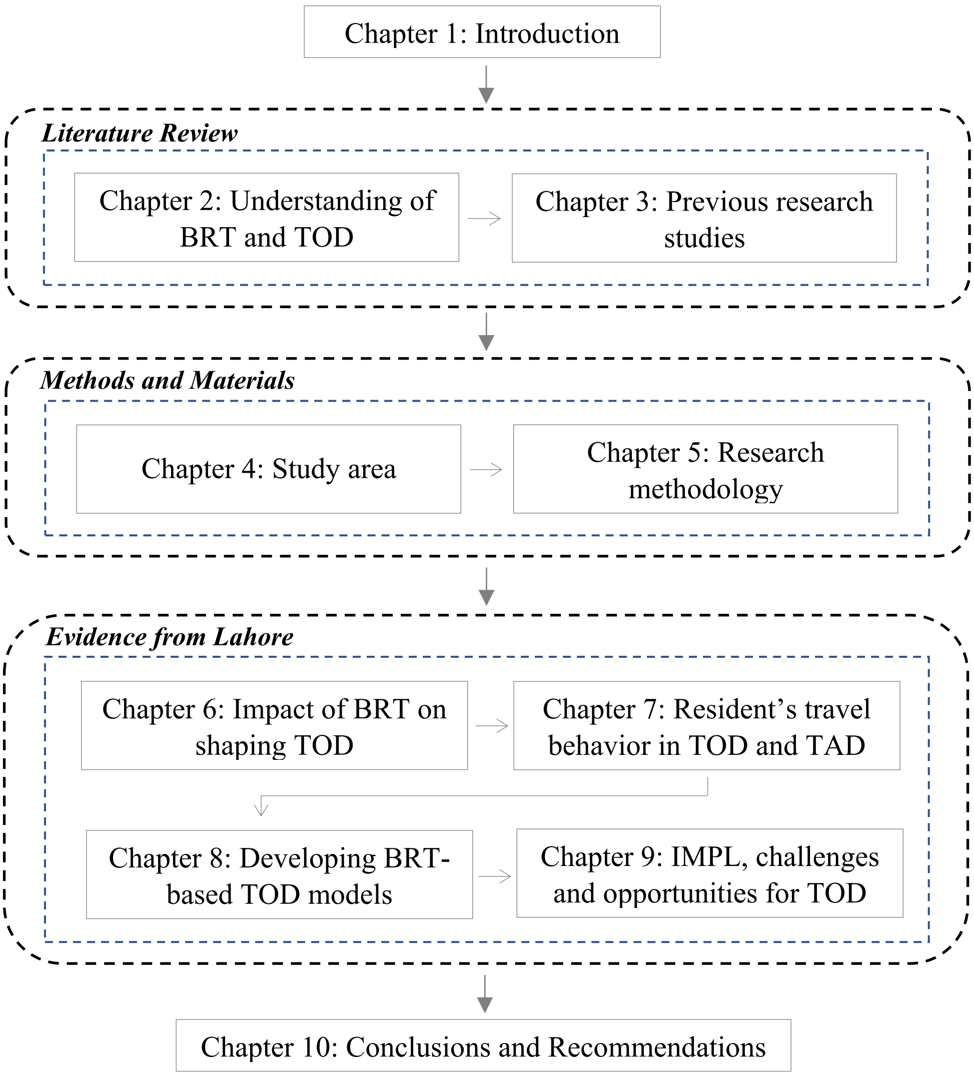


Figure 1.1 Flow chart of the thesis organization

CHAPTER NO.2: UNDERSTANDING THE CONCEPT OF BUS RAPID TRANSIT AND TRANSIT-ORIENTED DEVELOPMENT

2.1. Introduction

The BRT system has gained a reputation worldwide and operates in more than 181 cities globally. BRT has the potential to stimulate TOD and is expected to change the travel behavior around station areas. This chapter summarizes the basic understanding of the BRT system and its components. It gives valuable insights into the evolution of the BRT system globally with successful examples, i.e., Curitiba and Bogota. It also mentions the benefits of the BRT system. Moreover, this chapter provides a basic understanding of TOD along with the principles, scale, advantages, disadvantages, and typologies of TOD. Furthermore, case studies of BRT-based TOD were presented in this chapter.

2.2. Bus Rapid Transit

2.2.1. Bus rapid transit and its components

Mass transit is a massive-scale public transport system that is characterized by high passenger carrying capacity, high speed, and exclusive right of way. It includes rail-based and rubber-tired systems such as heavy rail transit, light rail transit, metro rapid transit, commuter rail, monorail, and BRT, offering high frequency and high service capacity (Midgley, 1994). BRT is a bus base rapid transit system that tries to imitate the high-quality service of the rail transit system. Many cities consider BRT a cost-effective mode offering high-quality transit service to fulfill their needs (Deng & Nelson, 2011). Various authors presented the different definitions of BRT that are given below;

Thomas (2001) defined BRT is

> *"a rapid mode of transportation that can combine the quality of rail transit and the flexibility of buses."*

Levinson et al. (2003) defined BRT is

> *"a flexible, rubber-tired form of rapid transit that combines stations, vehicles, services, running ways, and ITS elements into an integrated system with a strong identity."*

Canadian Urban Transit Association (2004) defined BRT is

> *"a rubber-tired rapid transit service that combines stations, vehicles, running ways and a flexible operating plan into a high-quality, customer-focused service that is fast, reliable, comfortable and cost-efficient."*

Institute for Transportation and Development Policy (2023) defined BRT is

> *"a high-quality bus-based transit system that delivers fast, comfortable, and cost-effective services at metro-level capacities. It does this through the provision of dedicated lanes, with busways and iconic stations typically aligned to the center of the road, off-board fare collection, and fast and frequent operations."*

BRT is a unified set of rapid transit features comprising seven significant components (Levinson et al., 2003), as presented in **Figure 2.1**. These components work collectively to ensure the success of the BRT system. BRT system can be categorized into four clusters: running in mixed traffic with signal priority, using exclusive busways, using shoulder bus lanes, and using median busways (Cain et al., 2009), represented in **Figure 2.2**. It shows that BRT is viewed as overcoming conventional bus and light rail differences. At the lower end of the investment scale lie the Rapid Bus, which usually runs in mixed traffic with signal priority, crossing queue jumps, headway-based timetables, and far-end stations to offer better commercial speed and safety. Metro Rapid in Los Angeles is a most successful case of this approach.

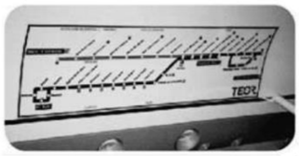
Running Ways	BRT vehicles operate primarily in fast and easily identifiable exclusive transit ways or dedicated bus lanes Vehicles may also operate in general traffic.	
Stations	BRT stations, ranging from enhanced shelters to large transit centers, are attractive and easily accessible. They are also conveniently located and integrated into the community they serve.	
Vehicles	BRT uses rubber-tired vehicles that are easy to board and comfortable to ride. Quiet, high-capacity vehicles carry many people and use clean fuels to protect the environment.	
Services	BRT's high-frequency, all-day service means less waiting and no need to consult schedules. The integration of local and express service can reduce long-distance travel times.	
Route Structure	BRT uses simple, often color-coded routes. They can be laid out to provide direct, no-transfer rides to multiple destinations.	
Fare Collection	Simple BRT fare collection systems make it fast and easy to pay, often before you even get on the bus. They allow multiple door boarding, reducing time in stations.	
Intelligent Transportation Systems	BRT uses advanced digital technologies that improve customer convenience, speed, reliability, and operations safety.	

Figure 2.1 Major components of the BRT system. *Source*: Levinson et al. (2003)

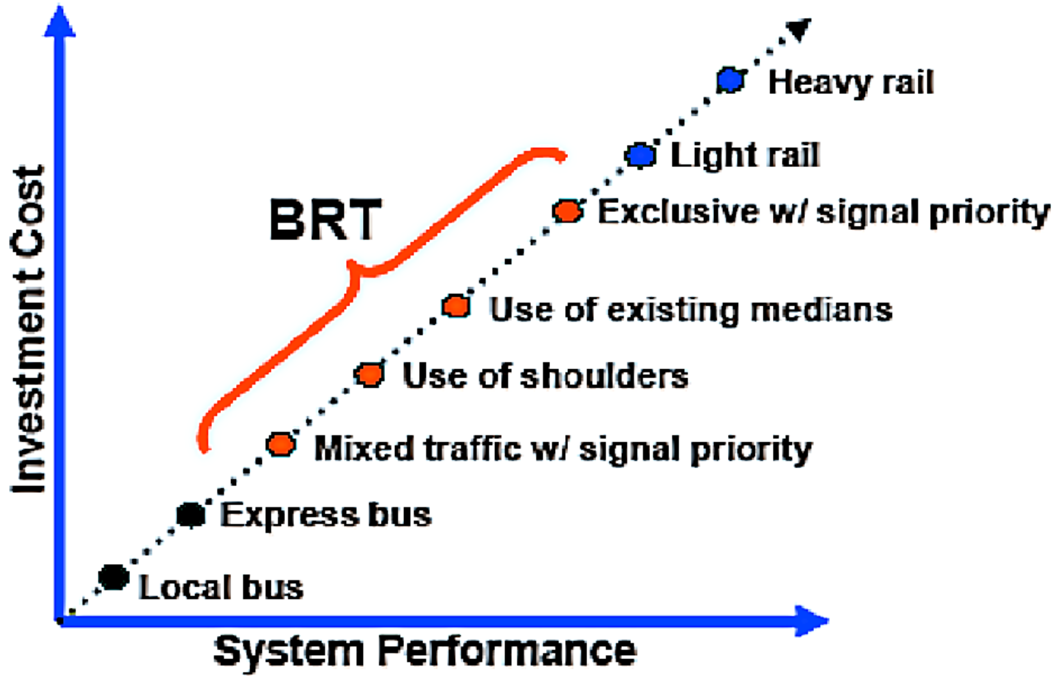


Figure 2.2 BRT system performance. *Source*: Cain et al. (2009)

2.2.2. Evolution of bus rapid transit system

The notion of BRT is not new and is well documented in plans that have been formulated since the 1930s. The first BRT proposal was prepared for Chicago in 1937, which converted three lines of rail rapid transit into express bus service on a super highway with on-street distribution in central areas. Later, proposals were formulated for Washington D.C. in 1956 – 1959, St. Louis in 1959, and Milwaukee in 1970 (Levinson et al., 2003; Wirasinghe et al., 2013). In 1969, the early concept of busways was employed on the Henry G. Shirley Memorial Highway in Northern Virginia, USA (Grava, 2003). Though on-site, the actual construction of an exclusive busway first happened in 1972 for a route length of 7.5 km known as "Via Expresa" in Lima, Peru. In 1973, Runcorn, United Kingdom, started its first busway corridor serving 22 km, which played a remarkable part in reforming urban development. At the same time, El Monte Busway in Los Angeles, USA, was constructed with a route length of 11 km (Wright, 2007).

The first actual BRT system was employed in Curitiba in 1963, while dedicated bus lanes were not functional until 1974 (Rabinovitch & Leitman, 1996). The BRT system in Curitiba is a successful example of integrated land use and transport to attain environmentally friendly urban development. However, the modern BRT system started operating in high-demand lower-income districts on the city's fringe in 1974. The initial busway system progressively grew to an innovative BRT system with five busways corridors and integrated with widespread feeder and inter-district buses in 1979 (Deng & Nelson, 2011). It has bi-articulated busses and tube stations to expand the corridor's capacity. The 25 m long buses operated on median exclusive ways with a carrying capacity of 260 passengers each (Menckhoff, 2005), as shown in **Figure 2.3**. Moreover, since the 1960s, the policymakers had the motivation to manage the city's growth by integrating land use, transport, and environmental preservation, adopting bus transit as their crucial tool (Nikitas & Karlsson, 2015). Later, the other Brazilian cities have shadowed this model including São Paulo in 1975, Goiânia in 1976, Porto Alegre in 1977, Belo Horizonte in 1981 (Maeso-gonzález & Pérez-cerón, 2014; Meirelles, 2000).

Figure 2.3 Curitiba BRT with buses and tube station. *Source:* Karl Fjellstrom, Far East Mobility

Another successful BRT system was TransMilenio in Bogotá operated in 2000. It was adapted as a long-term sustainable transport strategy to stimulate public transit use, cycling, and walking. It included articulated buses, exclusive bus lanes, enhanced stations, an advanced control system, fare collection via a smart card, and economical for low-income passengers. Feeder services integrated with TransMilenio extended to outer areas of the city. It has significantly improved travel time saving, passenger satisfaction, accident reduction, and reduced emissions (Cain et al., 2007). **Figure 2.4** shows Bogotá's TransMilenio BRT system with busways and stations.

Figure 2.4 Bogotá TransMilenio with busways and stations. *Source:* Karl Fjellstrom, Far East Mobility

Several cities in the world have customized the operationalized framework of Curitiba for developing BRT corridors, including Quito in 1995, Los Angeles in 2000, Mexico City in 2003, Jakarta in 2004, Beijing in 2005, Istanbul in 2008, and Guangzhou in 2010, to mention just a few (Nikitas & Karlsson, 2015). BRT is a bus mode that is being progressively used across the globe (Wirasinghe et al., 2013).

Almost 181 cities around the globe have implemented the BRT system, which is represented in **Figure 2.5**. BRT runs around 368 dedicated bus corridors, totaling 4,675 km. The BRT system benefited almost 31 million passengers daily (see **Figure 2.6**). The increasing number of BRT worldwide indicates that urban leaders realize the potential advantages of BRT for increasing sustainable urban mobility. From Curitiba, the BRT system has expanded globally with 368 dedicated lanes. Brazil only has 114 of these routes. The highest concentration of BRT is seen in Latin America. Moreover, Asia is evolving as the next significant market for the BRT system, including China and India. **Figure 2.7** shows the evolution number of cities and km per decade. Around the globe, 40 cities are expanding their BRT system. Interestingly, BRT is in the planning phase or under construction in 112 cities (see **Figure 2.8**). Moreover, Pakistan's BRT system operates in five big cities (Lahore, Karachi, Islamabad-Rawalpindi, Peshawar, and Multan), totaling 177 km.

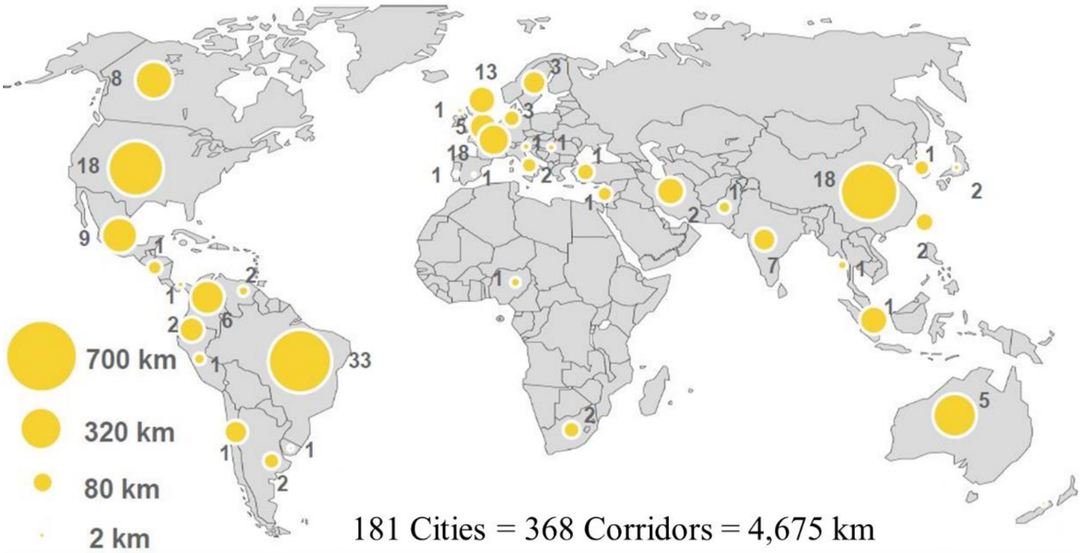


Figure 2.5 Number of cities and length (km). *Source:* www.brtdata.org

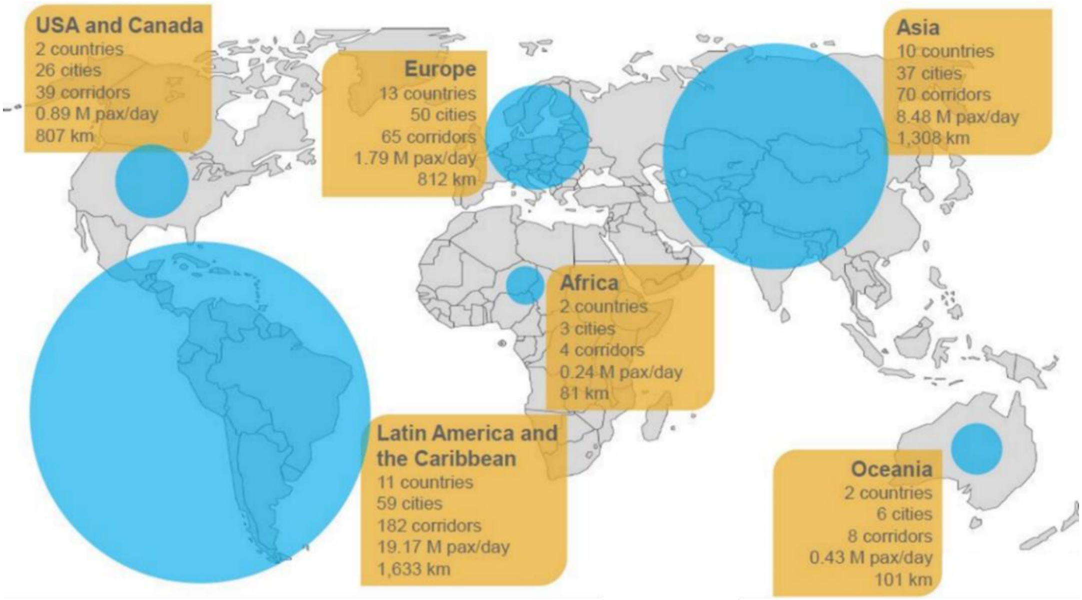


Figure 2.6 Number of passengers per day. *Source:* www.brtdata.org

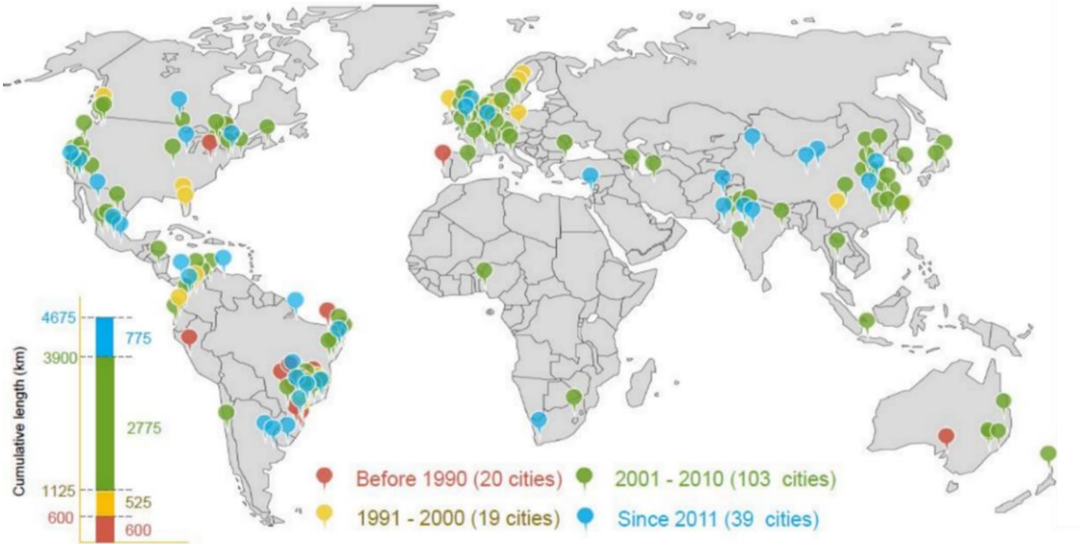


Figure 2.7 Evolution number of cities and km per decade. *Source:* www.brtdata.org

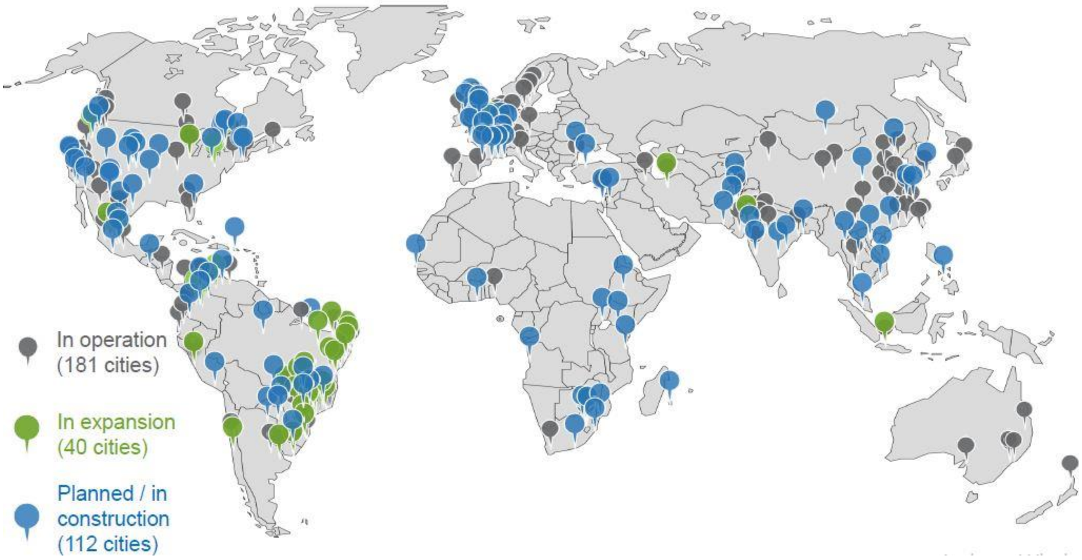


Figure 2.8 BRT under planning or construction around the globe. *Source:* www.brtdata.org

2.2.3. Benefits of bus rapid transit

BRT is frequently interconnected with positive economic, environmental, and social benefits. It has a dominant impact in supporting sustainable urban growth and new economic urban development around stops and along the corridors (Cervero & Kang, 2011; Munoz-raskin, 2010; Rodríguez & Mojica, 2009; Rodriguez et al., 2016). BRT stimulated TOD with higher residential densities, high levels of land use mix, and shorter trips distances to the destination (Currie, 2006; Wirasinghe et al., 2013). TOD outcomes in enhanced accessibility to the job and other services. Wright (2007) listed the direct benefits of BRT offered to the world's developing cities in **Table 2.1**. But, these benefits are context dependents.

Table 2.1 Benefits of BRT. *Source:* Wright (2007)

Benefits	Description
Economic	• Reduced travel times • More reliable product deliveries • Increased economic productivity • Increased employment • Improved work conditions
Social	• More equitable access throughout the city • Reduced accidents and illness • Increased civic pride and sense of community
Environmental	• Reduced emissions of pollutants related to human health (i.e., CO, SOx, NOx, particulates, CO_2) • Reduced noise level
Urban form	• More sustainable urban form, including densification of major corridors • Reduced cost of delivering services, such as electricity, sanitation, and water
Political	• Delivery of mass transit system within one political term • Delivery of high-quality resources that will produce positive results for virtually all voting groups

2.3. Transit-oriented Development

2.3.1. Basic concept of transit-oriented development

The concept of "sustainable development" was first proposed in a special report, "Our Common Future," issued by the United Nations in 1987. Sustainable development of urban transportation needs coordination between land use and transportation (Wu et al., 2011). Transit-oriented Development (TOD) establishes the integration between land use and transport to produce more sustainable communities (Singh et al., 2012). Generally, the "T" in TOD states the following modes: Mass Rapid Transit (MRT), Light Rail Transit (LRT), and Bus Rapid Transit (BRT). Meanwhile, the BRT system has a small opening investment and less execution time than MRT and LRT. More cities worldwide consider BRT a rapid transit mode to encourage TOD (Wu et al., 2011).

The concept of TOD was first developed in 1993 by Peter Calthorpe in "The Next American Metropolis." He defined TOD as a "mixed-use community within average 2000-feet (600m) walking distance of a transit stop and core commercial area. TODs mix residential, retail, office, open space, and public uses in a walkable environment, making it convenient for residents and employees to travel by transit, bicycle, foot, or car" (Calthorpe, 1993). He observed TOD as the complete substitute for urban sprawl, offering a walkable neighborhood and an ecological, social, and economic basis for regional development. **Figure 2.9** illustrates the concept of Calthorpe's Transit Oriented Development. In simple words, TOD is a process associated with mixed-use development around transit stops with high-quality and high-efficiency public services (Dittmar et al., 2004).

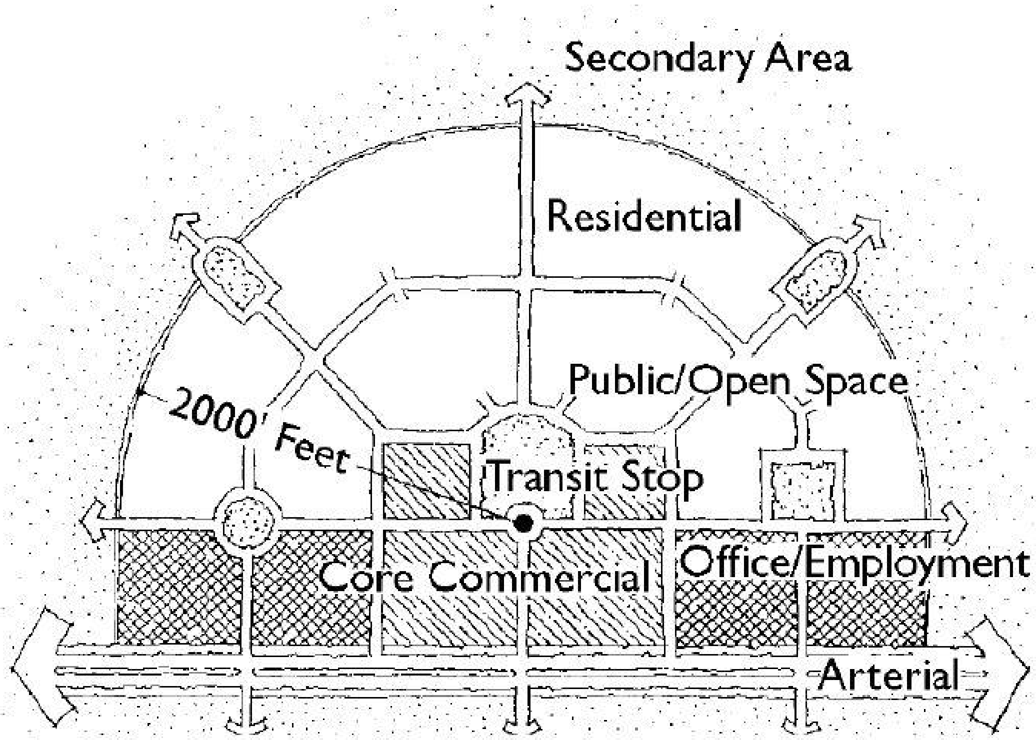


Figure 2.9 Calthorpe's TOD diagram. *Source:* Calthorpe (1993)

2.3.2. Principles of transit-oriented development

TOD is trying to transform travel behavior by encouraging transit and non-motorized use while reducing the use of cars (Cervero et al., 2004; Kamruzzaman et al., 2016; Kwoka et al., 2015; Nasri & Zhang, 2014; Noland & Dipetrillo, 2015; Venigalla & Faghri, 2015; Zamir et al., 2014). As a result, TOD areas can extend traffic convenience, expand economic development, and enhance air quality and transit ridership (Hess & Lombardi, 2004). On this foundation, the principles of TOD are well-known for new urbanism and smart growth. These are density, diversity, walkability, public and non-motorized transportation, affordable housing alternatives, and open spaces. In detail, Calthorpe (1993) presented the seven fundamental principles of TOD are;

- Compact and transit-supportive growth at a regional level
- Commercial, job, housing, civic, and parks use within walking distance from transit stations

- Pedestrian-friendly street network
- A mix of housing types, densities, and costs
- High-quality open spaces preservation, sensitive habitat, and riparian zones
- Public spaces focus on building orientation and neighborhood activity
- Redevelopment and infill along transit corridors within existing neighborhoods

2.3.3. Scales for transit-oriented development planning

TOD planning can be incorporated into different levels, from the macro scale (region) to the micro scale (station area or neighborhood). Initially, Calthorpe (1993) suggested two categories of TOD; urban TOD and neighborhood TOD. Urban TOD is associated with rail transit stations offering intensified commercial uses, higher employment opportunities, and higher-density residential uses. They are common spaces between 0.5 – 1.0 miles. Neighborhood TOD is associated with local bus or feeder service within ten minutes of transit travel length to a rail and BRT transit. They are commonly lower in density and focus mainly on local and residential uses. Zimbabwe & Anderson (2011) formulated four scales of TOD planning, including region, corridor, station area, and project.

2.3.4. Advantages and disadvantages of transit-oriented development

TOD strategies have been proven advantageous for the community, environment, and local economy (Higgins & Kanaroglou, 2016). TOD areas produced fewer private vehicle trips, less air pollution, reduced infrastructure and transportation costs, increased transit ridership, increased land and property values, improved accessibility to employment, and increased walking and biking (Zimbabwe & Anderson, 2011). TOD also offered mobility alternatives, enhanced public safety, reduced VKT, preserved land and open spaces, and encouraged economic development and affordable housing (Hess & Lombardi, 2004). Moreover, it tends to raise the sense of community in the neighborhoods (Newman & Kenworthy, 1998). BRT-based TOD proposes exploiting the advantages that rapid mass transit can offer cities, such as improving accessibility, increasing agglomeration economies, organizing urban development, addressing regional equity, and reducing personal vehicle dependency. Thus, BRT has specific features that encourage the potential of TOD (Munoz & Seekins, 2016). TOD provides many benefits in American cities, presented in **Figure 2.10**, that can vary in developing countries (HNTB, 2016).

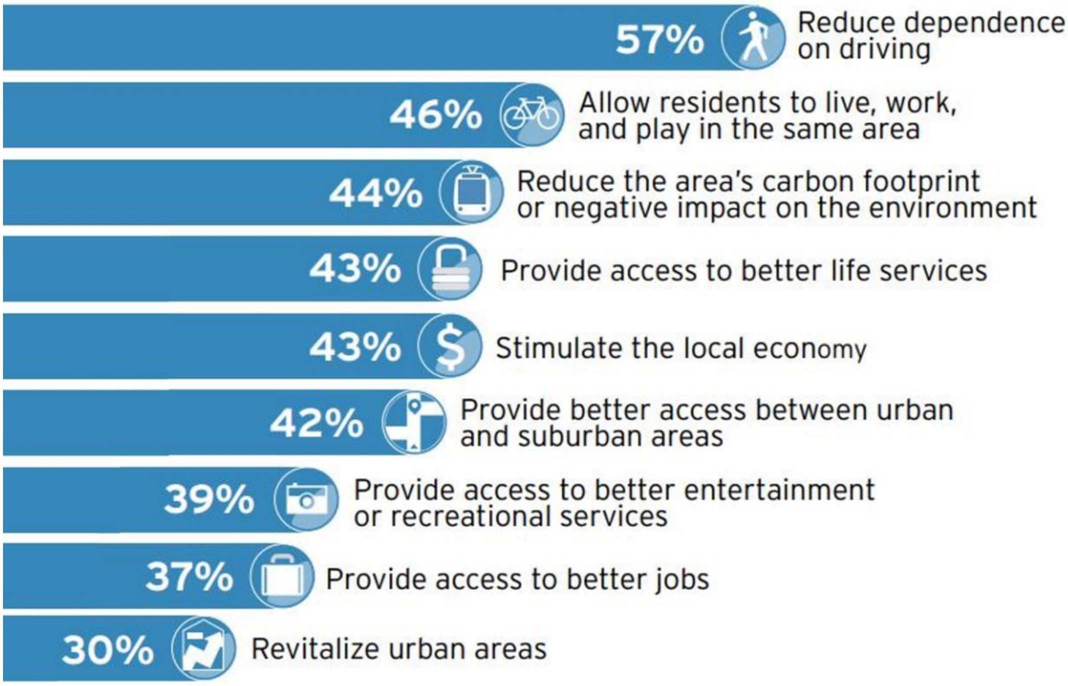


Figure 2.10 Advantages of TOD. *Source:* HNTB (2016)

On the other hand, TOD has some disadvantages. For example, Hess & Lombardi (2004) said that TOD is mainly carried out for greenfield sites and new suburban areas, which might be a basis for population declines and limited development in inner regions of the cities. In the USA, TOD is criticized as the population densities are higher than what residents can bear, and some measures, such as gridiron street network and mixed-use development, can support private vehicle use (Gilat & Sussman, 2003). Other disadvantages include higher construction costs, longer development time, and higher pressure on the rate of return (Venner & Ecola, 2007).

2.3.5. Typologies of transit-oriented development

Several criteria and indicators have been used in the literature to evaluate TOD. Many researchers have tried to categorize TOD using several elements of the transit station areas. Cervero & Kockelman (1997) established 3Ds of urban structures that influence travel behavior, including density, diversity, and design, as the main features of TOD. Later, two more dimensions were added, namely distance and destination, expanding to 5Ds (Ewing & Cervero, 2001). After that, Ewing and Cervero (2010) suggested 7Ds, added demand and demographics in 5Ds. These typologies help encourage TOD planning to formulate strategies for particular station areas (Ibraeva et al., 2020). Some studies have evaluated the TOD using 3Ds in Dhaka and Melbourne (Aston et al., 2016; Haquea et al., 2019).

Similarly, 5Ds used by various researchers in their studies to measure TOD (Islam et al., 2018; Dirgahayani & Choerunnisa, 2018; Zhang et al., 2020; Teklemariam & Shen, 2020; Liu, Zhang, & Xu, 2020; Niu et al., 2021; Su et al. 2021).

As for the node–place model was developed by Bertolini in 1996 based on railway stations and their surrounding areas (Bertolini, 1996). This model offers an analytical framework to delineate transit (node) and neighborhood (place), location features, and their associations. Bertolini (1999) presented a model of the node-place typology of TOD for train stations within a 700 m catchment in Amsterdam and Utrecht in the Netherlands (see **Figure 2.11**). The node index was developed by taking connectivity, diversity, and frequency of public transport services. This model established the place index by combining the number of dwellers, workers, and land use diversity. Four TOD typologies of train stations were identified, namely accessibility, stress, dependency, and unsustainable places. It offers a way to assess the land use characteristics and transportation supply simultaneously; both features are crucial for the TOD concept (Ibraeva et al., 2020). In various studies, the node–place model has been applied for TOD classification around transit stations (Balz & Schrijnen, 2009; Bertolini, 1999; Chorus & Bertolini, 2011; Ivan et al., 2012; Reusser et al., 2008). Many existing studies extended the original node place model. For example, node place model combined with pedestrian catchment area (Vale, 2015), design characteristics (Lyu et al., 2016; Vale et al., 2018; Zhang et al., 2019), demand and morphology (Liao & Scheuer, 2022), and background traffic (Olaru et al., 2019).

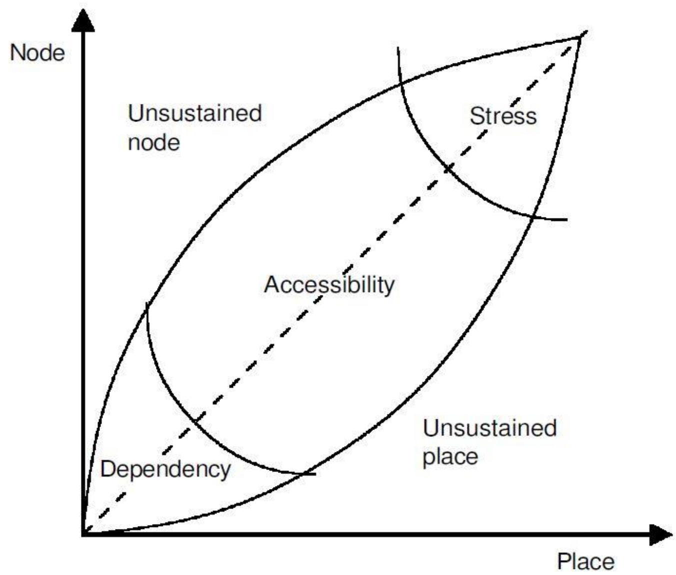


Figure 2.11 Node place model. *Source:* Bertolini, 1999

Apart from the node place model, some researchers proposed the TOD Index to classify the current level of TOD (Singh et al., 2014; Singh et al., 2017). The existing typologies of TOD were seldom validated against the actual performance of the transit stations in the context of mode choice, ridership, and private vehicle ownership. Kamruzzaman et al. (2014) suggested TOD typologies and validated whether they revealed the travel behavior commemorated at the transit station areas. They used cluster analysis that showed four TOD typologies: residential TOD, potential TOD, activity center TOD, and non-TOD areas. More recently, Huang et al. (2018) proposed three types of TOD: urban residential, urban mixed core, and suburban residential using correspondence analysis and latent class cluster analysis for the Arnhem Nijmegen City Region.

Moreover, “New Transit Town” was the best summary of Calthorpe and Poticha’s guidelines in “The Next American Metropolis” (Dittmar & Ohland, 2004). Dittmar & Poticha (2004) suggested six general typologies for TOD based on Calthorpe’s work are presented in **Table 2.2**. They help in planning a new TOD or assessing existing TOD.

Table 2.2 General typology for TOD. *Source:* Dittmar & Poticha (2004)

TOD Type	Land-Use Mix	Minimum Housing Density	Housing Type	Scale	Transit Modes	Frequencies
Urban Downtown	Primary office center Urban environment Multifamily housing Retail	>60 units/acre	Multifamily Loft	High	All modes	<10 min
Urban Neighborhood	Residential Retail Class B commercial	>20 units/acre	Multifamily Loft Townhome Single-family	Medium	Light-rail Streetcar Rapid bus Local bus	10 min peak 20 min off-peak
Suburban Centre	Primary office centre Urban environment Multifamily housing Retail	>50 units/acre	Multifamily Loft Townhome	High	Rail Streetcar Rapid bus Local bus Paratransit	10 min peak 10-15 min off-peak
Suburban Neighborhood	Residential Neighborhood Retail Local office	>12 units/acre	Multifamily Townhome Single-family	Moderate	Light-rail Rapid bus Local bus Paratransit	20 min peak 30 min off-peak
Neighborhood Transit Zone	Residential Neighborhood retail	>7 units/acre	Townhome Single-family	Low access to a center	Local bus Paratransit	25-30 min Demand responsive
Commuter Town Centre	Retail centre Residential	>12 units/acre	Multifamily Townhome Single-family	Low	Commuter rail Rapid bus	Peak service Demand responsive

2.4. Case Studies on BRT-based TOD

2.4.1. Curitiba, Brazil

Curitiba, Brazil, is one of the successful examples of TOD based on the BRT system (Rodriguez & Vergel-tovar, 2017). It is the capital city of the Parana state. The city's population was 1.9 million in 2019 (Zhang, 2022), with a total land area of 435 km^2 and a population density of almost 4365 per km^2 (ICLEI, 2016). The multimodal transit networks comprising BRT and conventional buses serve the city's residents well. More than 80% of the residents prefer to use BRT for everyday activities (Zhang, 2022).

Curitiba is one of the well planned and sustainable cities in the world. Curitiba has grown along comprehensive radial axes and linear corridors served by BRT to make a city for people rather than cars. The city has a system of 390 routes with 2,000 vehicles carried out by 2.1 million daily travelers, twice as many as in 1990. The planning effort started to integrate land use and transport in the 1960s. In 1964, Curitiba's city called a planning competition, "Curitiba de Amanhã" (Curitiba of Tomorrow), to overcome the city's development challenges. The winning team proposed a master plan with five structural axes radiating from the city center (see **Figure 2.12**). Zoning plans were considered a core part of the development vision of Curitiba. They have various zoning types, such as unique codes on density, land use, FAR, and heights concerning BRT corridors. The government of Curitiba has enforced medium and large-size development near BRT routes (ICLEI, 2016; UN-Habitat, 2013; Zhang, 2022).

The design has been centered on a 'trinary' idea, through which three parallel roadways are aligned by higher density and mixed-use development along the BRT corridor (see **Figure 2.13**). This figure shows that the mainline is dedicated to BRT circulation, stops, and slow traffic. The other two parallel one-way roads (traffic flow = 60 km/hr) are devoted to high-speed traffic. The first two floors of the building are reserved for retail and businesses along the BRT corridors. Adding upper-level housing permits land owners to density bounces towards vertical mixing of uses within the buildings. As a result, higher density development produced by the trinary design increased transit ridership. Mixed-use development has also generated trips from residences to the trinary corridors in a city (Cervero, 2013; Suzuki et al., 2013; UN-Habitat, 2013). In Curitiba, the share of transit trips is almost 45% higher than in Latin America (Cervero, 2013).

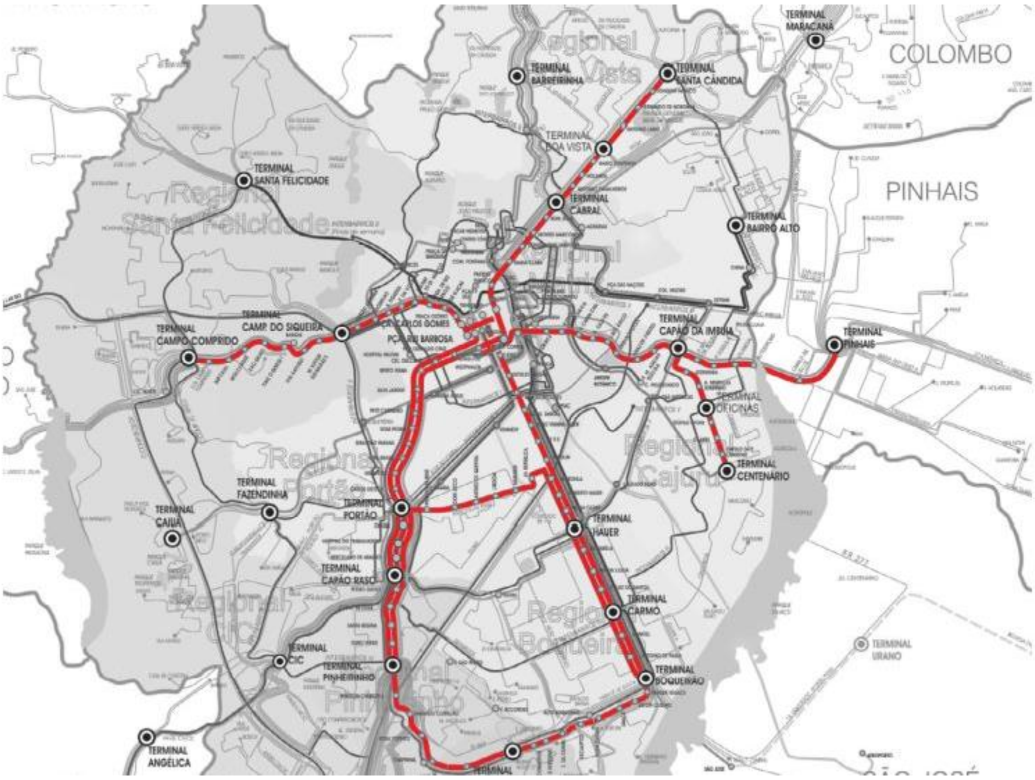


Figure 2.12 Curitiba's Axes with high-density areas marked in red. *Source:* ICLEI (2016)

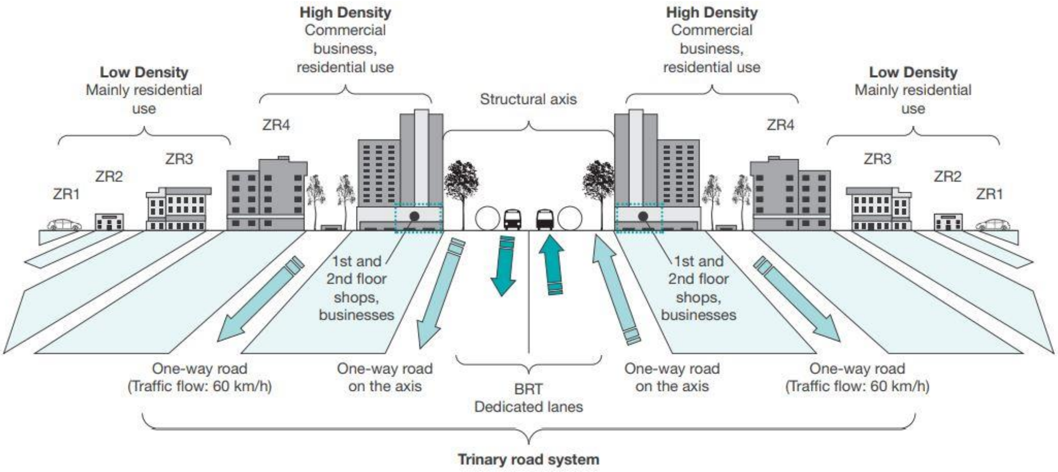


Figure 2.13 Transit-oriented Development in Curitiba. *Source:* UN-Habitat (2013)

Mayor Ivo Arzua established the Institute for Research and Urban Planning of Curitiba (IPPUC) in 1965 as a Municipal Independent Authority for coordinating TOD in the city. In 1972, the city developed a hierarchical transit network called the Integrated Transit Network (RIT) with several types of color buses according to route classification (ICLEI, 2016). **Figure 2.14** shows the hierarchical bus network with various colors of buses (Nakamura et al., 2017). The red color indicates the buses on the structural axes. The orange color represents the feeder lines connected to the structural axes. The green color shows the interchange connectors buses. Silver color buses operated parallel to red and green buses with limited stops.

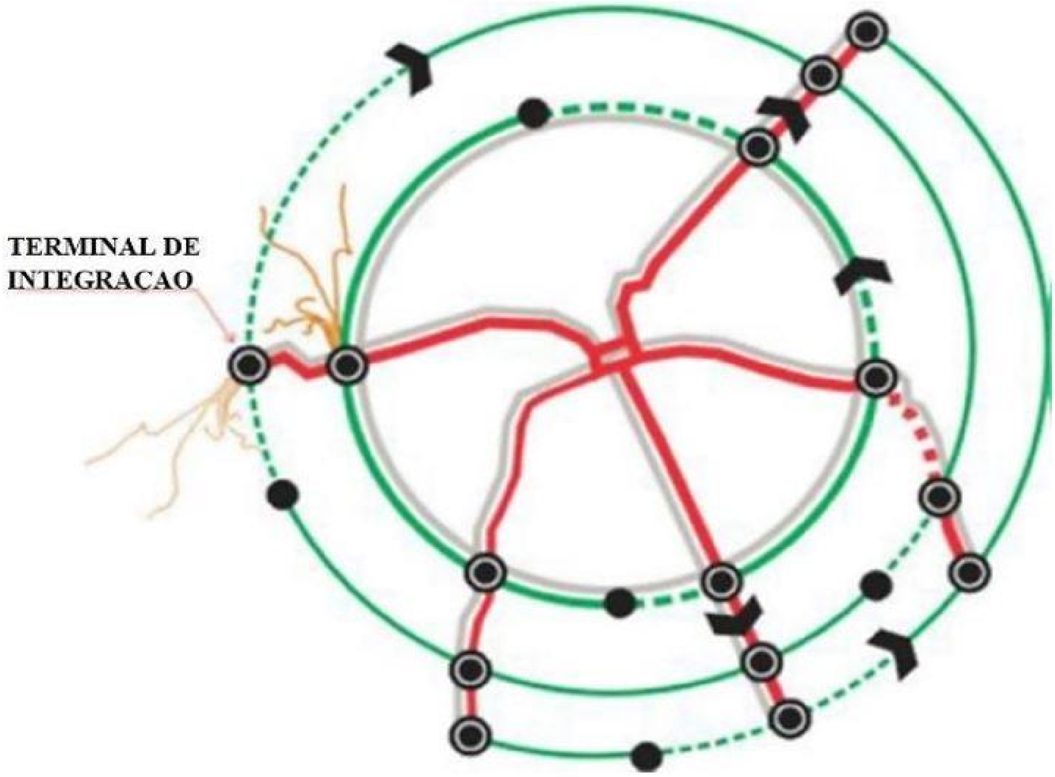


Figure 2.14 Hierarchical transit network in Curitiba. *Source:* Nakamura et al. (2017)

In Curitiba, the first pedestrianized street was connected to the BRT station in 1972 (Nakamura et al., 2017). The city has formulated a strategic plan known as PlanCal for sidewalks. This plan comprises guidelines to restore a city's sidewalks to increase accessibility, safety, and drainage infrastructure of 119 km of existing sidewalks and 115 km of new sidewalks across the city (ICLEI, 2016). As for bicycles, the total of off-street tracks was 114 km long, shared or segregated with pedestrian paths, which shows an example of a bicycle-friendly city. However, only 2% of the population used a bicycle daily (Duarte et al., 2014). However, bicycle tracks were poorly integrated with the BRT system in Curitiba. Only 2 out of 22 BRT stations have bicycle parking, even though bicycle lanes expanded to six stations (Duarte & Rojas, 2012). Nevertheless, the city has approved a plan called "Plano Director Cicloviario" for expanding cycle infrastructure by 300 km. Almost 25 km of cycle lanes are created along BRT corridors. This cycle-based infrastructure has encouraged electric bike-share systems in BRT stations and corridors (ICLEI, 2016).

In short, TOD in Curitiba enhanced low emission, sustainable mobility, lessened travel lengths, and reduced the use of private vehicles (ICLEI, 2016). Nonetheless, some drawbacks have appeared in BRT-based TOD in Curitiba since 2004, including long queues of passengers in tube-styled BRT stops, car-oriented policies leading to traffic congestion, less importance provided to traffic signals for the public buses, problems in platform usage, training of staff members, administration of operators, traffic management, and rules for automobile use, longer green lights operated for cars and short for public buses, and many new car parking garages were developed in the city center (Nakamura et al., 2017).

2.4.2. Bogotá, Colombia

Bogotá is the capital city of Colombia, with a total population of 7.2 million people in 2018, having an urban area of almost 380 km^2. Bogotá is a monocentric city characterized by a high level of mixed uses, high population density, higher public transit and walking rate, and fewer automobile ownership (Guzman et al., 2021). In the last 30 years, the city population has increased two times, whereas it is 2.8 times in the city's suburban areas (Guzman et al., 2017). Bogotá's city comprises 112 zonal planning units (UPZ). UPZ are territorial units used for urban development (Guzman & Bocarejo, 2017). The lower-income people lived in southern and western peripheral zones with higher population densities. In contrast, high-income people lived in the central district and northern side located zones with low population density (Guzman et al., 2021).

Bogotá has gained a reputation for its first-class TransMilenio BRT, transit-integrated social housing, linked transportation demand management (TDM) measures, and the longest pedestrian path in the world (Suzuki et al., 2013). TransMilenio BRT system is renowned as the "gold standard" with a ridership of 1.5 million per day. At the same time, the BRT carries a capacity of almost 45,000 travelers per direction per hour. Moreover, the share of BRT trips is 74% of public transport trips (Cervero & Dai, 2014).

The planners designed a trunk-feeder system for BRT and feeder buses. This system is marked by exclusive lanes and segregated BRT operation on arterial roads and feeder buses operated on regular roads that connected end of the line stops (Cervero & Dai, 2014). Most BRT routes targeted low-income people, and feeders routes performed in the peripheral areas with a service coverage of 200 km at no charge (Suzuki et al., 2013). The BRT system was constructed over three periods starting from the end of 2000. It has 6013 regular buses and 1984 BRT buses. TransMilenio BRT system contains 139 stops, 9 terminal stops, 13 trunk corridors, and a 112 km route length, as shown in **Figure 2.15**. Public transit significantly reduced travel time, particularly in low-income zones. Now, the BRT system carries around 2.4 million passengers daily (Guzman et al., 2021).

Meanwhile, the city's population has risen by 21% after the BRT operation. Building density has grown across the city; however, more increase was farther from the BRT areas, near end stops, and some peripheral feeder lines. The mean rise in building densities was 6% for the surroundings influenced by trunk and feeder routes, while building density increased by almost 10% for the entire city (see **Figure 2.16**). Less densification was observed for Phase I compared to the other phases of BRT because Phase I was constructed in built-up areas where vacant land was unavailable. The densification for commercial and residential use was 8% for both Phase II corridor and feeder line surroundings, which is relatively higher compared to Phase I and III by 5.5% and 4.5%, respectively. The development patterns advocate that the market was open in areas where more vacant land was available (Suzuki et al., 2013).

Nevertheless, this BRT system encouraged mobility rather than integration with land use. Moreover, the system in busy roadway medians limited land provisions for supporting TOD and caused an unpleasant pedestrian environment close to the stops. Small incentives for land owners to redevelop plots and proactive planning for BRT station areas reduced TOD (Cervero & Dai, 2014). Moreover, private developers have less interest in redeveloping or improving BRT station areas due to a lack of vacant land. While they have constructed residential and commercial buildings in the peripheral areas or nearby end stops due to the availability of vacant land. This development form marked a relationship between land use change and different phases of BRT construction (Suzuki et al., 2013).

Moreover, Bogotá has implemented several initiatives regarding TDM, from physical development (i.e., pedestrian and bike paths) to regulations and policies for less use of private vehicles. For example, the city started the construction of the biggest bike route in Latin America, having a length of 344 km, called cicloruta (Suzuki et al., 2013). Since 1974, road segments have closed for automobiles from 7 am to 2 pm on weekends and holidays, making around 128 km of bike and pedestrian paths called Ciclovia. Almost 0.6 million to 1.4 million people join this program every Sunday and holiday (Parra et al., 2021). In 1998, Bogotá started the peak and license plate program called pico y placa, which controls car use during peak hours in the morning and evening by using the last digit of the license plate. Other initiatives include car-free days called sin mi carro started in 2000 to teach the public about alternating public transport use. It is the biggest car-free weekday event globally and has now removed almost 1.5 million automobiles from the roads (Suzuki et al., 2013).

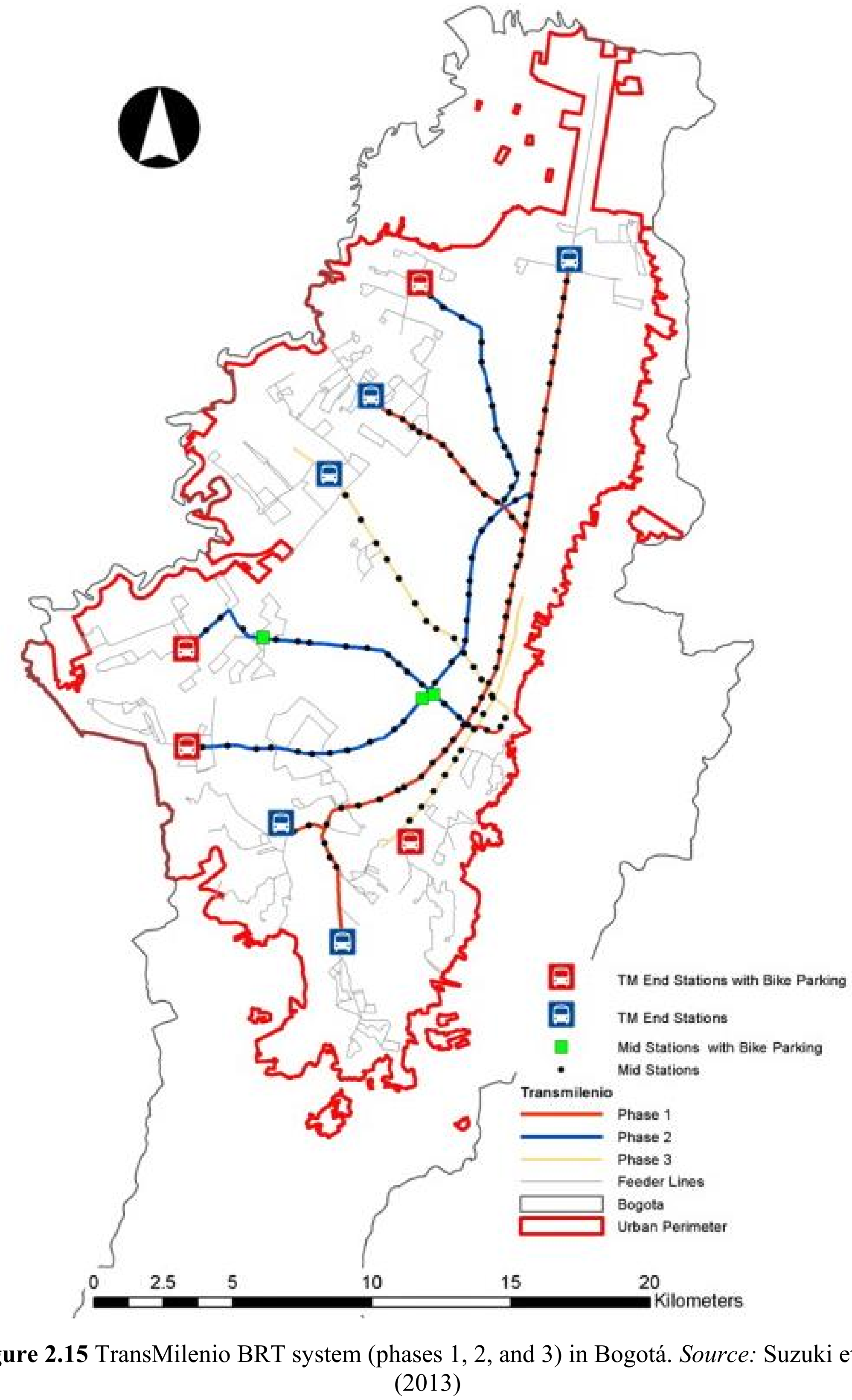


Figure 2.15 TransMilenio BRT system (phases 1, 2, and 3) in Bogotá. *Source:* Suzuki et al. (2013)

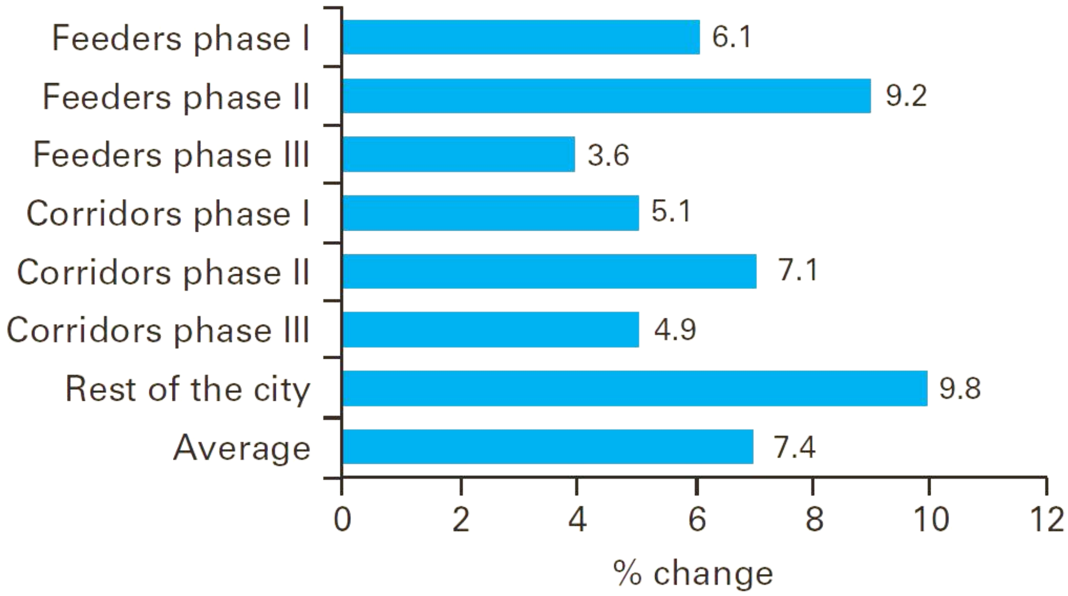


Figure 2.16 Changes in building density in areas influenced by TransMilenio BRT in Bogotá. *Source:* Suzuki et al. (2013)

In Bogotá, non-motorized use has been encouraged by developing pedestrian and public spaces. Firstly, sidewalks and parks were cleared by eliminating unlawful settlements and parking. After that, street furniture, pavement, and greenery were provided to make a more pedestrian-friendly environment. Bike parking spaces were created on BRT stations. Nowadays, greenways (alamedas) are increasing for the exclusive use of cycling and walking, including 17 km Alameda Porvenir, the largest pedestrian track in the world. It links TransMilenio, parks, libraries, and affordable housing. In addition, private land developers have added to the initiative by opening small shops and cafes to generate beautiful open spaces (Suzuki et al., 2013). Apart from TDM initiatives, the Metrovivienda offers affordable housing close to the BRT by integrating land use and transport. But, the project sites are in the peripheral areas (see **Figure 2.17**). Almost 45,000 housing units were sold to low-income people between 2001 and 2007 (Gilbert, 2009).

Though several studies have investigated the effects of Transmilenio on urban development around BRT stops and on vacant lands for the potentials of land use, density, land values, and built-up areas (Bocarejo et al., 2013; Rodriguez et al., 2016; Suzuki et al., 2013). Gilat & Sussman (2003) found that all these events cannot be provided as evidence of TOD in Bogotá. Suzuki et al. (2013) stated, "Bogotá continues to suffer from a limited long-term vision, regulations that set uniform densities, and little formal TOD guidance."

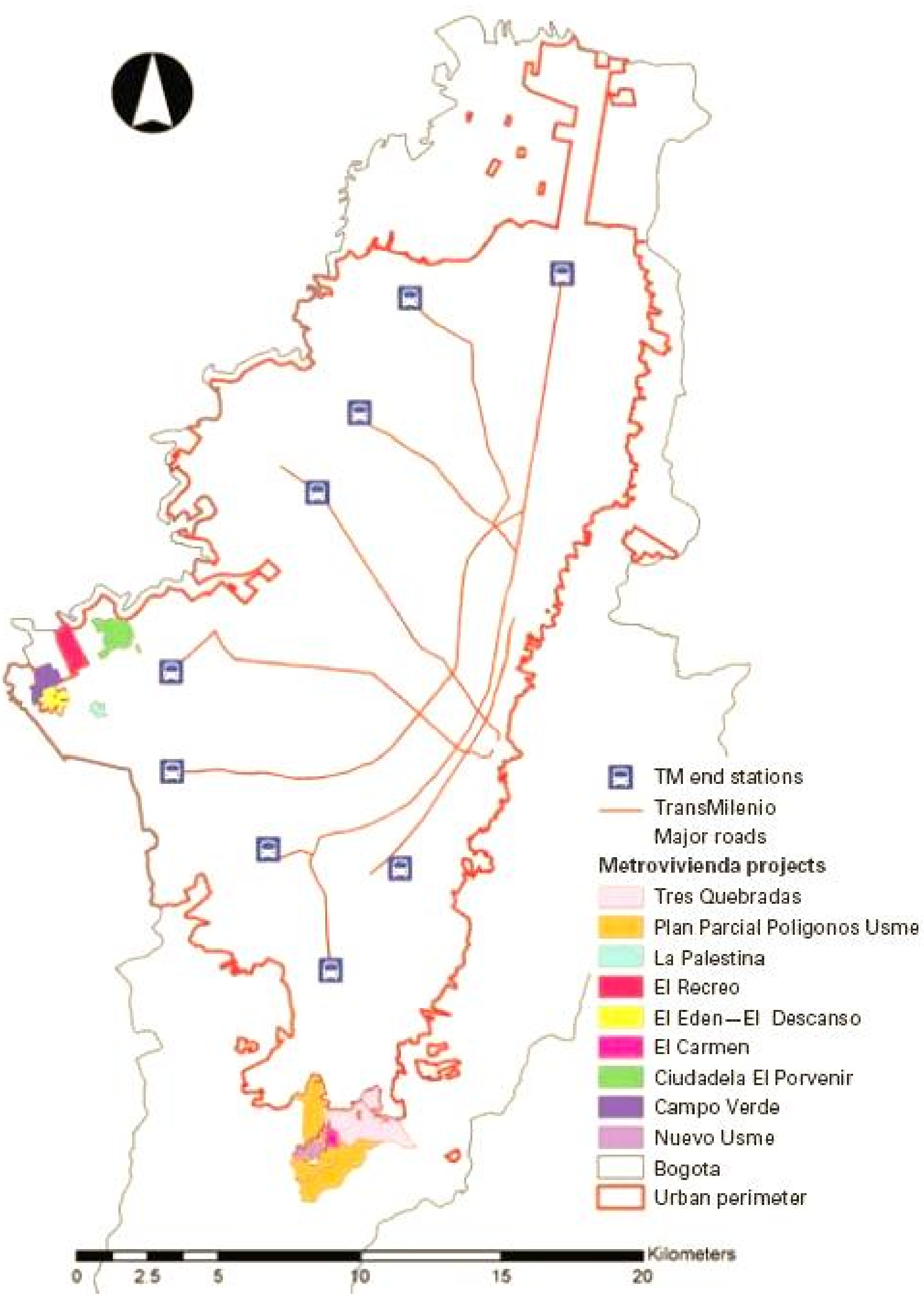


Figure 2.17 Metrovivienda affordable housing development sites in Bogotá. *Source:* Suzuki et al. (2013)

Bogotá's case study shows that the city has not formulated the BRT station areas plans and policies, changed zoning, and initiate complementary enhancements to induce private developments to encourage TOD (Bocarejo et al., 2013; Cervero & Dai, 2014). Moreover, (Suzuki et al., 2013) pointed out some obstacles to TOD, such as weak coordination, inefficiencies of the institutions, inadequate building density plans, and absence of station area design around BRT.

2.5. Conclusion

BRT is a high-quality bus-based transit system that delivers fast, comfortable, and cost-effective services at metro-level capacities. Currently, BRT is operating in more than 181 cities of the world. BRT system in Curitiba is a successful example which started in 1974 and integrated land use and transport to attain environmentally friendly urban development. Another successful BRT system was TransMilenio in Bogotá began in 2000. It was adapted as a long-term sustainable transport strategy to stimulate public transit use, cycling, and walking. Globally, several cities consider BRT a cost-effective mode offering high-quality transit service to fulfill their needs owing to small opening investment and less execution time than rail transit. Moreover, many cities worldwide consider BRT a rapid transit mode to encourage TOD. BRT-based TOD in Curitiba enhanced low emission, sustainable mobility, lessened travel lengths, and reduced the use of private vehicles. Whereas Bogotá's city has not formulated the BRT station areas plans and policies, changed the zoning, and initiated complementary enhancements to induce private developments to encourage TOD.

CHAPTER 3: PREVIOUS RESEARCH STUDIES

3.1. Introduction

TOD is not dependent only on the heavy rail transit (HRT) system but also depends on light rail transit (LRT) and bus rapid transit (BRT) (Knowles et al., 2020). BRT has remarkable potential to stimulate TOD (Chalermpong & Ratanawaraha, 2015), which is expected to change residents' travel behavior around transit station areas. TOD has several possible benefits, including encouraging transit and non-motorized use, decreasing car usage and congestion, and increasing job accessibility (Kamruzzaman et al., 2013; Sung & Oh, 2011). This chapter draws attention to previous research studies. It comprises three parts. The first part is about the impact of transit/BRT on urban development in shaping TOD, which offers studies from developed and developing nations on the effects of transit on urban development. The second part provides evidence of the impact of transit/BRT on travel behavior in TOD and non-TOD areas from developed and developing countries. The third part concerns barriers and challenges regarding TOD with transit.

3.2. Impact of Transit in Shaping TOD around Stations

The studies on the influence of transit on urban development patterns have concentrated primarily on heavy and light rail transit systems—new public transit impact land use patterns in two different means. On the one hand, similar to new highway investment, lessening travel length due to the new public transit system may allow people to reside away from the city center, backing urban sprawl. On the other hand, a public transit system might influence dense urban development around station areas and along the corridors because of enhanced accessibility to those regions, acting as a trade-off to continued urban sprawl (Handy, 2005; Jun, 2012).

The virtuous cycle between transit infrastructure investment and land development refers to how transit investments craft accessibility advantages for inhabitants and land owners (Rodriguez et al., 2016). Since the number of land plots benefiting from transit infrastructure is bounded, access advantages are likely to be capitalized by higher property values, land use change, renewal, and redevelopment. This virtuous cycle backs up BRT's potential to spur urban development in station areas and along the corridors.

A considerable amount of literature has explored the influence of rapid rail transit, particularly LRT and Metro, on land-use changes (Bhattacharjee & Goetz, 2016; Higgins et al., 2014; Hurst & West, 2014; Sahu, 2018; Tang et al., 2020; Wu et al., 2020; Zhao & Shen, 2019), density (Masoumi & Shaygan, 2016; Waintrub et al., 2016), and accessibility (Caset et al., 2018; Mulley et al., 2016; Yang et al., 2019; Zhai et al., 2021; Zhang et al., 2020) associated with transit infrastructure. But, there is some contradictory research on the impacts of BRT on urban development patterns. Levinson et al. (2002) concluded that BRTs in Ottawa (Canada), Pittsburgh (USA), Brisbane (Australia), and Curitiba (Brazil) had positive impacts on land use patterns, while Vuchic (2002) found that the urban development effects of BRT were significantly lower as compared to light rail transit.

Regarding BRT, Bocarejo et al. (2013) found that Transmilenio BRT experienced a significant increase in density relative to zones where the system was not operating in Bogotá. A study conducted by Rodriguez et al. (2016) to investigate the land development impact of BRT around stations in Quito and Bogotá found a heterogeneous influence of BRT on land development which was, however, highly dependent on the local setting. Some BRT stations indicated a higher effect, while others had less growth. Bocarejo et al. (2013) also found that few shopping centers have been constructed close to the stations of Transmilenio BRT in Bogotá. They also demonstrated that BRT occurrence had not encouraged a more significant increase in commercial and residential land use. Jun (2012) determined the influence of BRT on development patterns in Seoul. They found that the BRT system has influenced a rise in development density in urban areas, playing a vital role in attracting firms from the outskirts into urban areas. Basheer et al. (2020) found that commercial activities and density have increased due to land-use conversions close to the BRT stations in Lahore. Similarly, Adeel et al. (2021) found diverse impacts on commercial, apartment, and mixed-use conversions of BRT Lahore. Zhou et al. (2016) stated that BRT has significantly shaped land use in Brisbane.

Deng and Nelson found that the impacts of BRT were positive on residential and commercial development in Beijing (Deng & Nelson, 2010). In addition, Deng & Nelson (2013) found that Southern Axis BRT in Beijing positively impacts high-density residential development around the station areas between 2005 and 2011. On the contrary, Thomas & Deakin (2010) identified that excess auto-oriented land uses along the BRT route, midblock crossings, absence of walking infrastructure, and parking problems were the main obstacles to the implementation of BRT-based TOD in Jinan, China. Mullins et al. (1990) studied the land use impact of the Houston BRT system and concluded that BRT influenced the land development around stations to a certain extent. Brown (2016) studied the neighborhood change around BRT orange line in Los Angeles, California, between 2000 and 2013. This study concluded that neighborhoods within a half mile of BRT stations had changed more than the areas situated 2 and 5 miles from the transit stations.

Some studies have examined the impact of metro transit systems on urban development in literature. Guan (2019) explored the spatial patterns of urban development for the metro system in Shanghai from 1994 to 2010 and concluded that high-rise buildings constructed after 2000 and structures within the urban core had more significant spatial proximity to metro stations within 500 m. Yang et al. (2020) identified the relationship between distance to metro stations and changes in floor area in Shenzhen between 2008 and 2014, finding that distance to metro station shows a threshold effect on development intensity. Moreover, they found that the metro transit system significantly predicts the changes in floor areas compared to other transport investments. Zhang & Wang (2013) found that mass transit investments positively influenced Beijing's urban land development for South Axis BRT. Tang et al. (2020) broadly examined the spatial distribution of development and land use characteristics within 500 m of metro stations between 1981 and 2017 in Hong Kong. They inferred that commercial-office development and business uses are the most preferred land uses within a metro catchment.

Notwithstanding several studies investigating the significance of the built environment for rail transit, not many have focused on BRT, particularly its assimilation with the surrounding area. BRT is a renowned strategy for evolving good transit networks, and it would be a sound transport alternative if it were connected with walkability in the neighborhood (Pezeshknejad et al., 2020). They concluded that convenient usage of BRT needs constructed walkway networks that provide various station ways in Tehran. Wu & Zhou (2022) measured the accessibility of metro stations in Tianjin and found that accessibility to the metro depends on the street network around stations. The summary of major findings of the impact of BRT on urban development is summarized in **Table 3.1**.

Table 3.1 Major findings of the impact of BRT on urban development

Author	Case study	Study focus	Major findings
Bocarejo et al. (2013)	Bogotá, Colombia	Impact of Transmilenio on density, land use, and land value	Significant increase in density relative to zones where the system was not operating Few shopping centers have been constructed close to the stations of Transmilenio BRT, but no significant increase in commercial and residential land use Had a positive impact on retail property price
Jun (2012)	Seoul, South Korea	Influence of BRT on development patterns	Influenced a rise in development density in the urban areas and attracted firms from the outskirts into urban areas
Rodriguez et al. (2016)	Quito and Bogotá, Colombia	Land development impacts around BRT stations	Heterogeneous influence on land development in both cities Few BRT stations indicated higher development, while others have less development
Deng & Nelson (2010)	Beijing, China	Impact of BRT on land development	Positive impact on residential and commercial development along the BRT corridor
Basheer et al. (2020)	Lahore, Pakistan	Landuse transformation, urban density, and economic impact of BRT	Commercial activities, urban densities, and economic activities have increased due to land-use conversions close to the BRT stations
Adeel et al. (2021)	Lahore, Pakistan	Impacts of BRT on land development patterns	Diverse effects on commercial, apartment, and mixed-use conversions
Zhou et al. (2016)	Brisbane, Australia	Shaping land use with BRT	Significantly shaped land use
Mullins et al. 1990)	Houston, USA	land use impact of the BRT system	BRT influenced the land development around stations to a certain extent
Brown (2016)	Los Angeles, California	Neighborhood change around BRT Orange Line	Neighborhoods within 800m of BRT stations have changed more than areas situated 2 and 5 miles from stations
Deng & Nelson (2013)	Beijing, China	Impacts of BRT on property development	Positive impact on high-density residential development around the stations
Thomas & Deakin (2010)	Jinan, China	Land use challenges to implement TOD along the BRT corridor	Excess of auto-oriented land uses, midblock crossings, absence of walking infrastructure, and parking problems were the main obstacles to the implementation of BRT-based TOD
Guan (2019)	Shanghai, China	Spatial proximity between metro stations and high-rise buildings	High-rise buildings constructed after 2000 and buildings within the urban core had more significant spatial proximity to metro stations
Yang et al. (2020)	Shenzhen, China	Influence of metro stations on land development	Distance to metro station shows a threshold effect on land development intensity
Zhang & Wang (2013)	Beijing, China	Impacts of mass transit (BRT) on land development	Positively influenced urban land development
Tang et al. (2020)	Hong Kong, China	Spatial distribution of development around metro stations	Commercial-office development and business uses are the most preferred land uses within a metro catchment

The past studies also investigated the effects of TOD on real estate prices, travel behavior, and community life (Abdi & Lamíquiz-Daudén, 2020; Duncan, 2011; Ibraeva et al., 2020). Much research has focused on examining the relationship between property values and BRT. Rodríguez & Targa (2004) determined that the rental price was reduced between 6.8% - 9.3% for every 5 minutes of walking time to TransMilenio BRT stations in Bogotá using a spatial hedonic price model. Estupiñán & Rodríguez (2008) concluded that properties within 250 m from TransMilenio BRT stops gained considerable land price advantages by making a pedestrian-friendly environment close to the BRT stations. Moreover, Rodríguez & Mojica (2009) investigated the capitalization impact of TransMilenio network expansion before and after BRT operation between 2001 and 2006. They found that BRT increased the property values by 13% - 14% within 500 m from stations than the properties outside this proximity. In contrast, Munoz-raskin (2010) researched the association of BRT and residential property prices within walking distance of Bogotá's Transmilenio by conducting a city-wide econometric hedonic analysis for 2000 - 2004. This study concluded that negative impacts of the BRT were reported for most residential properties within 5 minutes walking distance from the system. Perdomo (2011) also found null results.

Zhang & Wang (2013) examined the capitalization impacts of the South Axis BRT line Beijing using a hedonic price model and found no significant relationship between BRT and residential property prices. Similarly, a study examined the impacts of rail transit and BRT on property values for apartment homes in Beijing in 2011 using hedonic price modeling (Liang et al., 2014). They found an average price premium of almost 5% around rail stations; however, BRT station's proximity has no significant impact on the properties. Deng & Nelson (2010) found that the average value of the apartments around stations has relatively increased compared to those located away from BRT stations in Beijing, China using longitudinal analysis of property values. Deng & Nelson (2012) conducted a study based on passenger perception for Beijing Southern Axis BRT Line 1. They concluded that BRT had obtained a considerable reputation among travelers and positively influenced the attraction of the residential property. Similarly, Zhang et al. (2014) found that the BRT South Axis line received a robust market appreciation while the other two BRT lines revealed insignificant impacts on housing prices in Beijing using the hedonic price modeling technique. BRT in Guangzhou increased real estate prices by 30% during the first two years of transit operations (Suzuki et al., 2013).

Mulley & Tsai (2016) studied the influence of BRT on residential property value using the multilevel model in Sydney, Australia. They found that the sales prices of residential housing within 400 m of BRT stations were slightly higher compared to the properties outside this catchment area after the inaugural of the BRT system in 2003 and 2004. Zhang et al. (2020) investigated the impact of BRT on property value using a Geographically Weighted Generalized Linear Model in Brisbane, Australia. They concluded that property sales prices within BRT catchment areas were 5.2% higher than those outside BRT catchment areas.

Cervero & Kang (2011) investigated the impacts of BRT on land values in Seoul, South Korea. They determined that residential property price rises between 5% and 10% within a 300 m radius of BRT stations, and land values increase by 3% and 26% for retail and other non-residential uses within proximity of 150 m from stations. They also found that the BRT system encouraged land owners to change single-family houses to high-density condominiums and apartments. Jun (2012) determined the influence of BRT on development patterns in Seoul and found that urban centers gained higher property prices while property prices were reduced in the outskirts.

A study was conducted to investigate the influence of bus-based TOD on single-family property value located within a 1.5-mile radius using Hedonic price modeling in Seattle metropolitan area (Shen et al., 2017). They found that sales prices for homes within half a mile of the transit stations were 3% - 5% higher than properties one mile from the transit stations. Perk et al. (2010) studied the effects of East Busway BRT on surrounding single-family house prices using a hedonic regression model in Pittsburgh, Pennsylvania. They found decreasing marginal results; property value increased about $18.90 for moving from 101 to 100 ft from BRT stations, and property price raised almost $2.71% for moving from 1001 to 1000 ft. Yu et al. (2018) evaluated the price changes of commercial properties around BRT stations in Austin and concluded that the effect of BRT proximity on commercial properties was modest. The major findings of the impact of BRT on property development are summarized in **Table 3.2**.

Table 3.2 Major findings of the impact of BRT on property development

Author	Case study	Study focus	Major findings
Rodríguez & Targa (2004)	Bogotá, Colombia	Impact of BRT on land value	Rental price reduced between 6.8% - 9.3% for every 5 minutes of walking time to BRT stations.
Estupiñán & Rodríguez (2008)	Bogotá, Colombia	Relationship between BRT and urban form	Properties within 250 m of the station gained considerable land price advantages
Rodríguez & Mojica (2009)	Bogotá, Colombia	Capitalization impact of BRT expension	Increased the property values by 13% - 14% within 500 m from stations than the properties outside this proximity
Munoz-raskin (2010)	Bogotá, Colombia	Relationship between residential property values and BRT	Negative impacts of the BRT on residential properties within 5 minutes of walking distance from the system
Zhang & Wang (2013)	Beijing, China	Capitalization impacts of BRT	No significant relationship between South Axis BRT and residential property prices
Liang et al. (2014)	Beijing, China	Impacts of BRT on property values for apartment homes	BRT station's proximity has no significant impact on the properties
Deng & Nelson (2010)	Beijing, China	Impact of BRT on land development	The average value of the apartments around stations has relatively increased as compared to those located away from BRT stations
Deng & Nelson (2012)	Beijing, China	Respondent's perception of residing close to BRT stations	Positive influence on the attraction of the residential property
Zhang et al. (2014)	Beijing, China	Capitalization of transit access in property prices	The south line received a robust market appreciation, while the other two BRT lines have insignificant impacts on housing prices
Suzuki et al. (2013)	Guangzhou, China	Real estate prices and BRT	Real estate prices increased by 30% during the first two years of transit operations
Mulley & Tsai (2016)	Sydney, Australia	Influence of BRT on residential property value	Residential housing values within 400 m of stations were slightly higher than properties outside this catchment area
Zhang et al. (2020)	Brisbane, Australia	Impact of BRT on property value	Property sales prices around BRT areas were 5.2% higher than properties outside BRT catchment areas
Cervero & Kang (2011)	Seoul, South Korea	Impacts of BRT on land values	Residential property prices rose between 5% and 10% within a 300 m radius of BRT stations, and land values increased by 3% and 26% for retail and other non-residential uses within proximity of 150 m from stations BRT also encouraged land owners to change single-family houses to high-density condominiums and apartments
Jun (2012)	Seoul, South Korea	Influence of BRT on development patterns	Urban centers gained higher property prices, while property prices were reduced in the outskirts areas
Shen et al. (2017)	Seattle Metropolitan area, USA	Influence of bus-based TOD on single-family property value	The sales price for homes located within 800 m of stations were 3% - 5% higher than properties located beyond one mile from the transit stations
Perk et al. (2010)	Pittsburgh, USA	Effects of BRT on surrounding single-family house price	Property value increased about \$18.90 for moving from 101 to 100 ft from BRT stations, and property price raised almost \$2.71% for moving from 1001 to 1000 ft
Yu et al. (2018)	Austin, USA	Price changes of commercial properties around BRT stations	The effect of BRT proximity on commercial properties was modest

Compared to rail transit, BRT is supposed to have various drawbacks in encouraging urban development. Firstly, the ability of the BRT system to promote economic growth may be finite due to its limited performance and locational rigidity (Dittmar & Poticha, 2004). Consequently, firms and land developers preferred to place residential, office, and commercial properties along the rail route compared to the BRT route. Hensher (2007) found this inconclusive and advocated deducting only one BRT line in Australia. Moreover, the vanishing of rail transit in Australia and the United States during the previous century is also evidence of the finite performance of public transit, irrespective of the technology. Secondly, the BRT system may be disliked owing to pollution, noise, etc. These pollution and noise impacts recommend that urban development effects be investigated farther the proximity of the BRT route, though these impacts decline quickly with the distance. On the other hand, rail transit has an attraction of innovation (Currie, 2006). The stigma of BRT seems to be associated with the technological alternatives, i.e., tire choice, diesel engines, chassis design, etc., that can be treated instead of the innate weakness of the transit. Further, based on the literature, Currie (2006) concluded that BRT users in Australia often had socio-economic features that seem more like users of rail transit markets than users of traditional bus service markets.

Nonetheless, few researchers question the potential of BRT to stimulate TOD (Cervero & Dai, 2014; Suzuki et al., 2013). Thus, land developers and firms are more likely to place their properties near rail transit instead of the BRT route. Hereafter, there is no common consensus among scholars on how BRT will influence the surrounding areas around the stations and along the route. But, a few scholars indicated that the effects of transit could not be entirely advocated without strategies supporting high-density mixed-use development (Cervero, 1984; Knight & Trygg, 1977). Higher density around public transit is based on existing land use, land availability, and regulations (Handy, 2005; Rodriguez et al., 2016). BRT has limited empirical evidence for shaping cities (Ogra & Ndebele, 2014). Most studies on the interaction concerning urban development and rail transit have widely been conducted in the cities of developed nations, whereas studies from developing countries are limited (Wang et al., 2019). Despite its growing reputation worldwide, BRT's impact on urban development remains unclear (Bocarejo et al., 2013; Jun, 2012; Krüger et al., 2021; Rodriguez et al., 2016). Moreover, the impacts of BRT are context-dependent (Mullins et al., 1990; Rodriguez et al., 2016).

To conclude, while the literature provides plentiful findings regarding the influence of rapid transit on urban development in advanced nations, these outcomes are not handy for developing economies due to the varying contexts. However, whether BRT infrastructure shaped TOD has not been well examined. It is evident as most studies investigated rail transit rather than BRT to enhance TOD. Moreover, compared to other transit infrastructures, the BRT and its role merit investigation to apprise the prioritization of transport investment in developing nations. To fill these research gaps, our study investigated whether BRT investment created urban fabric and what aspects of TOD are lacking in the station areas of Lahore.

3.3. Impact of Transit on Travel Behavior in TOD and Non-TOD Areas

BRT has remarkable potential to stimulate TOD (Chalermpong & Ratanawaraha, 2015), which is expected to change residents' travel behavior around transit station areas. TOD has several possible benefits, including encouraging transit and non-motorized use, decreasing car usage and congestion, and increasing job accessibility (Kamruzzaman et al., 2013; Sung & Oh, 2011). Previous studies have measured the benefits of TODs and their influence on travel behavior, such as mode choice (Griffiths & Curtis, 2017; Lindsey et al., 2010) and vehicle miles/kilometers traveled (Chen et al., 2017; Kwoka et al., 2015; Nasri & Zhang, 2014; Park et al., 2018; Zhang et al., 2012). In addition, previous studies have reported that TOD residents are more likely to use transit and non-motorized modes and drive less than those living in non-TOD areas (Kamruzzaman et al., 2014; Langlois et al., 2015; Nasri & Zhang, 2014, 2019).

Many previous studies have examined the relationship between TOD and travel behavior using rail transit station proximity in developed countries (Brown & Werner, 2009; Cao, 2015; Chen et al., 2017; Deboosere et al., 2018; Deng et al., 2021; Dill, 2008; Huang et al., 2016; Kamruzzaman et al., 2013; Kim et al., 2007; Matsuyuki et al., 2013; Noland & Dipetrillo, 2015; Pan et al., 2011; Park et al., 2018; Yu et al., 2019). However, very few studies have considered built environment characteristics related to travel behavior using BRT proximity. For example, Chalermpong and Ratanawaraha (2015) studied the influence of land use features on travel behavior around BRT stops in Bangkok, Thailand. They determined that walking, bus, and motorcycle taxis are the most common means of access to BRT stations within a 500m radius of BRT stations. They also concluded that land use features such as commercial, residential, financial, and retail land use concentration around stations influenced the commuter's propensity to walk to BRT stations. Nguyen et al. (2020) studied the relationship between TOD factors and travel behavior in Hanoi, Vietnam. They concluded that higher population density and mixed-use were related to fewer cars and motorcycles and more frequent use of BRT.

Previous studies have provided valuable insights into travel behavior in TOD and non-TOD areas. Kamruzzaman et al. (2014) conducted a study to explore residents' travel behavior based on commuting trips in Brisbane, Australia. They concluded that non-TOD residents were 1.4 times and four times less likely to use transit and active transport, respectively, than TOD residents around BRT and rail stations. Park et al. (2018) studied the impact of TOD and TAD areas on travel behavior for different types of transit stations in eight urban areas in the USA. They found that TOD areas encouraged transit and walking more and driving less. They also concluded that residents of TOD areas make vehicle miles traveled (VMT) and auto trips shorter (39% decline) and fewer (35% decline) than in TAD areas. A study compared residents' travel behavior in three San Francisco Bay Area neighborhoods (Renne, 2009). It was concluded that the transit rate for commuting was much higher in the TOD area (61.7%) than in the TAD area (16.1%). In contrast, TOD residents (26%) had lower car ownership, while it was higher for TAD residents (54.3%). Cervero (2007) surveyed 226 residents around transit stations in California who moved from non-TOD areas to TOD areas and concluded that the average personal daily VMT lessened by almost 42% from 33.3 miles to 23.5 miles.

Previous research has demonstrated that higher density and mixed land use reduce auto travel miles (Ewing & Cervero, 2010; Thomas & Bertolini, 2015; Zhang et al., 2014). A comparative study investigated the travel behavior of TOD residents in Washington, D.C., and Baltimore (Nasri & Zhang, 2014). It was concluded that TOD residents reduced their VMT by almost 38% and 21% in Washington, D.C., and Baltimore, respectively, compared with TAD residents with analogous land uses. It was also determined that higher density and mixed land use patterns encouraged residents to use transit and drive less. Chen et al. (2017) studied the reduction effect of TOD on the VKT in Shanghai, China, and found that the mean individual daily VKT was almost 20% less for those working in TOD areas than those working in TAD areas. They also concluded that residential density and land-use diversity were negatively linked with VKT. Kumar et al. (2018) found that workers used transit and non-motorized modes in TOD areas, while they used cars in non-TOD areas for more extended work trips in Delhi, India. Moreover, they concluded that residents living in areas with higher employment density and mixed-use were less likely to use private vehicles. Li and Zhao (2017) studied the influence of the built environment on car ownership and use by residents residing close to metro stations in fifteen neighborhoods in Beijing. They determined that the likelihood of car ownership and VMT for work and non-work trips was lower in mixed-use and higher residential-density areas near metro stations. Chiu (2022) studied BRT's potential effects on motorcycle use in Jakarta, Indonesia, and found that BRT proximity is connected with mode choice preference of BRT over motorcycle for office commute. Moreover, population density around BRT stations reduced motorcycle VKT. **Table 3.3** summarized the major findings of the impact of BRT on travel behavior.

In summary, previous studies have widely examined the impact of TOD on travel behavior, emphasizing rail transit areas in developed countries where travel behavior varies from developing nations. Moreover, past studies have focused on work trips and little interest in non-work trips, particularly shopping trips, which can account for daily trips, and the share of such trips is large. However, little is known about residents' travel behavior in TOD and TAD areas and the impact of TOD on VKT using BRT proximity, particularly in developing countries. Our study fills these research gaps and examines residents' travel behavior, and the effects of TOD attributes on VKT in TOD and TAD areas around BRT stations in Lahore.

Table 3.3 Major findings of the impact of BRT on travel behavior

Author	Case study	Study focus	Major findings
Chalermpong & Ratanawaraha (2015)	Bangkok, Thailand	Effect of land use features on travel behavior around BRT stations	Land use features (i.e., commercial, residential, financial, and retail) around stations influenced the commuter's propensity to walk to BRT stations
Nguyen et al. (2020)	Hanoi, Vietnam	TOD factors and travel behavior	Higher population density and mixed-use were related to fewer cars and motorcycles and more frequent use of BRT
Kamruzzaman et al. (2014)	Brisbane, Australia	Residents' travel behavior based on commuting trips in non-TOD and TOD areas	Non-TOD residents were 1.4 times and four times less likely to use transit and active transport, respectively, than TOD residents around BRT and rail stations
Park et al. (2018)	Eight urban areas in the USA	Impact of TOD and TAD areas on travel behavior	TOD areas encouraged transit and walking more and driving less TOD areas make VMT and auto trips shorter (39% decline) and fewer (35% decline) than TAD areas
Renne (2009)	Three San Francisco Bay Area neighborhoods	Comparison of residents' travel behavior	The transit rate for commuting was much higher in the TOD area (61.7%) than in the TAD area (16.1%) Car ownership was lower in TOD areas (26%) than in TAD areas (54.3%)
Cervero (2007)	California, USA	Changes in residences and ridership	Average personal daily VMT lessened by almost 42% from 33.3 miles to 23.5 miles for those who moved from non-TOD areas to TOD areas
Nasri & Zhang (2014)	Washington, D.C. and Baltimore	travel behavior of TOD residents	TOD residents reduced their VMT by almost 38% and 21% in Washington, D.C., and Baltimore, respectively than TAD residents Higher density and mixed land use patterns encouraged residents to use transit and drive less
Chen et al. (2017)	Shanghai, China	Reduction effect of TOD on the VKT	Average individual daily VKT was almost 20% less for those working in TOD areas than for those working in TAD areas Residential density and land-use diversity were negatively linked with VKT
Kumar et al. (2018)	Delhi, India	Commuter mode choice behavior in TOD and non-TOD areas	Workers used transit and non-motorized modes in TOD areas, while they used cars in non-TOD areas Residents living in higher employment density and mixed-use areas were less likely to use private vehicles
Li and Zhao (2017)	Beijing, China	Influence of built environment on car ownership and use	The likelihood of car ownership and VMT was lower in mixed-use and higher residential-density areas near metro stations
Chiu (2022)	Jakarta, Indonesia	Potential effects of the BRT on motorcycle use	BRT proximity is connected with the mode choice preference of BRT over a motorcycle Population density around BRT stations reduced motorcycle VKT in Jakarta, Indonesia

3.4. Barriers and Opportunities for Encouraging TOD with Transit

Nevertheless, some previous studies examined the barriers and opportunities that stand in the way of BRT-based TOD. Cervero & Dai (2014) investigated the obstacles and opportunities of supporting TOD with BRT by surveying 27 cities with urban and transport planners. They suggested that weak institutional support, lack of funding, and limited resources are hurdles in supporting BRT-based TOD. Further, they identified five obstacles to encouraging TOD: lack of funding, absence of TOD plans, lack of institutional coordination, little experience with TOD, and weak political backing. Moreover, they pointed out that the local government in Curitiba mandated that all types of medium and large-level urban development be placed along the BRT route. For this purpose, the government established implementation tools to encourage TOD around the BRT corridor. Another study was conducted by Vergel-Tovar (2023) to determine the barriers and opportunities for promoting TOD using BRT in Bogotá and Quito using semi-structured interviews. He found some obstacles, such as timing complications between land use and transport institutions, complex relationships between private and public sectors with different perceptions of urban development, the complexities of renewal and redevelopment measures in existing urbanized areas, general perspective of TOD as an idea foreign to all excluding transport planners. Similarly, Bocarejo et al. (2013) identified barriers to TOD using BRT in Bogotá. These include a lack of plans and policies around station areas, zoning, and complementary enhancements to induce private developments to encourage TOD.

Furthermore, Suzuki et al. (2013) pointed out the main obstacles to BRT-TOD in Bogotá and Ahmedabad, such as weak coordination, inefficiencies of the institutions, inadequate building density plans, and absence of station areas design around BRT. They also provided recommendations for promoting TOD using BRT, such as creating a vision and an enabling intuitional and regulatory framework, adopting a city-level planning approach, developing a diverse portfolio of TOD, value capture from transit infrastructure, and surrounding neighborhood improvements. Cervero (1998) identified that local governments proactively supported BRT-based TOD by zoning reforms, land assemblage, supportive infrastructure investments, and tax policies for pro-development. Nawaz et al. (2016) conducted a study investigating the challenges and opportunities of bus-based TOD for low-density, car-dependent Australian cities. They found that some amendments in the local development plans are crucial, including proposing locations for transit interchanges, land use rezoning along the bus corridor to encourage higher densities, assigning traffic network planning, and investment to improve coordination of the bus services. Thomas et al. (2018) conducted a study to overcome obstacles to TOD implementation in the Netherlands. They found that TOD implementation requires tools, policy ideas, processes, and relationships to practice.

In summary, most studies have focused on TOD using rail transit in developed countries, but very few studies have been conducted on TOD using BRT. This research is in the infancy stage in developing countries, particularly in the Asian region. Understanding the association between professionals working for TOD and its features around BRT station areas becomes more crucial, in line with the planning and implementation of various rules, regulations, and plans enforced with the involvement of several actors in forming the urban fabric and transit investments. Therefore, our study focuses on understanding the challenges and opportunities for promoting TOD with BRT using structured interviews of various professionals working in different land use and transport departments in Lahore.

3.5. Conclusion

Despite its growing reputation worldwide, BRT's impact on urban development remains unclear (Bocarejo et al., 2013; Jun, 2012; Krüger et al., 2021; Rodriguez et al., 2016). Moreover, the impacts of BRT are context-dependent (Mullins et al., 1990; Rodriguez et al., 2016). Some previous studies have advocated significant results, whereas others have failed to offer urban development impacts or travel behavior. Most of the studies have concentrated in developed countries; little is known regarding the effects of BRT in shaping TOD and travel behavior in developing countries. The following questions motivating this research are; what kind of urban fabric has been created in BRT station areas? Whether the urban fabric has elements of TOD? What are the travel characteristics of residents in the TOD and TAD areas around BRT stations? Can TOD reduce the VKT of residents living around BRT station areas? What are the BRT-based TOD models for urban and suburban areas in Lahore? Why TOD strategies in the previous master plans were not implemented, specific to IMPL 2021? What are the challenges and opportunities for enhancing TOD with BRT? Our study seeks the answers to the above questions in the context of a developing country, i.e., Lahore using BRT infrastructure.

CHAPTER 4: STUDY AREA

4.1. Introduction

Lahore is the second largest city in Pakistan, with about 13 million population in 2023, and consists of ten administrative zones. Due to the rapid urbanization process, Lahore city is expanding in an unplanned manner, and the motorization rate is increasing. This chapter focuses on the Pakistani and Lahore contexts. It provides the spatial dynamics of urban expansion and motorization trends in Lahore city. It also offers valuable insights into the BRT system in Lahore, along with the salient features of the system. In this chapter, the selection of the case study was also briefly described.

4.2. Pakistan Context

Pakistan is the fifth most populated country globally and the second largest in South Asia. It has a population of 241.49 million in 2023, with a land area of 796,096 km^2 (Pakistan Bureau of Statistics, 2023). Pakistan has four provinces Balochistan, Khyber Pakhtunkhwa, Punjab, and Sindh, with Islamabad Capital Territory. Moreover, Azad Jammu and Kashmir and Gilgit-Baltistan are administered by Pakistan (The Permanent Committee on Geographical Names, 2019). The country experienced rapid urbanization from 1950 to 2023 (see **Figure 4.1**). This increase has emerged megacities such as Karachi, with almost 20 million population, and Lahore, with more than 13 million inhabitants. Pakistan has 10 ten large cities with more than 1 million population.

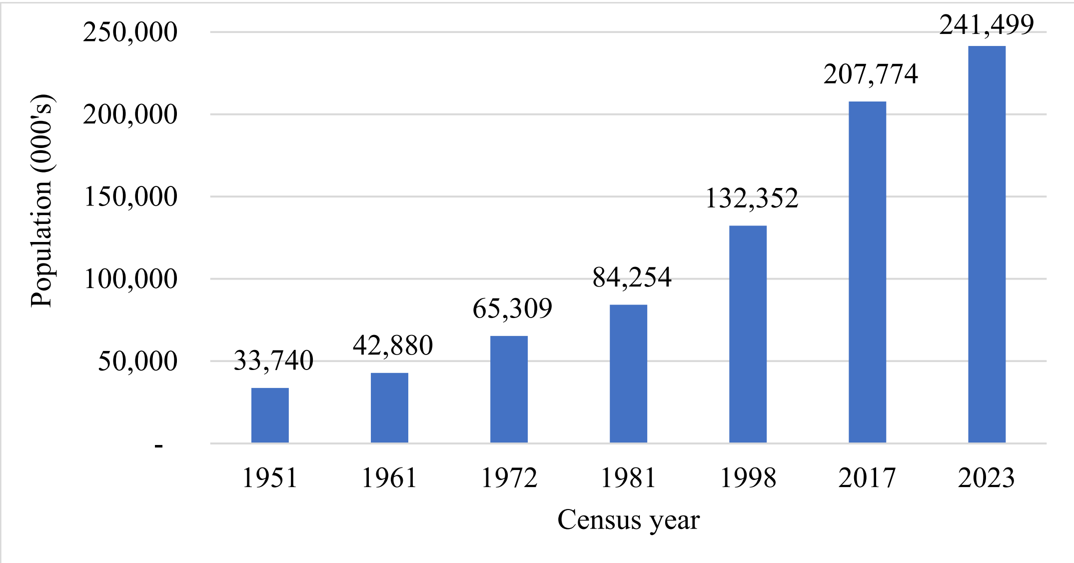


Figure 4.1 Population trend in the Pakistani context. *Source:* Pakistan Bureau of Statistics (2017, 2023)

4.3. Lahore Urban Context

This study focuses on Lahore, the second-largest city in Pakistan and the capital city of the province of Punjab. It comprises nine administrative zones with a cantonment (see **Figure 4.2**). **Table 4.1** shows that the total population of Lahore was 6.32 million in 1998, and in 2023, Lahore had a population of about 13 million, covering a total area of 1,772 km^2 (Pakistan Bureau of Statistics, 2023; Punjab Bureau of Statistics, 2017). The main reason for the growing population is the migration from other areas of the country towards Lahore to get good opportunities. Consequently, the substantial increase in population puts a considerable burden on urban land and transport infrastructure (Farhat et al., 2018). The city's population density was 3,566 persons/km^2 in 1998 and 7,339 persons/km^2 in 2023. However, urbanization and motorization have worsened, particularly in Lahore's transportation infrastructure. Due to rapid urbanization, the city has sprawled in an unplanned manner and crossed a radius of 38 km in 2017. As a result, the built-up area of Lahore city reached 925.8 km^2 in 2017, from 686.8 km^2 in 1998 (Nadeem et al., 2021).

Figure 4.2 Location of Lahore with BRT system

Table 4.1: Population, growth rate, and population density of Lahore. *Source:* Punjab Bureau of Statistics (2017) and Pakistan Bureau of Statistics (2023)

Census year	Total population (million)	Percentage increase in population (%)	Percentage of population growth rate (%)	Density/km^2
1951	1.13	-	-	640
1961	1.63	43.27	3.7	918
1972	2.59	59.16	4.1	1460
1981	3.54	37.00	3.8	2001
1998	6.32	78.25	3.5	3566
2017	11.12	75.98	3.0	6275
2023	13.00	11.94	2.7	7339

4.3.1. Spatial dynamics of urban expansion

Figure 4.3 shows the urban extent of Lahore from 1850 to 2023. The urban extent from 1850 to 1990 has been derived from master plans of Lahore, and the urban extent for 2000 – 2023 has been calculated in ERDAS Imagine and ArcMap using Landsat images from USGS Earth Explorer, then corrected using Google Earth. Initially, Lahore had compact development within a radius of 5 km; after 1970, the urban growth expanded. The transition started from the city's central core and remarkably extended towards the South, South West, and East. At the same time, urban development is relatively slow towards the West and East North due to River Ravi and the Indian border, respectively. As a result, Lahore city is touching the radius of 40 km in 2023 in an unplanned manner due to the absence of land use and building control.

Table 4.2 shows the historical growth of Lahore in different years. The urban extent of the city is considerably expanding over time. The urban extent is more than two times, reaching 743 km^2 in 2023, from 326 km^2 in 2000. The reasons for the increasing urban extent may be the strong political will, and private housing developers launched housing scheme projects in suburban areas due to the availability of cheap land.

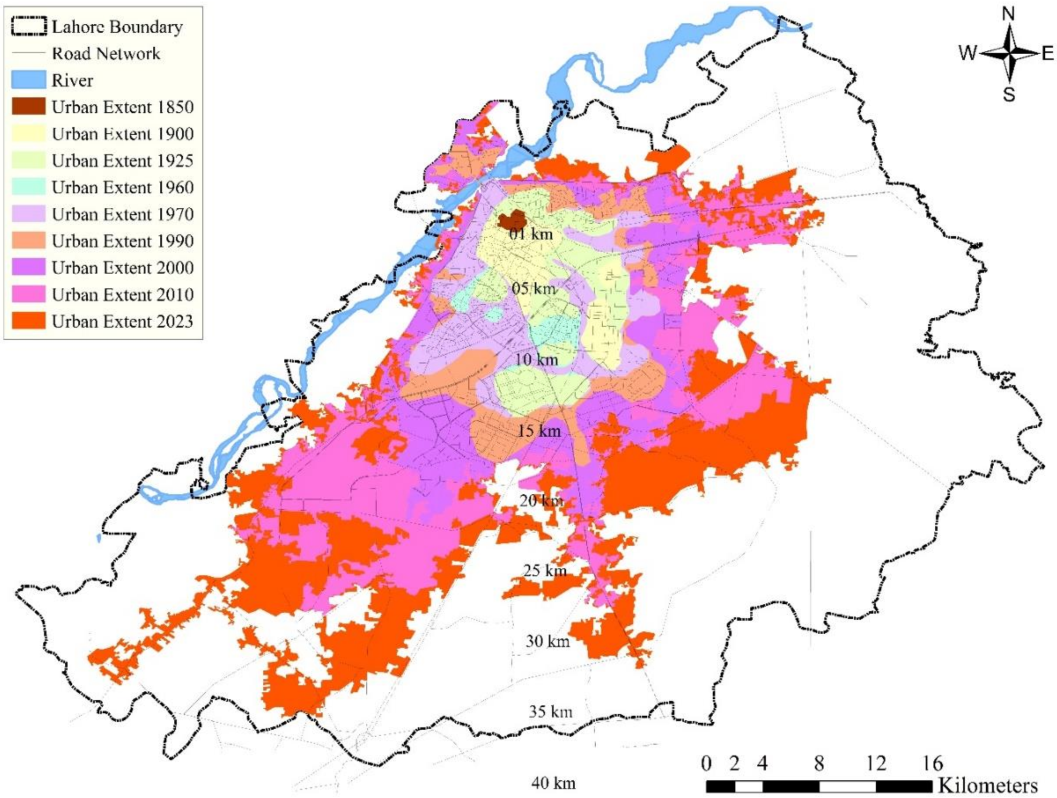


Figure 4.3 Spatial dynamics of urban expansion. *Source:* author

Table 4.2: Historical growth of Lahore. *Source:* JICA and author

Year	Cumulative urban extent (km^2)	Percentage change (%)
Pre-British	23.8	-
1850 - 1900	68.7	188.7
1901 - 1950	71.2	3.6
1951 - 1965	117.2	64.6
1966 - 1980	175.7	49.9
1981 - 1990	245.6	39.8
1991 - 2000	326	32.7
2000 - 2010	485.2	48.8
2011 - 2023	743.9	53.3

4.3.2. Motorization trend

In Lahore, private vehicles have been increasing at a rapid pace. **Figure 4.4** shows a steady increase in vehicle ownership due to the rapid urbanization process during 2003 – 2020. The majority of the Lahore residents prefer to travel by private vehicles. **Figure 4.5** shows the registered private vehicles and public transport during the same period. Private vehicles include cars, motorcycles, and taxis, while public transport includes buses, Hiace, and Qingqi. The number of private vehicles considerably increased from 2003 to 2017; however, private vehicle ownership declined in 2018 and 2019. It may be due to a change of Government that increased the duty on imported vehicles. After that, the rate of private vehicles increased, which may be due to foreign investors' manufacturing of local vehicles. Moreover, the average share of private vehicles is more than 95% of total vehicles. On the other hand, a negligible increase was seen in public transport, which percentage was less than 5% of the total vehicles. Consequently, motorization causes traffic congestion, accidents, and longer travel times.

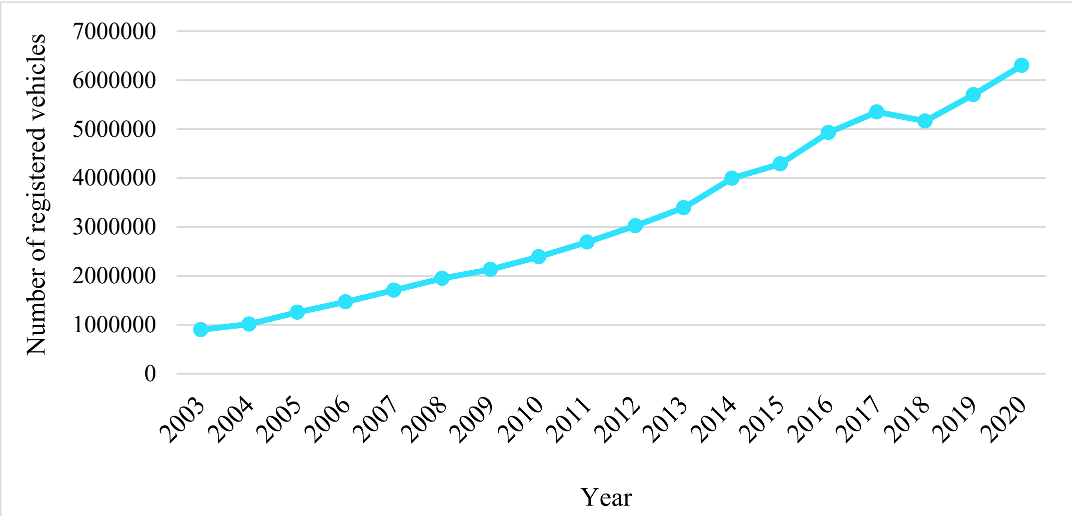


Figure 4.4 Motorization trend in Lahore. *Source:* Compiled by author from various reports from the Punjab Bureau of Statistics

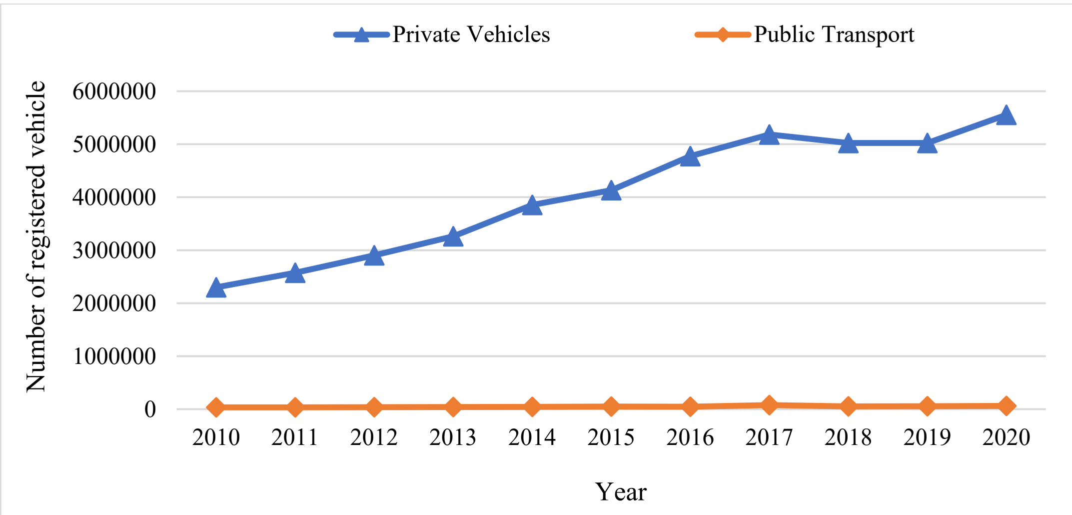


Figure 4.5 Share of private and public transport in Lahore. *Source:* Compiled by author from various reports from the Punjab Bureau of Statistics

4.4. Bus Rapid Transit in Lahore

In Lahore, the transport system is poorly developed and maintained. This is worsened due to a mix of traffic and a lack of pedestrian discipline. The Hiace (18-seater minibus) is a dominant public transport service, though growing incomes have increased the demand for a high-quality public transit system. As a result, Light Rail System was first proposed by Japan International Cooperation Agency (JICA) in their Comprehensive Study of the Transportation System in Lahore in 1991 to overcome the transportation issues in Lahore. This study was reconsidered and upgraded in Lahore Traffic and Transport Studies, funded by the World Bank in 1993. In 2005, the concept was reexamined, and conducted a feasibility study by the Hong Kong-based company MVA Asia Consultancy (a subsidiary of US-based engineering company Systra) funded by the Government of Punjab. This feasibility study was accomplished in 2006. The subsequent phase is a reference design study that will take the Rapid Mass Transit System (RMTS) design to 30% - 35% completion, enough to attract funding.

Moreover, the government of Punjab agreed on concept clearance for the project and timely implementation of effective and efficient RMTS. The system is likely to;

- A rise in residential and commercial development
- Reduce the overlapping of other transport on public transport lines
- Increase ridership through an integrated multi-model transport system
- Reduce dependency on private vehicles such as motorcycles and cars
- Provide good service, i.e., frequency, speed, and accessible
- Offer secure, safe, reliable, dependable, and environmentally sustainable transport system
- Connect the central area of the city and its suburban areas with convenient and fast access

This feasibility study covered 5% of the required design work with an integrated network of four lines of length almost 82 km with 60 transit stops (see **Figure 4.6**). The Lahore Rapid Mass Transit Rail Project (LMRTRP) comprises two phases, the first with Green and Orange lines and the second with Purple and Blue lines. The Green Line (priority line) has a route length of 27 km which comprises 11.6 km and 15.4 km underground and elevated, respectively. In the first year, the daily ridership of this priority line is projected to be around 250,000 – 300,000 passengers through 22 proposed stops, including 12 underground and ten elevated stations. This line would connect the central and suburban areas via two multimodal terminals. Moreover, this line offered five interchange stops with future rail lines. The Green Line would carry 30,000 passengers per direction during peak hours. This study estimated the cost of 2.4 billion for the Green Line (Asian Development Bank, 2008).

The Government started the construction of the BRT (Bus Rapid Transit) system in March 2012 on the same line with few modifications in the alignment proposed for the rapid rail system (green line) due to limited funding issues. In Lahore, the BRT system (also known as the Lahore Metrobus System) was introduced in February 2013 to reduce congestion problems. It serves 27 stations with a route length of 27 km and operates on an exclusive bus lane (see **Figure 4.7**). The average daily ridership is approximately 135,000 passengers, and it has achieved the highest daily ridership of nearly 180,000 persons (Punjab Mass Transit Authority, 2023). It was integrated with feeder bus services in 2017 (see **Figure 4.7**). **Figure 4.8** shows the BRT buses and stations with urban development patterns around the station in Lahore. Moreover, salient features of BRT Lahore are presented in **Table 4.3**.

Though TOD is being accepted in several world cities, private vehicles and urban sprawl are reduced by developing transit stations and enhancing the neighborhood's sustainable travel behavior. However, according to an interview with officials of the Lahore Development Authority (LDA), Local Government (LG), and transport department conducted in August 2021, no policy, regulations, rules, and incentives regarding BRT-based TOD have yet been prepared by the government to promote sustainable development and sustainable travel behavior. Therefore, studying the urban fabric around BRT stations and residents' travel behavior around BRT station areas is necessary. Understanding the challenges and opportunities to enhance TOD with BRT is also crucial.

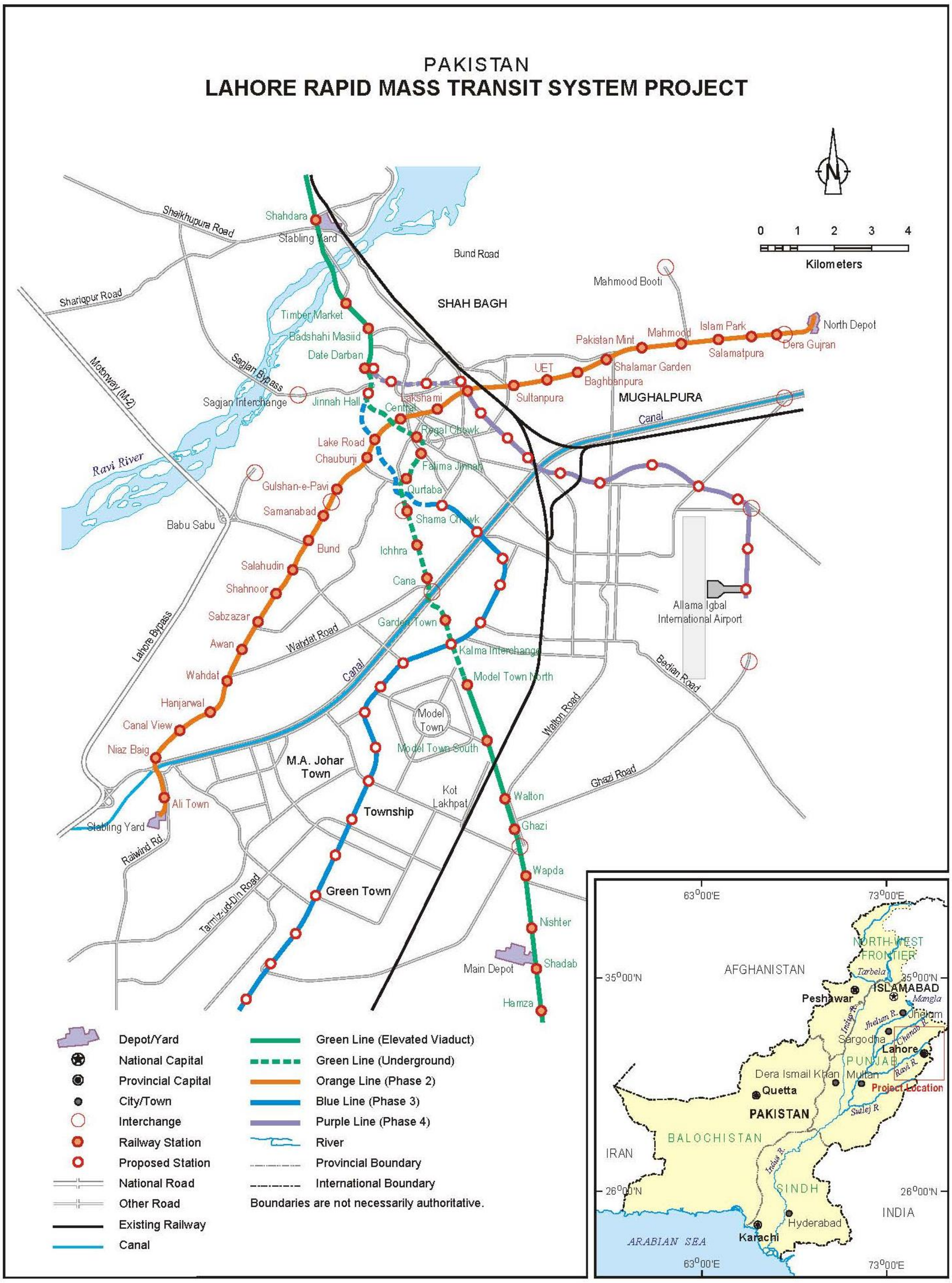


Figure 4.6: Lahore Rapid Mass Transit System Project. *Source:* Asian Development Bank (2008)

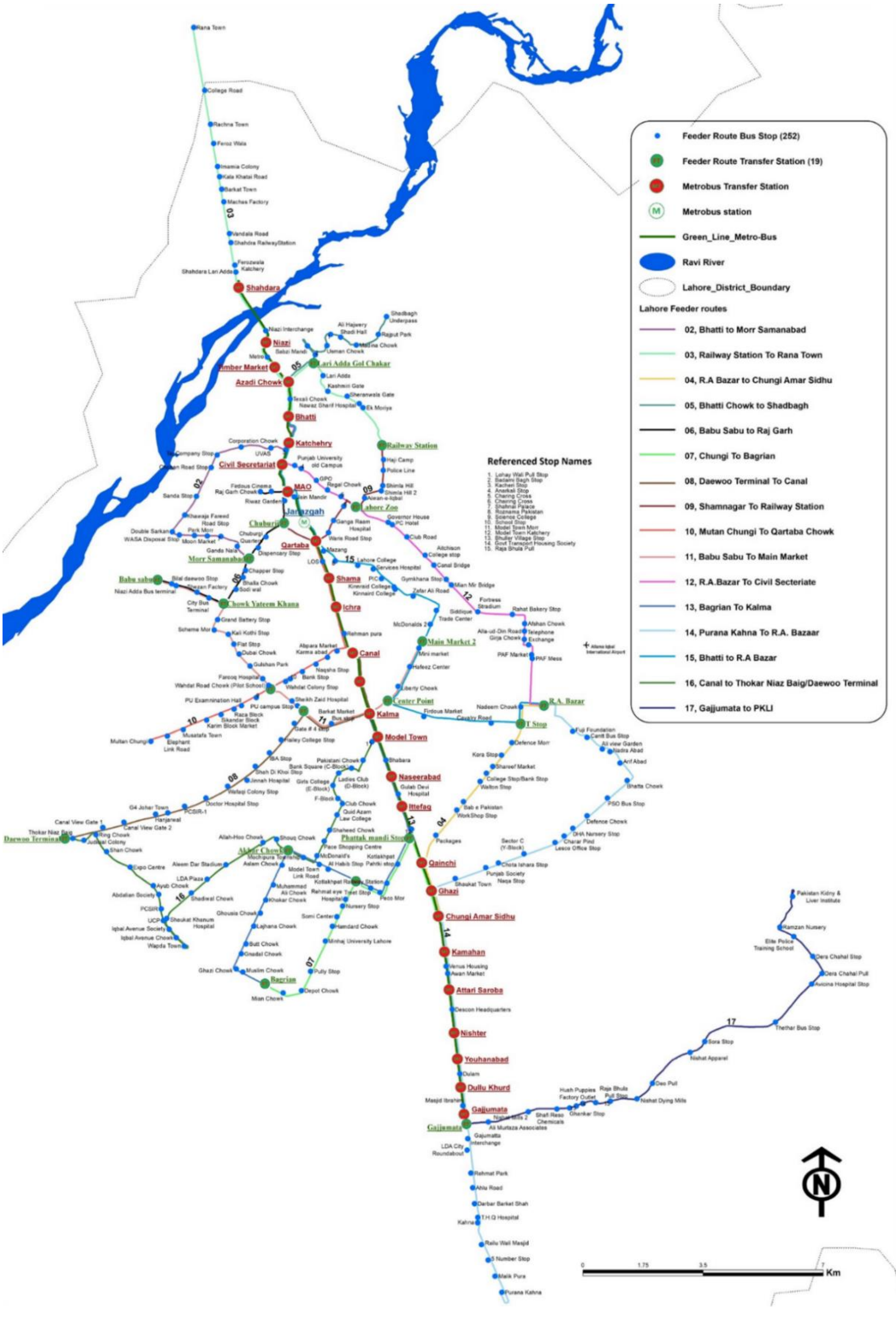


Figure 4.7 BRT route and stations with integrated feeder bus service. *Source:* Punjab Masstransit Authority (2023)

Figure 4.8 BRT station with buses in Lahore

Table 4.3 Salient features of BRT Lahore. *Source:* Punjab Masstransit Authority (2023)

Features	Description
Total station	27 (18 at-grade and 9 elevated)
Total route length	27 km
Average station spacing	1000 m
Corridor	Single corridor, dedicated exclusive lane, limited access corridor (4 at-grade intersections)
Platforms type	Two curb-side platforms, each with three docking bays and level boarding
Platform doors	Sliding
Access to platforms	Stairs, escalators (upward only),
Operating hours	6:15 AM to 10:00 PM
Fare	30 PKR (Pakistani rupee) flat fare = 0.12 USD
Operating buses	64 bi-articulated air-conditioned buses
Fare collection system	Automated fare collection system with off-board ticketing (pre-board fare collection)
Headway	2.25 - 3 minutes
Capacity	160 passengers
Ridership	135,000 per day (estimated)
Peak load	10,000 passengers per hour per direction
Peak frequency	23 buses per hour
Operating speed	26 km per hour
Integration stations	Two
Others	Bus scheduling system, vehicle location system, passenger information system, Intelligent Transportation System (ITS) for signal operations

4.5. Selection of Study Area

As this study collected some data via observation survey, we needed to select stations for the study. First, a discussion was conducted with five professionals of the LDA, LG, and the transport department officials in Lahore in August 2021 to select BRT stations for this study. From the discussion, we expected to learn about the location, population density, station ridership, development type (controlled/less controlled), development age, and area characteristics' effects on the density, diversity, and design in the station area. Less-controlled area refers to areas that are regulated and controlled by government authorities. Most of the city area is regulated and controlled by the local government, but overlapping functions and power among various local government departments and a lack of government staff result in weak control. The land use of some areas is regulated and controlled by the "cooperative housing societies."

A cooperative housing society is a community organization regulated by the Cooperative Society Act 1925, which has the authority to formulate its regulations and control the area following them. Model Town and Naseerabad have cooperative housing societies, and their land use is regulated by the local government and the housing society's regulations. It results in a well-planned and controlled area which we refer to as a controlled area. On the other hand, land use in other areas is regulated only by the local government, refer as a less controlled area. These criteria were applied to all BRT stations as selection criteria, and we chose the eight stations ensuring heterogeneity in criteria weightage. The selected stations were Shahdara, Bhatti Chowk, Ichra, Model Town, Naseerabad, Kamahan, Nishtar Colony, and Dullu Khurd (see **Figure 4.9**), and their characteristics are summarized in **Table 4.4.**

This study investigates the urban fabric in the station catchment area. Schlossberg (2006) considered a 10-minute walking distance of 800 m to evaluate the TOD level, which is pertinent to TOD planning. Our study also selected an 800 m radius from BRT stations in Lahore.

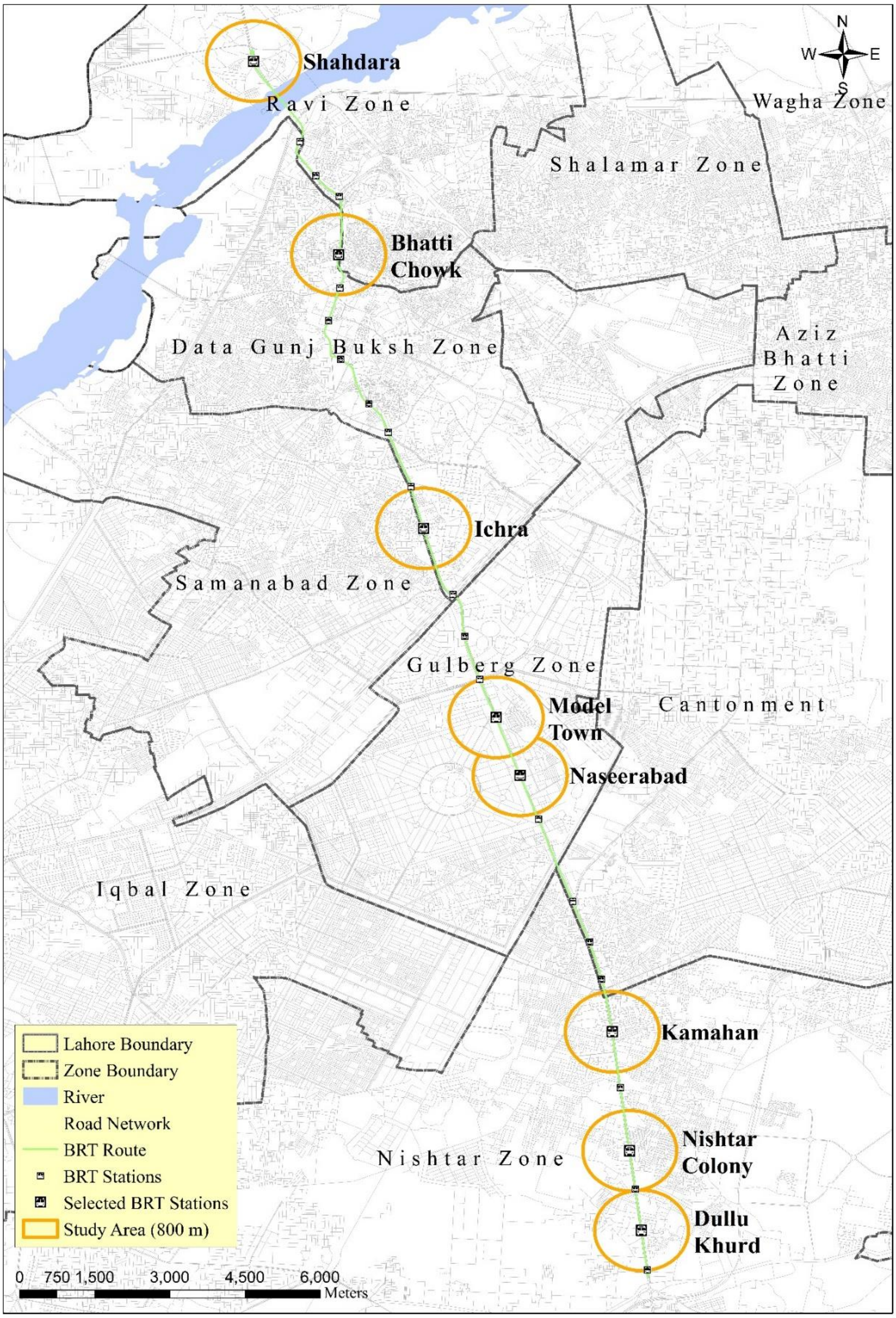


Figure 4.9 Selected BRT stations in Lahore

Table 4.4 Characteristics of the selected BRT stations in Lahore

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

4.6. Conclusion

In Lahore, urbanization and motorization have worsened, particularly in Lahore's transportation infrastructure. Due to rapid urbanization, the city has sprawled in an unplanned manner and crossed a radius of 40 km in 2023. The average share of private vehicles is more than 95% of total vehicles. On the other hand, a minimal increase was seen in public transport, which shares less than 5% of the total number of vehicles. Consequently, motorization causes traffic congestion, accidents, and longer travel times. To overcome the congestion problems in Lahore, the BRT system was started in 2013, the country's first BRT system. It serves 27 stations with a route length of 27 km and operates on an exclusive bus lane. Daily ridership is approximately 135,000 passengers. In Lahore, no policy, regulations, rules, or incentives regarding BRT-based TOD have yet been prepared by the government to promote sustainable development and travel behavior. Therefore, studying the urban fabric around BRT stations and residents' travel behavior around BRT station areas is necessary. We selected eight BRT stations in Lahore, including Shahdara, Bhatti Chowk, Ichra, Model Town, Naseerabad, Kamahan, Nishtar Colony, and Dullu Khurd, based on discussions with professionals of LDA, LG, and transport departments. After that, we selected a radius of 800 m from BRT stations pertinent to TOD planning.

CHAPTER 5: RESEARCH METHODOLOGY

5.1. Introduction

This chapter describes the detailed methodology used to conduct this study. It provides the criteria and indicators of TOD and their description used in this study. It offers the detailed classification of the BRT stations into TOD and TAD areas to investigate travel behavior. It explains the research instrument, surveys, and sampling technique. It briefly describes the multilevel mixed-effect regression analysis used to examine the impact of TOD on VKT in this study. It also provides insights for interviews conducted with the professionals of different departments and town planners to understand why TOD strategies in the previous master plans were not implemented in Lahore.

5.2. Criteria of TOD and the Data Source

In the literature, various approaches were used for measuring TOD. Cervero & Kockelman (1997) established the 3Ds of urban structures influencing travel behavior: density, diversity, and design. These 3Ds also explain how land use patterns influence travel patterns (Sarkar & Mallikarjuna, 2013). Singh et al. (2017) identified eight criteria to measure TOD-ness, including density, land use diversity, walkability and cyclability, economic development, user-friendliness of a transit system, accessibility, transit capacity utilization, and parking at the station. Moreover, Su et al. (2021) identified various indicators under the 5Ds framework of TOD, such as design, including intersection density and street network connectivity; density, which indicates the population and road density; diversity, which measures the land use proportion and mixture pattern; and destination, which represents the trip attractions accessibility; and demand management, which denotes the traveling services. We chose the 3Ds criteria to measure how close the urban fabric in a BRT station area is to TOD (see **Table 5.1**) because the 3Ds of urban structures influence travel behavior as a feature of TOD (Cervero & Kockelman, 1997; Sarkar & Mallikarjuna, 2013). Moreover, the selected criteria and indicators are measurable, evaluate the previous and current situations, and for which data is readily available and collectible.

Table 5.1 A set of criteria and indicators used in the study

Criteria	Indicators	Description	Data source
Density	Population density	Number of persons/ha in 2010 and 2016	Punjab Development Statistics
	Floor Area Density	Floor area density in 2012 and 2021	DCRP, UET (2012) and Observation survey (2021)
Diversity	Land use diversity	Entropy Index in 2012 and 2021	DCRP, UET (2012) and Observation survey (2021)
Design	Pedestrian paths	Length of footpaths (m) in 2012 and 2021	Observation survey (2021), Google Earth (2012/2021), and interviews with officials (2012)
	Open space ratio	Area of open spaces and parks (ha) in 2012 and 2021	
	Intersection density	Number of crossings/ha in 2012 and 2021	Open Street Map (2021), Google Earth (2012/2021), and interviews with officials (2012)

Higher density around the stations can encourage the use of BRT. Greater diversity can attract people to visit BRT station areas by BRT and walk around in the station area. Walking-friendly design can promote walking in the proximity of BRT. The indicators in each criterion are selected by the below reasons and the availability of data. To understand the impact of BRT, this study compares the situation before the BRT operation (2012) and the current one (2021) and examines the change in the indicators.

In terms of density, population density is used as criterion because if more people live in the station area, more people will use the BRT, and the population density attracts various urban development in the station area. The population data for the years 2012 and 2016 pertaining to the study area were collected from Punjab Development Statistics. The collected population was available at Union Council (UCs) level, also known as blocks. That is why average population density was considered at the UCs level for observed BRT stations. The concept of Floor Area Density (FAD) was introduced and calculated under density criteria. The following formula calculates FAD.

$$FAD = \sum_{i=1}^{n} \frac{l(i) \times f(i)}{total\ station\ area}, \tag{5.1}$$

where *l(i)* is the land plot area of developed land i and *f(i)* is the number of building floors in the developed land i. The data for floor area ratio (FAR), the total floor area of the building divided by the land plot area, is more accurate to show the development volume. However, the data size of each building is not available. Therefore, FAD is used to show the total volume of development in each station area in this study. Higher FAD means more development and activities; this attracts more people to settle down and visit the station area and promotes BRT use to visit this area. The floor area for 2012 and 2021 was calculated by multiplying the plot's total size with the building's height. After that, FAD was determined by dividing the total floor area by the entire station area.

In terms of diversity, land use diversity is used as a criterion because a range of land use leads to various activities and increases in convenience in the area. It attracts more people to the area and, therefore, more visitors to visit via BRT. The GIS data of land use of 2012 was obtained from the students of the Department of City and Regional Planning (DCRP), University of Engineering and Technology (UET) Lahore. The data divided the land use into nine categories: residential, commercial, mixed-use, public buildings, open space, vacant, agricultural, industry, and graveyard. In Lahore Development Authority (LDA) land use rules, residential land use is considered separately and added to the mixed-use (residential, commercial, and institutional, to be co-located in an integrated way) category if the entire building has one or more other land uses alongside residential land use. Thus, our study has considered the same land-use categories as the 2012 obtained data mentioned in LDA rules. We conducted a visual observation survey in September and October 2021 to know the current land use (see Annexure A). The collected land use data concerns the entire building. If a building has several kinds of usages, then we have taken information regarding building use from a display board that has floor information for the building or ground floor's shopkeeper(s) or resident(s), including the use purpose of each floor, such as the ground floor having commercial use and subsequent floors having residential or institutional use. We have included such buildings in the mixed-use category. The number and the types of land use categories were the same as the 2012 data, and we applied the same survey methods used then. To measure the land-use diversity, the 'entropy index' is applied. Cervero & Kockelman and other researchers used the land use entropy index to measure land use diversity in their study (Cervero & Kockelman, 1997; Frank et al., 2006; Kockelman, 1997; Nasri & Zhang, 2014; Niu et al., 2021).

$$Entropy\ Index = \frac{-\sum_{i=1}^{s}(Pi)\ ln(Pi)}{ln(n)} \tag{5.2}$$

Where Pi represents the proportion of each land-use type, and n shows the total number of land uses in the observed stations. The resulting value of the index falls between 0 and 1. Complete homogeneity of land use is indicated by 0, and 1 denotes absolute heterogeneity of land use. A higher entropy index value demonstrates higher land-use diversity, thus signifying higher levels of TOD (Huang et al., 2018).

Design is a critical part of establishing accessible environments for encouraging walking, a vital element for TOD (Teklemariam & Shen, 2020). In addition, the design element is not only associated with the travel choice; it also develops a critical link in the spatial organization between residents and stations, where it supports creating high-quality open spaces (Niu et al., 2021). In our study, the following criteria were selected; pedestrian paths (m), the area of open spaces and parks (ha), and intersection density (number of intersections/ha). In the 2021 observation survey, pedestrian paths were identified, and the length of footpaths was calculated using GIS. After that, interviews were carried out with LDA, LD, and transport department officials about whether pedestrian paths were developed/improved or not after the BRT infrastructure. Moreover, the ratio of pedestrian paths based on existing footpaths showed walkability and accessibility and was determined using the following formula.

$$Ratio\ of\ Pedestrian\ paths = \frac{Length\ of\ existing\ footpaths\ in\ the\ study\ area\ (m)}{Length\ of\ existing\ roads\ in\ the\ study\ area\ (m)} \tag{5.3}$$

In addition, the open spaces ratio is used as one of the indicators of walkability in this study. According to McCormack et al. (2010), the presence of high-quality green open spaces and parks encouraged walking in the neighborhood. The quality and size of open spaces influenced the neighborhood's pedestrian activities (Koohsari et al., 2013). Zhang et al. (2020) and Zlot & Schmid (2005) found that more walkable neighborhoods have more parks. Similarly, Adams et al. (2011) determined that transportation walking was higher proximate to parks. The area of open spaces and parks was identified from the land use data in 2012 and the observation survey in 2021 and calculated using GIS. In our study, the open space ratio was calculated using the following formula.

$$Open\ Space\ Ratio = \frac{Area\ of\ open\ spaces\ and\ parks\ (ha)}{Total\ cathcment\ area\ of\ a\ station\ (ha)} \tag{5.4}$$

To calculate intersection density, at first, the road network for 2012 was digitized by using the historical imagery option in Google Earth, and the road network for 2021 was taken from the Open Street Map. In addition, the road network for 2021 was corrected using Google Earth. We computed the intersection density using the road network considering the three or more-way intersection located in the study area using GIS. Cul-de-sacs were excluded from the analysis in this study. According to Islam et al. (2018), cul-de-sacs reduce accessibility to destinations and increase commuting distance. Islam et al. (2018) and Cervero et al. (2010) determined the intersection density using the following equation.

$$Intersection\ Density = \frac{TI}{A} \tag{5.5}$$

Where *TI* represents the total number of three or more-way crossings, and *A* shows the land area (ha) at observed BRT stations.

5.3. Classification of TOD and TAD Areas

A 10-minute walking distance of 800 m is appropriate for TOD planning (Schlossberg, 2006), so an 800 m buffer around the selected BRT stations was created to illustrate the TOD zones using ArcMap. We then identified the TOD and TAD areas using the quantitative methodology developed by Nasri and Zhang (2014). The transit station area (Z_i) is considered TOD if it satisfies the following settings:

$$Z_i \in \text{TOD if}$$
$$D_R^{Z_i} \geq D_R^{Avg}\ OR\ D_E^{Z_i} \geq D_E^{Avg} \tag{5.6}$$
$$\frac{Rank_{Z_i}^{Entropy}}{n} \geq 0.30$$
$$Z_i \in U_{1\leq i\leq n}\ Ball_{0.5}^{Ti}$$

Where,

$D_R^{Z_i}$	: Residential density of Z_i = residential population/land area (acres)
D_R^{Avg}	: Average residential density of the entire metropolitan area
$D_E^{Z_i}$	: Employment density of Z_i = employment/land area (acres)
D_E^{Avg}	: Average employment density of the entire metropolitan area
$Rank_{Z_i}^{Entropy}$	: Rank of entropy (Z_i) when sorted decreasingly according to entropy
$Ball_{0.5}^{Ti}$	: Buffer of radius 0.5 miles (800 m) around Ti
$Ti, 1 \leq i \leq n$	: Point where the transit station is located

We identified four BRT station areas such as Shahdara, Bhatti Chowk, Ichra, and Kamahan, as TOD, whereas the rest of the stations, including Model Town, Naseerabad, Nishtar Colony, and Dullu Khurd, as TAD. Classification of station area into TOD and TAD is presented in **Table 5.2**. Moreover, **Figure 5.1** shows the TOD and TAD areas around selected BRT stations in Lahore.

Table 5.2 Classification of station area into TOD and TAD

Station	Population density (acre)	Lahore's population density (acre)	Entropy Index	Rank of entropy	Rank of entropy/n	Classification of station
Shahdara	162	26	0.84	8	1.00	TOD
Bhatti Chowk	296	26	0.72	4	0.50	TOD
Ichra	239	26	0.69	3	0.38	TOD
Model Town	76	26	0.64	2	0.25	TAD
Naseerabad	52	26	0.61	1	0.13	TAD
Kamahan	78	26	0.78	5	0.63	TOD
Nishtar Colony	23	26	0.79	6	0.75	TAD
Dullu Khurd	23	26	0.81	7	0.88	TAD

5.4. Research Instrument

The questionnaire was divided into two main categories, socioeconomic and travel characteristics, to better understand travel behavior (See Annexure B). The socioeconomic characteristics of the respondents were gender, age, marital status, education, profession, monthly income, monthly household income, house ownership, number of persons in the house, number of workers in the house, number of cars, number of motorcycles, number of cycles, and driving license. Travel characteristics mainly include travel mode, distance, time, and cost to work and shopping trips. The distance to the CBD was also included and corrected using Google Earth software.

5.5. Survey and Sampling Technique

In our study, it was difficult to investigate the travel behavior of all residents in the study area, so we used Slovin's formula to select the target population, which is given below:

$$n = \frac{N^2}{1+Ne^2} \tag{5.7}$$

where n represents the sample size, N is the population size, and e is the margin of error. The population size of the buffer area was 42,349 households, including residential and mixed-use development. The computed sample size was 396 at a confidence level of 95%. The sample size was distributed according to the population size across the selected stations. A simple random sampling technique was used to collect data from the selected samples. Random samples were determined using MS Excel software and linked with ArcMap software to demonstrate the spatial location (latitude and longitude) of the sample (see Annexure C). For the survey, a rule was formulated if the sample house was locked or if women were present in the house who felt reluctant to answer the questionnaire; the next house must be taken into consideration from the left or right of the selected sample house.

The survey team conducted a household survey using a questionnaire in the selected BRT station areas in July–August 2022. The survey team comprised four urban planning undergraduate students at the University of Engineering and Technology in Lahore. First, three hours training session was held with the survey team to understand the contents of the questionnaire. After that, the first author conducted ten pilot surveys in station areas to understand the survey team and whether residents could understand the contents of the questionnaire. We found that the survey team and residents clearly understood the content of the questionnaire. The questionnaire was developed in English; however, the survey team asked the respondents questions in their native language (Urdu). Respondent's consent was also taken for participation in a questionnaire.

To understand residents' travel behavior, this study used a sample of 426 individual responses from the study area using a simple random sampling technique. The sample distributions for each station are listed in **Table 5.3**.

Table 5.3 Distribution of sample size in each station area

Stations	Residential parcels	Mixed-use parcels	Total parcels	Distribution of sample size	Collected sample size
Shahdara	3441	893	4334	41	45
Bhatti Chowk	4337	5594	9931	93	100
Ichra	4647	3534	8181	76	80
Model Town	1856	120	1976	18	20
Naseerabad	2060	373	2433	23	25
Kamahan	5141	1910	7051	66	70
Nishtar Colony	3946	1367	5313	50	55
Dullu Khurd	2420	710	3130	29	31
Total	27848	14501	42349	396	426

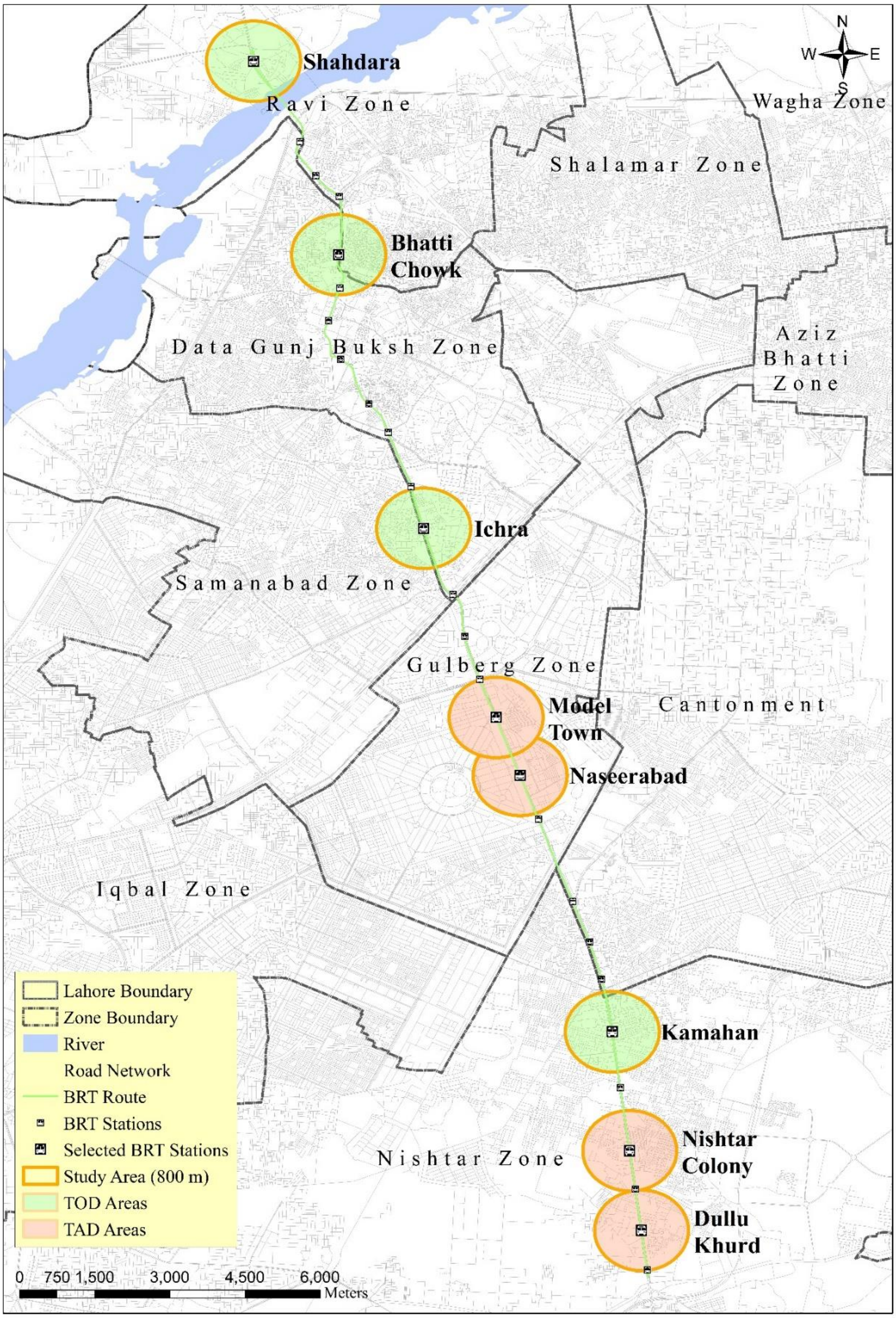


Figure 5.1 TOD and TAD areas around selected BRT stations in Lahore

5.6. Multilevel Mixed-effect Regression Model

We employed a multilevel mixed-effect regression model to investigate the impact of TOD attributes on VKT in the TOD and TAD areas using SPSS software. This modeling approach permits us to obtain distinct coefficients by subject cluster (TOD and TAD). Subjects within the same cluster are expected to be analogous to each other in the context of their features, and this means that residents residing in similar TAD have the same travel behavior and approach capable of interning these likenesses and their extent. Subsequently, a multilevel model can be conceptualized as follows:

$$y_{ij} = \gamma_{00} + \gamma_{01}Y_j + \mu_{0j} + \gamma_{10}X_{ij} + \varepsilon_{ij} \quad (5.8)$$

Where,

y_{ij} : Dependent variable for individual i in group j

X_{ij} : Individual-level variables for individual i in group j

ε_{ij} : Individual-level random error with a mean of 0 and variance of S2

Y_j : Group-level variable

γ_{00} : Common intercept across groups

γ_{01} : Effect of group-level predictors on group-specific intercepts.

γ_{10} : Common slope linked with individual-level variables across groups

μ_{0j} : Normally distributed with a mean of 0 and variance of τ_{00}

5.7. BRT-Based TOD Models

We proposed two BRT-based TOD models for urban and suburban areas to make Lahore a sustainable city in the future. For this purpose, we used the indicators of 3Ds of TOD (refer **Table 5.1**) and travel characteristics of the respondents (n = 426) around BRT station areas. As well as we considered the interviews conducted with professionals.

5.8. Review of Land Use and Transportations Planning Documents

Firstly, the transportation and urban planning system of Lahore was explored. Secondly, Lahore's Transportation and urban planning documents were reviewed to determine the TOD strategies. Many master plans were formulated to promote transportation and urban development in Lahore. We have extracted the proposed transport and land use strategies in different periods. Moreover, local ordinances and acts were formulated for Lahore's spatial and transportation planning. We also reviewed these ordinances and acts.

5.9. Structured Interviews with Professionals

We considered the Integrated Master Plan for Lahore (IMPL) 2021 for this research study, formulated for 2001 – 2021 and approved in 2004. This plan was prepared to guide the future urban development of Lahore (NESPAK & LDA, 2004). This plan mainly focused on urban road development and the construction of LRR. However, this plan did not overtly use TOD as a strategic option to transform the urban structure over the plan's lifespan. Moreover, IMPL was amended for the entire Lahore division in 2016 by LDA. Firstly, we reviewed this plan thoroughly, and it presented several strategies regarding urban development and transport, but unfortunately, most of them were not implemented partially or fully. Then, we extracted the strategies most closely related to urban development/land use and transport, as shown in **Table 5.4**.

Table 5.4 Land use and transport strategies in IMPL 2021

Master Plan	Timeline	Land use and transport strategies	Departments involved
Integrated Master Plan for Lahore (IMPL), 2021	2004 – 2021	Densification of the existing built-up areas Infill and consolidation of vacant pockets within the built-up areas - *Most of the plots (75% to 80%) in the formal housing market are held vacant, probably* Distribution of residential density across the city - *Periphery areas (adjacent to existing built-up areas) – 325 pph* - *South-West (formal housing scheme developed) – 175 pph* - *High-density zones (closer to the centre of employment in low-income areas, i.e., industrial clusters) proposed near the Shahdara area – 500 pph* Housebuilding incentives such as credits and tax reliefs for the lower income groups Free height zones in Central Business District (CBD) area - *Few roads where limited land pockets can be utilized for the construction of such multi-storeyed structures, including hotels, offices, and institutions but the plot area should not be less than 20 Kanal.* Undertaking projects for urban renewal in the central area Shifting of incompatible land uses (i.e., industries) from residential areas to reduce environmental hazard Green Belt as Buffer Zone (one km wide) around the industrial estate to save the environment from industrial hazards Creation of a new Town Centre *(Trade Centre in Johar Town)* and Business Districts *(South of Hudiara Drain and East of Ferozepur Road in the South)* comprising commercial and service areas Establishment of satellite towns having specialized facilities to curb in-migration and reduce travel time *(one-*	Lahore Development Authority, City District Government

		way travel time of about 90 minutes or within a radius of 75 km) Provision of trunk infrastructure in existing and partially developed areas for consolidation Construction of Lahore Ring Road for land consolidation Provision of facilities for pedestrians and cyclists Development of Light Rail Transit (LRT) of length 12.5 km along with upgrading of Heavy Rail Transit (HRT) utilizing existing rail track Improvement of the public transport system and development of bus terminals Provision of off-street parking facilities and rationalization of on-street parking provision Establishment of a GIS database on population, land use, infrastructure, and services for future planning decisions and coordination with other departments Development of green spaces - *100 mohalla parks, 40 neighborhood parks, one town park, and one riverside park* Preparation of strategic land use and transport plan at the Metropolitan level	
Amended Master Plan of Lahore Division (AMPLD), 2016	2016	Semi-circular and circular shape compact development Future urban growth in greenfield development in suburban areas towards South-East	Lahore Development Authority

After reviewing IMPL, a structured interview was conducted with professionals working in Lahore's land use and transport planning departments (see Annexure D). These professionals were randomly selected based on their experience with land use and transport planning. As well as the selection was based on their participation in the preparation, implementation, or review process of this master plan in their concerned departments. Firstly, an interview letter was sent to more than 40 professionals via e-mail, WhatsApp, and FB Messenger to obtain consent for their interview. Almost half agreed to participate in interviews via online platforms such as Zoom or WhatsApp. Later, the interview questions sheet was sent to the agreed participants and asked for their availability to interview with them. We conducted 11 structured interviews in June – July 2023. Out of 11, two interviews remained incomplete. The rest of the agreed persons (almost 10) were not given interviews due to uncertain reasons, i.e., unavailable at the arranged time. The interview of 9 professionals was completed successfully using Zoom and WhatsApp. Interview length varies from 120 – 180 minutes among the participants. The interviews were conducted and recorded in the Native language (Urdu). After that, the authors converted the recorded interviews into English language. All interviewees were assured confidentiality and privacy to gain honest answers. Firstly, the authors introduced the research theme and its objectives to the participants and asked the interview questions under the following four themes.

- Why land use and transport strategies of the IMPL 2021 were not implemented fully or partially?
- Why were TOD elements not considered in IMPL 2021?
- Why are some TOD elements declining around BRT station areas in Lahore?
- What are the challenges and opportunities for encouraging BRT-based TOD in Lahore?

We employed the word frequency analysis technique in connection with repeated close readings of the interviews using the themes mentioned above. Word frequency analysis provides a simple but complete first look at recurring themes in the interviews. The NVivo 14 software was used to process word frequency analysis using criteria such as the most frequent display words limit restricted to 150 with a minimum length of 5 words in the interview data, and exact grouping matches were also considered. This software creates word frequency counts with the support of a wordlist and aggregates words. Then, we produced a word frequency for interview data.

5.10. Conclusion

We chose 3D criteria to measure how close the urban fabric in a BRT station area is to TOD and the impact of TOD on VKT because the 3Ds of urban structures influence travel behavior as a feature of TOD. Moreover, the selected criteria and indicators are measurable, evaluate the previous and current situations, and for which data is readily available and collectible. Furthermore, we classified the station areas into TOD and TAD to better understand the resident's travel behavior. For this purpose, we collected a sample of 426 respondents from TOD and TAD areas using a simple random sampling technique based on questionnaire surveys. We employed a multilevel mixed-effect regression model to investigate the impact of TOD attributes on VKT in the TOD and TAD areas using SPSS software. We proposed two TOD models for Lahore based on observation data and travel behavior data. We conducted interviews with the professionals of different departments to identify the causes of not implementing land use and transport strategies of IMPL. Moreover, we investigated the challenges and opportunities that stand in the way of TOD with BRT. A research framework for the four objectives of this study is presented in **Figure 5.2**.

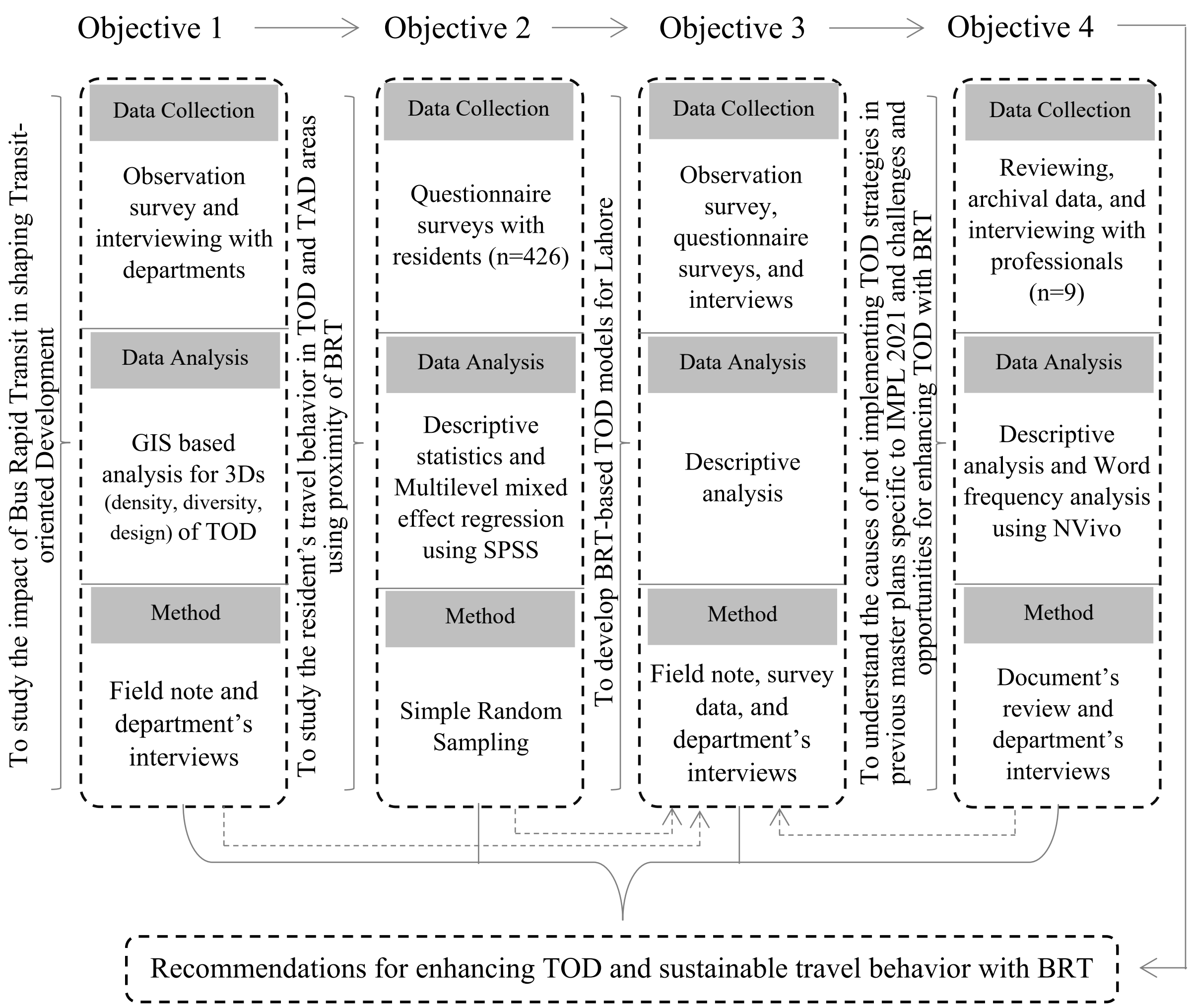


Figure 5.2 Research framework

CHAPTER 6: IMPACT OF BRT IN SHAPING TOD

6.1. Introduction

This chapter seeks to answer the following questions: What kind of urban fabric has been created in BRT station areas? Whether the urban fabric has elements of TOD, which encourage public transit use and walking rather than private vehicle use? It provides the results and findings of the impact of BRT on shaping TOD using 3D criteria of TOD, including density, diversity, and design around BRT station areas in Lahore. It also compares the findings of this study with previous research findings.

6.2. Density

6.2.1. Population density

Figure 6.1 shows the average population density within an 800 m radius for the eight selected BRT stations between 2010 and 2016. There are great differences in population density from station to station. The two stations in the city center, Bhatti Chowk and Ichra have the highest population density and the two stations in the suburban area, Nishtar Colony and Dullu Khurd station have the lowest population density consistent across time. Population density in all of the eight stations increased from 2010 to 2016. The biggest change was 14% in Kamahan, and the smallest change was 11% in the two suburban stations such as Nishtar Colony and Dullu Khurd. The differences in the rate of change are not as large as the differences in population density. The average population density of Lahore accounts for 45 Persons per hectare (PPH) in 2010 and 51 PPH in 2016, with a percentage change of 13%. Compared with this rate of population change in the whole city, the population density in the eight BRT station areas has not increased significantly. We have taken the population density data for 2010 and 2016, which was very close to the opening year of the BRT system. It is expected that the impact of BRT on population density might have emerged yet. Our findings are inconsistent with those of Masoumi & Shaygan (2016). They found that the population density of the observed metro stations significantly increased between 2005 and 2015 in Tehran, Iran. Similarly, Bocarejo et al. (2013) found that BRT has a significant increase in density relative to zones where the system was not operating in Bogotá.

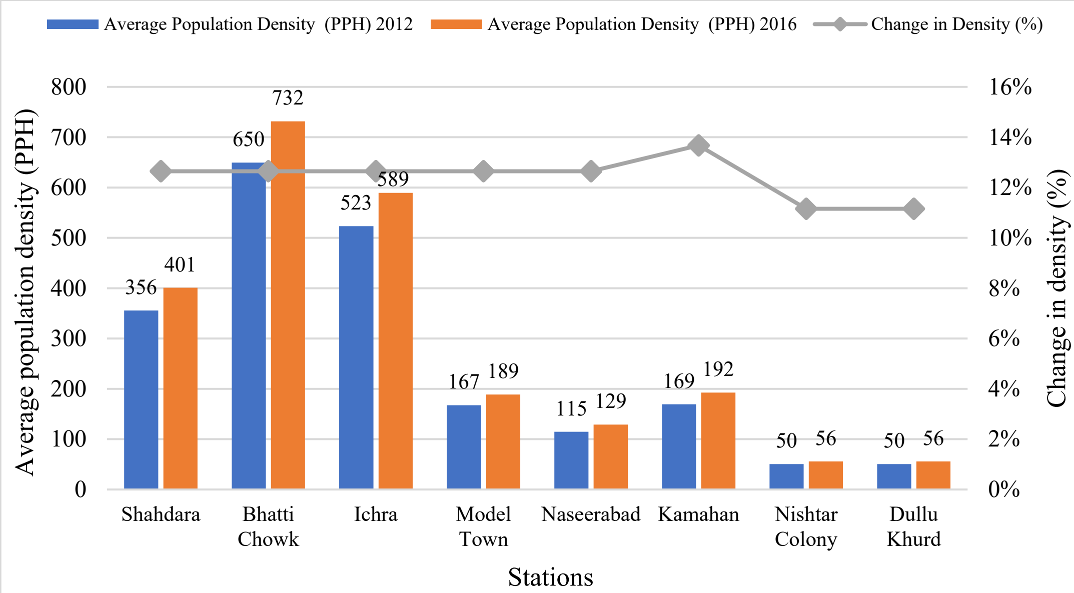


Figure 6.1 Average population density of 2010 and 2016 in BRT station areas

As we discussed in the methodology chapter, four BRT station areas are classified into TOD areas such as Shahdara, Bhatti Chowk, Ichra, and Kamahan, whereas the rest of the stations, including Model Town, Naseerabad, Nishtar Colony, and Dullu Khurd, are classified into TAD areas. **Figure 6.2** shows the average population density and rate of change in population density in TOD and TAD areas. The average population density was almost four times higher in TOD areas than in TAD areas because TAD areas comprise suburban and planned development. The average population density increased in both areas, but a higher increase was in TOD areas (55 PPH) than TAD area (11 PPH). However, the percentage rate of change was almost the same (13%) in TOD and TAD areas.

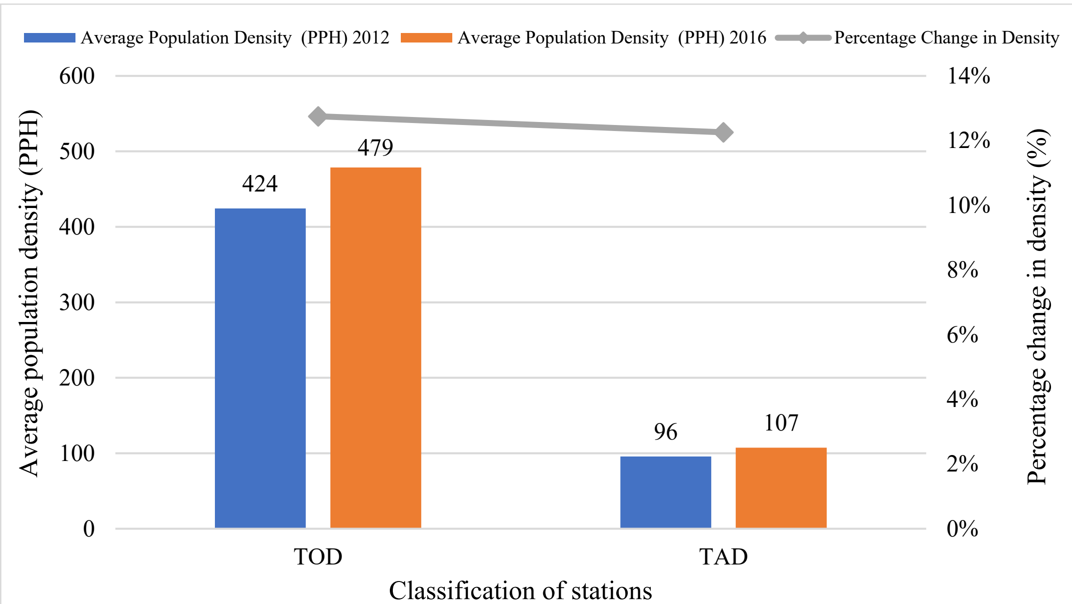


Figure 6.2 Average population density in TOD and TAD areas

6.2.2. Floor Area Density

Figure 6.3 shows the Floor Area Density (FAD) in the eight BRT station areas in 2012 and 2021. FAD was increased in all stations but there are great differences in FAD between the stations both in 2012 and 2021. In 2021, the two stations in the city center have the highest FAD, 2.14 and 1.92 and the Shahdara and Dullu Khurd have the lowest FAD, almost 1.15. The rate of change in FAD is highest in Nishtar Colony station. In 2012, the Nishtar Colony station area had large vacant and agricultural land. This type of land use has greatly decreased in proportion, and other land use such as mixed use and industry have increased. The FAD has greatly increased in these areas. The station area in the city center, Bhatti Chowk station, also increased in FAD significantly, by 18.5%. This station area has almost no agricultural land and a very small proportion of vacant land, so floor area was expected to be increased by rebuilding or adding additional floors. The two controlled areas, Model Town and Naseerabad, have the lowest rate of FAD change, 6.50% and 2.59%, respectively. This was expected because of strict land use control under building and zoning regulations. Our findings are consistent with those of Deng & Nelson (2013). They concluded that BRT has some positive impacts on land development around the stations in Beijing.

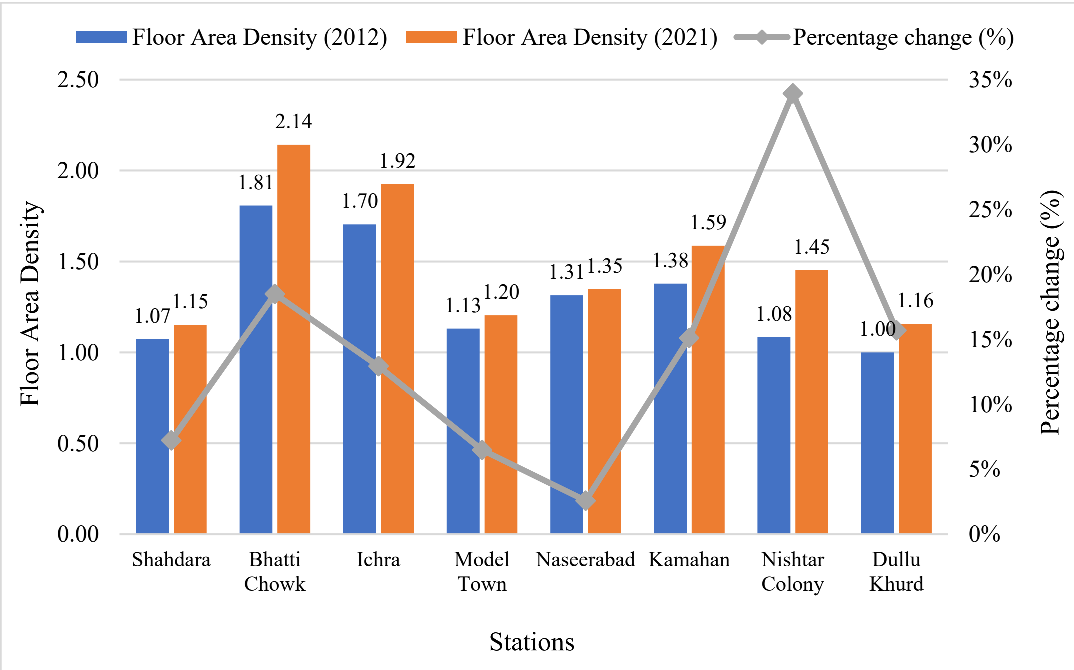


Figure 6.3 Floor Area Density in BRT station areas

Figure 6.4 shows the FAD for 2012 and 2021 around BRT stations in TOD and TAD areas. The FAD of TOD areas was higher than TAD areas in 2012. The FAD increased in both classified areas from 2012. In 2021, it was 1.70 and 1.29 in TOD and TAD, respectively. The percentage change in FAD was higher in the TAD area (14.68%) than in TOD areas (13.44%) because of most vacant and agricultural land. Whereas, FAD was expected to be increased by rebuilding or adding additional floors because they had no vacant land for further development.

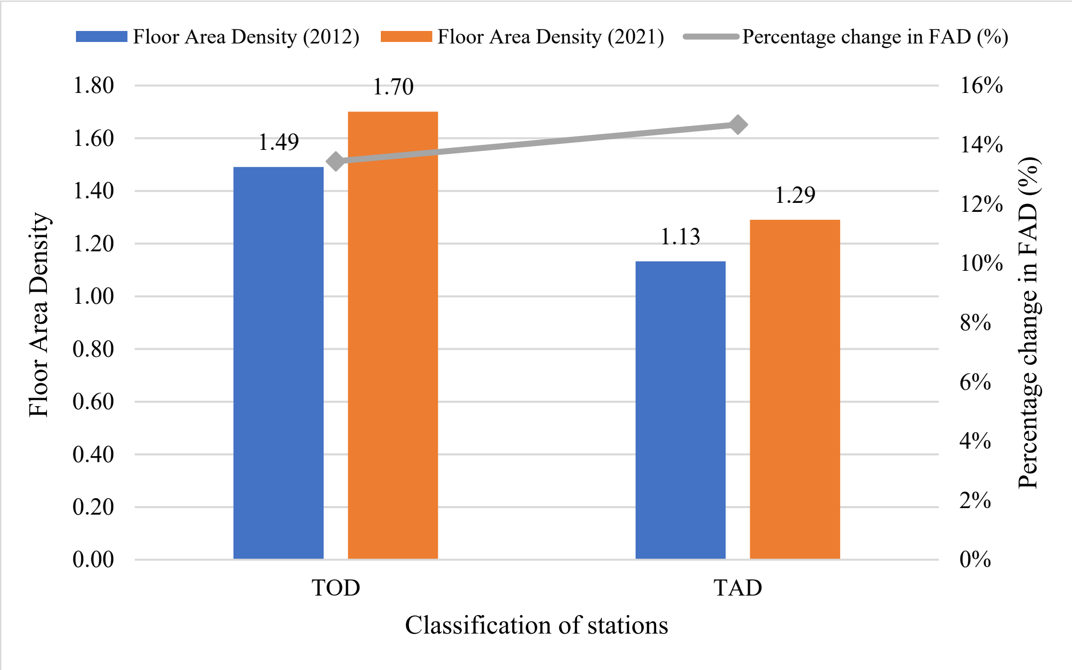


Figure 6.4 Percentage change in Floor Area Density in TOD and TAD areas

6.3. Land Use Diversity

6.3.1. Land use changes at the station level

The station-wise land-use percentage between 2012 and 2021 in the proximity of the observed BRT stations is described below. The development pattern is presented in Annexure E.

Shahdara Station: It is characterized by industrial and commercial activities with unplanned development patterns. The residential land use declined by 15.11% and transformed into commercial and mixed-use by 35.54% and 99.12%, respectively (see **Figure 6.5**). Our study estimates that industrial land use also increased by 9.01% during the study period. On the other hand, vacant land use is reduced significantly. BRT investment shapes TOD at this station, as mixed-use land doubled from 2012 to 2021.

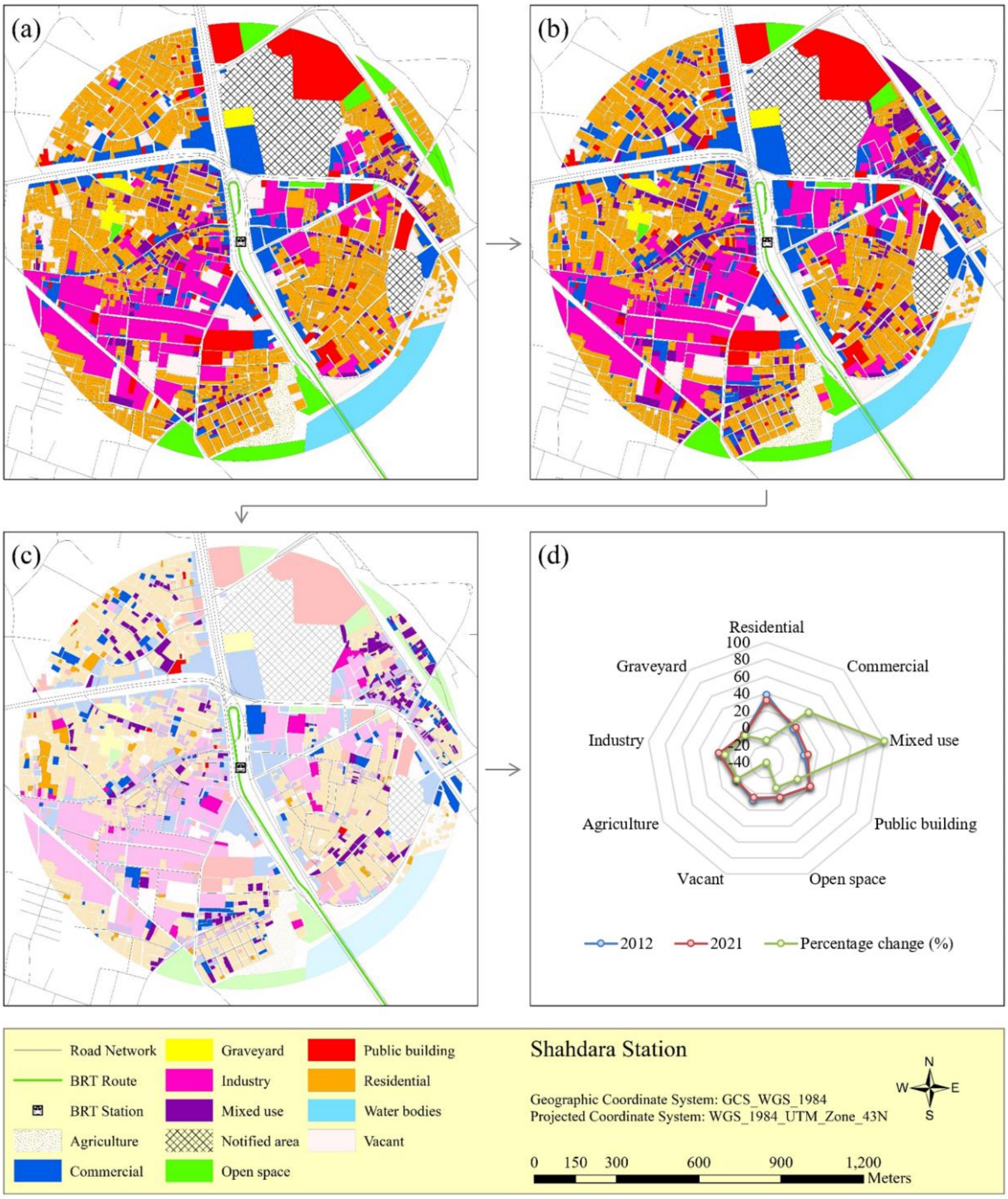


Figure 6.5 Land use changes at Shahdara station (a) land use 2012 (b) land use 2021 (c) change in land use between 2012 and 2021 (d) percentage change in land use between 2012 and 2021

Bhatti Chowk: It is a house of tourist places, public buildings, parks, and a general bus terminal. It is characterized by commercial, mixed-use, residential, and public spaces. The area around the station consists of old urban structures with a narrow street network. At this station, residential land use declined by 35.46% and converted into other land uses, including commercial and mixed-use by 8.68% and 61.19%, respectively (see **Figure 6.6**), after the introduction of BRT.

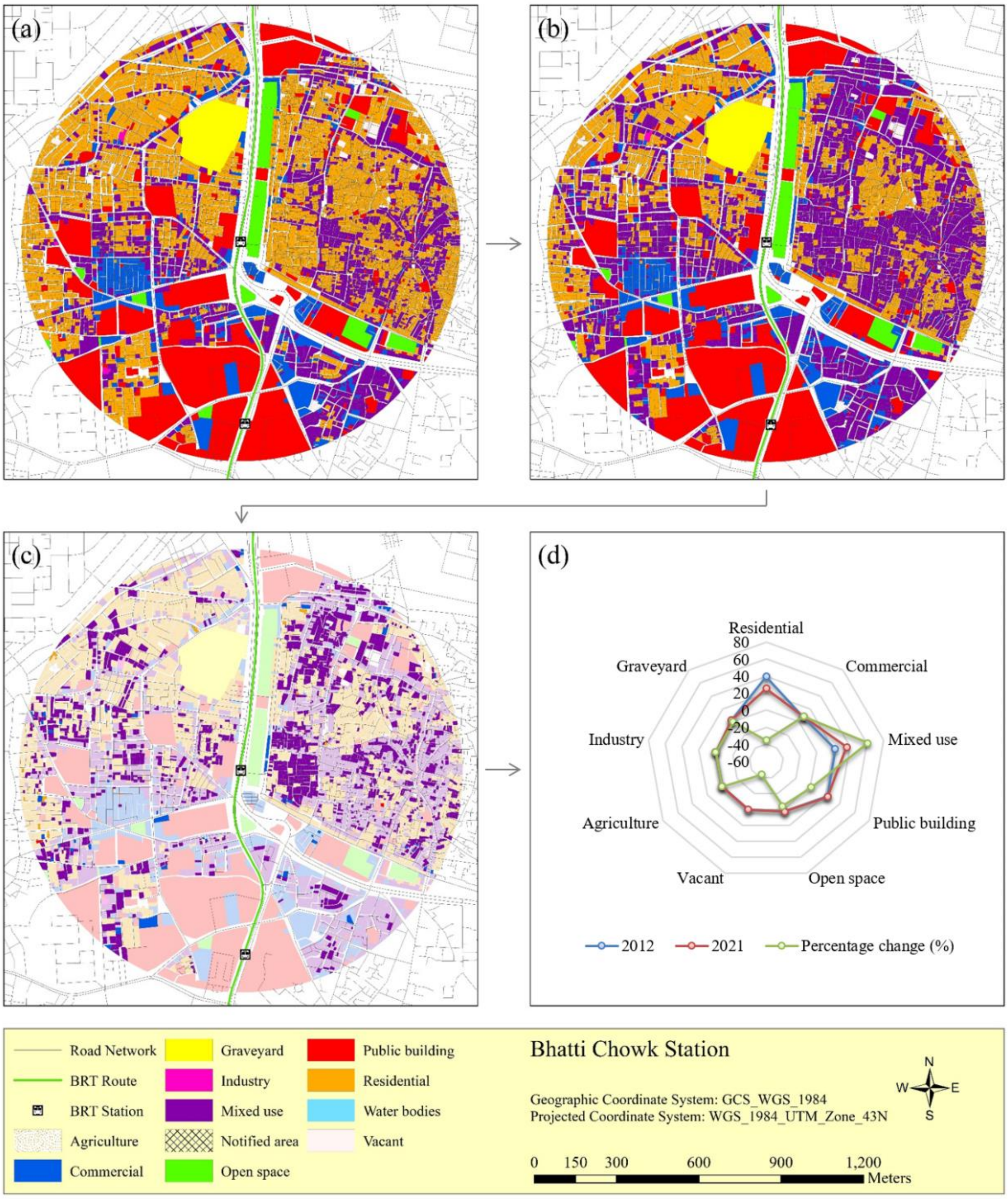


Figure 6.6 Land use changes at Bhatti Chowk station (a) land use 2012 (b) land use 2021 (c) change in land use between 2012 and 2021 (d) percentage change in land use between 2012 and 2021

Ichra Station: Ichra is an old built-up area and a hub for commercial and mixed-use activities, visited by people of all income groups for various shopping needs. Residential and vacant land use was reduced by 17.91% and 40.99%, respectively, after the BRT investment (see **Figure 6.7**). On the other hand, commercial and mixed-use increased by 45.31% and 37.94%, respectively, due to a transformation of vacant and residential land use. It is noticed that commercial land use increased considerably at this station than mixed-use due to the commercial hub.

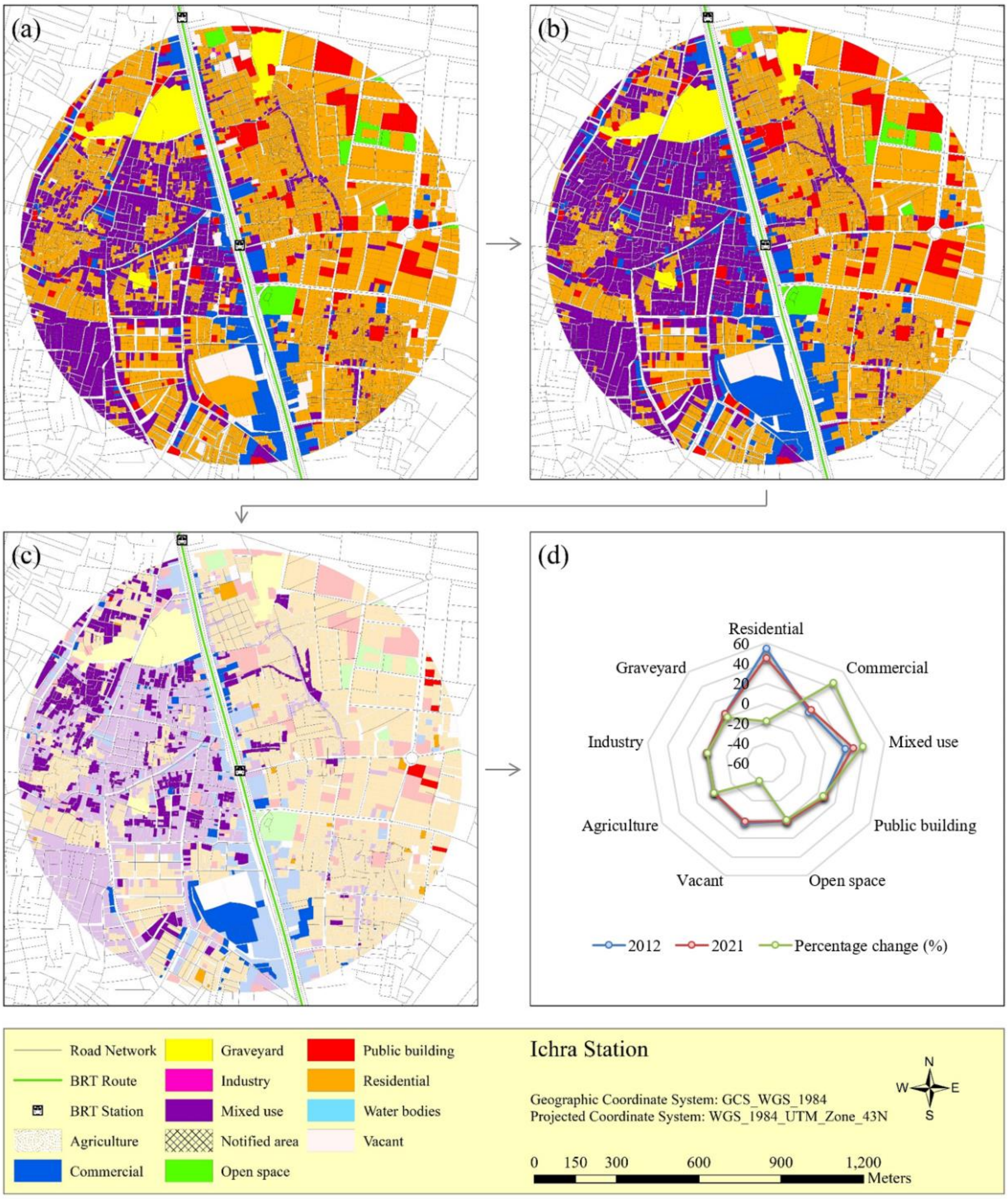


Figure 6.7 Land use changes at Ichra station (a) land use 2012 (b) land use 2021 (c) change in land use between 2012 and 2021 (d) percentage change in land use between 2012 and 2021

Model Town: It consists predominantly of residential areas and has a well-planned road network with a regulated development pattern. We observed that residential land use declined by only 4.29% due to controlled development. However, commercial and mixed-use land use boosted by 94.60% and 85.69%, respectively, due to the conversion of vacant land after BRT investment inducing TOD (see **Figure 6.8**). However, there is a potential to further stimulate TOD due to the availability of vacant land.

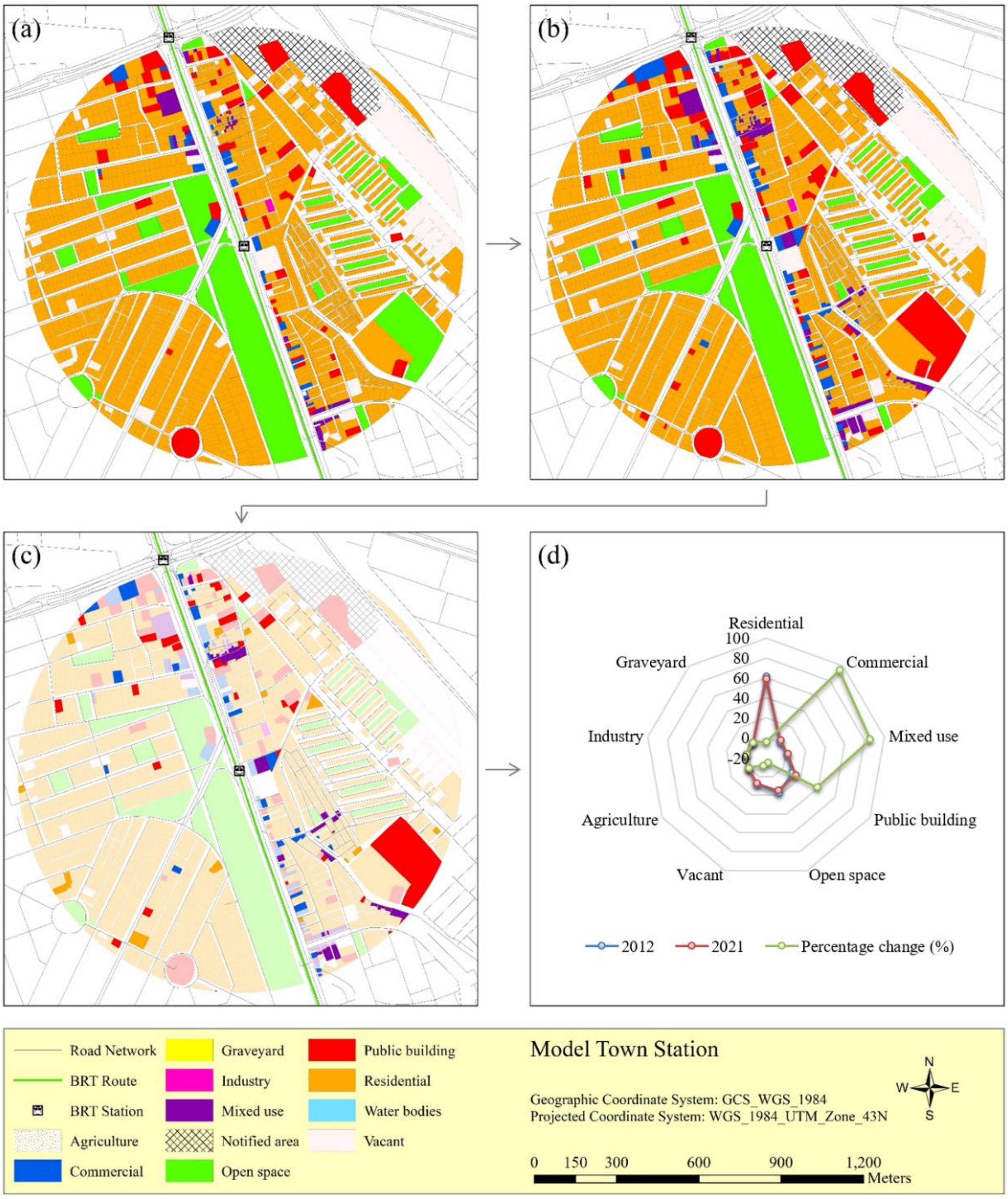


Figure 6.8 Land use changes at Model Town station (a) land use 2012 (b) land use 2021 (c) change in land use between 2012 and 2021 (d) percentage change in land use between 2012 and 2021

Naseerabad Station: It is comprised of residential and planned development patterns. A slight reduction is observed in residential use by 4.29% due to strict development control. It is noticed that commercial and mixed-use are increasing significantly by 142.91% and 103.84% (see **Figure 6.9**) due to the transformation of vacant land, shaping the TOD.

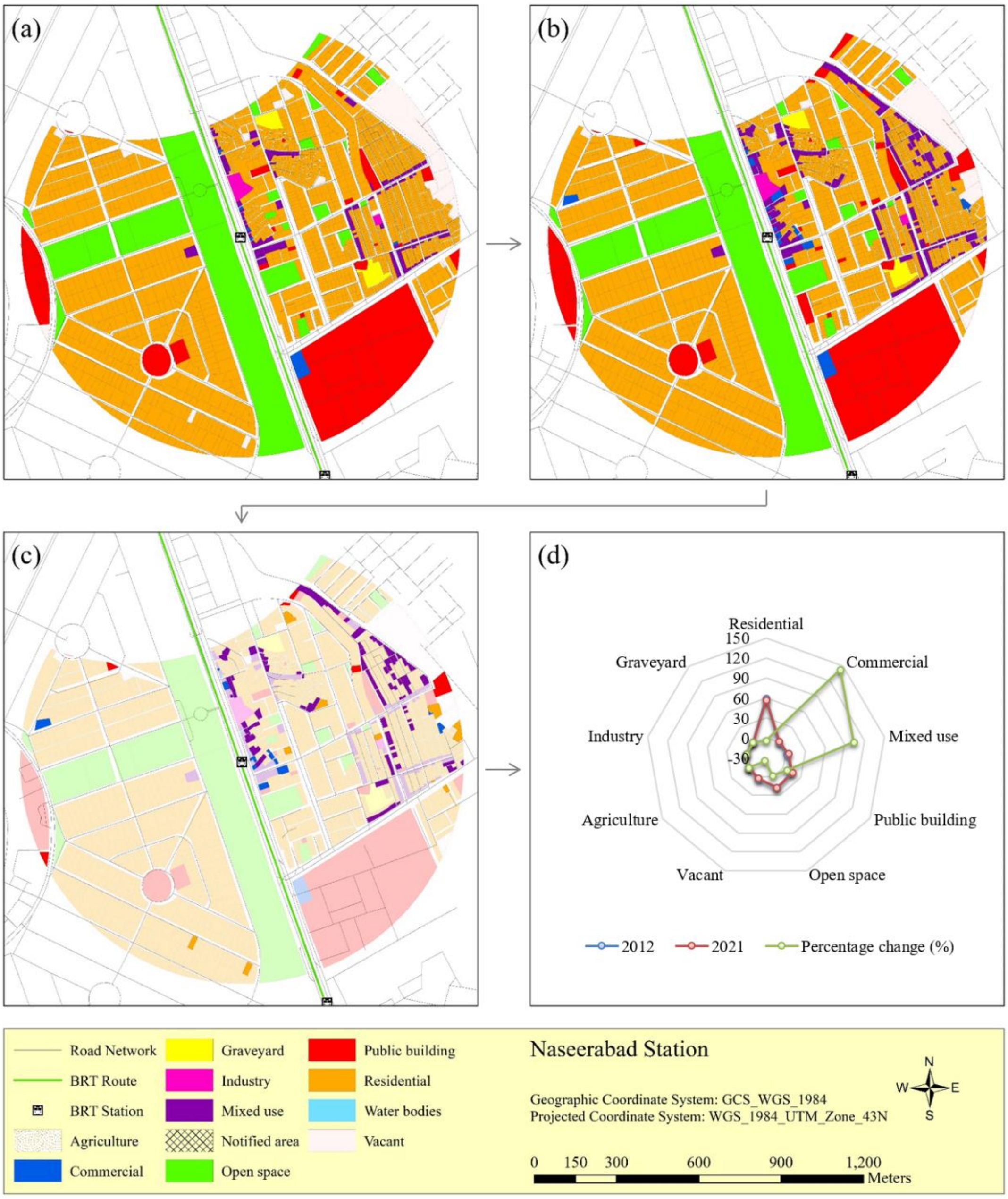


Figure 6.9 Land use changes at Naseerabad station (a) land use 2012 (b) land use 2021 (c) change in land use between 2012 and 2021 (d) percentage change in land use between 2012 and 2021

Kamahan Station: This station's area is residential, mixed-use, commercial, and unplanned. It is observed that residential and vacant land decreased by 22.64% and 35.82%, respectively, and considerably transformed into commercial and mixed-use by 93.87% and 207.46%, respectively (see **Figure 6.10**). It is noticed that mixed-use increased more than two times after the BRT investment, mainly shaping the TOD. Moreover, this station can further support the TOD due to vacant land availability.

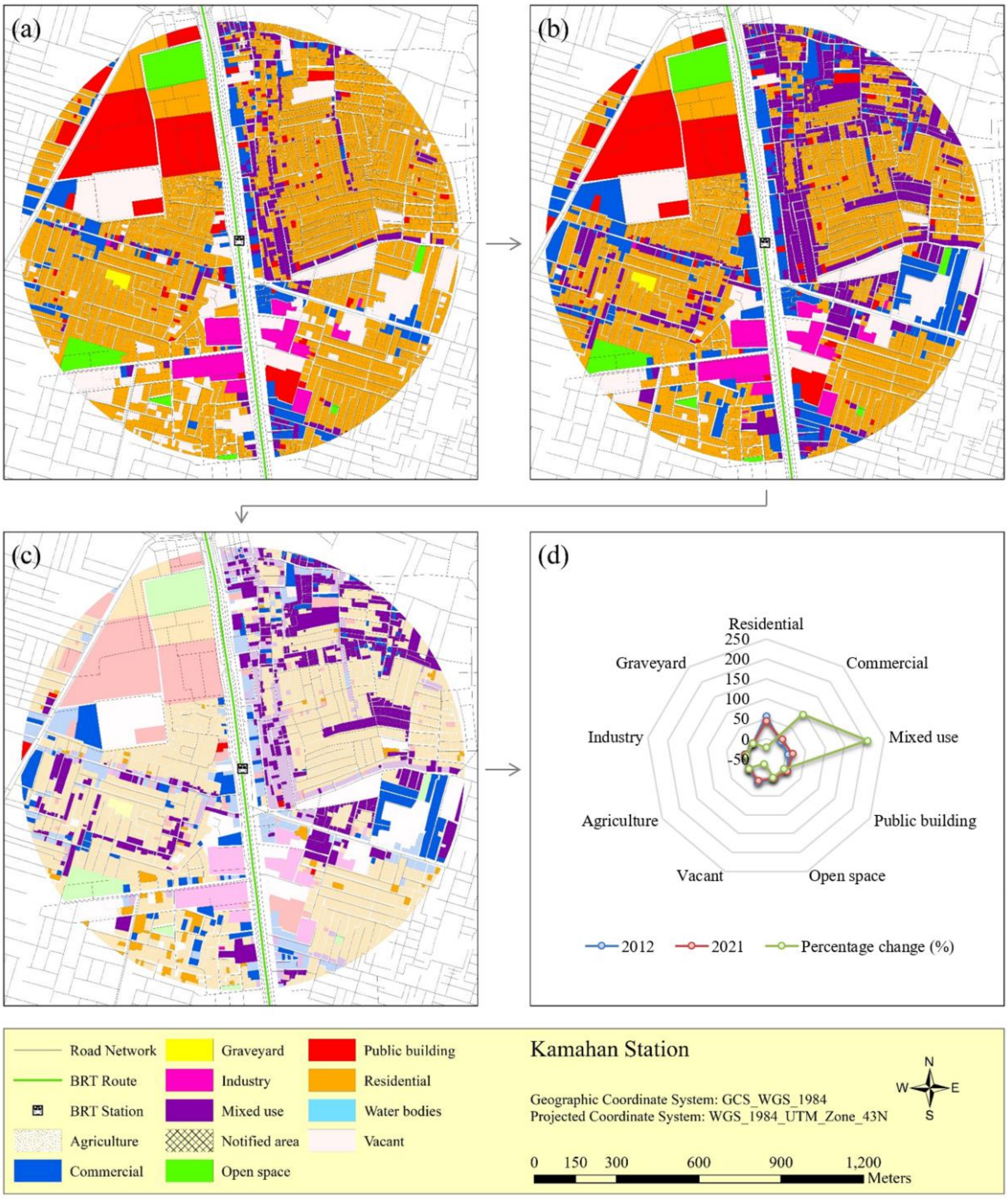


Figure 6.10 Land use changes at Kamahan station (a) land use 2012 (b) land use 2021 (c) change in land use between 2012 and 2021 (d) percentage change in land use between 2012 and 2021

Nishtar Colony Station: It is situated in a suburban area and contains unplanned industrial and residential development. Surprisingly, residential land use increased by 2.98% due to the huge availability of vacant and agricultural land. Vacant and agricultural land use by 59.54% and 67.07%, respectively, were significantly converted into commercial and mixed-use by 94.22% and 121.90% (see **Figure 6.11**). Furthermore, industrial land use also increased by 30.93% due to the potential of industries and cheaper land availability.

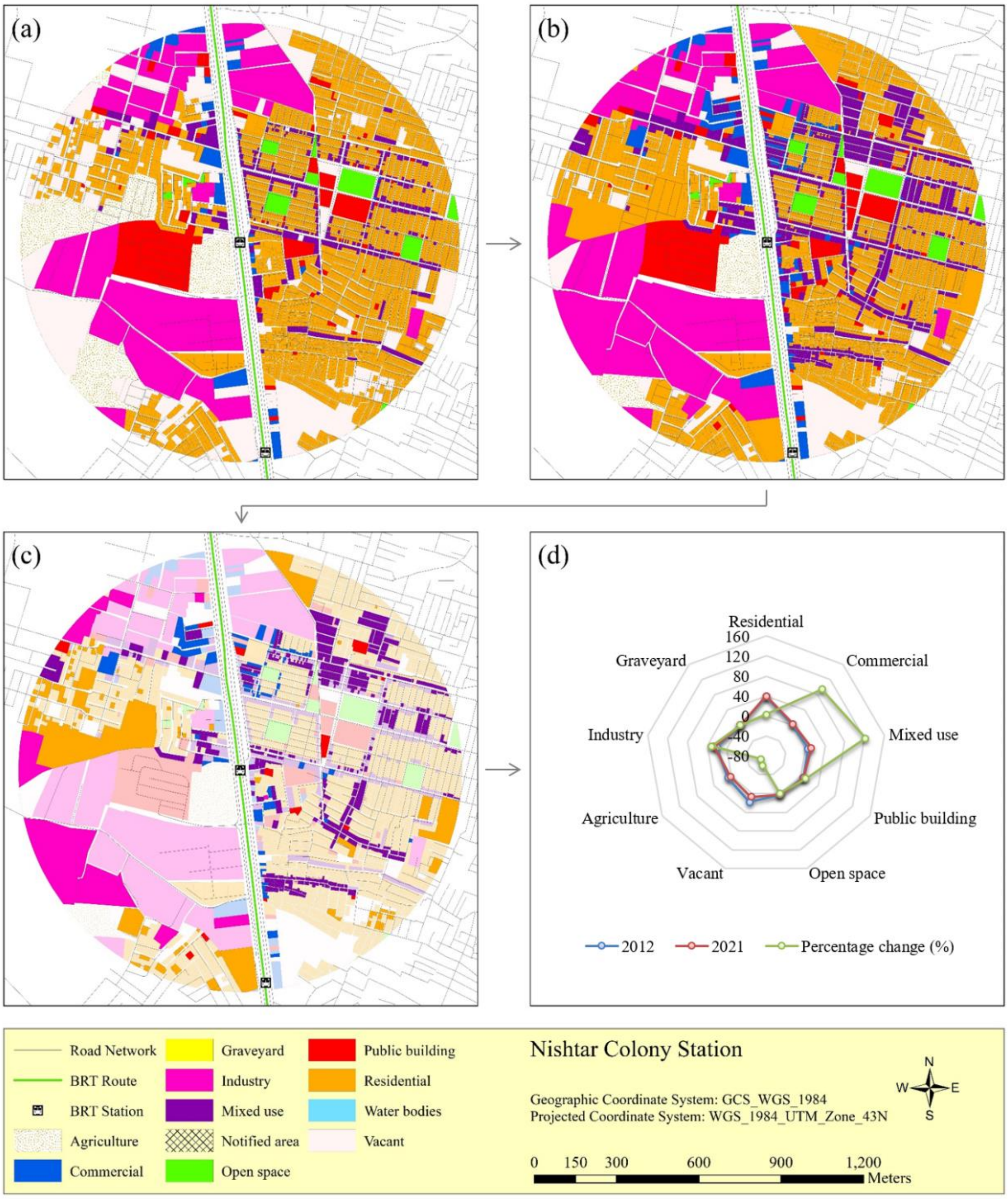


Figure 6.11 Land use changes at Nishtar Colony station (a) land use 2012 (b) land use 2021 (c) change in land use between 2012 and 2021 (d) percentage change in land use between 2012 and 2021

Dullu Khurd Station: It contains unplanned industrial and residential development. Residential, vacant, and agricultural land use declined by 23.59%, 43.86%, and 12.58%, respectively, after BRT introduction (see **Figure 6.12**). As a result, the commercial and mixed-use substantially increased by 100.97% and 243.39%, respectively. Interestingly, the suburban station had a tremendous change in mixed-use due to available vacant land. Moreover, industrial land use increased by 57.79% due to the considerable potential of industries and cheap land.

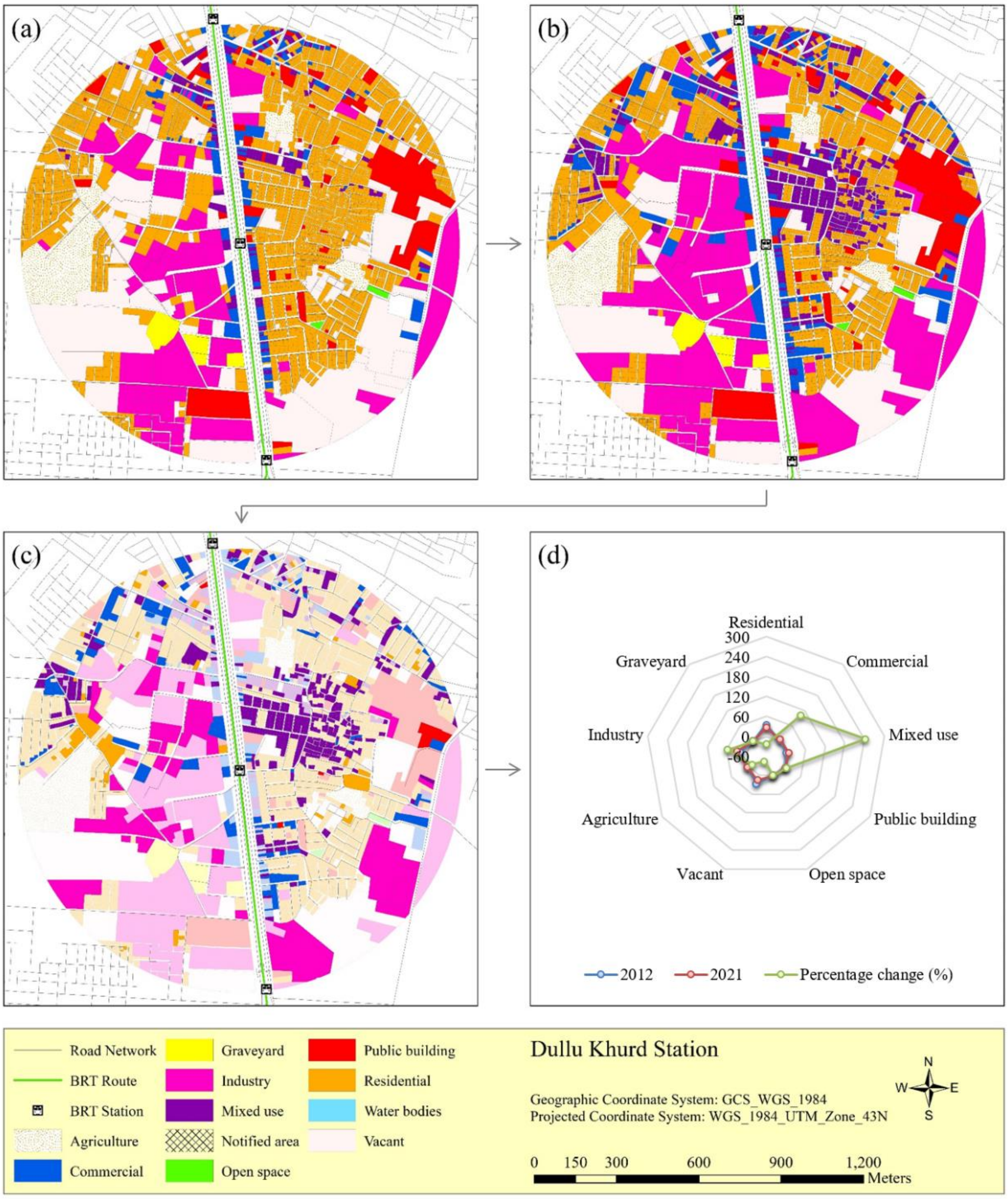


Figure 6.12 Land use changes at Dullu Khurd station (a) land use 2012 (b) land use 2021 (c) change in land use between 2012 and 2021 (d) percentage change in land use between 2012 and 2021

6.3.2. Land use changes in the study area

Figure 6.13 shows the land-use changes within the study area in 2012 and 2021. **Table 6.1** shows the commutative percentage change in the land use area of eight BRT stations for 2012 and 2021. Residential land use is continuously declining from 613 ha in 2012 to 523 ha in 2021, a decrease of 14.6%. Residential use has decreased significantly in Bhatti Chowk, Ichra, and Kamahan stations. In these three stations, mixed-use has significantly increased. Mixed-use is defined as "land use which enables a range of land use including residential, commercial, and institutional to be co-located in an integrated way" in the Lahore Development Authority's land use rules. Therefore, residential land use has not declined as much as 14.6% because it is included in the mixed-use category, which increased significantly by 83.3%. From the increase in population density, residential floor area, including both residential use and residential part in mixed-use, is expected to have increased in the study area. A significant increase is noticed in commercial use, by 54.1%. As commercial floors are also included in mixed-use, the floor area for commercial use is expected to have increased more than previously estimated. Commercial use has risen significantly in Shahdara, Ichra, and Kamahan stations. Industrial use has also increased by 31.4%, and significant changes were observed in Nishtar Colony and Dullu Khurd stations, which had a large industrial area in 2012. From these land use changes, increase in commercial and industrial usage, economic activities have been revitalized in the study area. Conversely, open spaces declined by 6.6%, while vacant and agricultural land use decreased significantly by 42.0% and 41.6%, respectively. In the two suburban stations, Nishtar Colony and Dullu Khurd, that had vacant and agricultural land in 2012, the proportion has decreased significantly. The two controlled areas, Model Town and Naseerabad, had large open spaces in 2012; however, Model Town lost a significant amount of these. In these two controlled areas, residential use has not decreased as much as in other areas, and that is due to the strict land use control.

Figure 6.14 shows the percentage of land use change in TOD and TAD areas. **Figure 6.15** illustrates the rate of change in land use in TOD and TAD areas. The decline in residential land use was higher in TOD areas (-22.46%) than in TOD areas (-6.61%). Due to vacant land, commercial and mixed land use significantly increased (more than two times higher) in TAD areas than in TOD areas. TAD areas have a higher percentage of change in public buildings than TOD areas. In TOD areas, the rate of change of open spaces was lower than in TAD areas. Industrial land use significantly increased (almost six times) in TAD areas than in TOD areas because they already had more industry sites. Vacant land use was converted into other land uses in both TOD and TAD areas, but more changes have occurred in TAD areas (-43.79%). The percentage of agricultural land significantly declined in TAD areas which were almost -45.92%.

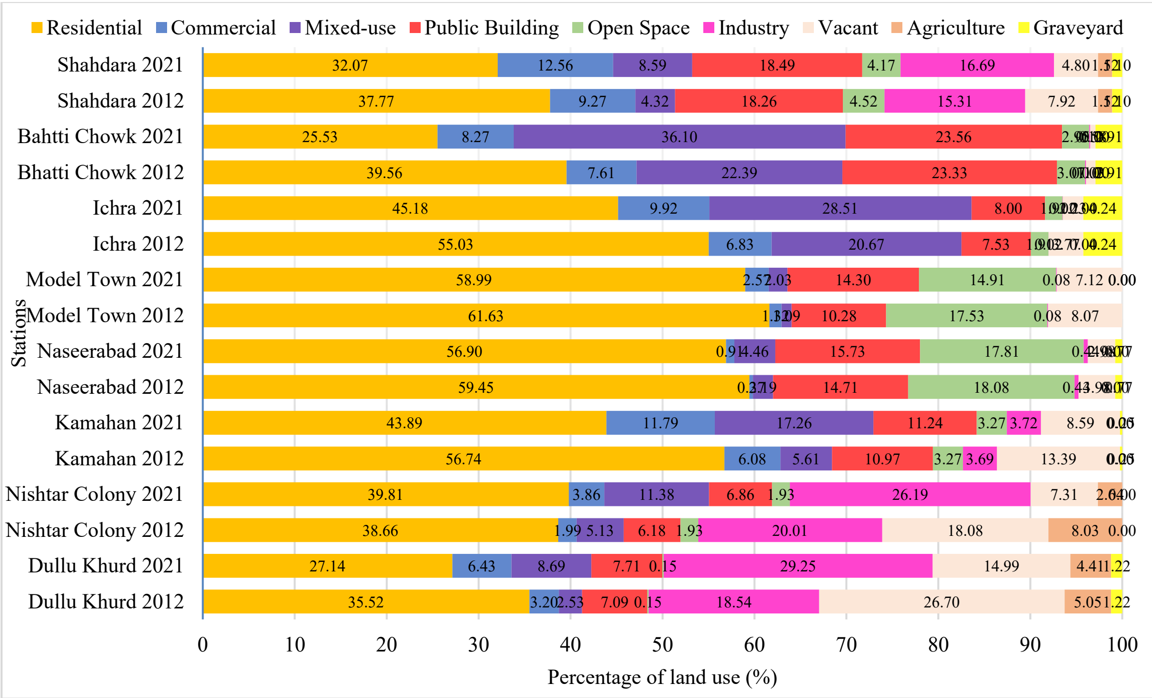


Figure 6.13 Percentage of land use in each station within the study area between 2012 and 2021

Table 6.1 Percentage change in land use area of eight BRT stations for 2012 and 2021

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

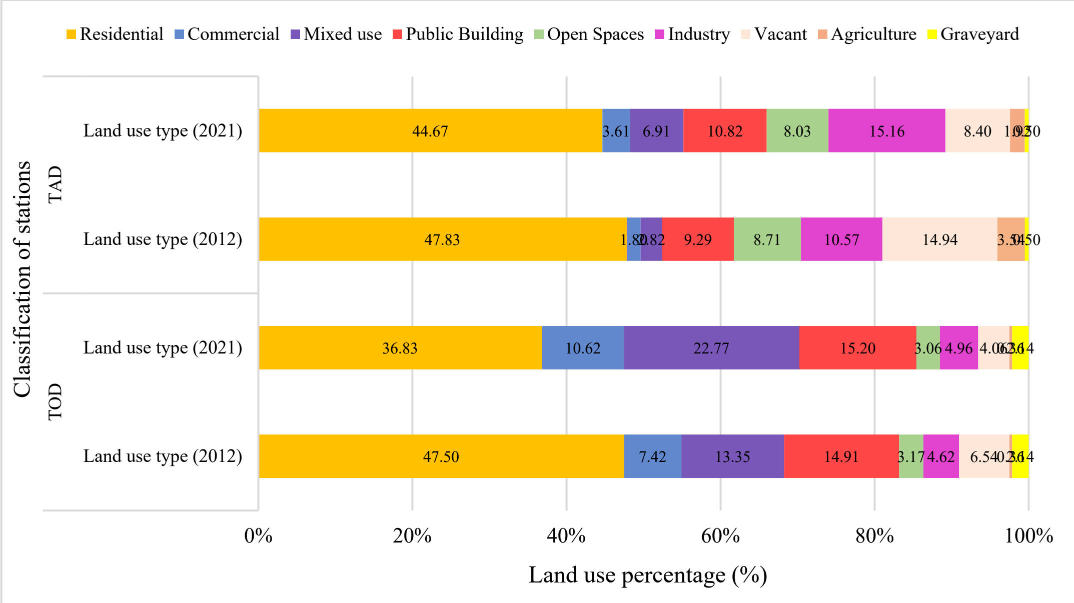


Figure 6.14 Percentage of land use in TOD and TAD areas between 2012 and 2021

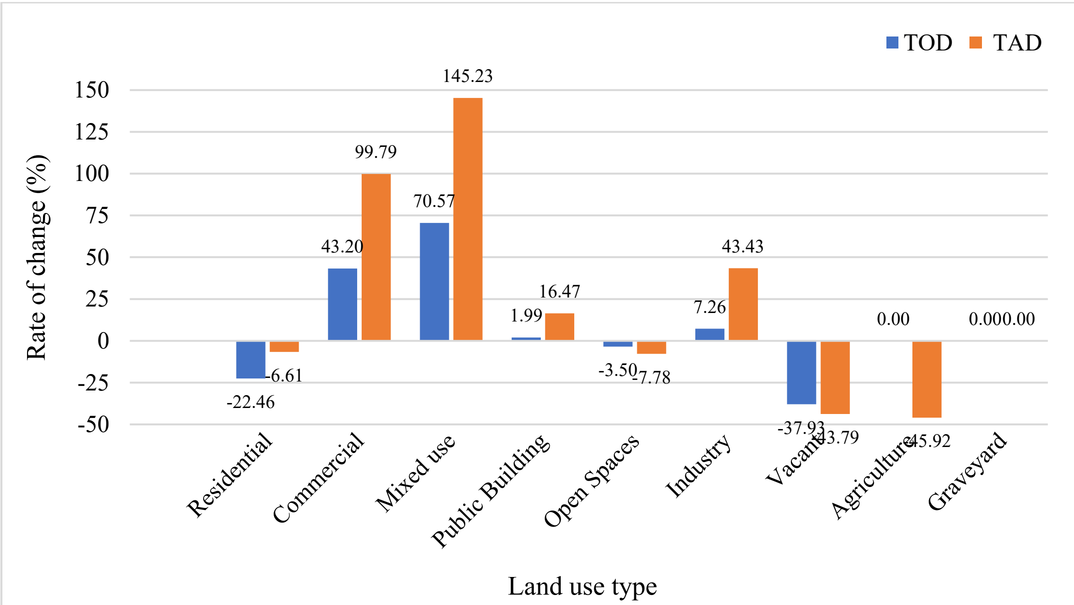


Figure 6.15 Rate of change in land use in TOD and TAD areas

Our study findings are inconsistent with those of Cervero & Dai (2014), who concluded that the BRT systems in Bogotá (Colombia) and Ahmedabad (India) failed to leverage mixed-use development around the station areas. Bocarejo et al. (2013) concluded that some vital shopping centers had been built around the terminals of the Transmilenio BRT in Bogotá; however, the BRT occurrence does not influence a greater rise in built-up areas for commercial and residential use. Our study findings are consistent with those of Deng & Nelson (2010). They found that BRT positively impacts residential and commercial development in Beijing. However, in our study, BRT investment does not influence a rise in residential land use.

6.3.3. Entropy Index

In our study, the entropy index was used to estimate the diversity of land use close to BRT stations. A higher value of the entropy index shows higher land use diversity. **Figure 6.16** shows the entropy index values around BRT stations. The entropy index value in the two stations was the lowest in the two controlled areas, Model Town and Naseerabad, both in 2012 and 2021, due to the strict land use control. The entropy index increased for all stations between 2012 and 2021, except Bhatti Chowk and Nishtar Colony, which had relatively high index values in 2012.

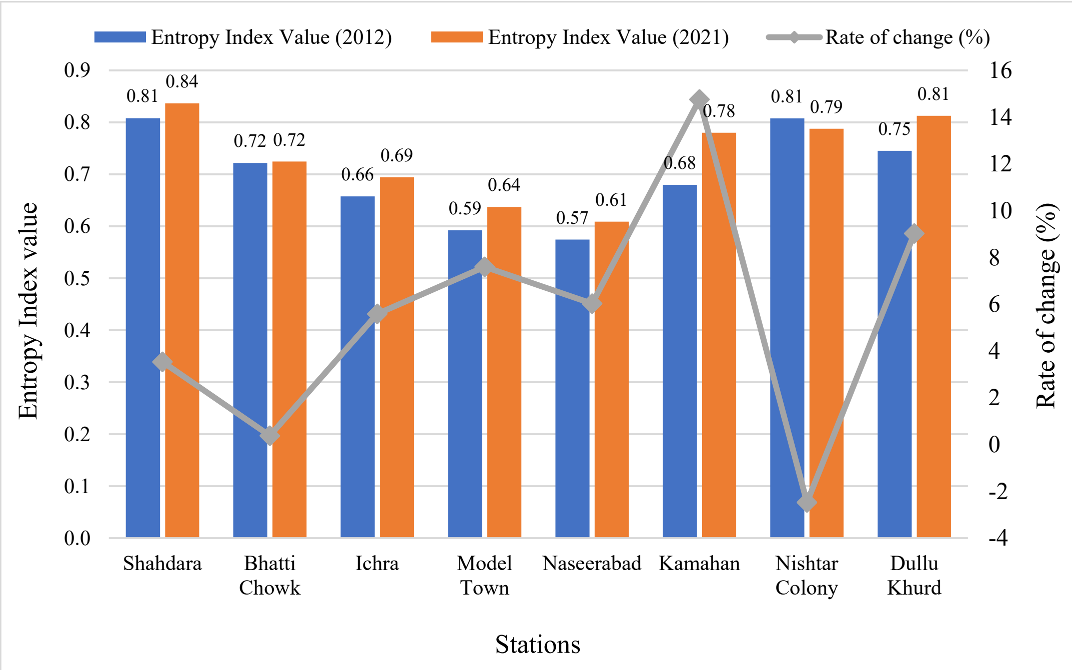


Figure 6.16 Entropy Index in BRT station areas

Figure 6.17 shows the entropy index value around BRT stations for 2012 and 2021 in TOD and TAD areas. The entropy index value was higher in TOD areas than in TAD areas in 2012. The entropy index value was increased after BRT introduction in TOD and TAD areas. However, the rate of change in entropy index value was two times higher in TOD areas (6.07%) than in TAD areas (2.78%). It may be due to Model Town and Naseerabad station areas; both are classified in TAD areas that have strict land use control.

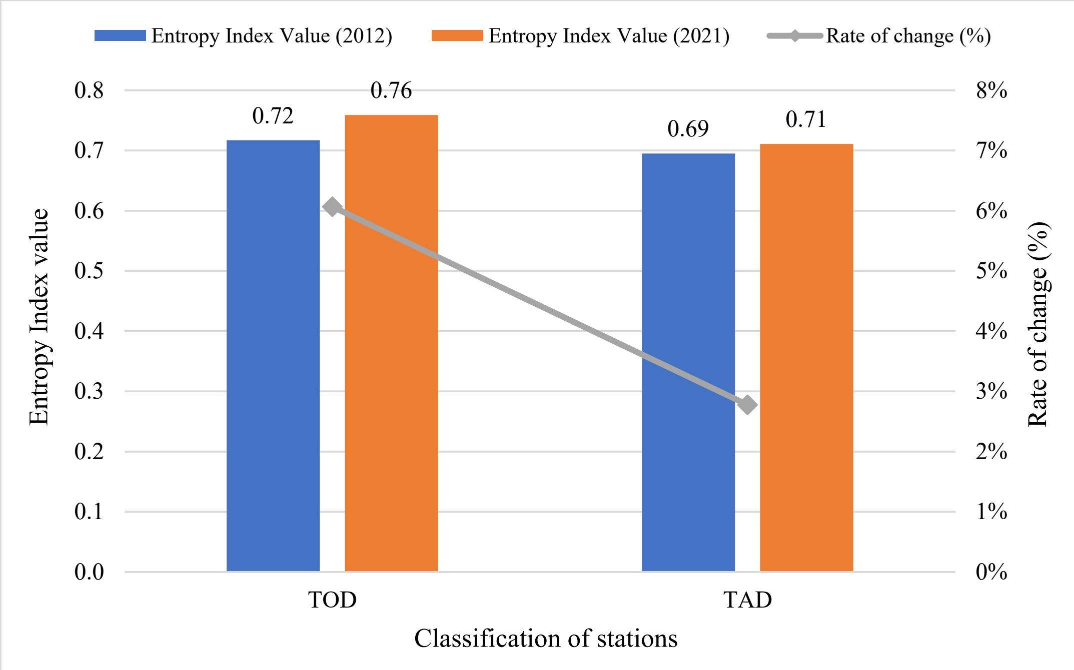


Figure 6.17 Entropy Index in TOD and TAD areas

6.4. Design

6.4.1. Pedestrian paths

Figure 6.18 illustrates the pedestrian paths and their ratios at the eight stations in 2021. Due to a lack of past data for pedestrian paths, we cannot calculate the ratio of pedestrian paths in 2012. However, according to interviews with officials of LDA, the local government, and the transport department, after the introduction of BRT, pedestrian paths were not developed in this study area. In addition, extensive changes did not occur in the road network. Therefore, the ratio of pedestrian paths was the same for each station between 2012 and 2021. The pedestrian path ratio in all stations is quite low, representing the lack of walkability and accessibility. The ratio of pedestrian paths was especially low in older areas such as Shahdara, Bhatti Chowk, Ichra, and Kamahan.

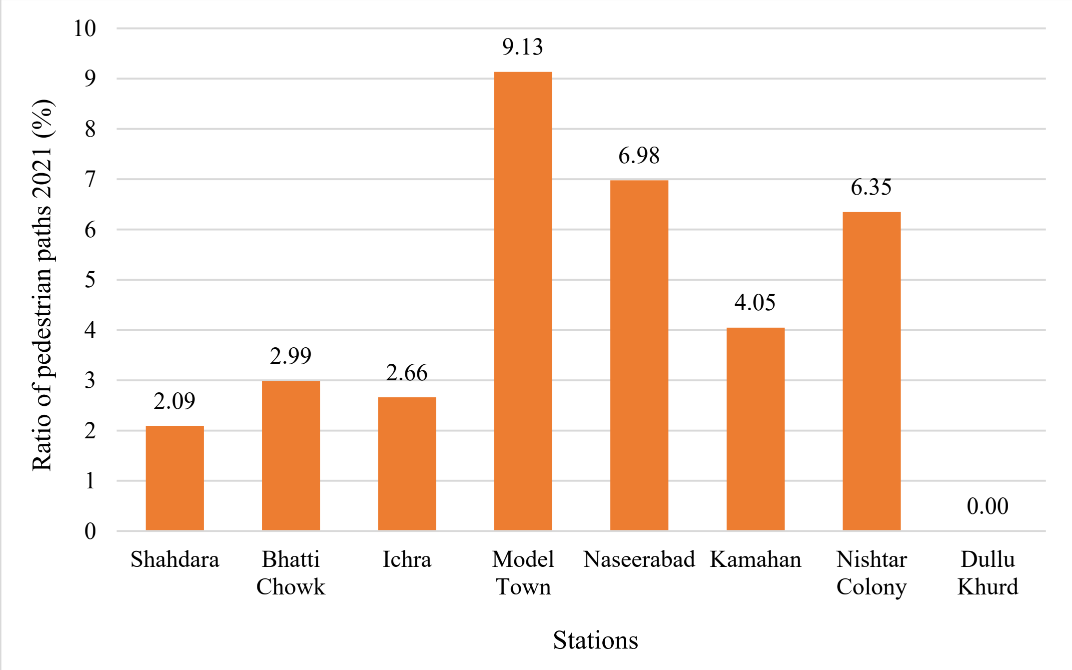


Figure 6.18 Ratio of pedestrian paths in BRT station areas

Figure 6.19 shows the ratio of pedestrian paths in TOD and TAD areas for 2021. Interestingly, the ratio of the pedestrian paths was almost two times higher in TAD areas (5.62%) compared to TOD areas (2.95%) due to planned and controlled development in Model Town and Naseerabad station areas.

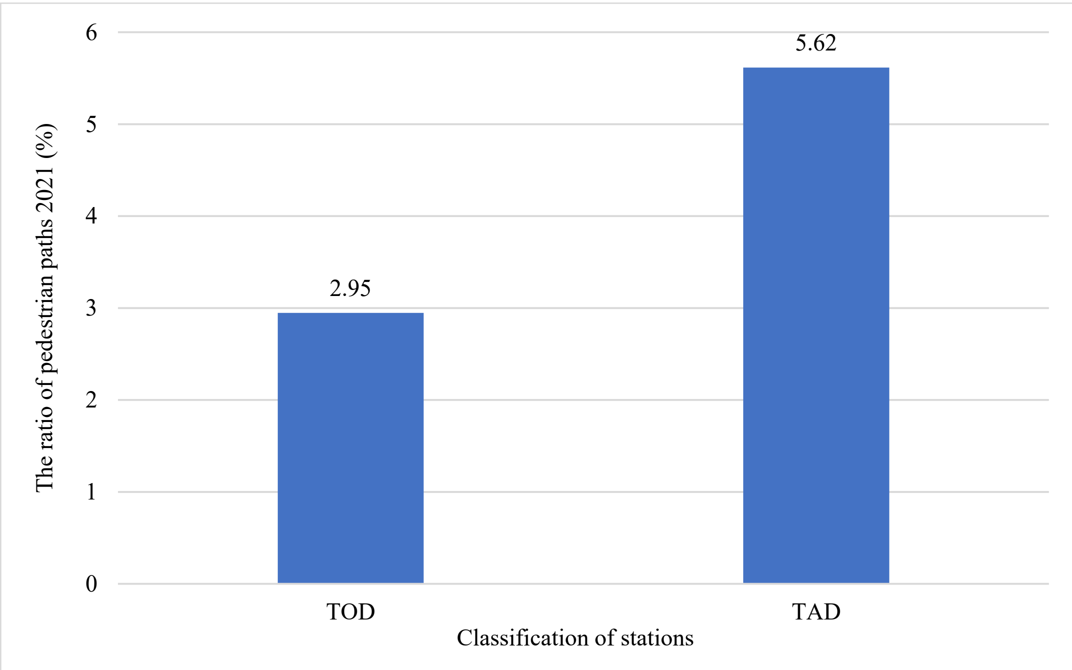


Figure 6.19 Ratio of pedestrian paths in TOD and TAD areas

6.4.2. Intersection density

Figure 6.20 shows the intersection density for 2012 and 2021. There is a wide range of intersection density, from 1.67 to 8.05 in 2012 and from 1.74 to 8.05 in 2021. Jacobs (1993) determined the intersection density in Venice was 5.79/ha, that of downtown Los Angeles was one-tenth that of Venice, and that of Irvine, California, was one-tenth that of downtown Los Angeles. Compared with the intersection density in these Western cities, some station areas are more walkable than Venice (Ewing, 1999; Jacobs, 1993).

Bhatti Chowk and Ichra have the highest intersection density of 8.05 and 7.80, respectively, due to the old built-up area and several public facilities. These station areas have an association between land use mix and street network. However, there was no improvement in the intersection density after the BRT investment at either station because there was no space for further development. In comparison, the intersection density has slightly increased at Shahdara, Model Town, Naseerabad, and Kamahan stations due to the availability of land for development. The percentage change in intersection density was high in the two suburban areas: Nishtar Colony and Dullu Khurd.

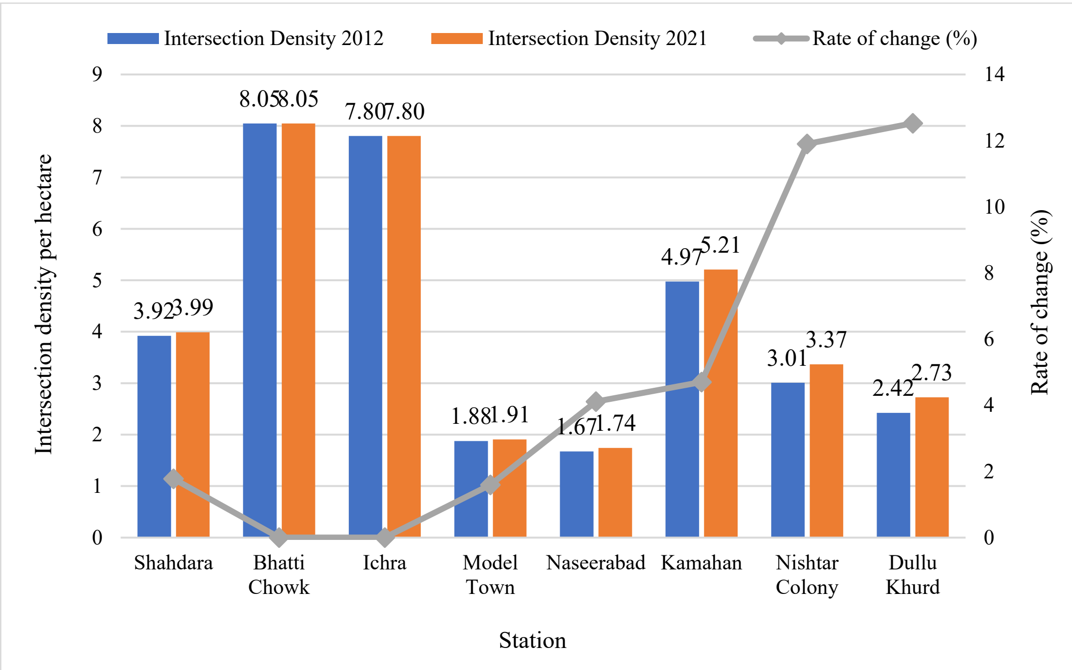


Figure 6.20 Intersection density in station areas 2012 and 2021

Figure 6.21 shows the intersection density for 2012 and 2021 in TOD and TAD areas. The intersection density of TOD areas was around three times higher than TAD areas due to the old built-up areas that consist of narrow street networks. It is demonstrated that higher intersection density shows higher walkability and accessibility in the TOD areas. In contrast, intersection density was lower in the TAD areas because of more vacant land. However, the rate of change in intersection density was higher in TAD areas (7.53%) than in TOD areas (1.62%) because they had more land for development.

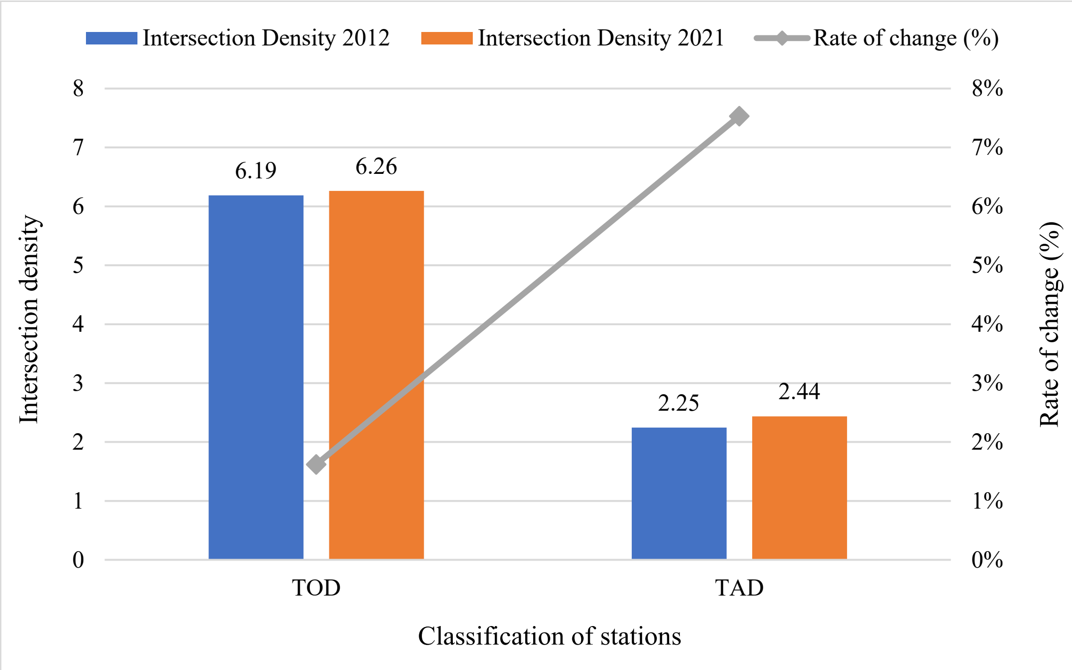


Figure 6.21 Intersection density in TOD and TAD areas

6.4.3. Open space ratio

Figure 6.22 shows the area of open spaces and parks (ha) with open space ratio in the eight BRT station areas for 2012 and 2021. The two controlled areas have the largest open spaces both in 2012 and 2021. The area of open space decreased in four stations and remained the same in the other four stations from 2012 to 2021. In all station areas, open space has not increased after BRT operation. Model Town has witnessed a significant decrease. At Shahdara and Bhatti Chowk, very few open spaces were converted into residential use, whereas in Model Town and Naseerabad, the open spaces were converted into public buildings. It is expected that a large number of open spaces and parks within the catchment area can foster more walking on their adjacent roads.

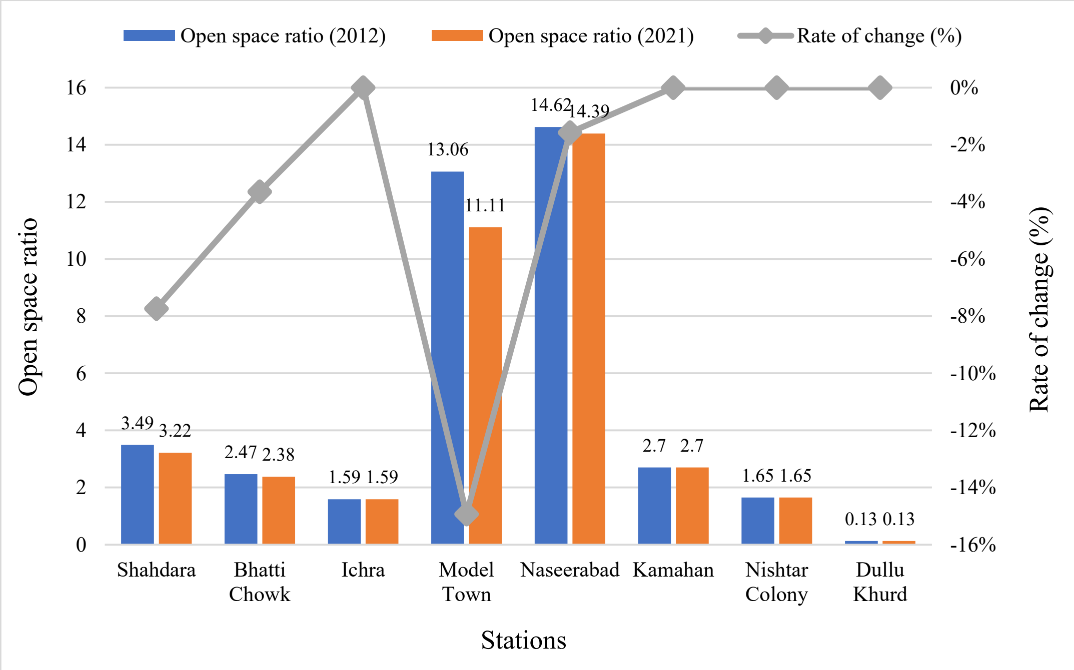


Figure 6.22 Open space ratio with a percentage rate of change for 2012 and 2021

Figure 6.23 shows the open space ratio for 2012 and 2021 in TOD and TAD areas. The ratio of open spaces was lower in TOD areas compared to TAD areas due to the old built-up area. The open spaces were declined after BRT introduction in both TOD and TAD areas due to weak building control in old built-up and unplanned areas. The rate of decline was higher in TAD areas (-4.13%) than in TOD (-2.85%) areas.

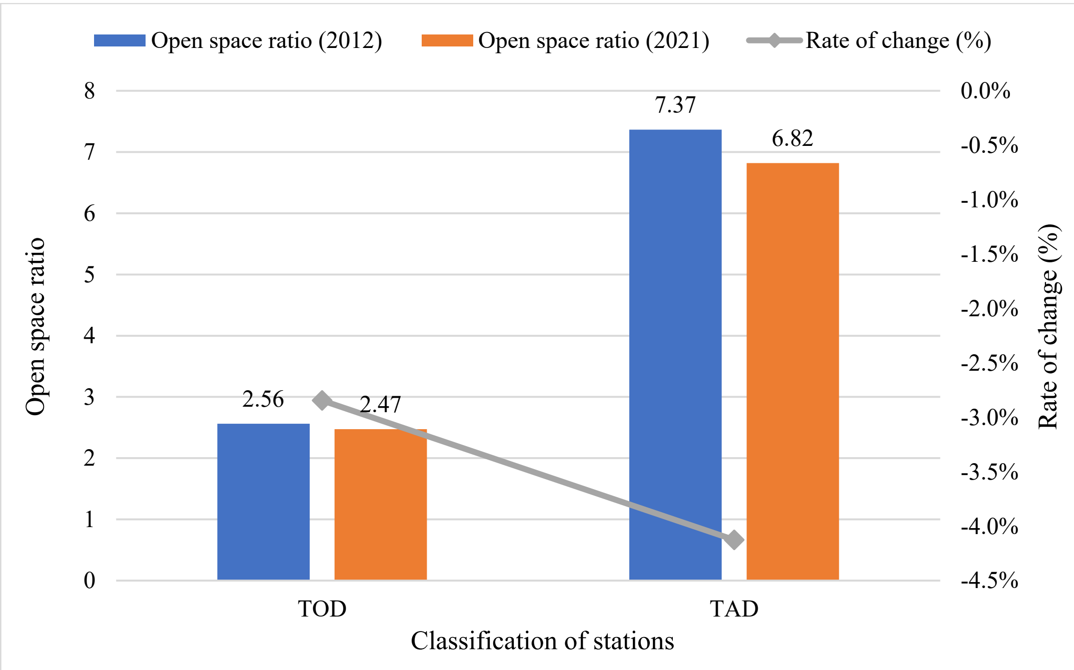


Figure 6.23 Open space ratio with a percentage rate of change in TOD and TAD areas

6.5. Conclusion

This chapter investigates the impacts of BRT on the urban fabric in Lahore from the viewpoint of 3D of TOD. The results show that the urban fabric has changed after the BRT operation, but it is dependent on the characteristics of each BRT station area. After the BRT operation, population density and development volume increased. However, the population density in the study area has not increased significantly compared to Lahore's population density rate. Additionally, land use for economic activities, such as commercial and industrial use, also increased. On the other hand, vacant land, open space, and agricultural land declined significantly in terms of area. Land use diversity also increased in most of the target stations. Thus, in density and diversity, elements of TOD were encouraged in the station area. Regarding design, which shows walkability in the station area, the three indicators declined or slightly increased. Before the BRT operation, the pedestrian paths were mostly well-equipped. There was no improvement after the BRT operation. The intersection density of the eight station areas lies almost in the same range as that of Venice, Italy, and it increased in some areas. The area of parks remained the same or declined in all areas. The area of parks decreased significantly in a controlled area, i.e., Model Town. From this result, after the BRT operation, the urban fabric created in the BRT station areas to some degree, such as density and diversity, improved, but design, especially pedestrian paths and open space, remained the same or declined. Moreover, the urban fabric around BRT station areas has elements of TOD to some extent.

The rate of change in population density was almost the same in TOD and TAD areas. However, the percentage of some indicators of the 3Ds was higher in TAD areas and some in TOD areas. For example, the percentage increase in FAD, percentage of commercial and mixed land use, the ratio of the pedestrian paths, and the rate of change in intersection density were higher in TAD areas because they had more vacant and agricultural land. In contrast, land use diversity was higher, and the decline in the ratio of open spaces was lower in TOD areas.

CHAPTER 7: IMPACT OF TOD IN BRT STATION AREAS ON RESIDENT'S TRAVEL BEHAVIOR

7.1. Introduction

This chapter seeks to answer the following questions: What are the travel characteristics of residents in the TOD and TAD areas around BRT stations? Can TOD reduce the VKT of residents living around BRT station areas? This chapter provides the classification of TOD and TAD areas in the context of TOD attributes and compares the respondent's socioeconomic and travel characteristics. It offers the reasons for choosing the current travel mode for work and shopping trips. It also studies the impact of TOD attributes on VKT using a multilevel mixed-effect regression model in the study area. In addition, this chapter provides the reasons for choosing the current address in TOD and TAD areas for 55 residents who moved from other localities.

7.2. Comparison of TOD Attributes in TOD and TAD Areas

The selected BRT stations were classified into TOD and TAD areas. Four stations—Shahdara, Bhatti Chowk, Ichra, and Kamahan—were classified as TOD areas, and the rest as TAD areas. A comparison of the TOD and TAD areas in terms of the TOD attributes is presented in **Table 7.1**. A set of TOD attributes was quantified across four built environment variables: population density, residential density, land use diversity, and intersection density. The average population density of TOD areas was approximately 194 persons per acre, almost four times higher than that in TAD areas, with an average population density of 43 persons per acre.

Similarly, the average residential density of the TOD areas was significantly higher than that of the TAD areas. Land use diversity was relatively higher in the TOD areas than in the TAD areas. In TOD areas, the intersection density is 1.5 times higher than in TAD areas. It is because TOD areas consist of old built-up areas, whereas TAD areas comprise planned and suburban areas. It is expected that TOD attributes tend to drive less and encourage the use of BRT and non-motorized modes around BRT stations in TOD areas than in TAD areas. Moreover, TOD areas are expected to increase BRT ridership and walkability around stations. Our findings are consistent with those of Chen et al. (2017), who found that residential density, entropy, and road network density were higher in TOD areas than in non-TOD areas in Shanghai.

Table 7.1 Comparison of TOD attributes in TOD and TAD areas

TOD attributes	TOD	TAD
Population density (persons/acre)	193.76	43.48
Residential density (units/acre)	8.84	5.33
Land use diversity (entropy)	0.76	0.71
Intersection density (3- or more-ways intersection/acre)	2.54	0.99

7.3. Socioeconomic Characteristics of the Respondents

The socioeconomic characteristics of respondents in the TOD and TAD areas are summarized in **Table 7.2.** This study mainly included male respondents because women are reluctant to respond to the questionnaire and avoid talking to an unknown person. Moreover, females prefer to go outside with males. The percentage of young people (31–50 years) was higher than that of teenagers and older adults in both areas. This may be because they were eager to travel more. The respondents were mainly married: nearly 86% were in TOD and 87% in TAD. Most respondents had completed high school education in the TOD (40%) and TAD (32%) areas. The share of below-high school education (29%) was higher in the TAD areas. In TOD areas, almost 80% of the respondents were private employees or associated with their businesses, while 59% were in TAD areas. The share of labor-class respondents was higher in the TAD areas (28%) than in the TOD areas (8%). This may be due to the lower education level in the TAD areas. Almost 84% of respondents have their own houses in TOD areas, which is relatively higher than in TAD areas (66%).

Table 7.2 also illustrates automobile ownership in the study area. Car ownership was relatively low in TOD areas compared to TAD areas. Approximately 10% and 19% of the respondents had one or two cars in the TOD and TAD areas, respectively. Residents are more likely to use motorcycles than cars for daily activities in the TOD areas than in the TAD areas. Almost 93% of the respondents had one or more motorcycles in a household in TOD areas and 76% in TAD areas. The share of motorcycle users is high in TOD areas because of the old built-up areas with narrow streets. The percentage of bicycles was minimal in both areas, and this may be due to hot and cold weather conditions or a lack of cycling lanes. Most respondents did not have a car- or motorcycle-driving license in either area.

Table 7.2 Socioeconomic characteristics of respondents in TOD and TAD areas

Characteristics	Attribute	TOD (n = 295)	TAD (n = 131)
		Percentage (%)	Percentage (%)
Gender	Male	100	99.2
	Female	0	0.8
Age (years)	≤ 18	0.7	1.5
	19–30	23.4	19.1
	31–40	45.4	30.5
	41–50	26.1	30.5
	51–60	3.4	18.3
	> 60	1	0
Marital status	Single	14.2	13
	Married	85.8	87
Education	Below high school	16.9	29
	High school	40	32.1
	Higher secondary school	26.4	19.8
	Bachelor	14.2	7.6
	Master	1.7	9.2
	Ph.D.	0.7	2.3
Profession	Government employee	7.5	9.2
	Private employee	46.1	30.5
	Business owner	33.9	28.2
	Labor	8.5	27.5
	Other	4.1	4.6
House ownership	Owned	84.4	66.4
	Rented	15.6	32.8
	Leased	0	0.8
Number of cars	No car	89.8	80.9
	1 car	9.5	5.3
	2 or more cars	0.7	13.8
Number of motorcycles	No motorcycle	6.4	23.7
	1 motorcycle	79.7	57.3
	2 or more motorcycles	13.9	19.1
Number of bicycles	No bicycle	96.9	98.5
	1 or more bicycles	3.1	1.5
Driving license of the car	Yes	13.2	19.1
	No	86.8	80.9
Driving license of the motorcycle	Yes	35.6	47.3
	No	64.4	52.7

Table 7.3 summarizes the socioeconomic characteristics relevant to the travel patterns of the respondents in the TOD and TAD areas. Residents in TOD areas had smaller households than those in TAD areas, indicating that people in the TAD areas may prefer to live in a joint family in Lahore. Surprisingly, the average monthly respondents' and household income are more than two times higher in TAD than in TOD areas because Model Town and Naseerabad station areas are well-planned and classified as TAD; high-income people and businesspeople live there. Income is considered a vital basis for car ownership, and high-income households may have higher travel demand. Therefore, they have more cars than lower-income households. TOD residents have lower average car ownership than TAD residents, and the households with no cars were almost 90% and 81% in the TOD and TAD areas, respectively. This significant difference in average car ownership indicates that TOD residents are less likely to drive than residents living in TAD areas. In the TOD areas, this may be due to less parking space availability in houses or narrow streets in old built-up areas, that is, Bhatti Chowk. Another reason may be the lower needs due to nearby work and shopping places in TOD areas. In contrast, TAD residents have large houses with parking spaces and wide streets.

Our study findings regarding certain socioeconomic characteristics are consistent with those of Nasri and Zhang (2014) and Chen et al. (2017). They found that TOD areas have fewer households and lower auto ownership than TAD areas in Washington, D.C., Baltimore metropolitan areas, and Shanghai. Regarding household income, Nasri and Zhang found that TOD residents have lower incomes, while Chen et al. found that TOD residents have higher incomes.

Table 7.3 Comparison of certain socioeconomic characteristics in TOD and TAD areas

Characteristics	TOD	TAD	Total
Average household size (No.)	5.4	6.6	5.8
Average monthly income (PKR)	38,731	83,641	52,542
Average household income (PKR)	50,067	110,473	68,642
Average car ownership (No.)	1.1	1.4	1.2
Percentage of households with 0 cars (%)	89.8	80.9	87.1

7.4. Travel Characteristics of the Respondents

Figure 7.1 shows the main travel mode to the workplace in TOD and TAD areas. The four modes with the largest share are motorcycle, walking, BRT, and car. The percentage of motorcycles and walkers was higher in TOD areas, while car share was higher in TAD areas. The largest share of motorcycle users said that BRT and other modes of transport take much time compared to a motorcycle. If we take BRT, we must change two or three modes to reach the workplace, increasing travel costs and time. One-fourth of respondents go to their workplace on a walk because the workplace is near their houses. While walking was not so attractive because of unsafe roads and lack of footpaths. Only 12% of respondents prefer to use BRT in both TOD and TAD areas because of the workplace near BRT stations, or some respondents may have no personal vehicle. The combined share of all other modes is less than 10% because respondents are just taken for long distances who have workplaces away from their houses or those who have no personal vehicle.

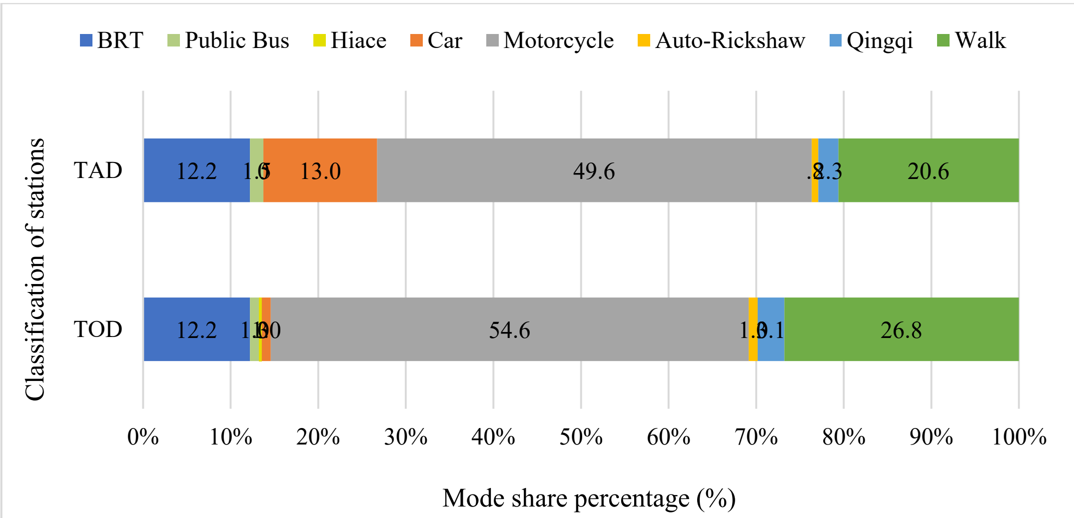


Figure 7.1 Main mode of transport to work trips

Figure 7.2 shows the reasons for choosing the current travel mode to work. For all respondents, almost 75% and 6% respondents strongly agree and agree with the given statements, respectively. It may be because of the higher share of motorcycles and walking as a travel mode. In contrast, almost 17% and 1% of respondents strongly disagree and disagree with the statements because of personal mode that was less safe from accidents, less environmentally friendly, most people don't like to travel with other unknown people and cannot carry heavy luggage on the motorcycle and with a walk. The remaining respondents (less than 2%) are neutral about the statements.

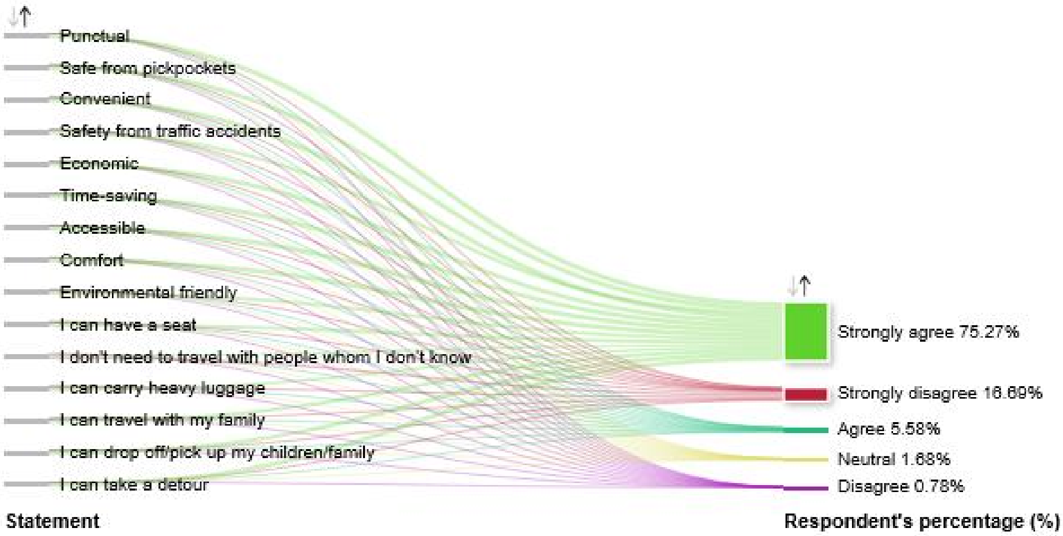


Figure 7.2 Reasons for choosing the current travel mode to work in TOD and TAD areas

Figure 7.3 shows the main travel mode for shopping trips in TOD and TAD areas. The four modes of transport with the highest share are motorcycle, walking, car, and BRT. The percentage of motorcycles and walkers was higher in TOD areas, while car and BRT share was higher in TAD areas. The walkers have shopping places near their houses. The share of cars is higher in TAD areas; it is expected that the respondents may want to go away from their residences for shopping purposes with their families frequently. Almost 6-7% of respondents use BRT mode to go shopping places in both TOD and TAD areas who want to go to shopping markets located near BRT stations or have no option to use other modes of transport.

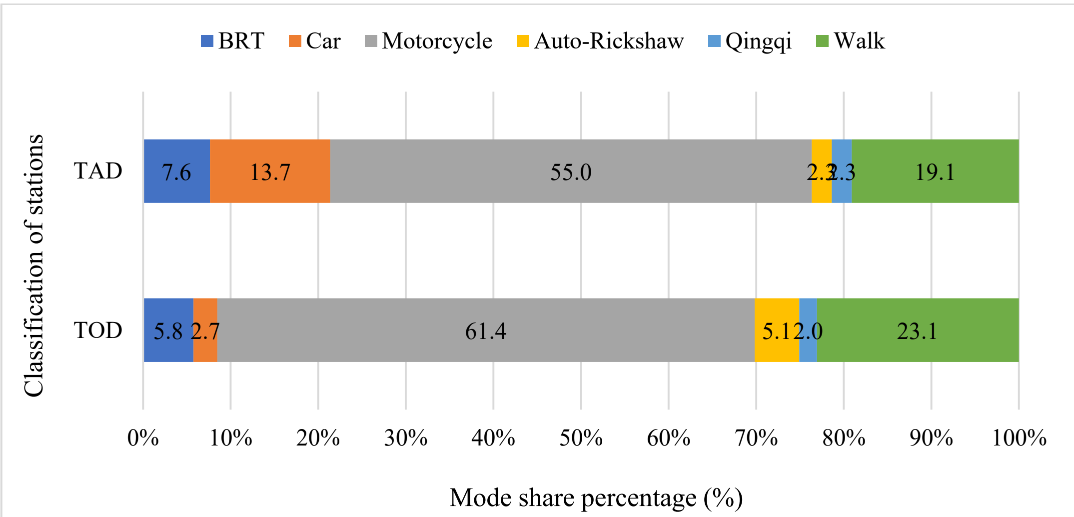


Figure 7.3 Main mode of transport to shopping trips

Figure 7.4 shows the reasons for choosing the current travel mode for shopping. For all respondents almost 75% and 7% of respondents strongly agree and agree, respectively, with the statements related to the travel mode to the shopping trips. It may be because most respondents have their vehicles, mainly motorcycles or walkers. In contrast, almost 13% of respondents strongly disagree, and 3% disagree with the travel mode's statements. It may be because of less safety from an accident on a motorcycle, less environmentally friendly, and I don't need to travel with people I don't know. At the same time, nearly 2% of respondents remain neutral about the statements.

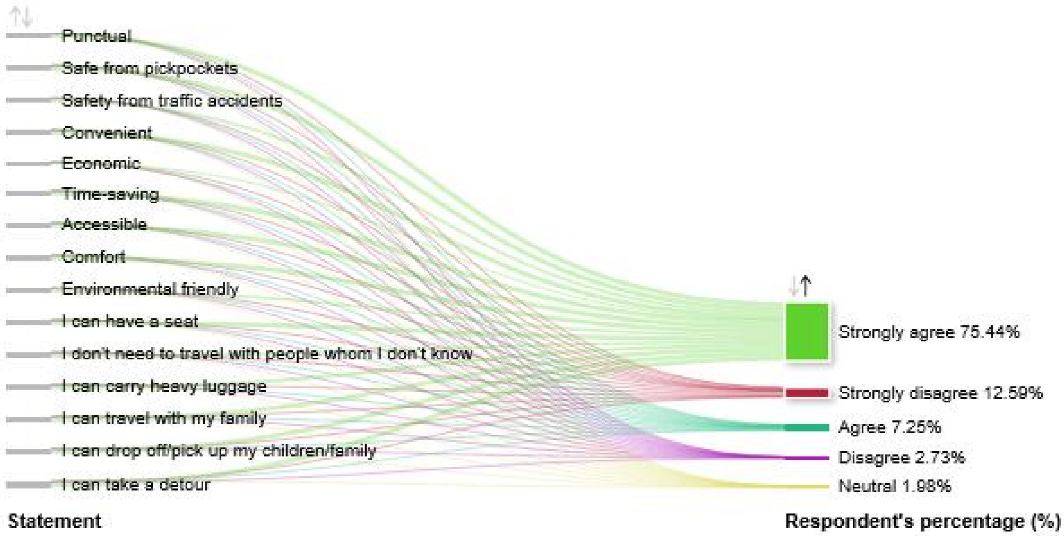


Figure 7.4 Reasons for choosing the current travel mode for shopping in TOD and TAD areas

A comparison of the travel characteristics in the TOD and TAD areas is summarized in **Table 7.4**. The VKT of TOD residents was smaller than that of the TAD residents. We separated work and shopping trips to understand better how TOD residents encourage BRT and non-motorized modes. For work trips, the BRT/walk/motorcycle mode share percentage for TOD residents was extremely high. However, residents of TAD areas were more likely to use cars for work trips than residents of TOD areas. The mean travel distance of the TOD residents was 5.9 km, which is approximately 40% less than that of the residents living in TAD areas, whose mean travel distance is 9.8 km. The mean travel length was 17.6 min for the TOD areas, which is almost 24% less than that of the TAD areas, whose travel time is 23.1 min. The mean travel cost of TOD residents was 39.7 PKR (USD 1.00 = PKR 284.00), while that of TAD residents cost was 123.9 PKR. This may be because most respondents' workplaces were located near their houses or short distances in TOD areas.

For shopping trips, residents of TOD areas have a high percentage of BRT/walk/motorcycle mode share and an extremely low percentage of car mode share. The percentage of car mode share was higher in TAD areas than in TOD areas. The mean travel distance for shopping trips was 4.8 km in TOD areas, which is almost 23% less than that of the TAD area (6.2 km). The mean travel length was 13% lower in TOD areas than in TAD areas. The mean travel cost of TOD residents was 39.5 PKR, which is almost 39% lower than TAD residents, which have a mean travel cost of 65 PKR. TOD areas have good shopping markets around the BRT stations, i.e., Bhatti Chowk and Ichra stations. It may be that TAD residents visited markets away from their houses.

In short, the BRT/walk/motorcycle mode share was significantly higher in TOD areas, while the car mode share was considerably lower for work and shopping trips. It is expected and indicated that TOD areas have the potential to encourage the use of BRT and non-motorized modes for both types of trips. In contrast, the share of car trips is relatively higher in TAD areas than in TOD areas. Unsurprisingly, residents with cars tend to drive for most work and shopping trips in TAD areas. Our travel characteristic findings are consistent with those of Nasri and Zhang (2014), Chen et al. (2017), and Faghri and Venigalla (2013). They found that the transit/walk/bike share was significantly higher in TOD areas, whereas the car share was extremely higher in TAD areas for work and non-work trips. Furthermore, Chen et al. found that the mean length (min) of TOD residents was lower than that of the TAD residents.

Table 7.4 Comparison of travel characteristics in TOD and TAD areas

Travel characteristics		TOD	TAD
	Vehicle kilometers traveled (km)	15.8	21.8
Work trips	BRT/walk/motorcycle mode shares (%)	98.9	86.4
	Car mode share (%)	1.1	13.6
	Mean distance (km)	5.9	9.8
	Mean lengths (min)	17.6	23.1
	Mean cost (PKR)	39.7	123.9
Shopping trips	BRT/walk/motorcycle mode shares (%)	97.1	85.6
	Car mode share (%)	2.9	14.4
	Mean distance (km)	4.8	6.2
	Mean lengths (min)	12.2	14.0
	Mean cost (PKR)	39.5	65.0

7.5. Multilevel Mixed-effect Regression Model Results

The multilevel regression model has been broadly applied in recent literature for the built environment and travel behavior studies (Ding & Cao, 2019; Nasri & Zhang, 2014). This model has several advantages compared to ordinary logistic regressions (Ding et al., 2014). First, it can reduce the spatial dependency issues between observations. Second, it can control multicollinearity problems between independent attributes by evaluating individual and neighborhood attributes at various levels. Considering these advantages, we employed a multilevel mixed-effect regression model to understand the impact of TOD attributes on VKT. Moreover, this model allows us to obtain distinct coefficients from subject clusters such as TOD and TAD. Regarding model fitting information, the p-value was 0.000, and the R square was 0.214, demonstrating a good model fit.

The results of the multilevel mixed-effect regression model in TOD and TAD areas are summarized in **Table 7.5**. The number of persons was not significantly associated with VKT, implying that households produce fewer VKT because TOD areas have smaller household sizes that drive less than TAD areas. The number of workers was also not significantly associated with VKT, and TOD areas had fewer workers than TAD areas. This may be because most residents' workplaces are near their houses, and they can easily go to the workplace by walking. As expected, the number of cars and motorcycles was significantly linked to VKT, influencing the amount of driving in the study area. Household income is considered a crucial element of car ownership, and VKT increases with higher household income and number of automobiles. Distance to CBD is significantly linked with VKT, meaning residents residing away from the central business district tend to drive more.

TOD attributes around the BRT station areas: population density, residential density, and land-use diversity had a significant negative relationship with VKT. The negative coefficient of land use attributes demonstrates that residents with higher population density, residential development, and mixed-use development have less drive and encourage the use of BRT and non-motorized modes to reach closer destinations. While intersection density had a significant positive association with VKT. A higher intersection density indicates a smaller block size and higher street connectivity. This is because, with a smaller block size, the distance to several activities would be short; therefore, residents would drive less toward those activities. However, higher intersections can encourage walkability in station areas, as residents can visit closer destinations by covering short distances and durations.

Table 7.5 Results of the multilevel mixed-effect regression model

Explanatory variables	Estimate	Std. Error	t	Sig. ($p \leq 0.05$)
Intercept	1.177	0.211	5.582	**0.000**
Number of persons in a house	-0.035	0.019	-1.848	0.065
Number of workers in a house	-0.055	0.068	-0.802	0.423
Number of cars	0.483	0.098	4.925	**0.000**
Number of motorcycles	0.517	0.076	6.831	**0.000**
Household income	0.018	0.372	-1.108	0.269
Distance to CBD	0.073	0.037	1.966	**0.050**
Population density	-0.010	0.003	-3.691	**0.000**
Residential density	-0.413	0.086	-4.801	**0.000**
Land use diversity	-5.019	2.511	-1.999	**0.046**
Intersection density	1.013	0.311	3.258	**0.001**
Dependent variable	Vehicle kilometers traveled			
Residual	0.795			
p-value	0.000			
R square/Adjusted R square	0.214/0.195			

The model results of our study are similar to those of Nasri & Zhang (2014), and certain findings are the same. They found that the number of vehicles significantly influenced VKT. Land use variables such as population density and land-use diversity were negatively linked with VKT. Simultaneously, the distance to the CBD and average block size were positively associated with VKT.

7.6. Reasons for Choosing the Current Address as a place to live in TOD and TAD Areas

Total 55 residents out of 426 were moved around BRT stations from other areas. Out of 55, 27 residents were moved to TOD areas, and 28 were moved to TAD areas. **Figure 7.5** shows the reasons for choosing the current address as a place to live around BRT areas. The following factors, such as transit, accessibility, walking, attractiveness, and safety, were very important for almost 85% of respondents moving in TOD areas. Whereas these factors were unimportant for nearly 12% of respondents who moved to TOD areas. Instead, the same factors were very important for 83% of respondents who moved to TAD areas (see **Figure 7.6**).

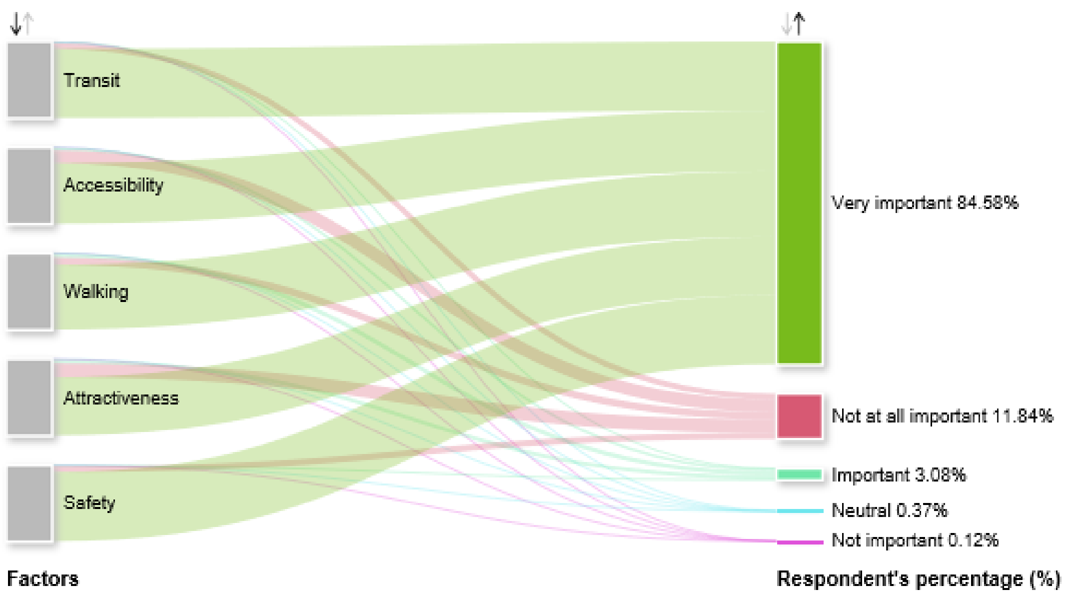


Figure 7.5 Reasons for choosing the current address in TOD areas

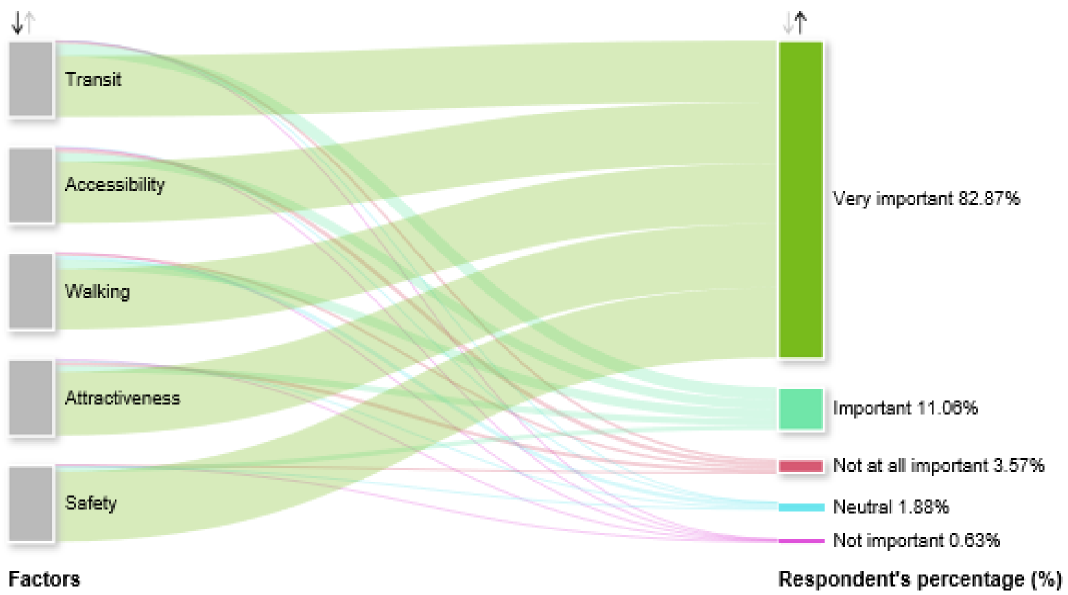


Figure 7.6 Reasons for choosing the current address in TAD areas

7.7. Conclusion

The chapter demonstrates that residents' travel behavior differs in the TOD and TAD areas around the BRT stations. It shows that TAD residents are more likely to use cars and less likely to use BRT and non-motorized modes. Not surprisingly, residents who have a car tend to drive more for most trips in the TAD areas. In contrast, respondents in TOD areas were more likely to use BRT/walk/motorcycles and drive less for work and shopping trips. This demonstrates that TOD areas can potentially encourage BRT and non-motorized use. For all respondents, almost 81% and 82% of respondents agreed with the statements related to the travel mode to the work and shopping trips, respectively. Moreover, the average travel distance, time, and cost were higher in the TAD areas than in the TOD areas, indicating that TAD areas have fewer employment opportunities and shopping places. Hence, residents come to the city center and TOD areas to meet their services, shopping, and daily needs. However, TOD residents have workplaces at short distances and visit shopping places close to their homes. Moreover, TOD areas around BRT stations have higher population density, residential density, land-use mix, and intersection density, encouraging the use of BRT and walking while driving less. The results obtained from our model demonstrate that highly dense and mixed land-use areas tend to encourage residents to use BRT and non-motorized modes more and drive less. In addition, we found the reasons for choosing the current address as a place to live based on the following factors: transit, accessibility, walking, attractiveness, and safety. Total 55 residents moved into TOD (27 residents) and TAD (28 residents) areas from other localities. It is estimated that almost 85% and 83% said that these reasons were very important for moving in TOD and TAD areas, respectively.

CHAPTER 8: DEVELOPING BRT-BASED TOD MODELS FOR LAHORE

8.1. Introduction

To propose BRT-based TOD models, we briefly compared the indicators of 3Ds (density, diversity, and design) in Transit–oriented Development (TOD) and Transit-adjacent Development (TAD) areas. Also, this chapter highlights the travel characteristics of the respondents (n = 426) in the TOD and TAD areas. Moreover, we discussed Calthorpe's TOD Model. After that, two TOD models for Lahore were developed for urban and suburban areas. Finally, in the conclusion, compare our BRT-based TOD models with Calthorpe's TOD model.

8.2. Comparison of Indicators of 3Ds and Travel Characteristics of the Respondents in TOD and TAD Areas

As discussed in the methodology chapter, four BRT station areas are classified into TOD areas: Shahdara, Bhatti Chowk, Ichra, and Kamahan. In contrast, the rest of the stations, including Model Town, Naseerabad, Nishtar Colony, and Dullu Khurd, are classified into TAD areas. **Table 8.1** shows that some indicators were higher in TOD areas, such as population density, Floor Area Density, land use diversity, and intersection density due to old built-up areas. In contrast, pedestrian paths ratio and open space ratio were higher in TAD areas because Model Town and Naseerabad station areas are classified in TAD areas; they have a higher value for both indicators.

Table 8.1 Comparison of 3D indicators to develop TOD models

Criteria	Indicators	TOD	TAD
Density	Population density (PPH)	▲ 479	▼ 107
	Floor Area Density	▲ 1.7	▼ 1.29
Diversity	Land use diversity	▲ 0.76	▼ 0.71
Design	Pedestrain paths ratio	▼ 2.95	▲ 5.62
	Open space ratio	▼ 2.47	▲ 6.82
	Intersection density/ha	▲ 6.26	▼ 2.44

We have also discussed the travel characteristics of the respondents in TOD and TAD areas in Chapter 7. **Table 8.2** shows the travel characteristics of the respondents in the TOD and TAD areas. The vehicle kilometer traveled (VKT) of TOD residents was smaller than that of the TAD residents. The BRT/walk/motorcycle mode share was significantly higher in TOD areas, while the car mode share was considerably lower for work and shopping trips. It is expected and indicated that TOD areas have the potential to encourage the use of BRT and non-motorized modes for both types of trips. In contrast, the share of car trips is relatively higher in TAD areas than in TOD areas. Unsurprisingly, residents with cars tend to drive for most work and shopping trips in TAD areas. The respondents' travel distance, travel time, and travel cost were lower in TOD areas than in TAD areas. The workplace and shopping centers are expected to be near the respondent’s residences in TOD areas. In contrast, residents of TAD areas went to other urban areas for their job and shopping needs.

Table 8.2 Comparison of travel characteristics of respondents to develop TOD models

	Travel characteristics	TOD	TAD
	Vehicle kilometers traveled (km)	▼ 15.8	▲ 21.8
Work trips	BRT/walk/motorcycle mode shares (%)	▲ 98.9	▼ 86.4
	Car mode share (%)	▼ 1.1	▲ 13.6
	Mean distance (km)	▼ 5.9	▲ 9.8
	Mean lengths (min)	▼ 17.6	▲ 23.1
	Mean cost (PKR)	▼ 39.7	▲ 123.9
Shopping trips	BRT/walk/motorcycle mode shares (%)	▲ 97.1	▼ 85.6
	Car mode share (%)	▼ 2.9	▲ 14.4
	Mean distance (km)	▼ 4.8	▲ 6.2
	Mean lengths (min)	▼ 12.2	▲ 14
	Mean cost (PKR)	▼ 39.5	▲ 65

8.3. Calthorpe's Transit-oriented Development Model

The concept of TOD was first developed in 1993 by Peter Calthorpe in “The Next American Metropolis.” He defined TOD as a "mixed-use community within average 2000-feet (600m) walking distance of a transit stop and core commercial area. TODs mix residential, retail, office, open space, and public uses in a walkable environment, making it convenient for residents and employees to travel by transit, bicycle, foot, or car" (Calthorpe, 1993). He observed TOD as the complete substitute for urban sprawl, offering a walkable neighborhood and an ecological, social, and economic basis for regional development. **Figure 8.1** illustrates the concept of Calthorpe's Transit Oriented Development, and various features of this diagram are described below;

Core Commercial Area: Each TOD area must have mixed-use core commercial areas near the transit station. It included convenience retail, a local serving office, public green or plaza, and an activity center. The commercial core must have at least 10% of the total TOD.

Residential Area: It includes housing within appropriate walking distance from the transit stations and core commercial areas. It should have a mix of housing types to meet the requirements, such as small single-family houses, condominiums, townhomes, and apartments. Urban TOD should have an average of 15 residential units per acre, while neighborhood TOD should have an average of 10 residential units per acre.

Park, Plazas, and Civic Buildings: Parks should be at least 5% of the total TOD area. Large parks should be placed towards the edge or near the school, and small parks or spaces should be placed throughout the TOD area. Plazas must be placed in the transit station and next to retail shops—civic buildings, including libraries, recreation, and courts. Post offices must be located around transit stations as obvious focal points.

Street System: The gridiron street system must be laid out to maximize the connections within TOD areas.

Pedestrian and Bicycle System: Pedestrian routes and well-connected bicycle systems should be integrated within the TOD area.

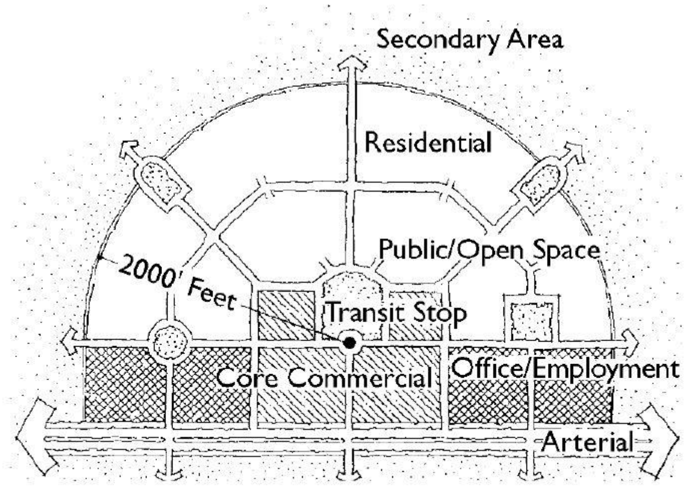


Figure 8.1 Calthorpe's TOD concept. *Source:* Calthorpe (1993)

8.4. BRT-based TOD Models for Lahore

TOD is considered a form of urban development that enhances residential and commercial places within walkable distances from transit stations (Chen et al., 2021; Lamour et al., 2019). Generally, TOD offers higher density, mixed-use, walkable urban development near mass transit stations and encourages public transit and walking rather than automobiles (Nasri & Zhang, 2014; Rahman et al., 2019). As TOD consists of various aspects, such as urban development and infrastructure in the station area, it is created through land use control to restrict/guide urban development and infrastructure development by the private sector (Lyu et al., 2016; Pojani & Stead, 2014; Renne, 2017).

Moreover, big cities worldwide are affected by unplanned growth, traffic congestion, and environmental problems, particularly in developing economies (Nguyen et al., 2020). The above-mentioned issues can be lessened through land use and transport integration, particularly in developing countries (Cervero, 2013). TOD establishes the integration between land use and transport to produce more sustainable communities (Singh et al., 2012), has reduced VKT, car ownership, and traffic congestion, and encourages transit use for sustainable travel behavior (Kumar et al., 2018; Nasri & Zhang, 2019).

Among the pressing issues in Lahore are urban sprawl, more use of private vehicles, inappropriate land-use mix and densities, lack of open spaces, and lack of pedestrian paths. To overcome these problems, it is crucial to develop a TOD model for Lahore according to the characteristics of the station areas, such as urban fabric, socio-economic factors, and travel characteristics. So, we have developed two BRT-based TOD models for Lahore: urban TOD and suburban TOD (see **Figure 8.2**). These TOD models are expected to shape the urban development around BRT station areas in Lahore. Moreover, these TOD models will increase the population density, mixed-use development, walkability, and public transport ridership around BRT areas to make Lahore a sustainable city.

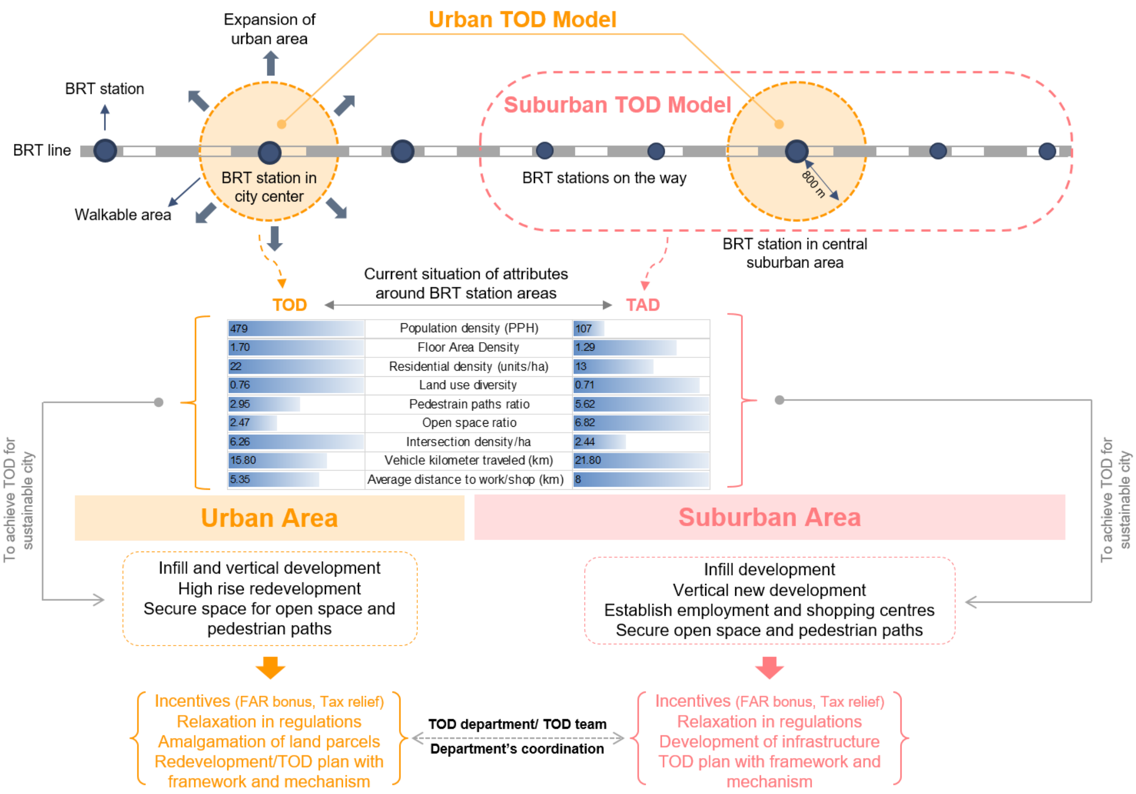


Figure 8.2 BRT-based TOD models for Lahore

8.4.1. Urban TOD model

The Urban TOD model is for BRT stations located in a central area of the city (i.e., Bhatti Chowk and Ichra) and central stations in suburban areas (i.e., Shahdara and Kamahan). This model considered the walkable area of 800 m that will be accessible within 10 minutes from BRT stations. It encourages the development of multi-function uses such as mixed-use development, commercial centers, and employment centers through infill and vertical development and high-rise redevelopment according to the characteristics of the station areas. It is also helpful to create pedestrian paths and open spaces to enhance walkability and accessibility. But, some old built-up areas have a narrow street network, like Bhatti Chowk (see **Figure 8.3**), so car/motorcycle-free days can be feasible to increase walkability. This model will also increase the value of the area around stations along with the route of the BRT line. It is expected that accessibility to the facilities and ridership of the BRT would be enhanced. To achieve this model, some measurements such as FAR bonus, relaxation in regulations and rules, amalgamation of parcels, and formulation of a specific TOD plan will be required.

Figure 8.3 Narrow streets (a) Bhatti Chowk (b) Ichra station areas. *Source:* Author

8.4.2. Suburban TOD model

The suburban TOD model is for the BRT stations in suburban areas (i.e., Nishtar Colony and Dullu Khurd) and planned areas (i.e., Model Town and Naseerabad). For this model, the proximity of 800 m was also considered because 10 minutes of walking distance was pertinent for TOD planning. This model encourages residential development for a high concentration of population, mixed-use development, commercial, and employment centers through infill development (more vacant land available) and vertical new development by offering a FAR bonus as incentives to secure land for pedestrian paths and open spaces, relaxation in regulations in planned and unplanned areas, and formulation of TOD plan according to the characteristics of the BRT stations. Moreover, it is crucial to develop the infrastructure and development of high-level shopping and employment centers to attract more people around the stations from other areas. The feeder bus network that will be connected to the BRT stations should be developed to enhance accessibility and reduce the number of private vehicles. In these ways, population concentration and BRT readership BRT will increase, and suburban areas will become TOD to make Lahore a sustainable city.

8.5. Conclusion

We have developed two BRT-based TOD models for Lahore, such as urban and suburban TOD model, that depends on the characteristics of the BRT station areas. Our Model is different from Calthorpe's TOD concept because he developed an urban TOD model for rail transit in a developed country, i.e., the USA—our models for developing countries with BRT infrastructure like Lahore. We have considered an 800 m distance from the BRT station, while he has considered a 600 m distance from the transit station. In our model, some urban areas are fully developed and have narrow street systems, such as Bhatti Chowk, which can have different strategies to encourage TOD. Creating new pedestrian paths and cycle tracks may not be feasible for this type of station area, so car/motorcycle-free days can be implemented in these areas like Bhatti Chowk and Ichra station areas to promote walkability. Moreover, our proposed TOD models can be employed in other developing country cities with similar urban fabric, size, and socio-economic characteristics.

CHAPTER 9: CAUSES OF NOT IMPLEMENTING LAND USE AND TRANSPORT STRATEGIES OF IMPL 2021 AND UNDERSTANDING CHALLENGES AND OPPORTUNITIES FOR ENHANCING TOD WITH BRT

9.1. Introduction

This chapter identified the causes of not implementing land use and transport (TOD) strategies in the previous master plans of Lahore. This chapter discusses the transportation and urban planning system in Lahore. Through this research, several master plans, rules, policies, ordinances, and acts regarding transit and urban development in Lahore were studied to understand the causes of not implementing TOD strategies for Lahore.

9.2. Urban Planning and Transport System in Lahore

9.2.1. Urban planning system

Generally, Pakistan has three tiers of governance structure such as federal, provincial, and local (see **Figure 9.1**). Generally, the federal/central government is a significant actor in urban policies through its five years plans, while provincial and local governments are the implementing institutions in development planning (Qadeer, 1996). The local government and community development (LG&CDD) works under the local governance structure, whereas the housing, urban development, and public health department (HUD&PHD) work under the provincial government.

In Lahore, the urban planning system is fragmented and under the control of various authorities and agencies with functional overlapping. For example, Defense Housing Authority (DHA) is under the central government and developing schemes and projects of land development. In the provincial tier, HUD&PHD oversees several authorities and agencies such as Lahore Development Authority, Ravi Urban Development Authority (RUDA), Lahore Central Business District Development Authority (LCBDDA), and Housing and Town Planning Agency (PHATA). These authorities have similar functions of urban development in Lahore, such as master planning, building, and zoning regulation, land use, building control, approval of private housing scheme projects, transportation planning, urban renewal projects, and vertical development. LG&CDD manages the lower tier, for which Metropolitan Corporation (MC) works in Lahore. However, the local government's functions are similar to the provincial government's operations.

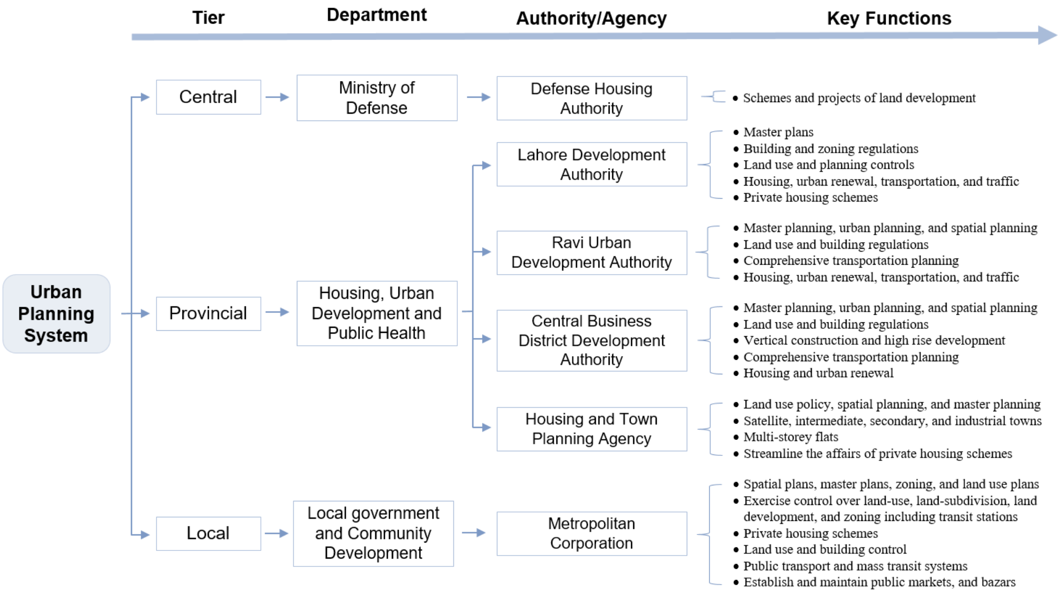


Figure 9.1 Urban planning system in Lahore. *Source:* Compiled by author

9.2.2. Transport planning system

There are several transportation authorities/agencies are responsible for transportation planning in Lahore: the Punjab Masstransit Authority (PMA), Punjab Provincial Transport Authority (PPTA), Punjab Transport Company (PTC), Transport Planning Unit (TPU), and Traffic Engineering & Transportation Planning Agency (TEPA) (see **Figure 9.2**). Most of their functions overlap, showing poor coordination among departments due to incomplete and poorly managed projects. The bureaucratic project-centric approach, funding, and vision are significant challenges in planning and implementing transportation projects.

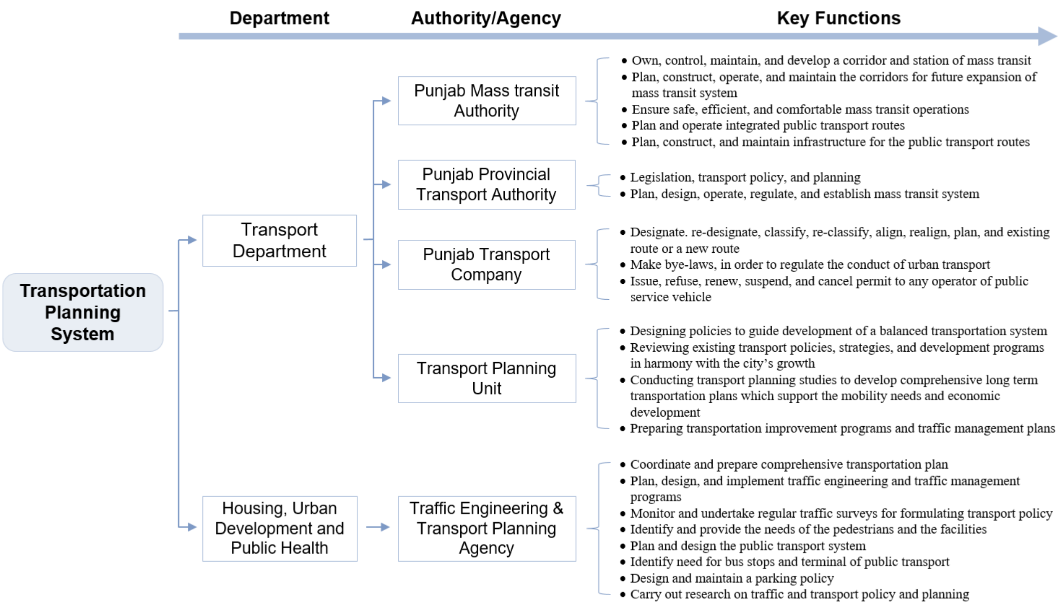


Figure 9.2 Transportation planning system in Lahore. *Source:* Compiled by author

9.3. The Context of Land Use and Transport Planning in Lahore

In Pakistan, the Municipal Administration Ordinance (MAO) 1960 was the first legislation about town planning. It was devised to prepare master plans by the local councils. After that, the government and development authorities prepared acts at the provincial scale. Pakistan joined the Colombo Plan in 1950 and made measures for formulating national level five years plans. The federal government developed a second five-year plan from 1960 – 1965, recognizing 11 main cities to prepare master plans, planning authorities established in major cities under their respective ordinances or acts, such as the Karachi Development Authority (KDA) Order 1957, the Lahore Development Authority (LDA) Act 1975, the Punjab Development of Cities Act 1976, and the Quetta Development Authority (QDA) Ordinance 1978. The MAO 1960 was substituted with the Provincial Local Government Ordinance (PLGO) 1979. PLGO 1979 was replaced by Local Government Ordinance (LGO) 2001 as a part of the devolution plan of the military regime. Under this ordinance, a new local government system was created, and Tehsil Municipal Administration (TMA) was required to formulate a master plan for their area of jurisdiction. The master planning process starts with the engagement of a private consultant, attainment of topographic maps, gathering secondary data, and conducting the socioeconomic, land use, and traffic surveys to analyze the existing conditions. It is shadowed by the stakeholder's consultation, preparation of land use maps, growth proposals, and reports. After that, various acts were prepared to carry out master and traffic planning, such as Punjab Local Government Act (PLGA) 2013, PLGA 2019, and PLGA 2022.

In Lahore, town planning happened with the formation of the Lahore Improvement Trust (LIT) in 1936. LIT's primary functions include preparing improvement plans and development schemes for the city. Initially, civil lines for administration, military cantonment, and citizens' housing schemes were established. In the 1960s, it was comprehended that a comprehensive master plan at a city level is essential to manage urban development. Several transportation and urban development plans were prepared for Lahore city under the provincial government (see **Figure 9.3**). On the other hand, the local government has prepared ordinances and acts for transportation and urban planning in Lahore.

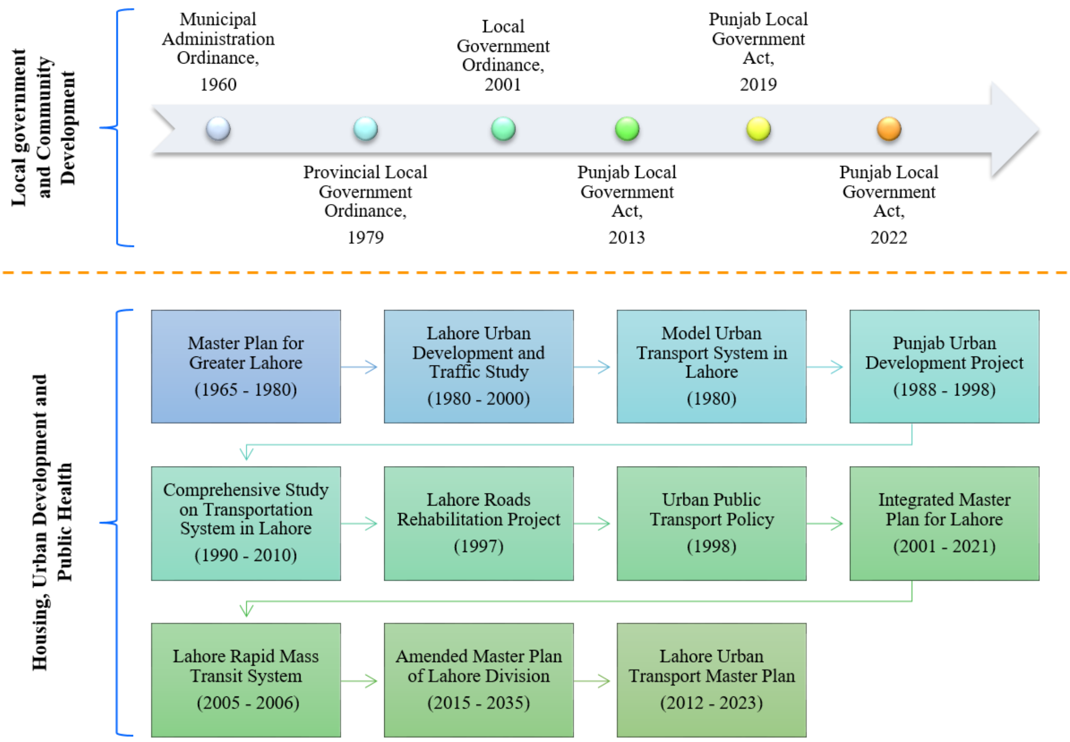


Figure 9.3 Chronology of Lahore's ordinances, acts, and land use and transport plans. *Source:* Compiled by author

9.3.1. Land use and transport planning by housing, urban development, and public health department

Master Plan for Greater Lahore (1965 – 1980)

The Master Plan for Greater Lahore (1965 – 1980) was the first planning struggle to manage the urban development of Lahore city. This study was carried out by Housing and Physical Planning, Government of Punjab. A master plan was prepared by foreign consultant Colombo Plan Advisors on Town Planning and Housing and local experts (H&PPD, 1973). This master proposed self-sustained industrial towns to accommodate the migrated population, a 24 km green belt around the city to stop the urban sprawl and ribbon development, redevelopment of CBD to enhance the economic potential of the land and establish divisional, district, neighborhood, and mohalla shopping centers to decentralize the commercial activities (see **Figure 9.4**). This plan suggested preparing some plans, such as a regional development plan for assessing the link between various urban centers and outline development plans (ODP) for existing urban centers around the city.

This plan also includes a proposal regarding transportation, such as a circumferential road (later named Lahore Ring Road) to divert the through traffic, an inner ring road to reduce the traffic congestion in the central areas, a mass transit system (circular railway) for commuter traffic, cycle tracks along all major roads, establish new bus and Omni-bus terminals, underground and multistory parking in the central areas, and creation of Traffic Department. Some road projects, such as Lahore Ring Road (a large part constructed recently), were ultimately implemented. But implementation of most of the proposals, such as green belt around the city, circular railway mass transit system and cycle tracks, and self-sustaining new industrial townships, remained unexecuted due to legal and institutional framework, multiple authorities, functional overlapping, technical resources, and coordination.

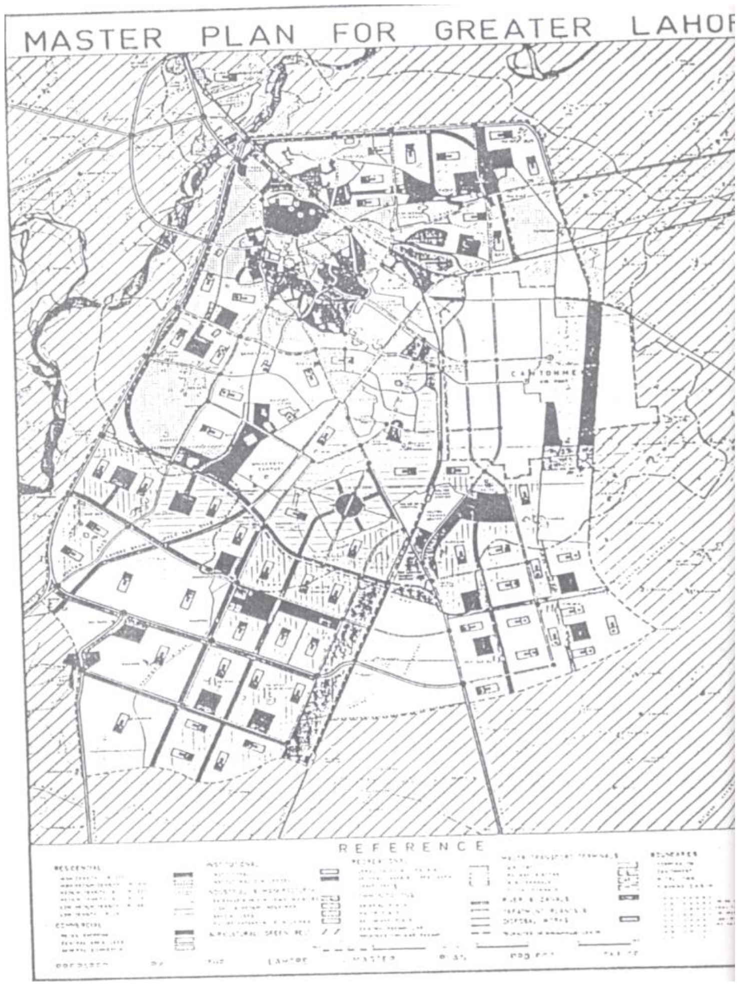


Figure 9.4 Master Plan for Greater Lahore (1965 – 1980). *Source:* H&PPD (1973)

Lahore Urban Development and Traffic Study (1980 – 2000)

This study was the second strategic master plan, also known as Lahore Structure Plan, financed by the World Bank. This study was carried out by foreign consultants such as CCH Associates (Copenhagen), Messrs Halcrow Fox (London), and BKM (Lahore) for LDA in 1980 (LDA, World Bank, & IDA, 1980). This plan suggested south and southwest urban growth sustained with high-speed roads. The primary argument for its recommendation was that a growing scale of economic activities would take low-density suburban development and can increase the rate of the private automobile. The other proposals in this master plan were given, such as the densification of built-up areas, decentralization of existing urban centers with new secondary and tertiary centers, the higher population density of 300 PPH, and the creation of new employment centers with better public transport facilities. These above-mentioned recommendations were not implemented; the private housing schemes have achieved an average density of 112 PPH, whereas 198 PPH in LDA-owned housing schemes.

Moreover, this plan proposed Traffic Engineering and Transport Planning Agency (TEPA) carry out transportation planning and Lahore Ring Road (LRR). However, this plan failed to recommend public and non-motorized transport strategies in Lahore. This plan could not implement the recommendations for the following reasons: weak legal and institutional framework, limited funds, weak political will, and weak enforcement mechanisms.

Model Urban Transport System in Lahore (1980)

This study was accomplished in 1980, and Volvo International Development Corporation provided technical and financial assistance. This study recognized various problems with Lahore's well-organized bus-based public transport system. This study suggested a mixed private and public bus network. Consequently, the Government of Sweden gifted almost 350 public buses to Lahore. After a few years, this bus system collapsed owing to the organizational inefficiency of the department concerned.

Punjab Urban Development Project (1988 – 1998)

The primary purpose of this project was to improve the road geometry in Lahore. This project was implemented in several cities of Punjab province with the financial assistance of the World Bank and collaborative efforts of various traffic engineering experts from different organizations such as the World Bank, TEPA, and international and local consultants. This project has key features, including channelization, road capacity, and junction improvement.

Comprehensive Study on Transportation System in Lahore (1990 – 2010)

This study was done by TEPA with the financial and technical assistance of the Japan International Cooperation Agency (JICA) in 1991 (JICA, 1991). The main features of this comprehensive study were that the future population would be settled via the intensification of existing urban areas and the development of road-based mass transit and fixed-track transit systems. This study has provided several proposals regarding transportation in Lahore, such as the introduction of an LRT of length 12.5 km, the opening of the electric rail of the length of 40 km on the existing intercity rail track of Pakistan Railway, the construction of an LRR and grade-separated road intersections, the introduction of bus priority lane of length 52 km, segregation of motorized and non-motorized traffic, and development of two multi-modal interchanges to create commercial core (see **Figure 9.5**). So far, most of this plan's recommendations were not implemented due to a lack of political will and resources.

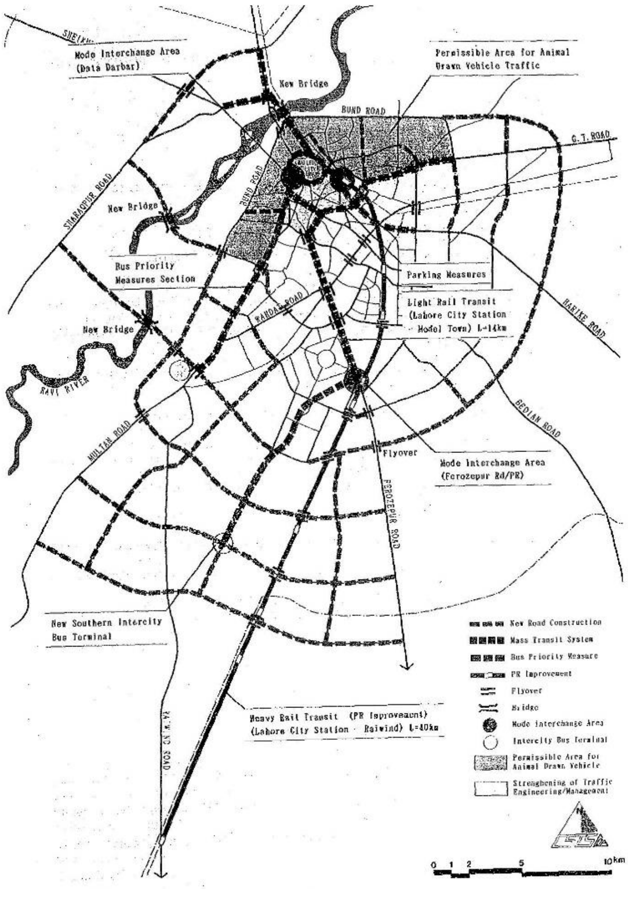


Figure 9.5 Comprehensive Study on Transportation System in Lahore (1990 – 2010). *Source:* JICA (1991)

Lahore Roads Rehabilitation Project (1997)

This project was financed by the Government of Punjab in 1997. The fundamental purpose is remodeling primary roads and improving the surface of secondary and tertiary roads.

Urban Public Transport Policy (1998)

The Government of Punjab prepared a bus-based public transport policy and creation of franchise system with the assistance of the World Bank and international consultants in 1998. The government offered several incentives to attract private investment under this policy. The incentives are customs duty exemption on importing CNG and diesel buses, subsidy on markup loan, and lease of the depot. As a result, more than 700 buses operate on thirty different routes (Imran & Low, 2005). Moreover, the users appreciated this policy on a large scale due to improved public transport quality. However, the government as a regulator has not played a significant role in the long run due to inadequate capacity.

Integrated Master Plan for Lahore (2001 – 2021)

This plan was prepared by a local consultant National Engineering Services Pakistan (NESPAK), to guide future development (NESPAK & LDA, 2004). This plan has provided several proposals for urban development of the city, such as densification of existing built-up areas, infill of vacant pockets, distribution of residential density, free height zones, creation of new town centers and business districts, creation of satellite towns, shifting of incompatible land uses (see **Figure 9.6**). On the other hand, Integrated Master Plan for Lahore (IMPL) gave some proposals regarding transportation, such as the provision of trunk infrastructure, construction of LRR, provision of facilities for pedestrians and cyclists, and development of an LRT system of length 12.5 km. Most proposals were not implemented due to weak land use and building control, weak enforcement mechanisms, lack of funds, and functional overlapping among the various departments.

Lahore Rapid Mass Transit System (2005 – 2006)

MVA Asia Consultancy prepared the feasibility study of the Lahore Rapid Mass Transit System (LRMTS) in 2005. It recommended four rail lines in two phases (green, orange, blue, and purple) to share the traffic burden. The first phase, including the green and orange lines, will be completed in 2015, while the second phase will be completed in 2020. Unfortunately, these projects were not implemented in the stipulated time. However, the green line (currently BRT) was operated in 2013, and the orange line was in 2022. Due to political scenarios, the rest of the mass transit lines are still not implemented.

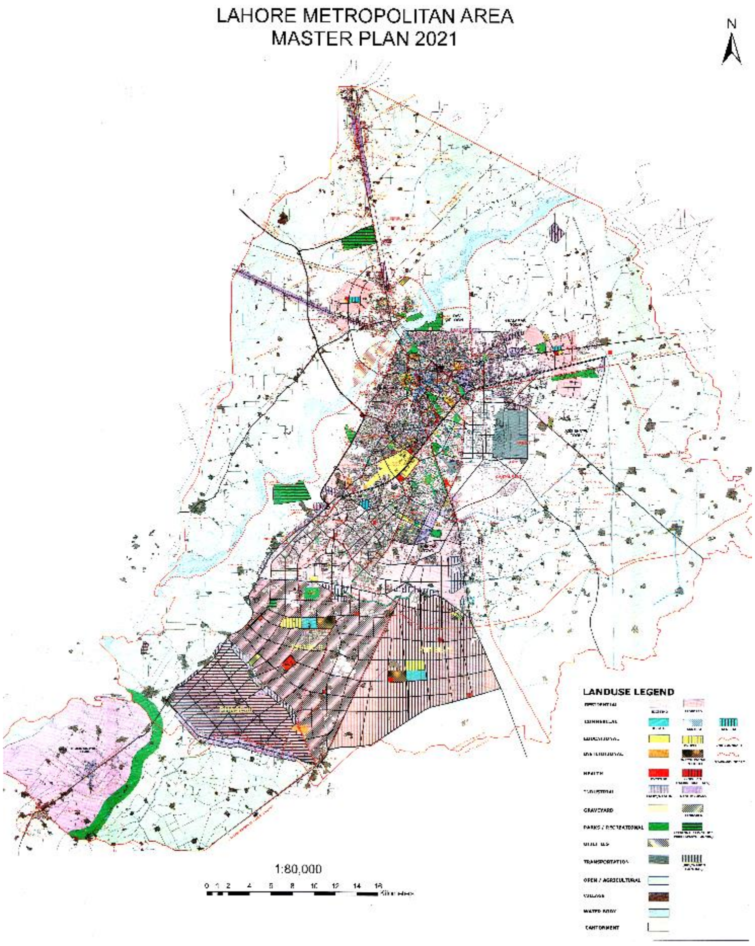


Figure 9.6 Integrated Master Plan for Lahore (2001 – 2001). *Source:* NESPAK & LDA (2004)

Amended Master Plan of Lahore Division (2015 – 2035)

Later, the limit of the LDA area was expanded to the whole Lahore Division in 2013 with the aim of master planning, sanction of private housing schemes, and commercialization by an amendment in the LDA Act 1975. LDA did not have any master plan for Lahore Division, but some extended areas have ODPs of the settlements. However, these ODPs were not ample due to the rapid urbanization trend. To assimilate the current land uses and agricultural area, an integrated map of the Lahore division was prepared in 2016 by integrating the available ODPs and Agroville Development Plans with IMPL 2021. Due to the short time, Amended Master Plan for Lahore Division 2016 was formulated without conducting surveys and preparing reports (Lahore Development Authority, 2016). The following proposals were recommended: adopting the semi-circular and circular shape to encourage compact development and urban growth towards the South-East in green field development areas that would lead to urban sprawl (see **Figure 9.7**).

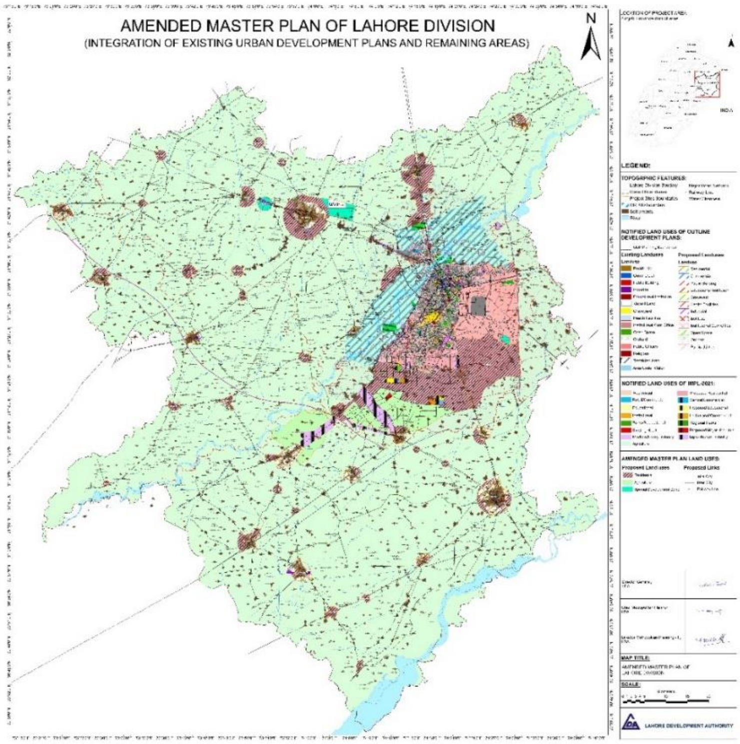


Figure 9.7 Amended Master Plan of Lahore Division (2015 – 2035). *Source:* LDA (2016)

Lahore and surrounding areas have experienced unprecedented urbanization, so a comprehensive, regional, strategic, and long-term plan is required. For this purpose, the LDA prepared a Master Plan of Lahore Division (MPLD) 2050 in 2023 with the assistance of Dar Al-Handasah Consultants (Lebanon) and Asian Consulting Engineers Pvt. Ltd. (Lahore). This plan comprises the Regional Plan of the Lahore Division and Master Plans of major urban settlements falling within the Lahore Division (Lahore Development Authority, 2023). Unfortunately, the implementation of this master plan was suspended by Honorable High Court earlier this year in January. Later, this court invalidated this plan and ordered the LDA to prepare a new master plan for Lahore. So, IMPL 2021 is still in implementation.

Lahore Urban Transport Master Plan (2012 – 2030)

This plan was prepared by ALMEC Corporation and Oriental Consultants Co. Ltd. with the assistance of JICA for urban transport in Lahore till 2030 (ALMEC Corporation, 2012). This study proposed a BRT and Rapid Mass Transit System (RMTS) and established three urban development scenarios: status quo, compact development, and dispersed multi-core development. As a result, the first BRT system and Orange Line Train (OLT) system were operated in 2013 and 2022, respectively. However, the Blue and Purple lines were not executed due to political instability. Urban development scenarios were not also implemented due to limited funds and resources.

The summary of the previous master plan strategies for land use and transport in different periods in Lahore is presented in **Table 9.1**

Table 9.1 Master plans strategies in the different periods in Lahore. *Source:* Compiled by author

Master plan	Timeline	Strategies/Proposal
Master Plan for Greater Lahore, 1966	1966 – 1986	• Creation of self-sustaining new industrial townships • Creation of a 24 km green belt around the city • Preparation of regional development plan and outline development plan • Redevelopment of central city areas • Establishment of divisional, district, neighborhood, and Mohalla shopping centers • Creation of circumferential arterial road and inner ring road • Construction of low-cost housing schemes, multi-storeyed dwellings in central areas • Establishment of the circular railway as a mass transit system • Creation of cycle tracks along all major roads • Development of multi-storeyed and underground parking lots in central areas
Lahore Urban Development and Traffic Study, 1980	1980-2000	• Future physical growth be planned towards the south and southwest • Densification of built-up areas • Decentralization of existing centers and establishment of new secondary and tertiary centers • Fixation of higher population densities closer to 300 PPH • Creation of new employment centers close to new residential areas with better public transport facilities • Proposed TEPA for transportation planning • Proposed the construction of a ring road named the Lahore Ring Road
Model Urban Transport System in Lahore, 1980	1980	• Mixed public and private bus-based transport system
Punjab Urban Development Project	1988 - 1998	• Improvement of the road geometry • Area upgrading of local urban services in a low-rise development • Walled City upgrading & conservation
Comprehensive Study on Transportation System in Lahore, 1991	1990–2010	• Intensification of the existing urban areas • Introduction of the Light Rail System with a length of 12.5 km and 18 stations • Development of 2-multi-modal interchanges (Bus and LRT) to create an urban business/commercial core around it • Introduction of electric railcar trains on the existing intercity rail track with a length of 40 km

		• Construction of LRR and grade-separated road intersections • Introduction of bus priority lane of length 52 km • Segregation of motorized and non-motorized traffic
Lahore Roads Rehabilitation Project, 1997	1997	• Remodeling of primary roads and surface improvement of the secondary and tertiary roads
Urban Public Transport Policy, 1998	1998	• Formulation of bus-based public transport policy on a franchise base
Integrated Master Plan for Lahore, 2021	2004 – 2021	• Densification of the existing built-up areas • Infill and consolidation of vacant pockets within the built-up areas • Distribution of residential density across the city • House-building incentives for the lower income groups • Free height zones in Central Business District (CBD) area • Undertaking projects for urban renewal in the central area • Shifting of incompatible land uses • Green Belt as Buffer Zone (one km wide) around industrial • Creation of new Town Centre and Business Districts • Establishment of satellite towns • Provision of trunk infrastructure • Construction of Lahore Ring Road for land • Provision of facilities for pedestrians and cyclists • Development of Light Rail Transit (LRT) of length 12.5 km • Improvement of the public transport system and development of bus terminals • Provision of off-street and on-street parking facilities • Establishment of a GIS database • Development of green spaces • Preparation of strategic land use and transport plan
Lahore Rapid Mass Transit System, 2005	2005 – 2006	• Feasibility study of RMTS for identification of potential mass transit corridors for four lines
Amended Master Plan of Lahore Division, 2016	2015 – 2035	• Semi-circular and circular shape compact development • Future urban growth in greenfield development in suburban areas towards South-East
Lahore Urban Transport Master Plan, 2012	2012 – 2030	• Introduction of RMT and BRT • Establishment of three development scenarios, including past trend, compact development, and dispersed multi-core development

9.3.2. Land use and transport planning by local government and community development department

Local Government and Community Development Department formulated several ordinances and acts for transportation and urban planning in Lahore (see **Figure 9.8**). In Lahore, Metropolitan Corporation is working under the local government. The main functions of the corporation are the preparation, approval, and implementation of spatial plans, zoning, and land use plans, land use and building control, approval and regulate private housing schemes, providing and operating public transport and mass transit systems, and establishing markets and bazaars.

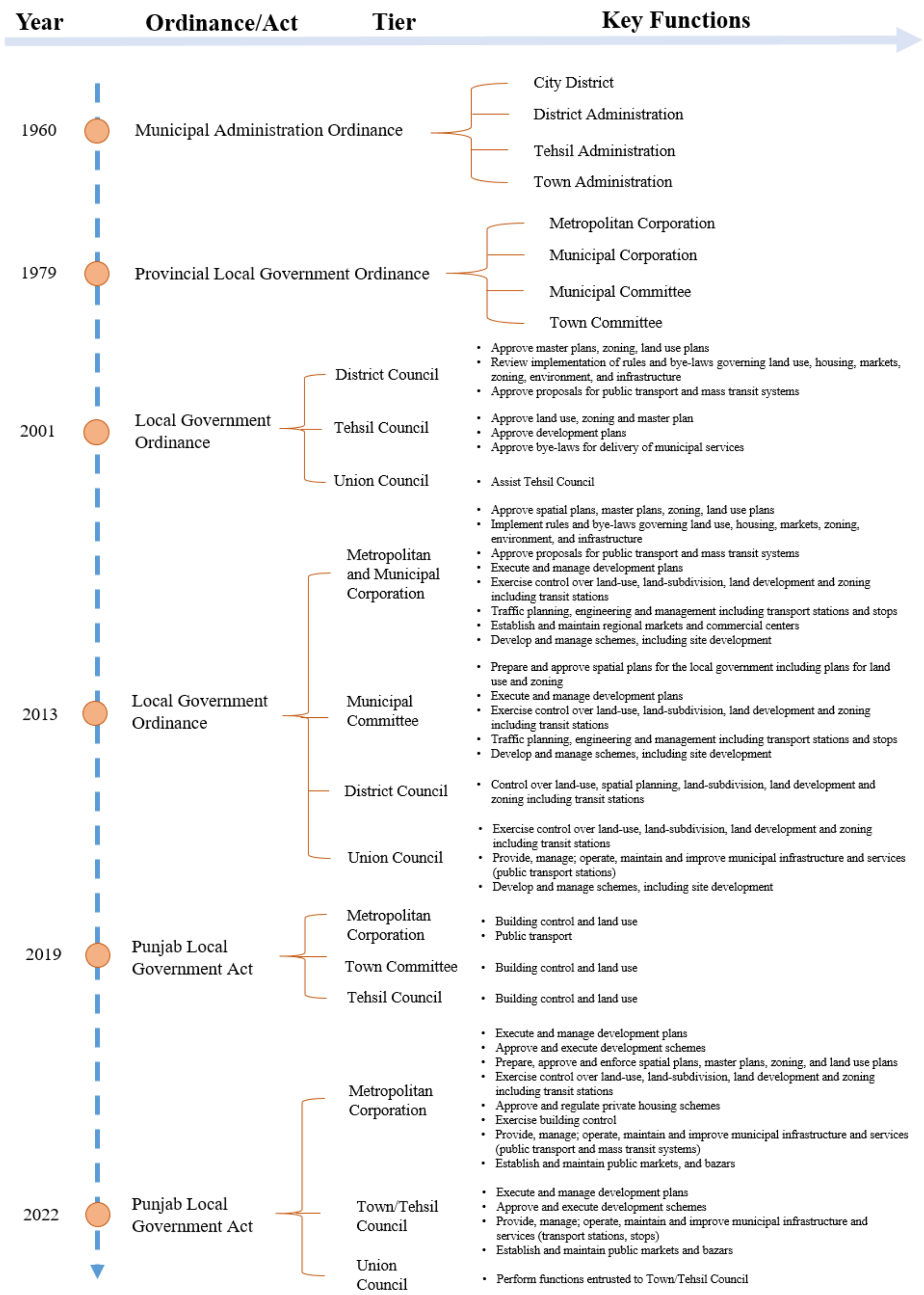


Figure 9.8 Local government functions. *Source:* Compiled by author

9.4. Land use and Transport Strategies in Previous Master Plans were not implemented

In the different periods, various master plans and acts were formulated by the different departments, but implementing these plans is in question. Most of the proposed strategies were not implemented yet for various reasons. Development authorities and Metropolitan Corporation have a substantial functional overlap because both perform almost the same functions, leading to unplanned development. This unplanned development is due to a lack of technical staffing, weak land use and building control, and inadequate enforcement mechanism in Lahore. Most of the strategies were not implemented because most of the master plans were prepared by foreign consultants. They proposed the strategy according to their local conditions, while Lahore city's condition differs from other countries. Path dependencies are a significant obstacle in implementing master plan strategies. Moreover, political will and bureaucratic and project-centric approaches are other causes of failure of master plans strategy because most of the plans were formulated without considering the general public and all stakeholders during the preparation and implementation process. The lack of funding resources and weak legal and intuitional framework for implementing strategies can be reasons (LDA et al., 1980; NESPAK & LDA, 2004).

9.5. Land Use and Transport Strategies of IMPL were not implemented, and Challenges and Opportunities to Enhancing TOD with BRT

9.5.1. Interviewee’s information

Table 9.2 shows the interviewee’s information of nine professionals working for land use and transport planning in Lahore. All participants were male. Seven interviewees were aged between 31 – 60 years. Five interviewees had master’s qualifications, whereas four had doctoral degrees. Six interviewees belonged to the Urban Planning profession, while the rest of the participants were associated with the architecture, civil engineering, and urban economics professions. Three interviewees worked in academic institutions, while the remaining participants were attached to Lahore Development Authority, Lahore Metropolitan Corporation, Ravi Urban Development Authority, Central Business Development Authority, and Walled City for Lahore Authority. One consultant working with land use and transport planning also participated in the interview. Four interviewees had professional experience of 5 – 10 years, while three participants had diverse professional experience of 21 – 40 years of urban development and transport projects in

Lahore. One interviewee had a professional background of over 40 years (almost 48 years), working for master planning in Lahore and Pakistan. Out of nine, eight had vast experience working on major projects of master planning. Regarding their involvement in IMPL 2021, two and four interviewees were involved in the preparation and implementation process of IMPL, respectively. Whereas two were engaged in both preparation and implementation of IMPL. One participant reviewed it. Interestingly, eight out of nine interviewees have heard about the TOD concept. One has heard of the concept of TOD before 2001, and one has heard of it before 2010. Six interviewees heard about the TOD concept between 2011 – 2020. One heard it recently.

Table 9.2 Interviewee's information

Characteristics	Attribute	Participants (n = 9)
Gender	Male	9
	Female	0
Age	25 - 30	1
	31 - 45	4
	46 - 60	3
	More than 60	1
Education	Master	5
	PhD	4
Profession	Urban Planning	6
	Architect	1
	Civil Engineering	1
	Urban Economics	1
Organization	LDA	1
	LMC	1
	RUDA	1
	CBDA	1
	WCLA	1
	Academic	3
	Consultant	1
Working Experience	5 – 10	4
	11 – 15	1
	16 – 20	0
	21 – 40	3
	Above 40	1
Engaged in major projects or master plan	Yes	8
	No	1
Contribution to IMPL, 2021	Preparation	2
	Implementation	4
	Preparation and Implementation	2
	Review	1
Heard about the TOD concept	Yes	8
	No	1
Year to hear about the TOD concept	Before 2001	1
	2001 - 2010	1
	2011 - 2020	6
	After 2023	1

9.5.2. Word frequency analysis

Figure 9.9 shows the word frequency analysis, and **Figure 9.10** displays the tree map for interview data. Moreover, the count and weighted percentage (%) are presented in Annexure F. This analysis shows the most frequent words used in the interviews in larger red and darker black. We have used four themes in this analysis that are described in the methodology section. Firstly, the following words are most frequently in red: priority, government, coordination, political, planning, rules, framework, and developers. On the other hand, some words are in darker black, such as departments, strategies, transport, plans, among, urban, areas, master, mechanism, development, department, regulations, and implementations. Firstly, rules, regulations, and frameworks are essential for planning and implementing TOD strategies. According to the analysis and interviews, there is no planning and implementation framework and mechanism for the proposed strategies of prevailing master plans and encouraging TOD with BRT. They also mentioned that clear rules and regulations are absent for implementing TOD around BRT stations. Some interviewees said that;

> *"Most of the strategies of the master plans are just generic terms and do not mention who and how will implement them. What are the rules, regulations, or policies to implement these strategies? Moreover, we need local plans to plan and implement TOD strategies that are widely absent in the case of Lahore."*

Secondly, the working relationship of government institutions is crucial. There is weak institutional coordination and an absence of trust among the departments working for urban development and transportation planning and with developers and individuals. According to one interviewee;

> *"Three levels of implementation of TOD strategies, such as government, developers, and individuals, somehow, government and developers are working in an organized way, but individuals are not organized in Lahore. If we want to implement TOD with transit, organization of three levels is essential."*

Thirdly, land use planning should encourage the private sector urban development opportunities around BRT stations. However, in the case of Lahore, there is an absence of incentives and redevelopment opportunities for developers to encourage TOD with BRT. Most interviewees mentioned that the size of parcels around BRT stations is more concerning and plays a vital role in development and redevelopment opportunities for transforming the urban fabric. BRT corridor is also passing from the central area of Lahore, where land parcel size is not so large, so amalgamation of land parcels is required there. The absence of a TOD master plan, incentives, and redevelopment opportunities discourages TOD around BRT stations. Such parcels require an urban transformation process that can increase the density through land use diversity and densification of the built-up areas. It can also be one reason for the decline of some TOD elements around BRT stations. The provision of incentives for private developers is associated with priority and will. A lack of priority from the government side and weak political will leads to more urban development at the urban fringe areas rather than around BRT stations and in central areas of Lahore. In Quito, every city mayor desired the BRT route they made to have a different signature to show the variation between each local government administration, so the city's urban plans allowed higher densities along the arterial roads, irrespective of BRT corridors (Vergel-Tovar, 2023).

Finally, funding can play a significant role in encouraging TOD projects around BRT stations. According to the interviewees, there is a lack of financing because foreign investors feel fear of investing in mega projects due to the absence of a clear framework and mechanism, political instability, absence of incentives, absence of TOD plan, unclear rules and regulations, the behavior of the institutions, and lengthy procedure of approval.

Figure 9.9 Word frequency analysis

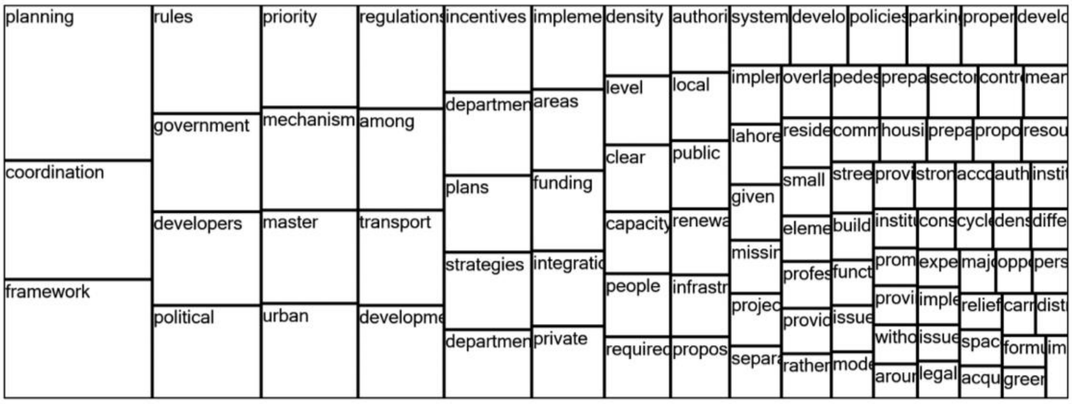


Figure 9.10 Tree map of word frequency

9.5.3. Land use and transport strategies of IMPL 2021 were not implemented

Integrated Master Plan for Lahore 2021 proposed several land use and transport strategies, including density, land use, urban renewal and redevelopment, incentives, compact development, mass transit, and facilities for pedestrians and cyclists relevant to TOD strategies described in the methodology section. However, no serious efforts could not take to implement these proposed strategies; thus, unplanned growth and private vehicles were encouraged. As a result, the city is expanded over a radius of 40 km haphazardly. The interviewees highlighted several reasons for the non-implementation of land use and transport strategies. Lack of planning and implementation framework and mechanism is a significant reason for not implementing strategies like densification, infill development, distribution of density, high rise development, incentives, urban renewal, and shifting of incomputable use and buffer around it. According to the interviewees, these strategies are just generic words used in the master plan without a proper framework and mechanism. They did not devise rules, regulations, policies, and plans to implement these strategies on the ground.

One of the main reasons is a lack of coordination among the institutions. For example, LDA, a provincial institution, prepared the IMPL, but some proposed strategies were related to the federal government, like upgrading HRT utilizing existing rail tracks. Most recently, the government established various authorities, including Central Business Development Authority (CBDA) for high-rise development in the CBD area and Walled City for Lahore Authority (WCLA) to carry out urban renewal in the central area within the walled city. Unfortunately, both authorities prepared their master plans without coordinating with other departments like Punjab Masstransit Authority (PMA), LDA, LMC, etc. Even they have not integrated the BRT system with their master plans.

According to the interviewees, the strategies of the IMPL required coordination among the departments, such as urban renewal, shifting of incomputable use and buffer around it, upgrading of HRT utilizing existing rail track, trunk infrastructure, facilities for pedestrians and cyclists, mass transit system, parking, and development of green spaces.

The lack of institutional incentives for developers and individuals was also a primary reason for not implementing IMPL strategies. According to the interviewees, several strategies required huge incentives for their successful implications, such as densification, infill development, high-rise development, urban renewal, shifting of industries, and development of satellite towns. But unfortunately, the mechanism was not devised in the master plan regarding incentives. It is due to less priority from the government and weak political will. Moreover, other reasons, including lack of funding, land acquisition, lack of expertise, lack of capacity, absence of vision, and professional ability and leadership, stand in the way of land use and transport strategies in Lahore.

Some other researchers conducted studies for implementing master plans in Lahore. Hameed & Nadeem (2008) identified the various barriers that stand in the way of implementing IMPL, such as excessive delays in the preparation and approval process, weak institutional setup, lack of financial resources, weak coordination among government institutions, legal gaps, weak political will, and lack of dissemination of plan. Similarly, Hussain & Nadeem (2021) studied the relationship between the urban growth strategies of master plans and spatial dynamics in Lahore. They concluded that the urban growth strategies of IMPL were not implemented due to some reasons such as poor land use control, lack of enforcement mechanism, lack of funding for land acquisition, lack of trust between government departments and developers, functional overlapping, weak institutional capacity, and weak political will.

9.5.4. TOD elements were not included in IMPL 2021

Local consultants prepared IMPL, so they have no TOD knowledge or expertise. Although the TOD concept was new then, some urban planners were familiar. Moreover, the time of preparation of this master plan was significantly less. This type of proposal, such as TOD, requires much time. So, consultants cannot do specific things on a small scale quickly. TOD was not the priority of the government and in political will, so it was not added to the scope and objective of the master plan. Moreover, departments were not integrated and had no coordination, so they did not integrate rules and regulations. Generally, the professional capacity of the authorities and leadership was not sufficient to consider the TOD projects in IMPL. According to one interviewee, no study was conducted before the implementation of the BRT system. Even though a rapid rail system was proposed in IMPL, the plan did not give a planning framework and mechanism for controlling urban development around the transit system.

9.5.5. Decline in TOD elements around BRT station areas

According to our observation survey was conducted in 2021 in selected eight BRT stations in the proximity of 800 m, some TOD elements are declining around these BRT station areas: population density was not increased significantly when compared with the entire Lahore city; residential land use declined; pedestrian paths were not improved; green or open spaces declined. According to the interviewees, there are several reasons for the decline of these TOD elements: absence of planning and implementation framework, no coordination among departments, no integration of departments and rules and regulations, lack of trust between government and developers, unclear rules and regulation, absence of incentives for developers and individuals, no political priority and will, no institutional capacity, lack of funding, weak land use control, functional overlapping, poor understanding with TOD concept, no TOD plan, and no TOD team. Moreover, interviewees said that people are moving to suburban areas due to cheap land, and they converted residential land use into commercial and mixed-use to get more rental yield and take more benefits of BRT infrastructure. One interviewee said;

> *"The population density at the individual level is increasing around BRT stations but not in a planned way; if we integrate land use and BRT, we can increase density in a planned way."*

9.5.6. Challenges and opportunities for enhancing TOD with BRT

Many challenges and opportunities stand in the way of encouraging TOD with BRT in Lahore. According to the interviewees, no planning and implementation framework or mechanism for supporting TOD exists. Even though the BRT system started in 2013, there are no zoning, rules, regulations, or policies for TOD around stations and corridor. Moreover, there is no coordination between land use and transport planning departments. In Lahore, several departments work for land use and transport planning in their jurisdiction area; they have their own rules and regulations, even separate master plans. However, they do not integrate rules, regulations, or master plans for promoting TOD. Although some new authorities, such as CBDA and WCLA, have separate master plans and regulations. Their jurisdiction area is abutting the BRT stations and corridor; they were not considered BRT in their master plans for encouraging TOD. Unfortunately, the departments and regulations are not integrated at the federal, provincial, and local levels. Many government departments with multiple roles and responsibilities, but the TOD plan is absent around BRT station areas and Lahore. According to Cervero & Dai (2014), the government established implementation tools to encourage TOD around the BRT corridor in Curitiba. One interviewee said that;

> *"There are two legs of urban planning: master planning/strategic planning/spatial plans and land use controlling. In the case of Lahore, both legs are fragmented, and no teeth of land use control."*

The departments' professional capacity and leadership are insufficient for TOD in Lahore. Professionalism and professional roles and responsibilities are missing on a large scale. The lack of expertise in planning and implementing TOD strategies among local urban and transport planners inferred that they do not know how to proceed with BRT-based TOD. So, it was difficult for them to discourse the potential effects of BRT on surrounding areas. The lack of expertise was due to weak political assistance and less government priority. Moreover, there is no separate team or directorate within the departments to deal with TOD planning and implementation matters. However, some professionals know about the TOD concept, but no one has the will to plan and implement it. Unfortunately, TOD plans and strategies are not the government's priority, and they have no firm commitment to take the city as a sustainable city. Infect institutions have no capacity, power, or legal backing to prepare and implement TOD plans in Lahore. Some interviewees said that;

> *"Most employees like to do just things mentioned in the rules and regulations. They are already overburdened, spending most of their time on court cases and field visits. They suffer from fear, impurity, and insecurity to take the next steps, so they prefer to work within the rules. TOD is not a part of the rules and regulations, not even mentioned in the prevailing master plans. So, they like to regulate the housing schemes and building plans. No doubt, TOD actively pursues the urban dream, but employees are doing passive things rather than active ones."*

Moreover, developers have no institutional incentives to develop and redevelop the areas around BRT. If any developer wants to create any project or redevelopment around BRT, they face complexities in rules and regulations and a lengthy approval process rather than getting any incentive. Along with this, the behavior and intentions of the departments are also a primary hurdle to encouraging TOD with BRT. Besides, the main obstacle to TOD is the small land parcels around the BRT stations, particularly in the central city area. For this purpose, no mechanism for the amalgamation of the plots has existed since BRT started in 2013. In addition, funding is another challenge to encourage TOD with BRT because TOD projects require immense finance. Foreign investors feared investing in TOD projects due to the absence of incentives and mechanisms. Unfortunately, rules and regulations are entirely salient in incentives and funding matters. For attracting investment opportunities, allied facilities/infrastructure are essential to provide around BRT stations. However, the government did not provide allied facilities/infrastructure, such as footpaths, street furniture, shaded walkways, parking, etc., near BRT station areas to attract investors and developers to promote TOD.

Nevertheless, TOD is not easy; it requires more institutional capacity, a robust planning framework, mechanisms, codes, incentives, development systems, government support, strong political will and leadership, TOD experts, and funding. The interviewees mentioned the various opportunities for encouraging TOD with BRT in Lahore. Some authorities are currently preparing master plans for their jurisdictions. For example, LDA is preparing a Master Plan for Lahore Division, CBDA is working on the CBD area, and WCLA is formulating a Master Conservation and Redevelopment Plan for the walled city. Multiple departments work for one city, and their roles and responsibilities are fragmented. It would be an opportunity to prepare a single master plan for the entire city in the light of BRT and other transit lines that can encourage TOD towards sustainable Lahore; however, local plans for each sector within the master plan are crucial to prepare with proper implementation framework and mechanism for land use and transport integration. According to Suzuki et al. (2013), land use and transport integration are contemplated persuasive measures for sustainable development, but master plans must lead them. In our study, institutional coordination can be enhanced, which will help to reduce the functional overlapping, and the city will have one uniform master plan to promote TOD. According to Guo et al. (2020), planning standards and implementation frameworks are essential for effectively controlling urban development. According to Cervero & Dai (2014), transit infrastructures, illustrative plans, and paper maps alone cannot encourage TOD. They must be required by definite tools such as zoning densities and infrastructure improvement to settle urban development, etc. Moreover, in the case of Lahore, we also need comprehensive land use and building control to implement the TOD successfully. It is an opportunity for the government to involve the private sector in TOD planning and implementation around BRT stations and corridor because they can develop it comprehensively to take more advantage of the transit infrastructure, and the role of the government should be as a regulator.

According to the interviews, land use and transport planning are running under various rules and regulations in Lahore because every authority has its own rules and regulations. LDA, LMC, and other authorities are working in parallel. So, it would be an opportunity for the integration of rules and regulations for efficient working for TOD planning and implementation. Moreover, there is also a need to integrate federal, provincial, and local departments for promoting TOD. It would be better to create a single department for the TOD or a TOD team under the existing departments that can carry out the functions of land use and transport integration. For this integration, strong government commitment or support and strong political will be required to move Lahore to a sustainable city. In parallel, professional capacity and leadership can play a significant role in encouraging TOD for sustainable development. Moreover, we also need a different level of integration, like funding, legislation, urban design, urban spaces, etc.

Likewise, institutional incentives to the developers play a significant role in encouraging TOD around the BRT areas. Incentives such as density bonus, FAR, an amalgamation of small land parcels, etc., around BRT stations should be devised in rules, regulations, and master plans to promote TOD. Each station has different characteristics, so they need to prepare different rules, regulations, and local TOD plans according to the features of each BRT station. Because some stations are located in central areas, they require urban renewal and redevelopment for mixed-use development. While some stations are situated in suburban areas, they have opportunities for encouraging TOD, but they need infrastructure improvements such as feeder routes and a walking and cycling environment. More funding is required, so the government should provide incentives to foreign investors, like relaxation in the approval process and tax relief. It is expected that the private sector has the potential to develop TOD if incentives are offered. **Table 9.3** summarizes the challenges and opportunities to encourage TOD around BRT station areas.

Table 9.3 Challenges and opportunities for enhancing TOD with BRT

		Summary
Challenges for TOD	Framework	Absence of planning and implementation framework and mechanism for encouraging TOD Absence of rules, regulations, policies, and TOD master plan around BRT station areas to encourage TOD with fragmentations of various rules and regulations of each department
	Coordination	Lack of institutional coordination among departments as well as with developers and individuals Lack of integration among rules and regulations as well as government level such as federal, provincial, and local Lack of trust among departments and developers
	Incentives	Absence of incentives as well as framework and mechanism for developers and individuals to promote TOD
	Department	Absence of a department to encourage TOD with BRT and in the city Weak political will and the department's priority No capacity, power, or legal backing to prepare and implement TOD
	Expertise	Lack of local expertise to prepare and implement rules, regulations, and policies to encourage TOD Inadequate professional capacity and insufficient leadership for planning and implementing TOD
Opportunities for TOD	Framework	The preparation of a planning and implementation framework and mechanism to promote TOD with BRT
	Coordination	The integration of rules, regulations, policies, and departments to promote TOD with BRT can reduce the functional overlapping Serious efforts to increase the institutional coordination with developers
	Incentives	Incentives framework and mechanism for developers and individuals Relaxation in rules and regulations to develop TOD projects with BRT Incentives such as density bonus, FAR, and amalgamation of small land parcels should be devised in rules, regulations, and master plans Involvement of the private sector in TOD planning and implementation
	Department	Separate department or team within the department to carry out TOD projects Strong political will and high government priority
	Expertise	Expertise from international experience in BRT-based TOD Academic research on TOD with BRT

The findings of our study are consistent with those of Cervero & Dai (2014) and Vergel-Tovar (2023). Cervero & Dai (2014) identified weak institutional support, lack of funding, and limited resources as hurdles in supporting BRT-based TOD using a survey of 27 global cities with urban planners and transport planners. Further, they identified five obstacles to encouraging TOD: lack of funding, absence of TOD plans, lack of institutional coordination, little experience with TOD, and weak political backing. Moreover, they determined that the government established the implementation tools to encourage TOD around the BRT corridor in Curitiba. Vergel-Tovar (2023) conducted 86 semi-structured interviews with urban planners, transport planners, community leaders, developers, and real estate experts in Bogotá and Quito. He identified several barriers and opportunities for BRT-based TOD such as timing complications between land use and transport institutions, complex relationships between private and public sectors with different perceptions of urban development, the complexities of renewal and redevelopment measures in existing urbanized areas, general perspective of TOD as an idea foreign to all excluding transport planners. These studies were conducted mainly for developed countries with large sample sizes of urban planners and developers. However, our study was conducted in the context of a developing country like Lahore where situation varies from developed countries. Moreover, our study sample was small and only considered the perceptive of professionals working in different departments in Lahore.

9.6. Conclusion

The previous master plans failed to offer land and transport integration proposals. The urban planning and transport planning system of Lahore is in the hands of several authorities, resulting in functional overlapping. These authorities have no experience formulating and implementing the TOD strategies, so separate authority need to be established to plan for transit infrastructure and formulate the TOD strategies for stations and corridors. The Lahore planning system is reactive and needs to be changed with proactive planning based on TOD in recently built BRT stations. Lahore City should learn from Curitiba and Bogota's experience to integrate BRT with urban development by implementing a proactive planning approach. Lahore needs to formulate the TOD plan around BRT stations to encourage sustainable urban development and the use of BRT. Strong political will and coordination among the departments are required to prepare and implement land use and transport policy for built-up and brownfield areas around the BRT stations.

The absence of planning and implementation framework and mechanism, lack of institutional coordination, less government priority and political will, absence of incentives for developers, absence of clear rules and regulations, lack of specific TOD plan, and absence of professional capacity and leadership were the foremost challenges for encouraging TOD around BRT station areas. Moreover, our study suggested that clear planning and implementation framework, rules, regulations, TOD plan, local plans, coordination, strong political will, capacity and leadership, and incentives mechanism are crucial to promote TOD around BRT stations. Moreover, a separate TOD or TOD team department within departments is also essential to enhance BRT-based TOD in Lahore.

CHAPTER 10: CONCLUSIONS AND RECOMMENDATIONS

10.1. Introduction

This chapter summarizes this study's major findings and suggests recommendations for urban planning/TOD in Lahore. This chapter ends with future research directions as they came from the limitations of this research.

10.2. Conclusions

This study investigates the impacts of BRT on the urban fabric in Lahore from the viewpoint of 3Ds of TOD. The results show that the urban fabric has changed after the BRT operation, but it is dependent on the characteristics of each BRT station area. After the BRT operation, population density and development volume increased. However, the population density in the study area has not increased significantly compared to Lahore’s population density rate. Additionally, land use for economic activities, such as commercial and industrial use, also increased. On the other hand, vacant land, open space, and agricultural land declined significantly in terms of area. Land use diversity also increased in most of the target stations. Thus, in density and diversity, elements of TOD were encouraged in the station area. Regarding design, which shows walkability in the station area, the three indicators declined or slightly increased. Before the BRT operation, the pedestrian paths were mostly well-equipped. There was no improvement after the BRT operation. The intersection density of the eight station areas lies almost in the same range as that of Venice, Italy, and it increased in some areas. The area of parks remained the same or declined in all areas. The area of parks declined significantly in a controlled area, i.e., Model Town. From this result, after the BRT operation, the urban fabric created in the BRT station areas to some degree, such as density and diversity, improved, but design, particularly pedestrian paths and open space, remained the same or declined. Moreover, the urban fabric around BRT station areas has elements of TOD to some extent. In some measures, TOD elements such as density are satisfied but do not significantly grow, and diversity is fully satisfied, while other elements such as walking are not fully satisfied. It is expected that the diversity element can encourage the use of BRT rather than private vehicle use around station areas. Therefore, to achieve TOD, the government should give priority to improving the walking environment, for instance, by creating more pedestrian paths and open spaces. Comparing the change in population density in the station area with the whole city, the population density growth in the station area is almost the same as in the entire city. Although the station area became more convenient because of the increase in FAD and land use diversity, the station area did not attract people as a residential area would. Thus, to increase population density, improvement of convenience is not enough, and improving the living environment is also very important.

Most previous studies on TOD and travel behavior have been conducted in developed countries using rail transit proximity, and little is known about developing nations, particularly in Asian regions. Therefore, our study also examines residents' travel behavior in TOD and TAD areas and the impact of TOD attributes on VKT using BRT station proximity in Lahore. The results demonstrate that residents' travel behavior differs in the TOD and TAD areas around the BRT stations. We found that TAD areas had a larger household size and income than TOD areas, resulting in higher car ownership. Thus, TAD residents are more likely to use cars and less likely to use BRT and non-motorized modes. Not surprisingly, residents with a car tend to drive more for most trips in the TAD areas. In contrast, respondents in TOD areas were more likely to use BRT/walk/motorcycles and drive less for work and shopping trips. This demonstrates that TOD areas can potentially encourage BRT and non-motorized use. For all respondents almost 81% and 82% of respondents agreed with the statements related to the travel mode to work and shopping trips, respectively. Moreover, the average travel distance, time, and cost were higher in the TAD areas than in the TOD areas, indicating that TAD areas have fewer employment opportunities and shopping places. Hence, residents come to the city center and TOD areas to meet their services, shopping, and daily needs. However, TOD residents have workplaces at short distances and visit shopping places close to their homes. Moreover, TOD areas around BRT stations have higher population density, residential density, land-use mix, and intersection density, encouraging the use of BRT and walking while driving less. We also found that socioeconomic characteristics and TOD attributes significantly impacted the vehicle kilometers traveled in the study area. TOD areas have smaller household sizes and workers and are less likely to drive, reducing their VKT. Residents with cars tended to drive more than those with BRT and non-motorized modes. A higher household income is linked to more automobile trips, lower BRT, and lesser non-motorized trips. The results obtained from our model demonstrate that highly dense and mixed land-use areas tend to encourage residents to use BRT and non-motorized modes more and drive less. This can ultimately transform station areas into more transit and pedestrian-friendly environments.

Our study also found the reasons for choosing the current address to live in TOD and TAD areas based on the following factors: transit, accessibility, walking, attractiveness, and safety. This study determined that almost 85% and 83% said these reasons were very important for moving in TOD and TAD areas, respectively.

Our study proposed two BRT-based TOD models for urban and suburban areas, which will help make Lahore a sustainable city in the future. Moreover, the master plans strategies were not implemented due to multiple causes, such as functional overlapping, path dependencies, bureaucratic and project–centric approach, and weak land use and building control, to mention just a few. The previous master plans failed to offer land and transport integration proposals. The Lahore transportation and urban planning system is reactive and needs to be changed with proactive planning based on TOD in recently built BRT stations. Lahore City should learn from Curitiba and Bogota's experience to integrate BRT with urban development by implementing a proactive planning approach.

Our study focuses on understanding the causes of not implementing land use and transport strategies of IMPL 2021 and the challenges and opportunities for encouraging TOD with BRT using structured interviews of professionals working in Lahore's different land use and transport planning departments. The structured interview data was analyzed using word frequency analysis in NVivo 14. Based on the interviews, the following causes of the decline in TOD elements around BRT stations and challenges were identified that stand in the way of implementing land use and transport strategies and encouraging TOD with BRT in Lahore: absence of planning and implementation framework and mechanism; absence of rules, regulations, policies, and TOD master plan; lack of institutional coordination among departments as well as with developers and individuals; weak political will and department’s priority; absence of integration among rules and regulations as well as government level such as federal, provincial, and local; lack of local expertise to prepare and implement rules, regulations, and policies to encourage TOD; insufficient professional capacity and leadership; lack of incentives; absence of a separate department to encourage TOD; lack of trust between departments and developers; absence of funding opportunities; and functional overlapping.

10.3. Recommendations

This study offers the following recommendations for urban planning/policy in Lahore: in city centers and some urban areas, there is almost little to no vacant land. In order to secure space for open space and pedestrian paths, the introduction of the incentive system where developers receive incentives such as a FAR bonus as a reward for providing open space or pedestrian paths in their development plots would be effective. In suburban and some urban areas, vacant land remains, and securing space for pedestrian paths and open space in the vacant land before development should be necessary. In the city centers and urban areas, the new development will be infill and vertical development because of the unavailability of more vacant land. To achieve higher density, high-rise redevelopment is to be necessary for a subdivided lot. In such places, it would be effective to introduce an urban redevelopment scheme that facilitate subdivided lands to be developed in an integrated manner. In the controlled area, there were large open spaces, but parts of the open space were developed. To maintain open space, encouraging infill and vertical development is also essential in the controlled area. In less-controlled areas, more development proceeded than in controlled areas. Accumulation of new development might harm the living environment in the less-controlled area. Therefore, policy guidelines should be necessary to prevent environmental deterioration due to urban development.

Moreover, BRT stations require different policy measures to enhance TOD toward sustainable travel behavior. Evidence on mode share can be utilized to design suitable facilities close to BRT stations, including employment centers and shopping markets. Moreover, our findings support that high-density, mixed-use TOD strategies, should be encouraged around BRT stations to reduce travel distance and duration and promote BRT and non-motorized use, particularly for employment and shopping centers in TAD areas. Encouraging infill and vertical development in controlled areas is crucial, and high-density mixed-use development should be carried out in less controlled TAD areas than in controlled areas. Redevelopment plans/schemes should be initiated for TOD areas to encourage high-density mixed-use development further. Overall, increasing density, land use diversity, and walkability around BRT station areas can increase the use of BRT and reduce VKT, but this depends on each station’s characteristics. Therefore, more attention is required for TAD areas than TOD areas to promote sustainable travel behavior and produce sustainable communities.

Our study offered the following recommendations for encouraging TOD with BRT in Lahore. Firstly, the preparation of local TOD plans and policies incorporating the implementation and financial framework and mechanism around BRT stations according to the characteristics of the station areas. Because some BRT stations are located in central urbanized areas, they require urban renewal and redevelopment by the amalgamation of small land parcels. In contrast, some stations pass through suburban neighborhoods, requiring highly dense mixed-use development and infrastructure improvements. It is also recommended that formulations of clear rules and regulations are essential for promoting TOD with BRT. Moreover, integrating rules, regulations, and departments is crucial for planning and implementing TOD because the land use and transport planning system is fully fragmented and in the hands of several departments, creating functional overlapping. It would be better to create a separate department for the TOD or TOD team within the existing departments because the transit system is expanding, i.e., BRT and rapid metro train system. For this purpose, more political will and priority are required. Secondly, the developers have no incentives to promote urban development or redevelopment around BRT stations and Lahore. So, it is essential to offer incentives (i.e., density bonus, FAR bonus, tax relief, an amalgamation of small land parcels, relaxation in the approval process, etc.) to the developers and individuals to attract them to develop TOD projects around BRT stations. More importantly, the government should devise incentive mechanisms for developers in rules and regulations to promote TOD with BRT. However, TOD projects require expertise and coordination between departments and developers. Developers are expected to develop TOD projects comprehensively if incentives are provided. The government's role should be just as a regulator for TOD projects. So, private sector involvement in TOD planning and implementation is recommended. Thirdly, professional capacity and leadership are insufficient for TOD projects in Lahore. So, professional ability and leadership are required with a city's vision of TOD with BRT. This vision should also be incorporated into rules, regulations, policies, and plans that encourage the integration of land use and BRT with statutory master plans that are realistic with the market.

10.4. Future Research Directions

In future studies, comparing the station area and the whole city or non-station area is necessary to understand the characteristics of the station area. This study can also be enhanced by considering more criteria and indicators and the whole route of BRT, which would offer a more thoughtful identification of TOD areas after BRT investment in Lahore.

We classified the selected BRT stations into TOD and TAD areas. This study needs to be extended by taking the entire BRT route and classifying the stations in the TOD and TAD areas to better understand the residents' travel behavior. The TOD attributes are smaller owing to the data availability, and this study could be extended by considering additional criteria. This study classified planned station areas, such as Model Town and Naseerabad, into TAD owing to their characteristics. Nevertheless, the travel behaviors of planned and unplanned areas can differ; therefore, the planned station areas need to be dealt with separately to understand the differences in travel behavior clearly. Furthermore, the number of respondents was small in this study, which impacts the overall significance of the model. Overcoming these limitations requires additional data and effort, which can be carried out in future research.

This study has the following limitations: in this study, we just conducted structured interviews with professionals working in different land use and transport planning departments in Lahore. This study can be extended by taking the perspectives of private developers and individuals for promoting TOD around BRT stations. Our sample size is not so large, so the study can be extended using a large sample of other professionals, developers, and individuals.

LIST OF PUBLICATIONS

- Muhammad Nadeem, Mihoko Matsuyuki & Shinji Tanaka (2023). Impact of bus rapid transit in shaping transit-oriented development: evidence from Lahore, Pakistan, *Journal of Asian Architecture and Building Engineering*, https://doi.org/10.1080/13467581.2023.2172341
- Muhammad Nadeem, Mihoko Matsuyuki & Shinji Tanaka (2023). Impact of Transit-oriented Development of Bus Rapid Transit Station Areas on Resident's Travel Behavior in Lahore, Pakistan, *Eastern Asia Society for Transportation Studies* (Under Review)
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- Muhammad Nadeem & Mihoko Matsuyuki (2021). A study on the Impacts of Bus Rapid Transit on Urban Development towards Transit-oriented Development: A case of Lahore, Pakistan, *The 17th Conference of International Development and Urban Planning* (19 December 2021)*, The University of Tokyo, Japan*
- Understanding the challenges and opportunities to encouraging transit-oriented development with bus rapid transit in Lahore (Ongoing)

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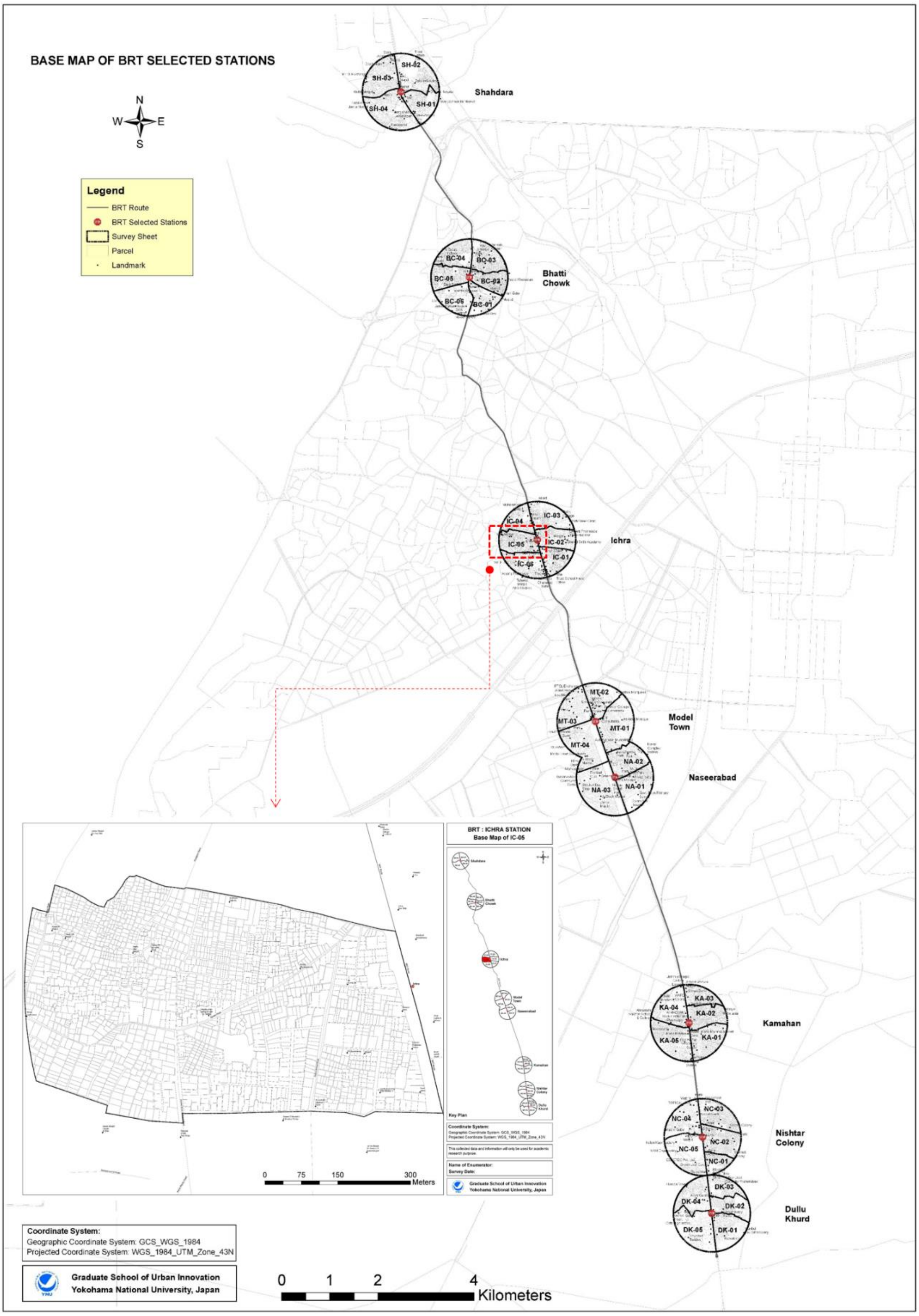
ANNEXURES

Annexure A: Land Use Survey

For land use data 2021, 38 survey sheets were prepared for eight BRT stations shown in the key map. One sheet from Ichra station is presented in this map as a sample.



Annexure B: Questionnaire for Resident's Travel Behavior around BRT Stations

Transportation and Urban Engineering Laboratory
Graduate School of Urban Innovation, Yokohama National University, Japan

Questionnaire No.: 000 Sr. No. 00000 Date: YYYY/MM/DD BRT Station: ____________
Respondent's Name: ______________________ Interviewer: ______________
Coordinates of respondent's house: Longitude / Latitude Survey Method: (☐ Interview ☐ Drop/Pick)
Address of respondent's house: ____

This questionnaire survey is being conducted to understand the travel behavior of residents in bus rapid transit (BRT) station areas. Your response will be an excellent contribution to this research. I assure you that the collected information and data declared here will remain confidential. It will be used only for academic research purposes.

Are you currently working? ☐ Yes ☐ No	Do you need to commute to work? ☐ Yes ☐ No

If both questions are marked **"Yes"** by the respondent, proceed with the questionnaire further.

Part-1: Socio-demographic characteristics

Please use ✓ for your option in each row (single choice).

Gender	☐ Male ☐ Female
Age (years)	☐ ≤18 ☐ 19 – 30 ☐ 31 – 40 ☐ 41 – 50 ☐ 51 – 60 ☐ >60
Marital status	☐ Single ☐ Married ☐ Other ________ (specify)
Education	☐ Below High School ☐ High School ☐ Higher Secondary School ☐ Bachelor ☐ Master ☐ Ph.D.
Profession	☐ Government employee ☐ Private employee ☐ Business owner ☐ Labor ☐ Others ________ (specify)
Monthly income	________ Rs. | Monthly household income ________ Rs.
House ownership	☐ Owned ☐ Rented ☐ Leased
Number of persons in your house	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ More than 10 ______ (specify)
Number of children under 12 years in house	☐ No child ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ More than 5 _____ (specify)
Number of workers (income earner)	☐ No worker ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ More than 5 _____ (specify)
Number of cars	☐ No car ☐ 1 ☐ 2 ☐ 3 ☐ >3 ______ (specify)
Number of motorcycles	☐ No motorcycle ☐ 1 ☐ 2 ☐ 3 ☐ >3 ______ (specify)
Driving license	Car: ☐ Yes ☐ No Motorcycle: ☐ Yes ☐ No
Number of bicycles	☐ No Bicycle ☐ 1 ☐ 2 ☐ 3 ☐ >3 ______ (specify)
Do you have any parking space in your house?	☐ Yes, _____ Car, ____ Motorcycle, ____ Cycle ☐ No
Do you need to pay a parking fee at residence?	☐ Yes, how much? ________Rs. ☐ No

Part-2: General travel behavior and residential choice

Please use ✓ for your option in each row (single choice).

2.1. What is the name of your nearest BRT station from home? ____________

2.2. What is the distance from your home to the nearest BRT station? _________ meters

2.3. What is your most frequent access mode to reach the BRT station from your home?

☐ Public Bus _________ time (minutes) _________ cost (Rs.)
☐ Hiace _________ time (minutes) _________ cost (Rs.)
☐ Car _________ time (minutes) _________ cost (Rs.) _________ parking fee (Rs.)
☐ Taxi _________ time (minutes) _________ cost (Rs.)
☐ Motorcycle _________ time (minutes) _________ cost (Rs.) _________ parking fee (Rs.)
☐ Auto-Rickshaw _________ time (minutes) _________ cost (Rs.)
☐ Qingqi _________ time (minutes) _________ cost (Rs.)
☐ Cycle _________ time (minutes) _________ cost (Rs.)
☐ Walk _________ time (minutes) _________ cost (Rs.)

2.4. What is the reason for choosing this travel mode?

Reasons	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Punctual					
Safe from pickpockets					
Safety from traffic accidents					
Convenient					
Economic					
Time-saving					
Accessible					
Comfort					
Environmental friendly					
I can have a seat					
I don't need to travel with people whom I don't know					
I can carry heavy luggage					
I can travel with my family					
I can drop off/pick up my children/family					
I can take a detour					

2.5. What is your average daily vehicle kilometers traveled?(Only for personal vehicle users) _____km

2.6. What is the frequency of non-commuting trips? ____________times/month

2.7. What is the frequency of using each travel mode for the non-commuting trip?

Mode	Never	Few times a year	Once a month	Once a week	Few times a week	Every weekday
BRT						
Public Bus						
Hiace						
Car						
Taxi						
Motorcycle						
Auto-Rickshaw						
Qingqi						
Cycle						
Walk						

2.8. When did you start to live in your current residence? __________ year

Questions 2.9. – 2.12.
Only those who started to live in their current residence after the BRT operation in 2013.

2.9. What was the location of your previous residence?

☐ Same as the current workplace
☐ Different from the current work, Address______________________
☐ I did not work at that time

2.10. How many cars and motorcycles were in the previous residence? ___Car, ___Motorcycle

2.11. What is your previous and current main travel mode and frequency for the following trips?

Trip purpose	Main Travel Mode*		Frequency**	
	Previous	Current	Previous	Current
Work/school				
Shopping of grocery				
Shopping mall				
Restaurant/cafe				
Banks/post office				
Theatre/Cinema				

***Travel mode:** BRT, Public Bus, Hiace, Car, Taxi, Motorcycle, Auto-Rickshaw, Qingqi, Cycle, Walk
****Frequency:** Never, few times a year, once a month, once a week, few times a week, every weekday, every day

2.12. What is reason for choosing your current residence that best corresponds with your opinion?

Statements	Not at all important	Not important	Neutral	Important	Very important
Easy access to BRT station					
Easy access to main road/street					
Easy access to CBD					
Parks and open spaces nearby					
Access to markets/shops for daily goods					
Shopping areas nearby					
Good schools and health centers nearby					
Closeness to worship places					
Closeness to workplace					
Amenities (community center, banks) available nearby					
Ease of walking to places i.e., parks, shopping, worship, school, amenities					
Good walking environment					
Clean neighborhood					
Very quiet neighborhood					
Variety and quality of housing styles					
Cost of housing					
Low cost of travelling					
Low cost of parking					
Close to family and friends					
Good street lighting					
Safe neighborhood for walking and cycling					
Low crime rate					
Low level of car traffic on neighborhood streets					
Safe for kids to play outdoors					

Part-3: Travel characteristics for commuting trips
Please use ✓ for your option in each row (single choice).

3.1. What is the location of your workplace? (write address and coordinates)
Address: ____________________________ Longitude: _____________ Latitude: _____________

3.2. How many average trips do you made for work? ___________trips/week

3.3. What is the nearest BRT station from your workplace? ___________

3.4. What is the total distance of the workplace from the nearest BRT station? ______ meters

3.5. How do you go to the workplace

Location/Segment		Mode of Transport*	Total time (minutes)	Total distance (meters)	Total fare (Rs.)
From *(Origin)*	To *(Destination)*				
Home					
	Workplace				
Total trip travel					

* BRT, Public Bus, Hiace, Car, Taxi (car, motorcycle, auto), Motorcycle, Auto-Rickshaw, Qingqi, Cycle, Walk
Very important: Please be careful asking for waiting time at the station/stop and walking as a feeder transport.

3.6. What is the reason for choosing this travel mode to go workplace?

Reasons	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Punctual					
Safe from pickpockets					
Safety from traffic accidents					
Convenient					
Economic					
Time-saving					
Accessible					
Comfort					
Environmental friendly					
I can have a seat					
I don't need to travel with people whom I don't know					
I can carry heavy luggage					
I can travel with my family					
I can drop off/pick up my children/family					
I can take a detour					

Questions 3.7 – 3.9: For personal vehicle users

3.7. Is there any parking space at your workplace? ☐ Yes ☐ No

3.8. Where do you park your vehicle at the workplace?
☐ Parking lot inside the building
☐ Parking lot on the premises
☐ Off-street parking
☐ On-street parking
☐ Other building

3.9. Do you need to pay a parking fee at the workplace? ☐ Yes, how much? ___ (Rs.) ☐ No

Part-4: Travel characteristics for daily shopping trips (grocery)
Please use ✓ for your option in each row (single choice).

4.1. What is the location of shopping place you often visit for daily necessities? (write address and coordinates)
Address: ________________________________ Longitude: _____________ Latitude: _____________

4.2. How many average trips are you made for daily shopping? ____________trips/week

4.3. What is the nearest BRT station from your shopping place? ____________

4.4. What is total distance of shopping place you often visit from nearest BRT station? ___ m

4.5. How do you go to the shopping place?

Location		Mode of Transport*	Total time (minutes)	Total distance (meters)	Total fare (Rs.)
From *(Origin)*	To *(Destination)*				
Home					
	Shopping place				
Total trip travel					

* BRT, Public Bus, Hiace, Car, Taxi (car, motorcycle, auto), Motorcycle, Auto-Rickshaw, Qingqi, Cycle, Walk
Very important: Please be careful asking for waiting time at the station/stop and walking as a feeder transport.

4.6. What is the reason for choosing this travel mode to go shopping?

Reasons	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Punctual					
Safe from pickpockets					
Safety from traffic accidents					
Convenient					
Economic					
Time-saving					
Accessible					
Comfort					
Environmental friendly					
I can have a seat					
I don't need to travel with people whom I don’t know					
I can carry heavy luggage					
I can travel with my family					
I can drop off/pick up my children/family					
I can take a detour					

Questions 4.7 – 4.9: For personal vehicle users

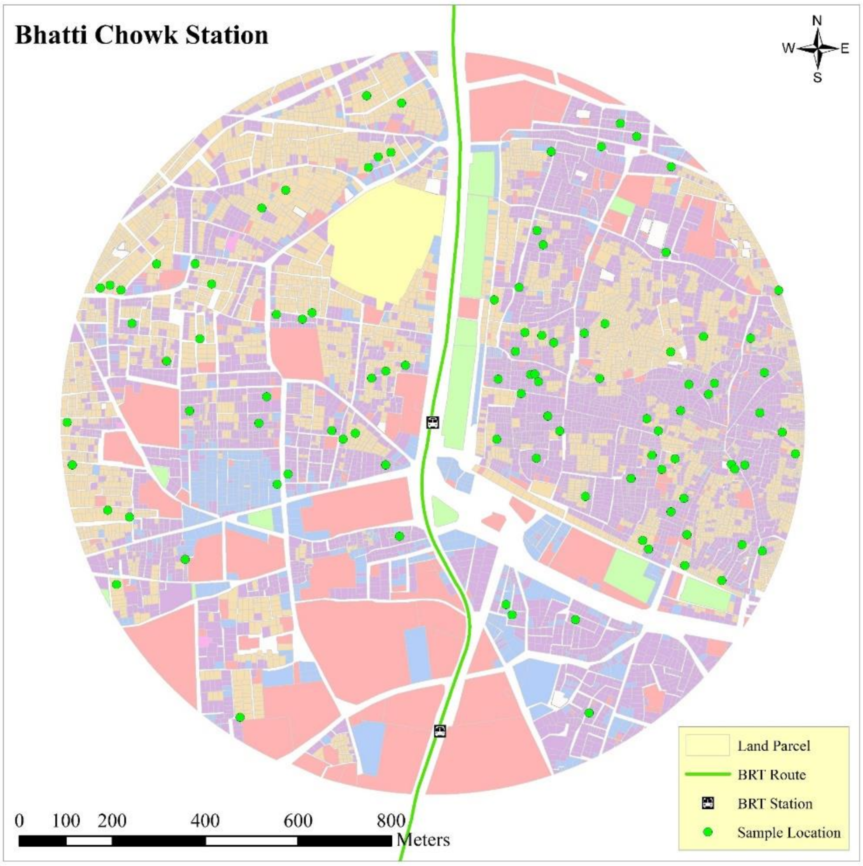
4.7. Is there any parking space in a shopping place area? ☐ Yes ☐ No

4.8. Where do you park your car/motorcycle in a shopping area?
☐ Parking lot inside the building
☐ Parking lot on the premises
☐ Off-street parking
☐ On-street parking
☐ Other building

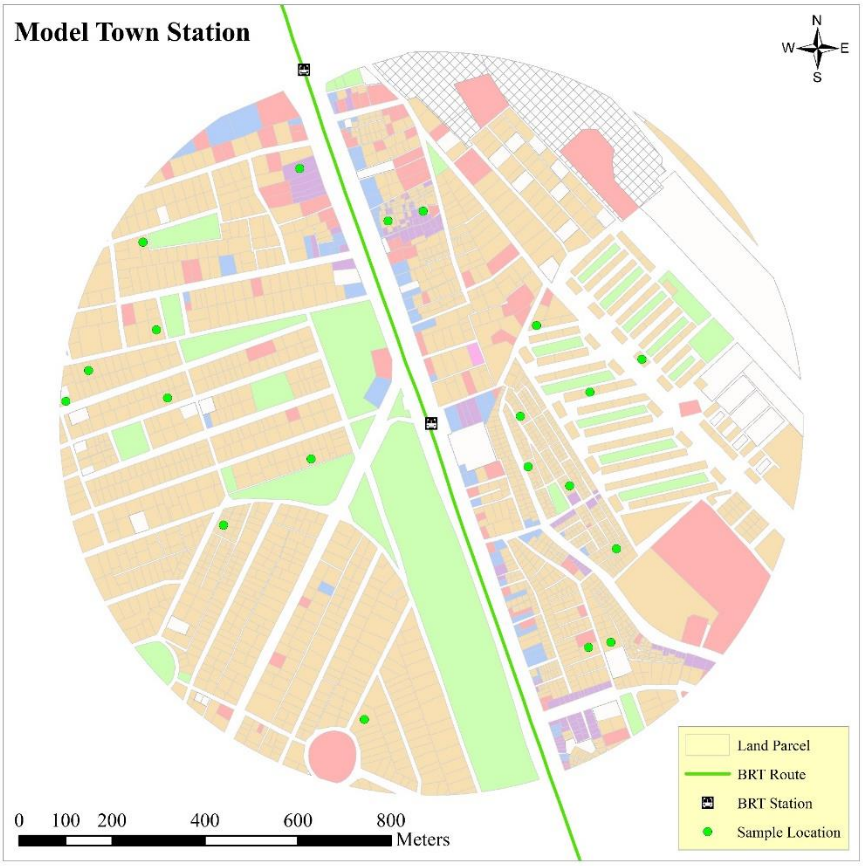
4.9. Do you need to pay a parking fee in a shopping place? ☐ Yes, how much?___ (Rs.) ☐ No

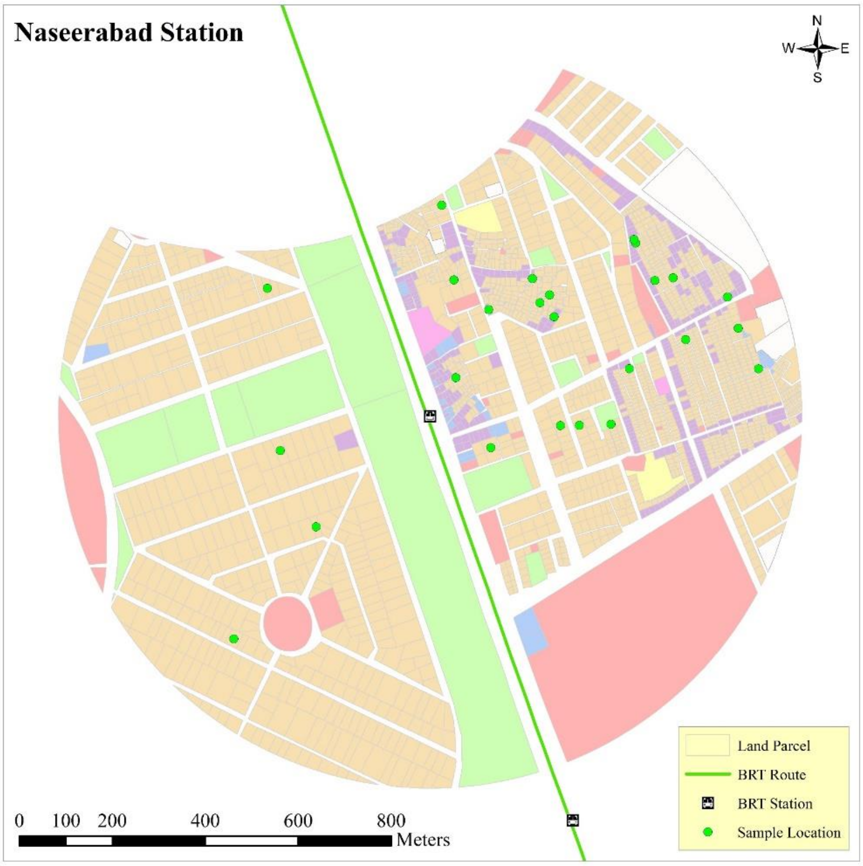
I thank you for your time and cooperation.

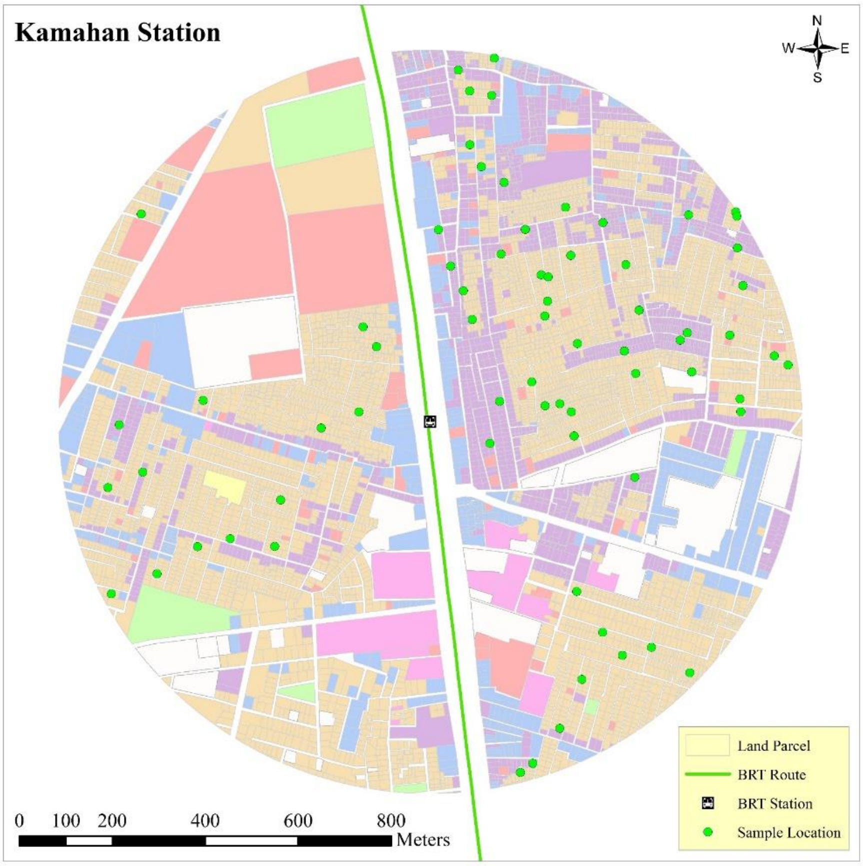
Annexure C: Sample Locations of Travel Behavior Survey

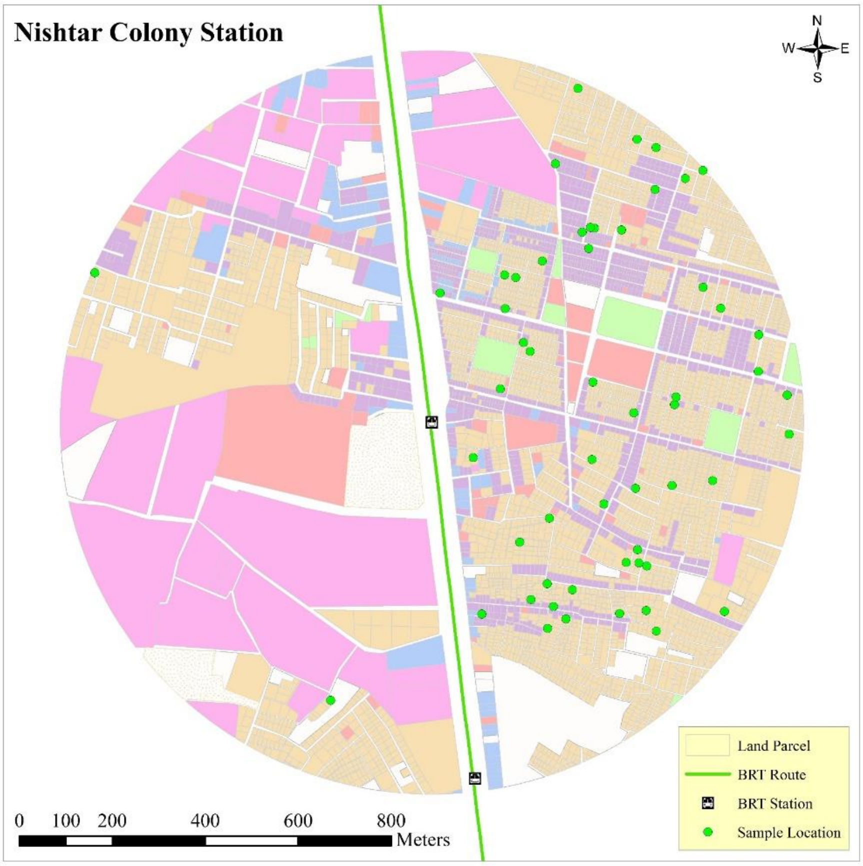


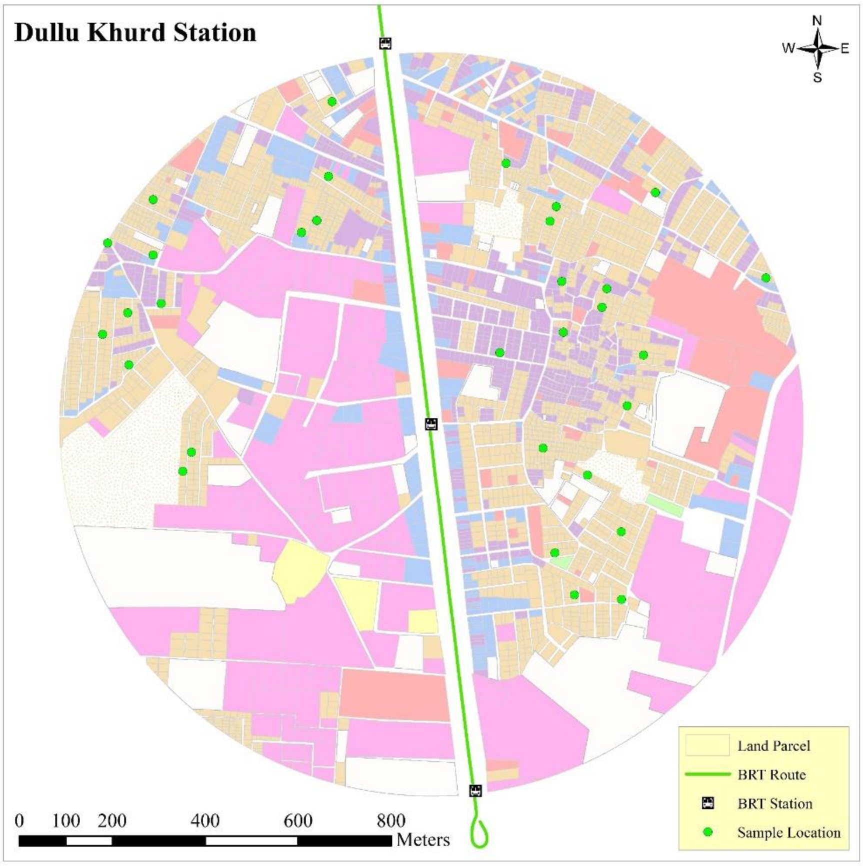

Ichra Station
N
W
E
S
0 100 200 400 600 800
Meters
Land Parcel
BRT Route
BRT Station
Sample Location


Model Town Station
N
W
E
S
0 100 200 400 600 800
Meters
Land Parcel
BRT Route
BRT Station
Sample Location


Naseerabad Station
N
W
E
S
Land Parcel
BRT Route
BRT Station
Sample Location
0 100 200 400 600 800
Meters


Kamahan Station
N
W
E
S
Land Parcel
BRT Route
BRT Station
Sample Location
0 100 200 400 600 800
Meters


Nishtar Colony Station
N
W
E
S
Land Parcel
BRT Route
BRT Station
Sample Location
0 100 200 400 600 800
Meters


Dullu Khurd Station
N
W
E
S
Land Parcel
BRT Route
BRT Station
Sample Location
0 100 200 400 600 800
Meters

Annexure D: Structured Interview Questions

Land use and Transport Integration in Lahore, Pakistan

Transportation and Urban Engineering Laboratory
Graduate School of Urban Innovation, Yokohama National University, Japan

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Urban sprawl, excessive use of private vehicles, traffic congestion, inappropriate land-use mix and densities, lack of urban spaces, and lack of pedestrian paths are among the pressing issues in Lahore. Transit-oriented Development (TOD) is an integration of land use and transport and urgent planning alternatives to address the above-mentioned issues. Moreover, Bus Rapid Transit (BRT) was initiated in 2013 in Lahore to overcome some of the aforementioned issues.

This interview is being conducted to identify the causes of not implementing land use and transport strategies in Lahore, specific to the Integrated Master Plan for Lahore (IMPL), 2021. Your response will be an excellent contribution to this research. I assure you that the collected information and data during the interview will be kept confidential and used solely for academic research purposes.

Part-1: Interviewee Information

Please use ✓ for your option in each row.

Interviewee name	________________________________
Gender	☐ Male ☐ Female
Age	__________ years
Organization name	☐ LDA ☐ LMC ☐ PMA ☐ Others _________
Designation	________________________________
Education level	☐ Bachelor ☐ Master ☐ Ph.D.
Educational background	☐ Urban Planning ☐ Architecture ☐ Real Estate ☐ Others ________
Working experience	☐ Below 5 years ☐ 5 – 10 years ☐ 11 – 15 years ☐ 16 – 20 years ☐ Above 20 years ___________ (Specify)
Have you done/engaged in any major projects/master plans that encourage sustainable development?	☐ Yes ☐ No *If **Yes,** then mention* _________________________
What's your contribution in IMPL, 2021?	☐ Preparation ☐ Implementation ☐ Others ______
Did you hear about Transit-oriented Development (TOD) concept? *TOD offers higher density, mixed-use, walkable urban development near mass transit stations, and encourages the use of public transit and walking rather than automobiles.*	☐ Yes ☐ No *If **Yes**, when* YYYY

Part-2: Integrated Master Plan for Lahore (IMPL), 2021

2.1. Causes of not implementing land use and transport strategies of IMPL, 2021 in Lahore

IMPL (2004 – 2021) was prepared by NESPAK for Lahore Development Authority and City District Government to guide the future urban development of Lahore. This plan mainly focused on urban road development and the construction of Lahore Ring Road. However, this plan did not overtly TOD as a strategic option to transform the urban structure over the plan's lifespan. Moreover, IMPL was amended in 2016. It has presented several urban development and transport strategies/proposals but unfortunately, most of them were not implemented partially or fully. However, we expected that transit (BRT) has a potential to encourage TOD in Lahore to make Lahore a sustainable city in future

Please state the causes of not implementing the following strategies/proposals of IMPL, 2021.

Sr. No.	Strategies/Proposals	Causes of not implementing strategies/ proposals of IMPL, 2021 partially or fully
1	Densification of the existing built-up areas	
2	Infill and consolidation of vacant pockets within the built-up areas	

	- *Most of the plots (75% to 80%) in the formal housing market are held vacant probably*	
3	Distribution of residential density across the city - *Periphery areas (adjacent to existing built-up areas) – 325 pph* - *South-West (formal housing scheme developed) – 175 pph* - *High density zones (closer to the centre of employment in low income areas i.e., industrial clusters) proposed near Shahdara area – 500 pph*	
4	House building incentives such as credits and tax reliefs for the lower income groups	
5	Free height zones in Central Business District (CBD) area - *Few roads where limited land pockets can be utilized for the construction of such multi-storeyed structures including hotels, offices, and institutions but plot area should not be less than 20 Kanal.*	
6	Undertaking projects for urban renewal in central area	
7	Shifting of incompatible land uses (i.e., industries) from residential areas to reduce environmental hazard	
8	Green Belt as Buffer Zone (one km wide) around industrial estate to save the environment from industrial hazards	
9	Creation of new Town Centre *(Trade Centre in Johar Town)* and Business Districts *(South of Hudiara Drain and East of Ferozepur Road in the South)* comprising commercial and service areas	
10	Establishment of satellite towns having specialized facilities to curb in-migration and reduce travel time *(one-way travel time of about 90 minutes or within a radius of 75 km)*	
11	Provision of trunk infrastructure in existing and partially developed areas for consolidation	
12	Construction of Lahore Ring Road for land consolidation	
13	Provision of facilities for pedestrians and cyclists	
14	Development of Light Rail Transit (LRT) of length 12.5 km alongwith upgrading of Heavy Rail Transit (HRT) utilizing existing rail track	
15	Improvement of public transport system and development of bus terminals	
16	Provision of off-street parking facilities and rationalization of on-street parking provision	
17	Establishment of a GIS database on population, land use, infrastructure, services for future planning decisions and coordination with other departments	
18	Development of green spaces - *100 mohalla parks, 40 neighborhood parks, 1 town park, and 1 riverside park*	
19	Preparation of strategic land use and transport plan at Metropolitan level	
20	Semi-circular and circular shape compact development	
21	Future urban growth in greenfield development in suburban areas towards South-East	

2.2. Some TOD strategies/elements are missing in IMPL, 2021

In IMPL, LRT of length 12.5 km was proposed but BRT was constructed on the same route with a length of 27 km serving 27 stations. However, most of the elements were not proposed or considered in IMPL to encourage TOD around transit stations and along route to make Lahore a sustainable city. Higher population density, higher residential density, mixed-use development, and walkability are good representatives of TOD.

Please state the reasons why the following TOD elements were not considered in IMPL, 2021.

Sr. No.	Elements	Why not considered
1	High population density	
2	High residential density	
3	High level mixed use development	
4	Incentives to encourage high density and mixed use development	
5	Pedestrian paths	
6	High level/preservation of green spaces	

2.3. Challenges and opportunities in implementations of TOD strategies in Lahore

Please give your opinion for the following statements.

1. In your opinion, what are the major challenges/obstacles to implement TOD around BRT station areas and in Lahore?
2. What do you think, how the above-mentioned challenges/obstacles can be overcome to implement TOD around BRT stations and in Lahore to make a sustainable city in the future?
3. What are the institutional obstacles in implementing TOD strategies around BRT stations and Lahore?
4. In your opinion, what types of institutional reforms are crucial to encourage the TOD to make Lahore a sustainable city in future?
5. Any suggestions/comments to encourage TOD around BRT stations and in Lahore?

Part-3: Decline in TOD elements around BRT station areas in Lahore

According to our research findings, some elements of TOD have declined around some BRT stations after the BRT operation in Lahore. Please state the reasons for declining the following elements.

Sr. No.	TOD element	Reasons of declining the TOD elements
1	Population density was not increased significantly when compared with density rate of Lahore	
2	Residential land use declined	
3	Pedestrian paths were not improved	
4	Open/green spaces declined	

Thanking you for your precious time.

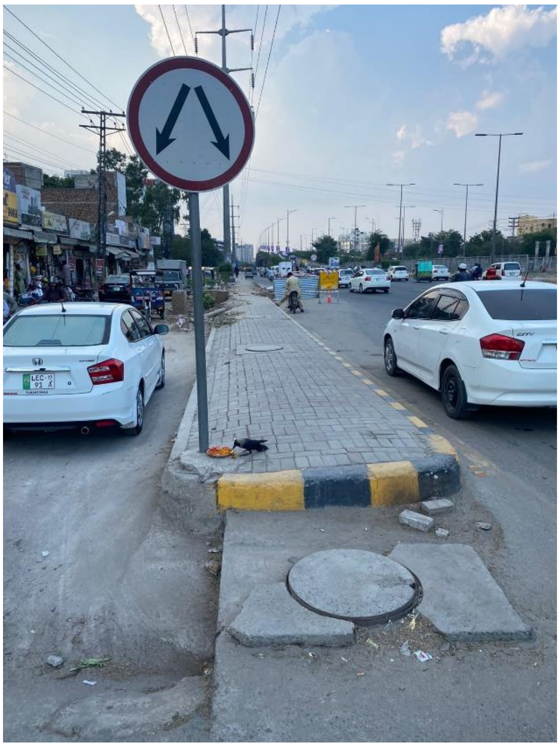
Annexure E: Development Patterns around BRT Station Areas

Shahdara Station

Bhatti Chowk Station

Ichra Station

Model Town Station



Naseerabad Station

Nishtar Colony Station

Kamahan Station

Dullu Khurd Station

Annexure F: Count and Weighted Percentage (%) of Word Frequency Analysis

Word	Length	Count	Weighted Percentage (%)
planning	8	133	2.55
coordination	12	102	1.96
framework	9	102	1.96
rules	5	67	1.28
government	10	61	1.17
developers	10	58	1.11
political	9	58	1.11
priority	8	58	1.11
mechanism	9	57	1.09
master	6	53	1.02
urban	5	53	1.02
regulations	11	51	0.98
among	5	50	0.96
transport	9	47	0.90
development	11	46	0.88
incentives	10	44	0.84
department	10	42	0.81
plans	5	39	0.75
strategies	10	39	0.75
departments	11	35	0.67
implementation	14	35	0.67
areas	5	34	0.65
funding	7	33	0.63
integration	11	31	0.59
private	7	30	0.58
density	7	27	0.52
level	5	27	0.52
clear	5	25	0.48
capacity	8	24	0.46
people	6	24	0.46
required	8	24	0.46
authorities	11	23	0.44
local	5	23	0.44
public	6	23	0.44
renewal	7	22	0.42
infrastructure	14	21	0.40
proposal	8	21	0.40

system	6	21	0.40
develop	7	20	0.38
policies	8	20	0.38
parking	7	19	0.36
proper	6	19	0.36
developed	9	18	0.35
implement	9	18	0.35
Lahore	6	18	0.35
given	5	17	0.33
missing	7	16	0.31
project	7	16	0.31
separate	8	16	0.31
overlapping	11	15	0.29
pedestrian	10	15	0.29
prepare	7	15	0.29
sector	6	15	0.29
control	7	14	0.27
means	5	14	0.27
residential	11	14	0.27
small	5	14	0.27
elements	8	13	0.25
professional	12	13	0.25
provided	8	13	0.25
rather	6	13	0.25
commercial	10	12	0.23
housing	7	12	0.23
prepared	8	12	0.23
proposed	8	12	0.23
resources	9	12	0.23
street	6	12	0.23
building	8	11	0.21
functional	10	11	0.21
issues	6	11	0.21
model	5	11	0.21
provide	7	11	0.21
strong	6	11	0.21
according	9	10	0.19
authority	9	10	0.19
institutional	13	10	0.19
institutions	12	10	0.19

promote	7	10	0.19
provincial	10	10	0.19
without	7	10	0.19
around	6	9	0.17
consultation	12	9	0.17
cycle	5	9	0.17
densification	13	9	0.17
different	9	9	0.17
expertise	9	9	0.17
implemented	11	9	0.17
issue	5	9	0.17
legal	5	9	0.17
major	5	9	0.17
opportunities	13	9	0.17
person	6	9	0.17
relief	6	9	0.17
spaces	6	9	0.17
acquisition	11	8	0.15
carry	5	8	0.15
distribution	12	8	0.15
formulated	10	8	0.15
green	5	8	0.15
important	9	8	0.15
leadership	10	8	0.15
owners	6	8	0.15
regulation	10	8	0.15
responsibilities	16	8	0.15
study	5	8	0.15
working	7	8	0.15
zones	5	8	0.15
backing	7	7	0.13
challenges	10	7	0.13
corruption	10	7	0.13
credits	7	7	0.13
defined	7	7	0.13
federal	7	7	0.13
interest	8	7	0.13
involved	8	7	0.13
moreover	8	7	0.13
program	7	7	0.13

projects	8	7	0.13
providing	9	7	0.13
roles	5	7	0.13
somehow	7	7	0.13
statue	6	7	0.13
support	7	7	0.13
zoning	6	7	0.13
concept	7	6	0.12
decline	7	6	0.12
define	6	6	0.12
design	6	6	0.12
employees	9	6	0.12
encourage	9	6	0.12
functions	9	6	0.12
generic	7	6	0.12
income	6	6	0.12
increase	8	6	0.12
minister	8	6	0.12
organized	9	6	0.12
plaza	5	6	0.12
practically	11	6	0.12
reduce	6	6	0.12
satellite	9	6	0.12
scope	5	6	0.12
specific	8	6	0.12
station	7	6	0.12
stations	8	6	0.12
strategy	8	6	0.12
sufficient	10	6	0.12
things	6	6	0.12
transit	7	6	0.12
available	9	5	0.10
basically	9	5	0.10