A FRAMEWORK FOR IMPLEMENTATION OF TRANSIT-ORIENTED DEVELOPMENT

PRASHANTH SHEKAR LOKKU

(Roll No. 714102)

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL

TELANGANA, INDIA

2021

A FRAMEWORK FOR IMPLEMENTATION OF TRANSIT-ORIENTED DEVELOPMENT

Submitted in partial fulfilment of the requirements
for the award of the degree of

DOCTOR OF PHILOSOPHY

by

PRASHANTH SHEKAR LOKKU

(Roll No. 714102)

Supervisor

Prof. C.S.R.K. Prasad

TRANSPORTATION DIVISION
DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL

TELANGANA, INDIA

JULY – 2021

NATIONAL INSTITUTE OF TECHNOLOGY-WARANGAL

CERTIFICATE

This is to certify that the thesis entitled "**A FRAMEWORK FOR IMPLEMENTATION OF TRANSIT-ORIENTED DEVELOPMENT**", being submitted by **Mr. PRASHANTH SHEKAR LOKKU**, for the award of the degree of **DOCTOR OF PHILOSOPHY** to the Faculty of Engineering and Technology of **NATIONAL INSTITUTE OF TECHNOLOGY, WARANGAL** is a record of bonafide research work carried out by him under my supervision and it has not been submitted elsewhere for award of any degree.

(Prof. C.S.R.K. Prasad)

Thesis Supervisor

Department of Civil Engineering

National Institute of Technology

Warangal-INDIA

APPROVAL SHEET

This thesis entitled **"A FRAMEWORK FOR IMPLEMENTATION OF TRANSIT-ORIENTED DEVELOPMENT"** by **Mr. PRASHANTH SHEKAR LOKKU** is approved for the degree of Doctor of Philosophy.

Examiners

____

____

____

Supervisor

____

(Prof. C.S.R.K. Prasad)

Chairman

____

(Prof. P Ratish Kumar)

Date:

DECLARATION

This is to certify that the work presented in the thesis entitled "**A Framework for Implementation of Transit-Oriented Development**", is a bonafide work done by me under the supervision of **Dr. C.S.R.K. Prasad**, Professor, Department of Civil Engineering, NIT Warangal, Telangana, India and was not submitted elsewhere for the award of any degree.

I declare that this written submission represents my ideas in my own words. I have adequately cited and referenced the original sources where others ideas or words have been included. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/date/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

(PRASHANTH SHEKAR LOKKU)

(**Roll No. 714102**)

Date: __________

ACKNOWLEDGEMENTS

I thank and express my gratitude to my supervisor **Prof. C.S.R.K. Prasad,** Department of Civil Engineering, for his guidance, support, encouragement and comprehensive critical remarks in bringing out this research work with artistry. His guidance and philosophy is not only in professional but also in personal life is helped me to enrich me so much.

I am thankful to DSC members **Dr. K.V.R. Ravi Shankar**, **Dr. S.Shankar**, Department of Civil Engineering **Prof. V.T. Soma Sekhar**, Department of Electrical Engineering for their valuable suggestions and comments during my research work.

I am perspicuous to divulge my sincere gratefulness to **Prof. P. Rathish Kumar**, Head, Department of Civil Engineering and Chairman, Doctoral Scrutiny Committee for his enlightening guidance and immense help rendered in bringing out this work.

I am also thankful to **Dr. Venkaiah Chowdary**, **Dr. Arpan Mehar**, **Dr. K.B. Raghuram**, and **Dr. Vishu** the faculty members of Transportation Division, Department of Civil Engineering, for their encouragement and support throughout my research.

I thank my dear friends **Mr. J. Jaya Krishna, Dr. K. Adithya, Dr. Harsha Praneeth**, **Dr. D. Abhigna** and **Mr. Utsav Vishal** for their moral support in completion of my research work. I also extend my thanks to all my co-research scholars.

I am thankful to **Mr. T. Suhas**, **Mr. K. Bala Krishna**, and **Ms. Y. Swetha** students of M.Tech (Transportation) for their help in data collection.

I am thankful to **Transportation cell, HMDA** and **Lea Associate of South Asia Pvt. Ltd.** for their support in collection of secondary data. I also extend my thanks to **Mr. Chandra Kumar Yadav Jala**, AEE, HMDA for his continuous support and encouragement though out the research period.

I am thankful to all staff of Civil Engineering Department and administrative staff for their support in completion of my work.

I thank my **Parents, Late. Mr. Sekhar Babu** and **Mrs. Anuraga mani** for their love and encouragement. I would like to express my deep gratitude to my BIG brother, **Mr. Pranith Raja Sekhar Lokku**, for his encouragement, support and guidance throughout my life. I am really blessed to have a brother like him. I thank my uncle **Mr. Doji Samson** for his valuable advices to make a change over in my life. I thank each and every one of my family member and relatives for their wishes.

Last but not the least; I thank my better half **Dr. Shirisha Pulukuri** for being with me for all my good and bad times with lots of love and encouragement. I thank her for standing behind me and holding me to see my rise in near future.

Finally, I thank everyone, who contributed either directly or indirectly in successful completion of this work.

PRASHANTH SHEKAR LOKKU

ABSTRACT

Urbanisation is taking place rapidly all around the world. Urban population will be two thirds of world's population by the year 2050. Because of urbanization there is noticeable impact on social, environmental and economic conditions in positive and negative manner as well. As population increases, need and dependency on private vehicles increases. So, increase in private vehicles on urban roads leads to negative impact on the environment and quality of life. Achieving sustainability in urban lives is the biggest challenge for urban transportation planners. From the past few decades, it has been proved that, Transit-Oriented Development (TOD) can be a tool for achieving sustainability as TOD will be addressing the sustainability aspects like socio, economic and environmental.

TOD is a well-known concept for more than five decades; however research is still going on and has seen resurgence in recent years. Developing countries are trying to establish their own policy, design and implementation strategy for TOD. Hence, the research work is mainly focused on developing a framework for Implementation of TOD in developing countries. By looking at the ground realities and understanding of existing situation, an attempt is made to know, how TOD can be implemented and what are the possible ways to incorporate TOD concept into current urban scenario? To address these queries, in this research a frame work for implementation of TOD is proposed. The proposed framework consists of several steps in sequence as follows:

To carry out the analysis and application of the framework of the present study Hyderabad Metropolitan Area (HMA) is selected. Based on the population and employment densities across the study area, it is divided into urban and sub-urban area to have more sensible approach. First phase is identification of feasible TOD locations: In this step, Spatial Multi Criteria Analysis (SMCA) is adopted to identify the most important/feasible TOD locations for urban area (within GHMC). SMCA process involves four layers of data viz., transit network, traffic flow characteristics of road, bus network and land-use details. As a result of this analysis, a total of 34 urban TODs are identified. In a similar way, analysis is carried out for sub-urban area (rest of HMA) and a total of 35 sub-urban TODs are identified. The 34 urban TODs are further processed to typology in next step. Also, an attempt is made to rank/prioritise all the TODs present in urban area by using Analytical Hierarchy Process (AHP). This will help the authorities to make decisions in stage wise implementation process.

Further, TOD typology is performed at two different levels, one is at city level and other is at sub-area level, for better understanding of exiting built-environment conditions. A city-level typology is performed by considering 34 urban feasible TODs by using four criteria's namely urban morphology, transportation system, built environment, and land use. As a result of this analysis, 23 types of TODs (or urban forms) are categorised. Further, based on this data a TOD priority strategy is drawn to ease the decision making process of the authorities. Also, an attempt is made to derive sub-area level TOD typology for Gachibowli-Hitech city Area (GHA). To perform this analysis, parameters considered are Mix land use Index, Plot ratio, Proportion of Transport Area, Development Mix Index, and Intersection Density. K-Means clustering technique is used to categorise identified 20 TODs in GHA and as a result of it five clusters (namely activity centre, balanced, commercial, mixed use, residential neighbourhood TODs) are formed. Design proposals and implementation strategies are suggested based on typology derived. The design parameters such as plot ratio, development mix, land use mix index, affordable housing, and proportion of transport area, NMT facilities, and open space preservation are considered to strengthen the TOD area. Subsequently, a schematic generalized TOD model is developed to address the identified challenges (viz., local markets, parking, traffic circulation etc.) for Indian dense cities context.

In final stage, TOD Index is measured for GHA to evaluate the design proposals. For calculating the TOD Index, parameters considered are transit facility capacity, density, economic development, land use diversity and street design. For these parameters, weightages are assigned based on their role in making successful TOD. Calculating the TOD Index before and after proposals would give the exact improvement happening based on given proposals. As a result of it, an average of 22% increase in TOD Index is observed based on before and after design proposals. And also, an attempt is made to know the impact of TOD via, property value assessment through percentage change in residential property value.

Thus the proposed framework implemented on Hyderabad Metropolitan area and the results obtained are satisfactory. So, the research methodology can be applied to any dense cities in developing countries.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
AOT	Auto-Oriented Transportation
BART	Bay Area Rapid Transit
CTS	Comprehensive Transportation Study
DOT	Development-Oriented Transportation
FAR	Floor Area Ratio
GDP	Gross Domestic Product
GHA	Gachibowli Hi-tech city Area
GHMC	Greater Municipal Corporation of Hyderabad
GIS	Geographic Information System
HMA	Hyderabad Metropolitan Area
HMDA	Hyderabad Metropolitan Development Authority
IPT	Intermediate Public Transport
IRR	Inner Ring Road
LRT	Light Rail Transit
MCH	Municipal Corporation of Hyderabad
MMTS	Multi Modal Transport System
MRTS	Mass Rapid Transit System
NMT	Non-Motorized Transport
NUTP	National Urban Transport Policy
ORR	Outer Ring Road
ROW	Right of Way
SMCA	Spatial Multiple Criteria Analysis
TCRP	Transit Cooperative Research Program
TOD	Transit-Oriented Development
UK	United Kingdom
UN	United Nations
URDPFI	Urban and Regional Development Plans Formulation and Implementation
US	United States

Chapter 1

Introduction

1.1 General

Urbanization is taking place very rapidly across the globe. According to the United Nations (2019), more than half of the world's population is in urban areas. The report also says that, by 2050, two-thirds of the world's population will be urban. More than 34% of people live in urban areas in India and are expected to increase to 68 % by 2050. Whereas India's percentage of urban population share is doubled from 1950 to 2018 (17% to 34%), it is expected to reach 600 million by 2030(UN, 2019). Developing countries like India have to bear this situation to allow economic growth as urban areas contribute 65% of the country's Gross Domestic Product (GDP). Also, their contribution is expected to increase to 75% of the GPD in the next 15 years. Hence, urbanization is inevitable. Also, hasty economic development leads to urban sprawl, inefficient infrastructure utilization, and traffic congestion, which affect the quality of life in urban areas. In terms of urban planning, it can be said that Development-Oriented Transportation (DOT) will be taking place in such situations. The DOT has noticeable impacts on social, environmental, and economic conditions positively and negatively as well.

On the other hand, as the population increases, the need, and dependency on private vehicles increases. An increase in private vehicles on urban roads leads to traffic congestions, travel delays, increased air pollution emissions, road crashes, etc. It also affects the urban planning aspects such as irregular urban settlements, formation of local markets, lack of parking facilities, roadside hawkers, and the behavior of road users. Therefore, it can be said that the negative impact on the environment and quality of life is present over here. To address these challenges, the first idea is to control the private vehicle on the roads and provide an alternative travel mode, Mass Rapid Transit (MRT). Further, the opportunity for its maximum usage through first and last-mile connectivity is created. The thought behind this is the integration of land use and transit to maintain sustainable measures and a healthy environment (Bertolini et al., 2005).

Achieving sustainability in urban lives is the biggest challenge for urban planners or transportation engineers (Cervero, 1995). In this context, exploring TOD (Transit-Oriented Development) seems to be an essential attempt to address the issues mentioned above related to urbanization.

1.2 TOD Concept

TOD is a well-known concept for more than five decades; as it is a multifaceted objective, achieving sustainability in urban lives is the most prominent one. Also, research on the TOD implementation plan is still going on and has seen a resurgence in recent years. TOD is an urban planning concept which integrates land use and transportation. Calthorpe is the first person to contribute to the design of TOD and became a fixture of modern planning (Calthorpe,1993). He published a book named "The Next American Metropolis," major work responsible for reintroducing the concepts in planning and development. According to him, TOD is generally defined as "a mixed-use community that encourages people to live near transit services and to decrease their dependence on driving." In the same era, considerable research was done by Cervero and Kockelman (1997) with the core objectives, like reduction in motorized trips; reduction the trip length of personal vehicles; and increase of Non-Motorized Transport (NMT) trips. Many researchers worked and mentioned advantages such as reduction in travel expenses, improvement in the quality of life via less pollution emission, healthy environment for walking, and non-motorized transport (NMT) facilities nearby station (TCRP,2002). Also, much research occurred on TOD application, implementation, publication of planning manuals, and toolkits (Salat and Ollivier, 2017; Suzuki et al., 2013; TCRP,2004,2008).

Typically, TOD is a mixed-use of land within a 500 m radius from the transit station and offers commercial, residential, civic, and entertainment activities at one place with a high density of built environment and a pleasant healthier atmosphere. The strategy also encourages the mixed uses of land and NMT facility-oriented design to increase the use of public transportation (NTOD Policy, 2014). Studies also revealed the importance of the role of TOD in constructing such as rearrangement of urban forms effectively, recapture the public transport share, and improving the quality of urban lives (Hasibuana et al., 2014). The advantages mentioned about TOD are generating economy, inducing the people towards public transportation, establishing more liveable communities, and encouraging NMT in creating a quality living environment (Bernick and Cervero, 1997; Cervero et al., 2002).

1.3 Historical Phases: Towards TOD

Land use and transportation are an integral part of development. Over the centuries, how these two elements were coping with each other, and the impact of urban planning concepts are discussed below. According to the literature review, it can be said that three significant eras are recognized according to the planning and development concerns as follows (Belzer and Aulter, 2002; Li and Lai, 2009):

1) Development Oriented Transportation (DOT)
2) Auto-Oriented Development (AOT)
3) Transit-Oriented Development (TOD)

1.3.1 Development Oriented Transportation (DOT)

From the mid of 18th century to the early 19th century, private developers built rail transit to serve the urban settlements. Eastern and mid-western cities followed DOT between the years 1850 to 1920. After that, the usage transit serves ripped off and abandoned because of the effect of World War II. Hence, travel mode choice further depended on an automobile, which is the stepping stone for AOT.

1.3.2 Auto-Oriented Development (AOT)

After World War II, many cities have lost their transportation infrastructure for the next thirty years, especially rail transit, due to which dependency on the automobile increased, which led to AOT. Moreover, the nations have chosen the automobile sector, which is the one that can enhance their economy too. However, this did not last long as conditions became worse on the roads due to congestion within a few decades. Hence, again the transit system came into the picture to relieve congestions on roads just by considering land use and not by any other means. Therefore, a rethinking of linking land use with transit leads to TOD.

1.3.3 Transit-Oriented Development (TOD)

Since the 1960s, many research reports have stated the transit system integration with land development and new urban designs. For example, transit-supportive development, transit-friendly design, transit villages, transit-adjacent development, etc., are few urban and transport planning concepts. After the 1990s, TOD is well defined and has goals like a reorientation of urban sprawl, relieving congestion on roads, improving air quality in cities, offering affordable housing, refining the economy, encouraging people to use transit, etc.

1.4 TOD in the Indian context

As urbanization is taking place rapidly in India, Indian cities have already reached choked conditions on roads with worse volume-capacity ratios. To ease this condition, the introduction of MRT is the first and foremost solution for government bodies. Subsequently, authorities are working for the past two decades rigorously and succeeded in the direction of the implementation of MRT. At present, 20 cities in India are running MRT successfully, and another ten cities are on the way to reach it (**Table 1.1**). Except for Kolkata and Delhi, all other cities have established metro in the present decade (i.e., 2011 -2020) only, which shows the increase in interest in public transportation from the Government of India. Subsequently, interest is expanded toward integrating surrounded land with the transit system to ensure its financial viability via inducing the people toward transit. With this positive sign, planning many transit projects to encourage people to use public transportation instead of private vehicles leads to the planning of TOD for cities in India.

Table 1.1: Transit project in India (2016)

Status	BRTS	Metro Rail	MonoRail	LRT
Operational	12	13	01	-
Under Construction	07	07	-	
Under Planning/Expansion	09	09	04	01
Under Proposal	01	09	14	05

Source: www.urbantransportnews.com

The authorities are looking for solutions to handle the urban sprawl and transportation-related issues by providing public transport infrastructure. With the Ministry of Urban Development (MoUD) taking a bold initiative, metropolitan and class I cities are looking forward to finding short-term solutions to traffic problems and envisioning a city's long-term traffic and transportation needs in the form of Comprehensive Mobility Plans. The MoUD has formulated the National Urban Transport Policy (NUTP) to describe objectives, policies, and tool kits to ensure sustainability. Accordingly, NUTP (2014) and URDPFI (2015) have made an appreciable attempt on the urban planning approach by stressing the TOD concept. According to NUTP (2014), people's mobility is the primary concern rather than vehicular mobility. URDPFI (2015) emphasized the compact city concept to ensure reduction in vehicular traffic and high population density near mass rapid transit stations, which meets the notion of TOD. MoUD formulated National Transit Oriented Development Policy in the Indian context to address nation-level issues like lack of affordable housing (Noland et al., 2017), value capture financing, NMT, parking, etc. (NTOD, 2017).

As most cities in developing countries are unplanned, reflecting the irregular pattern of urban forms, evaluation of urban morphology is complex. Researchers have mentioned 3D laws for TOD – Density, Diversity, and Design (Cervero,2002). In the Indian context, the existence of Density and Diversity are present by nature up to a certain level where design elements are lacking. There is a need for the best suitable and optimal plans for developing countries to make the city a sustainable city. TOD planning and implementation issues are considerably high in developing countries due to the high cost of initial investment, risk at long-term projects, institutional coordination, etc. (Tan et al., 2014; Guthrie and Fan, 2016). Therefore, developing countries should have optimum plans to implement it. In India, efforts have been made for more than a decade on TOD planning and implementation strategy.

1.5 TOD Planning Issues

It is obvious to adopt the TOD concept in many developing nations like India as it gained worldwide popularity, but suitability or transferability will be a significant concern. According to the previous studies, the definition of TOD or TOD models that are developed may not impose directly because of diverse conditions in the nation. In recent years, many studies explained the implementation process of TOD for developing countries by understanding their ground realities and adaptability of TOD to nations to simplify planning for authorities. Also, having the policy or implementation strategy at a national level is encouraged for successful TOD (Ibraeva et al., 2020). Also, TOD planning is explained in two distinct ways: one is planning policy, and the other is a planning tool. Planning policy talks about policy transferability, opportunities of stakeholders, implementation issues, and value capture mechanism.

In contrast, planning tools focus on the decision-making process in the implementation process, like finalizing feasible TOD locations or ranking of alternatives by Multi-Criteria Decision Analysis (MCDA) and multi-objective optimization. MCDA tool is used for TOD planning to assess the suitability of land use by applying the Analytic Hierarchy Process (AHP) (Banai, 1998). TOD typology is an integral part of the planning process, which plays a vital role in evaluating existing transit stations and detecting common issues on a metropolitan scale. Consequently, the typology will be supporting the identification of general development potentials and necessary future adoptions for the whole class or within classes.

Comprehensively, planning-related issues are listed, which are common in developing countries that are necessary to be addressed before the planning process. Various implementation issues have been discussed as follows:

- The restructuring of the existing patterns around transit stations and making a successful TOD is a long and tedious process taking several decades.
- Institutional setup is required for central as well as state government for successful TOD projects.
- Uncertain Market Viability: Private investors often look for a successful example of TOD projects for financial viability.
- Fragmented Land Parcels: it is challenging to gather small and disjointed land parcels for authorities to develop TOD.
- Existing Land Use Patterns: The surrounding land use plays a significant role in an attractive and safe TOD project.
- Neighborhood Opposition: Unwillingness of the neighborhood people for new developments.
- Street Design: Availability of Right of Way (RoW) is the primary concern in cities, and in such cases, land acquisition will be a significant constraint.

1.6 Need for the Present Study

Urban planning concepts like TOD cannot be implemented directly from developed countries to developing countries. A thorough understanding of planning issues as discussed previously in need of the study has been established and proposed a framework to minimize the TOD planning-related issues. Therefore, it is necessary to understand various influencing factors such as demographical features, traffic conjunction level, transportation network, land use, environmental, social, economic, political, institutional issues. Hence, the TOD planning and implementation process's complexity should have a proper framework with a planning mechanism and decision-making tool. Also, for developing countries, economic viability will play a crucial role, so it must have optimal design plans. Hence, identifying the most appropriate transit stations that can convert them as TOD is a vigorous stage in the planning process. Besides, TOD typology is used to figure out the common set of problems by revealing clusters in a city, where these results can be used in the planning process. Hence, the present study aimed to establish a framework for the implementation of TOD.

1.7 Research Objectives of the Study

The present research work is proposed with the following objectives:

1. To develop a framework for identifying feasible TODs in the inner-city and the outer part of the city.
2. To develop a TOD typology at the city level and sub-area level based on the existing scenario.
3. To formulate the design and implementation strategies for upcoming TODs based on derived typology.
4. To measure the TOD index for the evaluation of proposed design strategies.

1.8 Organisation of the Report

The present study on "A Framework for Implementation of TOD" is presented in this report by segregating it into eight chapters. A brief about each chapter is mention below:

Chapter 1: Overview of TOD concept, historical planning phases, TOD planning issues, TOD typology are presented in this chapter.

Chapter 2: This chapter presents a literature review to support the present study's needs and support the research methodology. From the literature review, research gaps are identified.

Chapter 3: In this chapter, Research Methodology is presented with a neat flow chart, explaining various steps.

Chapter 4: The study area (HMA) and subarea (GHA) are explained in detail, and data collected for analyzing the problem statement is presented in this chapter.

Chapter 5: In this chapter, the Analysis and Results of the research work are presented. The stages involved, i.e., identification of feasible TODs, TOD typology, are also discussed.

Chapter 6: Design proposals and implementation strategies are furnished in this chapter. Also, a generalized TOD model is presented for the Indian context with a schematic approach.

Chapter 7: Complying the TOD index before and after the design proposals to perform the evaluation process is explained in this chapter.

Chapter 8: Finally, a summary and conclusions are presented based on the study results.

Chapter 2

Literature Review

2.1 General

This chapter reviewed past studies and categorized them based on the nature of the work. Firstly, briefing about TOD concepts, definitions, types, benefits, components, etc., are explained. Further, the TOD planning approach is discussed, along with implementation strategies. Studies regarding typology have been mentioned and discussed in detail here. The discussion about the planning approach process will help in adopting concepts like TOD from developed countries to developing countries. Consequently, a literature survey has been carried out and discussed for a clear understanding of planning approaches. Literature review regarding measuring TOD or TOD Index, the impact assessment of TODs is considered for witnessing TOD's success stories and explained in brief about their past studies.

2.1 TOD conceptual view

Around the globe, everyone is looking for sustainable development as an important goal in urban areas. As transportation is playing a pivotal role in cities' activity, numerous efforts have been made to use sustainable transportation. The first row is occupied by public transit service, which is not successful for some reason. In this context, exploring TOD became essential as it integrates transit and land use to make the project successful in building a healthy environment and pulling the crowd towards transit. The fundamental idea of TOD is abstracted in the late 1980 s, considering this as a new trend in urban planning. The literature also states that TOD is inspired by traditional concepts like the Garden City and the Linear City, and TOD targets to shape the settlements around transit stations accordingly. Easing access to transit stations, densification of station areas, and diversification of the land-use composition of these areas seem to be critical elements of implementing a successful TOD project. However, TOD projects worldwide maintain socio-economic balance and make a healthy and environment-friendly atmosphere of core urban areas around the transit stations.

The TOD concept by Peter Calthorpe (1993) was first introduced in his book called "The Next American Metropolis." According to him, the concept of urban planning is for a better environment for pedestrians and transit and not to neglect the private vehicle but to balance it. He put efforts to define TOD as "a mixed-use community that encourages people to live near transit services and to decrease their dependence on driving." Land use covers residential, retail, office, open space, and public uses within the TOD area with a walking atmosphere. Main commercial activities are planned very close to the transit station, and it is said to be a primary area. The residential neighborhood (secondary area) is proposed in the remaining area up to 1.6 km by dropping the densities from the primary area.

Additionally, in the secondary area, low-density housing, huge park areas, schools, and civic function for the local community are placed. The road network design is taken care of by providing direct access to the core, mainly by bicycle, and provide park-and-ride lots. Likewise, the initial version of the concepts focused mainly on neighborhood organization; then, afterward, the importance of TOD is increased to a larger scale via regional TOD along with the public transportation planning for future generations.

Change of lifestyle in urban areas demands the need for trendy urban planning over the decades. Likewise, the objective of TOD is also streamlined, and sustainable development (in terms of socio, economic, and environmental) is explored. Over the decades, the TOD applications and strategies have been changing to meet the sustainability measures. In the beginning, the TOD technique is introduced to reduce the travel demand on the road network and also improved life quality. In some cases, similar models are implemented to develop economically backward areas like lying on the rail track and inviting the investors to spend their money over, thereby giving tax exemptions (Jacobson et al., 2008). Also, a few researchers stated that the TOD concept adopted to allocate the maximum number of people to stay and work within a walkable distance from a transit station, which affects their travel characteristics such as travel cost, trip length, safety, comfort, etc. (Ewing and Cervero, 2001).

2.2.1 Definition of TOD

Around the world, various authors have defined TOD in different terminologies. Salvesen (1996) defined in his study as "Development within a specified geographical area around a transit station with a variety of land uses and a multiplicity of landowners," where the concern is about socio as well as economic aspects. Bernick and Cervero (1997) have concentrated more on the economic and environmental issues for their proposed research by defining the TOD as "A compact, mixed-use community, centered around a transit station, by design, invites residents, workers, and shoppers to drive their cars less and ride mass transit more." Consequently, at the early stages, few researchers defined according to their objective of study about TOD as mentioned in Table 2.1 (Li and Lai, 2009).

Table 2.1: TOD Definitions

S.No	Author	Year of Publication	Definition
1	Boarnet and Crane	1998	The practice of developing or intensifying residential land use near rail stations.
2	Boarnet and Compin	1999	TOD is consistent with the mixed-use, pedestrian-friendly character.
3	Maryland Department of Transportation	2000	A relatively higher density is a mixture of residential, employment, shopping, and civic uses and types located within an easy walk of a bus or rail transit center.
4	Bae	2002	A means of reducing automobile dependence, promoting more compact residential development, and fostering mixed land use.
5	Belzer and Aulter	2002	TOD focuses on desired functional outcomes. TOD's three primary outcomes or goals: location efficiency, choice, and value capture/financial return.
6	California Department of Transportation	2002	Higher density development, located within an easy walk of a major transit stop, with a mix of residential, employment, and shopping opportunities without excluding the automobile.
7	Still	2002	A mixed-use community that encourages people to live near transit services and to decrease their dependence on driving.
8	Cervero et al.	2004	TOD is a tool for promoting smart growth, leveraging economic development, and catering to shifting housing market demands and lifestyle preferences.
9	Lund et al.	2004	The design and mixed-use features of TOD may reduce both work and non-work automobile trips.

Source: Li and Lai, 2009

Comprehensively, the concept of TOD may be defined as "careful coordination of urban structure around the public transport network" (Hickman and Hall, 2008). According to Thomas and Bertolini, "TOD can be described as land-use and public transportation planning that makes cycling, walking and transit use convenient and desirable, and that maximizes the efficiency of existing public transit services by focusing development around public stations, stops, and exchanges" (Thomas and Bertolini, 2017). Also, the regional TOD importance is increased. It is described as "an approach to station area projects which reaches further than single-locations, and aims at the re-centering of entire urban regions around transport by rail and away from the car"

(Bertolini et al. 2012). According to Ewing and Cervero (2001), without considering the regional level transport network, the concept of TOD would be incomplete.

Bay Area Rapid Transit (BART) TOD Guidelines (2003) adopted a "No one-size-fits-all" formula for development around a BART station. Access hierarchy at the station is pedestrian followed by Transit and Shuttles, Bicycles, Carpools, and last Single-Occupant Automobiles. TOD cannot assure freeway congestion relief for a region. However, it can allow people to live near one station, working near another, and shop at the same or nearer without using a car. The viability of a regional TOD network depends upon the extensiveness and convenience of the transit services that link it together. Suggested targets for minimum residential densities in the station area are 80-100 residents per acre for individual projects and an overall station area of 20 residents per gross acre. The proposed employment densities are of a minimum of 10 jobs per gross area.

2.2.2 Advantages of TOD

As mentioned, TOD is a tool for achieving sustainable development in urban lives. Usually, sustainable development is expressed in three significant aspects like social, economic, and environmental. Until recent times, most economists assumed that increased mobility provides net economic benefits. However, new research states that increased motor vehicle travel has negative economic impacts beyond an optimal level as the productivity of increased travel is declining. This suggests that sustainability planning need not consider adjustments between economic, social, and environmental objectives always, instead find strategies that help achieve all the purposes in the long run by improving the efficiency of the transportation system (Todd & David, 2006). The best way to address the issues is to integrate land use and transportation system. **Table 2.2** shows impacts on urban lives concerning sustainable elements.

Table 2.2: Impacts on Urban Lives Along with Sustainability Criteria

Economic	Social	Environmental
Traffic Congestion	Inequity of impacts	Air and water pollution
Mobility barriers	Mobility disadvantaged	Habitat loss
Accident damages	Human health impacts	Hydrologic impacts
Facility costs	Community interaction	Depletion of non-renewable resources
Consumer costs	Community liveability	
Depletion of non-renewable resources	Aesthetics	

Source: Todd & David, 2006

On the other hand, the integration of land use and transportation system at the transit node is well known as TOD. Creating a healthy environment for residential and commercial land uses around a transit station will encourage people to use transit facilities more and cars less. The primary goals of the TOD are to increase the ridership of transit and decrease the pollution level emitted by automobiles. Traffic congestion levels are reduced, where TOD is implemented (Ewing et al., 2001). Air quality is also increased when decreasing the dependency on private modes. TOD projects comprise stakeholders on a broader range than other development projects, as transit agencies and government funding sources are involved. Not only that, TOD does not focus only on the improvement of mixed land-use planning and transportation infrastructure but also provides many benefits to the residents. For a successful TOD, many factors must be considered in the planning and implementation process. The advantage of potential TOD focusing on future benefits are as follows:

- Increases accessibility and mobility.
- Reduces the dependency on the automobile.
- Integration of land uses and transportation facilities.
- Maximizing the utilization of land adjacent to transit stations.
- Generating the revenue sources for transit agencies (through adjacent development or property sales).
- Decrease in traffic congestion level.
- Improvement in air quality.
- Increases the value of government-owned land assets.
- Economic development through station-area redevelopment/revitalization and stimulation of new development activity.
- Creation of interesting and functional community focal points or gathering places.

The non-transportation related advantages are:

- Better housing choices.
- Improved quality of life.
- Generate development openings.
- The flexibility of expansion from more congested regions to less congested regions.
- Decreases sprawl by increasing the FSI

2.2.3 Components of TOD

According to the TOD definition, it can be said that the major components are density, diversity, and design. It is also well known as 3-D law. The presence of these three components along the transit corridor will enhance sustainable development in the direction of intelligent growth.

Density

Providing a facility with an intense manner to live and work within the TOD area will lead to higher density. Usually, density is noted in terms of population density and employment density. The ridership will be improved, and hence the economic viability will be fulfilled.

Diversity

Denser developments promote smarter land use that tends to be more transit-supportive in a community. Transit-supportive land uses also include mixed-use developments, often with housing or offices above retail areas, which leads to increased pedestrian and cycling traffic and, in turn, creates vibrant street life. So, it is evident that there will be a reduction in automobile usage.

Design

More people intend to walk around the transit stations with an increase in density and land-use diversity. So, the design of streets in the TOD area becomes one of the crucial components. TOD focuses on pedestrian-friendly street design. The streets are narrower, lined with trees and lights, wide sidewalks, well-marked crosswalks, buildings entrance faces the sidewalk, parking lots are reduced, and on-street parallel parking is provided. The mix of residential and commercial uses provides a diverse environment for walking.

2.3 TOD Planning Approach

Over the decades, the objective and planning of TOD have been changing according to the needs of urban lives concerning transportation and sustainability measures. Primarily TOD concept is introduced to decrease private vehicle dependency and improve the quality of the urban environment. Also, in a few cases, similar concepts like TOD were used to develop economically backward areas (Jacobson et al., 2008). Few researchers worked to allocate a maximum number of people to stay and work within a walkable distance from a transit station, which affects their travel characteristics such as travel cost, trip length, safety, comfort, etc. (Ewing and Cervero, 2001). Planning of TOD in developed countries is successful, like the US, Australia, UK, etc. However, adopting planning concepts to developing countries is difficult as they are different in urban form, transportation system, narrow and congested roads, economic viability, political issues, etc.

In particular, TOD planning and implementation issues are considerably high in developing countries due to the high cost of initial investment, risk at long-term projects, institutional coordination, etc. (Tan et al., 2014; Guthrie and Fan, 2016). Few researchers have revealed the advantages of TOD (Galelo et al., 2014, Lin et al., 2006, Nahlik et al., 2014), which helps bring up the concept to developing countries. Consequently, developing countries have started exploring the TOD concepts and suitability of TOD from the existing studies of developed countries. Researchers have found the suitability of existing developed countries' TOD models to Chinese cities, where it cannot be simply transferred and ultimately developed TOD designs and procedures appropriate for China (Li et al., 2009). The study also mentioned the requirements for successful implementation of TOD in China based on past experience. The requirements include the economic conditions to support TOD, comprehensive plan preparation before development, land availability for development, the vast capacity of the public transportation system, and integrated planning among different transportation systems.

Given cities in China, Zou et al. (2014) proposed planning principles of TOD in the aspects of rational size of TOD, land-use intensity, land use structure, and road system. Also, the concept, background, and history of TOD, classification, and function of different TOD communities are discussed. Zhao (2008) presented the planning of TOD for sustainable Chinese cities. TOD aspects are analyzed at different levels (macro, meso, and micro) through qualitative and quantitative descriptions. Fard (2013). provided a quantitative measure of TOD levels based on existing situations, facilitating prioritization of development interventions. Serge and Gerald (2017) mentioned transforming the urban space through TOD. The main focus of the study is to derive the planning and strategies of TOD at the city level, network level, and local level.

In the Transit Cooperative Research Program (TCRP) report (2004), experiences, challenges, and prospects of TOD in the United States (US) are given. This report discusses the institutional setup for TOD practice, implementation tools, financial prospects, barriers, and benefits, along with 10 case studies of US cities. The report concluded that political and institutional factors play a crucial role in the decision-making process and mentioned various benefits and impacts, financial consideration, and design challenges for review purposes. Similarly, Dittmar et al. (2004) made considerable efforts to explore the critical challenges in implementing TOD for future generations. It is suggested that learning the lessons by examining the past case studies or initial projects of TOD helps to set the guidelines for future TOD projects. Likewise, the book is also helpful for planners, developers, community groups, transit agency staff, and finance professionals in urban and regional planning/development.

Numerous studies are conducted on TOD planning towards policymaking. Dumbaugh (2004) worked to overcome the financial and institutional barrier to TOD. For this, Atlanta's Lindbergh Station is considered a case study to understand the ground reality of the development happening around the station area. Similarly, research on TOD planning policy has been carried out by Dittmar et al. (2004), Pojani and Stead (2014), Tan et al. (2014), McIntosh et al. (2014, 2017), Yang et al. (2016), Staricco and Brovarone (2018), Thomas and Bertolini (2017), and Thomas et al. (2018).

Zimbabwe and Anderson (2011) stressed that TOD planning to be carried out at regional, urban, and local levels. The importance of station level TOD planning is emphasized where the demarcation of primary area of TOD noted by a person willing to walk (acceptable walking distance) to transit station from home will be the radius of TOD measured from station premises (The City of Calgary, 2004). However, it is essential to plan TOD comprehensively at the station level in a larger picture. It is also advisable to have futuristic thought by considering the existing scenario of each station at the network level. A regional TOD plan should also ensure the coordination of master plans of the city for its growth so that identifying the common goals and coordination for different urban bodies will be more appropriate (Singh, 2012). For any planning project, a better understanding of ground realities is the most critical element, and driving towards an issue-oriented solution at a larger scale will be able to achieve a success story of TOD.

2.3.1 TOD Implementation Issues

Tan et al. (2014) conducted a study on identifying and conceptualizing formal and informal barriers for TOD implementation by rigorous literature surveys, interviews, and policy analysis of the approach. As a result, the changing of the planning process in the Netherlands and also international best practice by covering the perspective of stakeholders and governance are conveyed.

Thomas and Bertolini (2017) aimed to recognize the critical success factors in TOD implementation and Policy transformation at the city and region level to address the solution to sustainable transportation via TOD implementation. The meta-analysis is proved to be a successful method in filtering critical success factors (CSFs) in TOD implementation. A total of 16 CSFs are taken into consideration for rough set analysis. These 16 factors are again categorized into three groups: plans and policy, actors, and implementation. By rough set analysis, the highest frequency factors are political stability-national (plans and policy), regional land use-transportation body (actor), public participation (actor), interdisciplinary implementation teams (actor), and certainty for developers (implementation). Local authorities can use these results in policies, practices, and governance models to establish successful TOD.

Ibraeva et al. (2020) described TOD planning policy in four significant segments, i.e., policy transferability, stakeholders view, implementation issues, and value capture mechanism. Also, planning tools, which means the decision-making process of TOD implementation, are discussed. Precisely, implementation issues are discussed according to various perspectives, planning authorities, transit agencies, and developers. The major issues identified are lack of institutional coordination (Cervero and Dai, 2014; Pojani and Stead, 2014; Staricco and Brovarone, 2018; Tan et al., 2014), lack of dedicated funding (Cervero and Dai, 2014; Searle et al., 2014;), high right-of-way costs in already developed areas (Yang et al., 2016), scarce or fragmented land availability in inner-city or already urbanized areas (Guthrie and Fan, 2016; Levine and Inam, 2004; Pojani and Stead, 2014; Searle et al., 2014; Tan et al., 2014; Thomas et al., 2018), obligation to fulfill local regulations like minimum parking requirements impedes to create walkable neighborhoods (Guthrie and Fan, 2016; Levine and Inam, 2004), and the risk of long-term infrastructure project will be revised/canceled (Guthrie and Fan, 2016; Noland et al., 2017), etc.

In General, it is necessary to have overall existing knowledge on TOD implementation issues to make it more suitable for the given site conditions. Dittmar et al. (2004) stated that "without standards and systems, successful TOD is the result of clever exceptionalism and beyond the reach of most communities or developers." Hence, exploring the site conditions for planning/implementation of TOD is the best way to proceed. Thus, the present study explored literature on typology, measuring of TOD Index, and impact assessment. This planning approach will help the authorities to make a confident framework for TOD success.

2.4 Earlier Studies on TOD Typology

TOD typology is grouping or categorizing TODs that have a similar set of characteristics. The typology process would help understand the TOD area in a better way to enhance planning, design, and operational activities (CTOD, 2010). So, it can be said that typology is defining the different types of TODs by their nature which are having their own desired density, land-use mix, connectivity, and transit system function. Therefore, the process of typology will be enhancing the optimal design requirements of a site-specific TOD. Usually, the process of station area evaluation is done by 3-D law, namely density, diversity, and design (Cervero and Kockelman, 1997), as these are the main components of TOD. Based on the indicators considered, the relative impact of these components results in the typologies contributing to how the concept is implemented. Also, it reduces the complexity; grouping together and working on the cluster level would be efficient in terms of time and money. TOD typology helps define a high-level vision for station areas and focuses on identifying the critical activities necessary to implement a vision for TOD and plan for mixed-income communities (Kamruzzaman et al., 2014). The relevant studies are presented in this section.

2.4.1 Node-Place based Typology Studies

The literature survey found that a node-place approach is the best and most promising one, which is developed by Bertolini (1996, 1999). Here node represents transit station, and place represents the surrounded area, which converts into a two-dimension diagram (an XY-diagram), where the Y-axis characterizes the availability of a node and the X-axis represents a place characteristic. This is an analytical framework to describe Transport (node) and Urban Development (place), characteristics of the location, and their relationships. According to their study, typology is categorized into five typical situations, i.e., balance, stress, dependency, un-sustained nodes, un-sustained places. A balanced situation offers better positive impacts on development. The schematic framework is shown in **Figure 2.1**. The description of each node – place type is explained below.

- **Balance Condition** is noted to be where the node and the place values are likely equally strong, indicating the development potential of either has been realized.
- **Stress Condition** is noted as the potential for land use development (Strong Node), and also the potential for transport development (Strong Place) is high.
- **Dependency condition** is observed to be where demand for both land use and transport development is insufficient to generate autonomous development dynamics.
- **Un-sustained Nodes Condition** is observed in areas where transportation facilities are more developed than urban activities.
- **Un-sustained Places Condition** is observed in areas where urban activities are much more developed than transportation facilities.

Thus, the node-place approach offers a simultaneous evaluation of transport supply and land-use characteristics of a site. Subsequently, these two elements are fundamental for the TOD concept; various studies have applied this process to classify TOD, either with or without modifications (Reusser et al., 2008; Monajem and Nosratian, 2015; Chen and Lin, 2015; Groenendijk et al. 2018).

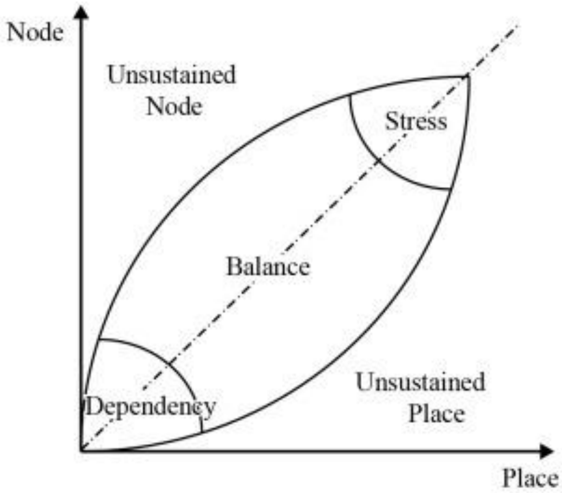


Figure 2.1: Node-Place Typology Diagram
(Source: Bertolini, 1996)

Schlossberg et al. (2004) conducted a study in Portland, and transit stations are classified into 11 TODs in terms of pedestrian friendliness using six built environmental indicators at two different scales as 5 and 10 minutes walk from the station. The indicators considered are quantity of accessibility paths, pedestrian catchment areas, impedance path, impedance pedestrian catchment area, intersection density, and density of dead ends. Each TOD is rated as excellent or poor on each indicator and assigns a positive or negative score. The total sum of scores for each TOD was then visualized as a prelude to their classification.

2.4.2 Performance-based Typology Studies

Kim et al. (2007) analyzed the mode choice of the user accessing the LRT in the St. Louis metropolitan area in the US by on-board passenger surveys. A multinomial logit model was used to study drive and park mode choices, pick up or drop off, bus, and walk. The study also found that private vehicle availability, bus availability, and convenience were associated with the choice of drive and park and bus modes, respectively. The straight-line distance between transit users' homes gives adequate representation for travel distance.

Austin et al. (2010) considered a place indicator (use mix) and a performance indicator-household Vehicle-Mile Travelled (VMT) to develop TOD Typologies. Use mix indicator was calculated in terms of a percentage of workers within the TOD area to the overall count of residents and workers. Three mix-use indicators are residential, balanced, and employment. The household VMT indicator was based on a regression analysis that used nine independent variables, including household income, household size, and commuter per household, the journey to work time, household density, block size, transit access, and job access. The derived VMT is classified into five categories to a different level of performance. 5x3=15 Typologies are formulated.

Queensland TOD Guide Report (2010) categorized TOD precincts in terms of the role they play in the regional network, and those are city center, activity center, specialist activity center, urban center, suburban center, and neighborhood. It provided guidelines for planning and appropriate levels of development in each precinct. The study suggests development around nodes or corridors where infrastructure capacity exists or can be created. These identified areas with high levels of transit frequency are to be prioritized. A peak-period service frequency of utmost 15 min and an off-peak service frequency of not more than 30 min is essential for TOD.

Xiangnan (2011) conducted a study and categorized different TODs using the Agglomerative Hierarchical Clustering Algorithm into five categories based on mix index and plot ratio indices by considering land use as a parameter. The TOD cluster with the highest mix index is considered the most typical type of TOD community.

Zemp et al. (2011) conducted a study in Switzerland on 1700 passenger stations for strategic transport and land use planning. The various indicators considered for quantification of context factors are jobs, population, centrality, regional center, frequency distribution, tourism, reachability, intercity trains departing, regional trains departing, busses departing. Clustering of the TODs with parameter indices resulted in the formulation of 6 sets of TOD clusters as class 1 to 6.

Cervero et al. (2011) conducted a study in Seoul to determine BRT impacts on land uses and land values. The study examined the land-market effects of converting regular bus operations into median lane bus services. The study revealed that improvements of BRT are promoted to high-rise apartments from the single individual property. It is also observed that Land prices are increased by up to 10% for residential uses and 25% for non-residential purposes within the core TOD area.

The Atlanta Report (2013) revealed about typology study in Atlanta. The study classified Atlanta's transit stations into a series of place types based on Market Strength and Social equity characteristics used to define Vulnerability. The Vulnerability Index within the half-mile radius formed by considering parameters of Median household income, percentage of Zero Car households, Percentage renters, percentage of the walk, bike, and transit commuters (combined) are scored and led to the formation of 3 categories, namely Highly, Moderate, and Low Vulnerable. Market Strength and TOD sustainability are characterized by TOD demographics, employment, commercial, residential, physical characteristics. These are scored and grouped into four categories: Mature, Emerging, Emerging Potential, and Lagging. Grouping of 3 Vulnerability and Market strength indices led to the formation of 5 TOD clusters.

Singh et al. (2014) made a considerable effort about the TOD typology study. The main focus of the study was evaluating the existing TOD based on ground conditions and classified them by considering the potential TOD Index. The exiting TOD index refers to those already served by transit, whereas the potential TOD index targets to recognize the location that already has high levels of TOD (in terms of the built environment, density, etc.) but lacking the "transit" element. The study was conducted in the Arnhem Nijmegen City Region (in the Netherlands). The study focused on identifying potential TOD locations based on 3D law and economic activity (number of business establishments). A grid cell of 300m×300m was considered a unit of analysis to calculate potential TOD index values using spatial multi-criteria analysis (SMCA). The maximum value of a potential TOD index obtained was 60 points, which means the demand for TOD in that region might not be robust. The majority of sites with high scores were found in proximity to urban areas.

Kamruzzaman et al. (2014) performed TOD typology to test the travel behavior of commuters at the station. Based on cluster analysis, four categories of stations are obtained in Brisbane, Australia. Indicators used in the analysis are public transport accessibility level (PTAL), net residential density, net employment density, land use mix, intersection density, and cul-de-sac density. The categories of TOD's are residential TOD, activity center TOD, potential TOD, non-TOD areas. For validating these results, a multinomial logistic regression model was used to understand the mode choice behavior.

Correspondingly, Higgins et al. (2016) established a TOD typology for the Toronto region to evaluate the station performance in terms of the modal split. A latent class method is used to cluster all station types (existing and proposed) and found 10 TOD clusters. Parameters considered for this analysis are Density, Development Mix, Street Connectivity, Interaction Potential, Residential, Commercial/Institutional, Mixed Use, Industrial Land Use. Clusters are Urban Commercial Core, Urban Mixed – Core, Inner Urban Neighbourhood, Urban Neighbourhood, Sub – Urban Neighbourhood, Outer – Urban Neighbourhood, Sub – Urban Center, Outer Sub – Urban Commerce Park, Outer Sub – Urban Industrial Park, and Airport. Latent Class methods also permit the explicit accommodation of covariant relationships among manifest variables, offering more precision in accommodating the complex spatial relationships common in geographic datasets.

Lyu et al. (2016) conducted a study on Developing Context-based TOD typologies in Beijing. The Node Place model is used, and five typical situations are drawn as Balance, Stress, Dependency, Un-sustained Nodes, and Un-sustained Places. The study considered TOD as a three-dimensional orientation. Based on local experts' review opinion, five transit parameters, five development parameters, five oriented parameters are selected for the analysis. Based on Duda

Index, 268 TODs are classified into 6 TOD clusters. The study observed that even though local expert input is used to select the TOD indicators, the point of departure is still the set of indicators documented in the international TOD literature.

A recent work done by Huang et al. (2018) discussed TOD typology that can target potential TOD's role concerning associated parameters. A latent class cluster analysis is used for the case of Arnhem Nijmegen City Region. In the analysis, the variables considered are population density, job density, business density, land-use diversity, mixed-ness of land uses, intersection density, and length of bicycle and pedestrian networks. As a result, three types of TODs were observed: urban mixed-core, urban residential, and suburban residential. Only three categories are distinguished because the network is relatively small and dominated by two central stations.

2.5 Evaluation of TOD

Measuring the TOD index is an essential step in the planning process to know the level of TOD existence and, in other words, to evaluate the TOD based on the index achieved. Understanding any project is crucial as it involves huge investments. Projects like TOD construction involves high-rise buildings, and redevelopment of existing land use will cost even more if it is not planned and executed well. So, measuring TOD before and after its implementation will ensure its success or failure. At the same time, measuring the TOD after the construction of the project will teach the lessons and become formulae for future success (Renne et al., 2005).

The identification of TOD indicators is the most crucial step in evaluating a TOD. Usually, indicators are representative elements of TOD components, as explained in the early section. In mathematical terminology, it can be said that indicators are independent, and components are dependent on nature. The selection of indicators purely depends on the site-specific conditions. These may vary from city to city or nation to nation etc. For fruitful results in measuring TOD, indicators will play a vital role and depend on the targeted TOD policy. Few researchers have made their efforts at their places by considering suitable components to represent their study area, and based on the results obtained, a successful TOD planning is ably proposed (Singh et al., 2014).

2.5.1 Review on TOD Indicators

The selection of TOD indicators is the most critical step in the evaluation process as it is obvious to know how these indicators influence components of TOD. As mentioned earlier, the three major components of TOD are density, diversity, and design (3D-law) (Bernick and Cervero, 1997). Further, 3D-law is extended to “six Ds” (destination accessibility, distance to transit, and demand management in addition to density, diversity, and design), and then one more “D” (seven

Ds) is also added that is demographics of the area (Ewing and Cervero, 2001). Most of the research is done related to the evaluation of transit ridership and impact on land value, but the aspects that indirectly influence transit ridership are not considered (Cervero et al., 2004). Cervero and Kockelman (1997) observed the influence of built environmental indicators within the TOD area on travel behavior. The list of indicators is mentioned below in **Table 2.3**.

Table 2.3: List of TOD Indicators

Component	Indicator
Density	Population, Employment
Diversity of land use	dissimilarity index, vertical mixture, activity center mixture, land use mix, proximity to commercial areas
Design	street connectivity, site design

Source: Cervero and Kockelman, 1997

Belzer and Autler (2002) stated that there is no specific procedure for TOD evaluation universally. Also, there is no benchmark design for TOD to accomplish 100% TOD. They believe in achieving TOD at the most, by considering various definitions, state of the art literature, physical form of existing TOD will be playing the most critical role. Hence, they proposed six criteria to evaluate at the station level and looked forward to the vision of potential TOD. Components considered for the analysis are location efficiency, value recapture, liveability, choices, efficient land use patterns, and financial return. The indicators list is mentioned in **Table 2.4**

Table 2.4: TOD indicators

Component	Indicator
Location efficiency	Ability to access jobs, Recreation activities and amenities, Retail etc. (within walkable or biking distance)
Value recapture	Local efficient mortgage program, Increased homeownership, Reduced money on transportation
Livability	Better air, health, safety, economic health, access, and reduced congestion.
Choices	Housing, transport mode, retail, recreation, etc.
Efficient land use patterns	Lesser sprawl, more road (at regional level)
Financial return	Higher tax and fare revenues, return on investment

Source: Belzer and Autler, 2002

Renne et al. (2005) identified five major components viz., travel behavior, built environment, economic aspect, environmental aspect, and social dispersion to regulate the TOD designs more appropriately. Further, to represent these five, 56 indicators are considered for evaluating TODs. The top 10 are given below.

1. Transit ridership.
2. Population density.
3. Quality of streetscape.
4. The number of mixed-use structures.
5. Pedestrian safety.
6. Increase in property value.
7. Increase in tax revenue.
8. Public perception.
9. The number of feeder bus connections to the transit station.
10. The number of parking spaces.

Singh et al. (2015) adopted four criteria based on the literature review that are important to measure TOD – density, land use diversity, walking, and cyclability encouraged by the urban design and economic development. Within those criteria, the following indicators, a mix of spatial and non-spatial, were chosen to measure TOD such that they cover the different aspects of TOD sufficiently while being measurable and quantifiable at the same time.

1. Criteria: Urban densities
    a. Residential density
    b. Commercial density
    c. Employment density
2. Criteria: Land use diversity
    a. Land use diversity mix index
3. Criteria: Walkability and Cyclability
    a. Intersection density
    b. The total length of the NMT facility
    c. Mixed-ness of residential land
4. Criteria: Level of economic development
    a. The density of business establishments
    b. Tax earnings of municipalities
    c. Employment levels

To calculate the TOD index, it is necessary to bring all indicators into a single scale or platform that are different (scales and units). These indicators are related to the transit system, built-environment, functional aspects, economic aspects and must be obtained from different secondary sources and site surveys. These indicators represent their different scales and units, which contribute differently to the index value. Usually, the Index value ranges between 0 to 100. The value '0' (zero) represents that there is no TOD existence on the ground, and 100 represents TOD fully functional according to the definition quoted in the study. Multi-criteria analysis is used to achieve the TOD index by combining both indicator scores and weights.

2.5.2 TOD Index Related Studies

Most of the studies are based on the evaluation of completed TOD projects. Few studies mentioned the evaluation of TODs at the planning stage via urban, regional, or station level (Yang and Lew, 2009; Balz and Schrijnen, 2009; Cascetta and Pagliara, 2009; Howe et al., 2009; Curtis, 2009; Arrington, 2009). The role of the private sector in implementation is considered to overcome the implementation issues to make it successful (Chorus, 2009; Cervero and Murakami, 2009). From the literature survey, it is understood that a comprehensive and quantitative measurement of the TOD area is limited to few studies. Schlossberg and Brown (2004) measured TOD with quantitative measurement by considering the 'walkability' indicator in Portland, Oregon. It is an excellent example of quantitatively measuring TOD using a spatial platform, i.e., GIS.

Evans and Pratt (2007) attempted to establish measuring criteria of TOD, which is represented by the term "TOD-ness." TOD-ness is defined as a "potential device for considering the degree to which a particular project is intrinsically oriented towards transit." The need for determining TOD-ness for evaluation purposes and for planning new TODs has grabbed attention. Here, the TOD-ness term is used to represent the characteristic of TOD. Finally, the TOD index is achieved by identifying and categorizing the indicators to work more efficiently.

Singh et al. (2014) contributed to the performance of measuring TODs within the transit network. Spatial Multiple Criteria Analysis (SMCA) is adopted to analyze an aggregated TOD value (TOD index) for different locations. Based on the arrived index, TODs are evaluated so that TOD is oriented towards transit and understanding of built environment characteristics. In this study, evaluation of the TOD network for the city region of Arnhem-Nijmegen is carried out by aggregating multiple spatial indicators using the SMCA framework to arrive at a general TOD index value.

Consequently, Singh et al. (2015) made another attempt to evaluate TOD in two levels: first is to measure TOD using its index, and the second is to understand TOD from a different point of view, i.e., improving transit access to areas where development is already transit-oriented, rather than making the development around existing transit nodes more transit-oriented. The methodology includes measuring several TOD indicators spatially over the entire region and using Spatial Multi-Criteria Analysis (SMCA) to arrive at a TOD index value. Further, in the year 2017, similar efforts are made in measuring TOD around 21 stations in the city region of Arnhem and Nijmegen, Netherlands. Here, the TOD index is calculated to understand and draw TOD policy for the study area by identifying the stations that need to improve more, rather than considering all. The study also suggested the direction in which TOD characteristics can be improved based on indicator values arrived.

A study (TRB, 2009) discussed developing a strategy to measure the success of TOD. This study considered several American cities as case studies. The study has identified the ten best indicators and evaluated TODs in the region. The research showed that except for studies focusing on transit demand and land values near the stations, empirical studies are to be carried out to evaluate TOD in a generalized way. Evaluation of TOD can be bifurcated into different levels depending on the existing situations. The most feasible ways are urban level, regional level, and local level. Another approach found in the literature is evaluating urban level TOD; factors influencing are increased tax revenues, increased transit ridership, and increased land values. However, it is very tough to measure the regional level impact of the TOD. In this study, 16 factors are considered that determine the success of TOD at regional as well as local scale as 'Factors Determining the Success of TOD.' At the same time, it is also stated that the measurement of regional level TOD is a theoretical approach of planners that cannot be quantified.

According to Renne (2009), the methods for measuring and evaluating TOD have two approaches. One is the regional performance approach (RPA), and the second is the community performance approach (CPA). These methods are intended to evaluate the success or failure of TOD plans. The RPA method comprises of comparison technique among the different TOD projects within a region. The CPA method monitors the system specific to that community to track TOD indicators towards achieving the local goals. However, it is most difficult to find two TOD projects that show similar characteristics for comparison purposes. Hence, the study suggested collecting the existing data for a location before and after TOD implementation. So, the evaluation can be done by witnessing the on-site improvements (Renne, 2007). This method is adopted for Perth, Australia.

Kamruzzaman et al. (2014) stated that based on various conditions of the site, implementation issues also vary. Hence, to understand the ground realities well before implementation, it is necessary to obtain the information by measuring/evaluation process so that future TOD can ensure its success. Further, after implementation, the effects of TOD are studied, and impact assessment is suggested and discussed in the following section.

2.6 TOD Impact Assessment Studies

TOD impact assessment is also an integral part of the evaluation of TOD. Based on the literature survey, the evaluation of TOD can be analyzed in five significant ways, i.e., travel behavior, real-estate price, urban forms, residential location, and community life. The literature-based on this concept is discussed in detail below:

2.6.1 Impact of Metro on Property Values

Zhang and Jiang (2014) studied the impact of metro station proximity on property value in Nanjing, China, and presented a positive partial effect of the metro on property value. Hedonic Price analysis is used to estimate the impact considering the variables like age, area, plot ratio, distance to the station as dummy variables, greenery, sightseeing view, distance to hospital, etc. The data collected is organized in a cross-sectional pattern. To a distance of 500m, there is a significant impact of the metro, and up to 2km, there is a remarkable impact; beyond 2000m, the impact is negligible. As the distance increases, the price variation reaches peak value to a distance of 1000m and then decreases. Also, the metro station located in the sub-urban area has shown a higher positive impact than the station located in an urban area.

Mohammad et al. (2015) studied the effects of Dubai Metro on the value of residential and commercial properties and presented a positive influence of metro on the sales value of residential and commercial properties. However, commercial properties have a more substantial effect using difference-in-difference and hedonic price methods on both repeated cross-sectional and pseudo panel data. The model also revealed that the impact is significant within 701 to 900 meters from the metro station.

Jan Laznicka (2016) studied the impact of proximity to the metro station on apartment value in Prague using real transaction data to identify the possible differences between actual transaction prices and offer prices. The simple Capitalization model of Agostini and Palmucci (2008) is followed to look at the problem from the consumer view. Based on the above model, the maximization statement is given as:

$\max U(s,d,o)$

With a budget constraint:

$$U = o + P(d)s + T(d) \tag{2.1}$$

Where,

s is the area of the property in square meters

d is the distance of the house from the nearest station o is a compound good made of other consumers goods

U is the income of the consumer

P(d) is the price of property per m2 and

T(d) is a function of the cost of transport.

Assuming U as continuous and smooth with continuous derivatives of second-order, U is increasing in s and o and decreasing in d because the increase in distance increases the travel time. From the equation, the maximum utility function obtained is considered. The increase in distance from the station to the property, considering the decrease in utility and the increase in travel costs, leads to a decrease in the willingness of the consumer to pay for the same property. A hedonic model was developed by considering the single variable to indicate the distance from the apartment and the second by considering the distance zone variable, indicating a 250m vast distance from the station. The results have shown the statistical significance of impact in 0-250m and 750-1000m due to different aspects and surrounding various metro stations. There is a positive impact on apartments located in 250-500m and 500-750m.

Forouhar (2017) analyzed the effect of the Tehran metro rail system on residential property values between high-income and low-income neighborhoods. The value of properties before and after the metro construction is taken to estimate the impact by the difference-in-differences (DID) model. DID model for residential properties estimates a positive impact on property located in low-income neighborhoods compared to high-income neighborhoods. In this study, the impact is significant to a distance of 250m. This model demonstrates a negative impact on the properties close to northern stations as the car possession percentage is high, and there is a vast network of highways, which facilitates them to use the personal car, while the coverage of highways and car possession percentage is limited in southern parts. As a result, the impact is high. The study also suggested TOD in Tehran to minimize the nuisance effects through a multi-objective planning model that integrates land use and transport.

Haitao et al. (2017) discussed the value-added effects of TOD and the impact of urban rail on commercial property values considering spatial heterogeneity. The Spatial Durbin model was employed to provide an average coefficient estimate for the overall system, and the Geographically Weighted Regression (GWR) model was developed for the local level. GWR model shows a relatively moderate price premium associated with the light rail system significantly higher in the central business district (CBD). This heterogeneity in price is helpful in the design of project financing and TOD strategies.

Gallo (2018) identified that only high-frequency metro lines have appreciable effects on real estate values than low-frequency lines. A hedonic model was developed and calibrated for Naples, which is used to estimate the external benefits concerning property values for the city of Naples. The study suggested that an increase in high-frequency metro lines produces an appreciable increase in real estate values.

2.6.2 Impact of transit line other than metro on property values

Al-Mosaind et al. (1993) analyzed the home sales in areas of Portland that are within acceptable walking distance to a light rail transit station. Two hedonic models are developed, choosing 1000m and 500m as the reasonable walking distance between homes and metro stations. A positive effect on home values is obtained with a 500m distance. The findings indicate positive impacts of accessibility that are stronger than the nuisance effects.

Hong et al. (1997) measured the impact of a light rail system using a hedonic approach with GIS application. The impact of proximity to metro on single-family house values in Portland using the distance to metro station and distance to line itself as variables. GIS techniques are employed to create spatially related variables. The study resulted in both positive and negative effects, with positive effects dominating the adverse effect. It also suggested that hedonic models have reached contradictory results because the nuisance effect differs for different rails.

Bowes and Ihlanfeldt (2001) identified the impacts of rail transit stations on residential property values in the Atlanta region by considering factors like access to the station in terms of commuting cost savings, neighborhood commercial service, pollution, and crime. Hedonic Price models are developed to study the direct and indirect impacts of stations on property values. Two models are discussed: one is by excluding all interactions, and the other is by including interactions of the station (i.e., distance to CBD, income, whether a parking lot is available). The results of the basic model have shown that the properties located near the station are affected by negative externalities. At the same time, the properties located at an intermediate distance benefit from the station's transportation access. The model with interactions shows that the property values paid for being close to the station are greater in high-income areas than in low-income areas and the house owners who must drive to the nearby station are willing to pay for parking at the station. The crime model results have shown that crime is higher in the area near to station though many neighborhood characteristics are controlled with other characteristics.

Celik and Ugur (2006) tried to model the relationship between residential property values and accessibility changes caused by a rail transit investment. The accessibility to the metro is measured in terms of distance and travel times. The model showing proximity to the metro is statistically significant in determining the price of the property. Distance to the nearest metro station and sizes of buildings are the most influencing variables in determining the property's price. The property value decreases as the distance from the station increases.

Hess and Almedia (2007) studied the impact of proximity to light rail transit stations on residential property values in Buffalo, New York, where light rail has been in service for 20 years, but the population is declining, and ridership is decreasing. Hedonic models are constructed for residential properties. The model developed suggested that the homes located near the station have an increase in property value. Also, the independent variables like the number of bathrooms, size of the home, location from the station are more influential than other variables. The results are positive in high-income areas and harmful in low-income areas.

Vichiensan et al. (2010) examined the varying relationship between the property value and its determining factors, such as accessibility to the rail, using spatial hedonic analysis. Two models, i.e., the ordinary least squares method (OLS) and geographically weighted regression model (GWR), were employed to estimate the coefficients. The results have shown that the influence is complicated and immensely varied over space. Also, the high-density area is along the metro rail corridor, which implies that the area that is well accessible to the railway station has high value compared to the area away from the station. This is the huge benefit brought by the railway in Bangkok.

Yan et al. (2012) explored the impact of the new light rail system in Charlotte, North Carolina, on single-family property values by using hedonic price analysis for four different periods, i.e., before planning of metro, at the time of planning, construction, and operation stage. Based on the fact that a single house will provide numerous data and is simple to analyze, the sales data of the houses are collected from the local information center for the properties within a 1-mile distance. Only the ordinary market value is considered to eliminate extreme values. The hedonic model is developed, taking the logarithm of price as the dependent variable. It is concluded that the distance to the metro station has a modest impact on the property value. The property values before the metro operation are less compared to the values after the operation because of the industrial land use zone around the station.

Seo et al. (2014) analyzed house values' positive and negative relationship with proximity to station and highway. Using multi-distance bands, the distance decay is captured, and a spatial hedonic model is used to test the hypotheses that accessibility benefits arise at nodes. Distance to highway and LRT station is measured in bands. Multiple linear regression analysis is carried using SPSS. Both highways and LRT have shown a significant result, i.e., the positive effect is larger than the adverse effect and decreasing from stations. The effect of highway accessibility is also significant, with motor vehicles having a higher speed of travel than other modes of travel. The tests on the effect of highway design on house values revealed that below-grade highways positively impact houses nearby compared to the houses located at ground level or above.

Sun et al. (2016) revealed that the construction of the subway plays a significant role in promoting an increase in the surrounding property values. Other variables like distance to CBD and nearest school/park/hospital also affect the property values along with the distance to the metro station. A hedonic Pricing Model in Logarithmic-Linear form and Semi logarithmic form is developed to analyze the data.

Wang (2010) researched the impact of light rail Transit-Oriented Development on residential property value in Seattle using the light rail system. Hedonic Price model is developed, and dummy variables represent the proximity to metro and structural location and socio-economic attributes. The results have shown no statistical influence of the metro on the residential properties after the constructed period. Moreover, there is a positive impact on the values of properties located within 0.25 to 0.50 miles from the station.

Ransom (2018) interpreted the impact of the construction of light rail transit on nearby residential property values around seven metro stations using difference-in-difference analysis. The difference-in-difference model was developed for two data sets, i.e., construction beginning time and operation of rail transit. For the variables considered, the effect of individual estimates is determined. The results show that the properties located near to station experienced a price appreciation at all stations except Columbia station.

2.7 Summary of the Literature Review

From the extensive literature review, the success of TOD planning and implementation strategies in developed countries worldwide are explained. Extensive research on planning issues is carried out before forming up the guidelines for implementation of TOD. In this chapter, the TOD planning approach, implementation issues across the globe are addressed. The role of TOD typology in the planning of TOD is also addressed. Various typology studies by considering different variables are discussed. Critically from the literature review, typology studies are carried out based on planning requirements and various opinions for each case study. The selection of variables purely depends on on-site conditions. In the literature survey, the importance and need of the evaluation process in the planning and design of effective TOD are discussed. It is observed that the adoption of any urban planning concepts like TOD from developed countries is difficult. So, its own set of guidelines for each country is to be framed to represent urban planning issues.

Accordingly, to frame the implementation strategies for developing countries, the following research gaps are identified and presented below.

2.8 Research Gaps

Based on the extensive literature review, it is understood that the planning of TOD has lots of challenges as it is a long-term and expensive investment plan. Hence, to have the optimum plans at the region or country level, the research gaps are identified to support the objectives of the present study as follows:

- Selecting the feasible TOD location for planning and implementation is the primary concern where the promotion of development is too complex in the inner city, corresponding to time, money, and possibility of land use concerns.
- Most of the existing TOD models are developed for greenfield development in advanced countries. However, those models do not fit developing countries as these are densely populated and unplanned.
- From the literature, it is understood and necessary to have a definite Framework on the TOD implementation process for developing countries, to overcome the region-specific planning and implementation issues.
- TOD typology is an integral part of the planning process; however, it is not used for future prediction TOD planning. In many existing studies, TOD Typology monitors the performance and spatial equity of policies for existing TODs alone.
- The design implementation strategy for forthcoming stations using typology lacks in the existing research studies.

2.9 Summary

The present study is aimed to develop a framework for the implementation of TOD. Hence, literature is sub-divided into five major sections and discussed accordingly, related to the work done. The five major sections are concept, planning approach, typology, evaluation, and impact assessment. Firstly, literature deliberated the concept of TOD to understand the historical perspective, definition, advantages, and components of TOD. Then, the planning approach of TOD is discussed in detail, where implementation issues can be understood and helpful to overcome at an early stage. The next step in the framework is TOD typology. The work done on typology is presented and discussed in detail.

Further, the evaluation of TOD is considered, and relevant literature is presented. As part of this, the importance and selection of TOD indicators, calculation of TOD index-related studies are mentioned and discussed. Finally, TOD impact analysis studies are taken into account concerning changes in real estate value. After a fair understanding of the background of TOD, the following chapter framework is proposed for the present study, i.e., methodology.

Chapter 3

Research Methodology

3.1 General

The present study is aimed at developing a framework for the implementation of TOD. Accordingly, the literature review is carried out and furnished in chapter 2. The name framework itself reveals that study methodology consisting of several steps. The first step is to identify the feasible TODs and prioritization of TODs. Here, two approaches are adopted; approach 1 identifies the most feasible TODs, and approach 2 prioritizes transit stations. The second step is to perform TOD typology at the city and sub-area levels. Based on results obtained from city typology, the opportunity strategy is drawn.

Moreover, based on sub-area level typology, design implementation strategies are drawn. Then a generalized TOD model is developed to suit and address the study area issues. Finally, the proposed TOD model is evaluated by measuring the TOD Index, and property value assessment is proposed to get to know about the impact of development. The study methodology is given in **Figure 3.1**. The input parameters are shown in extreme right and left boxes. Various steps in study methodology are explained below.

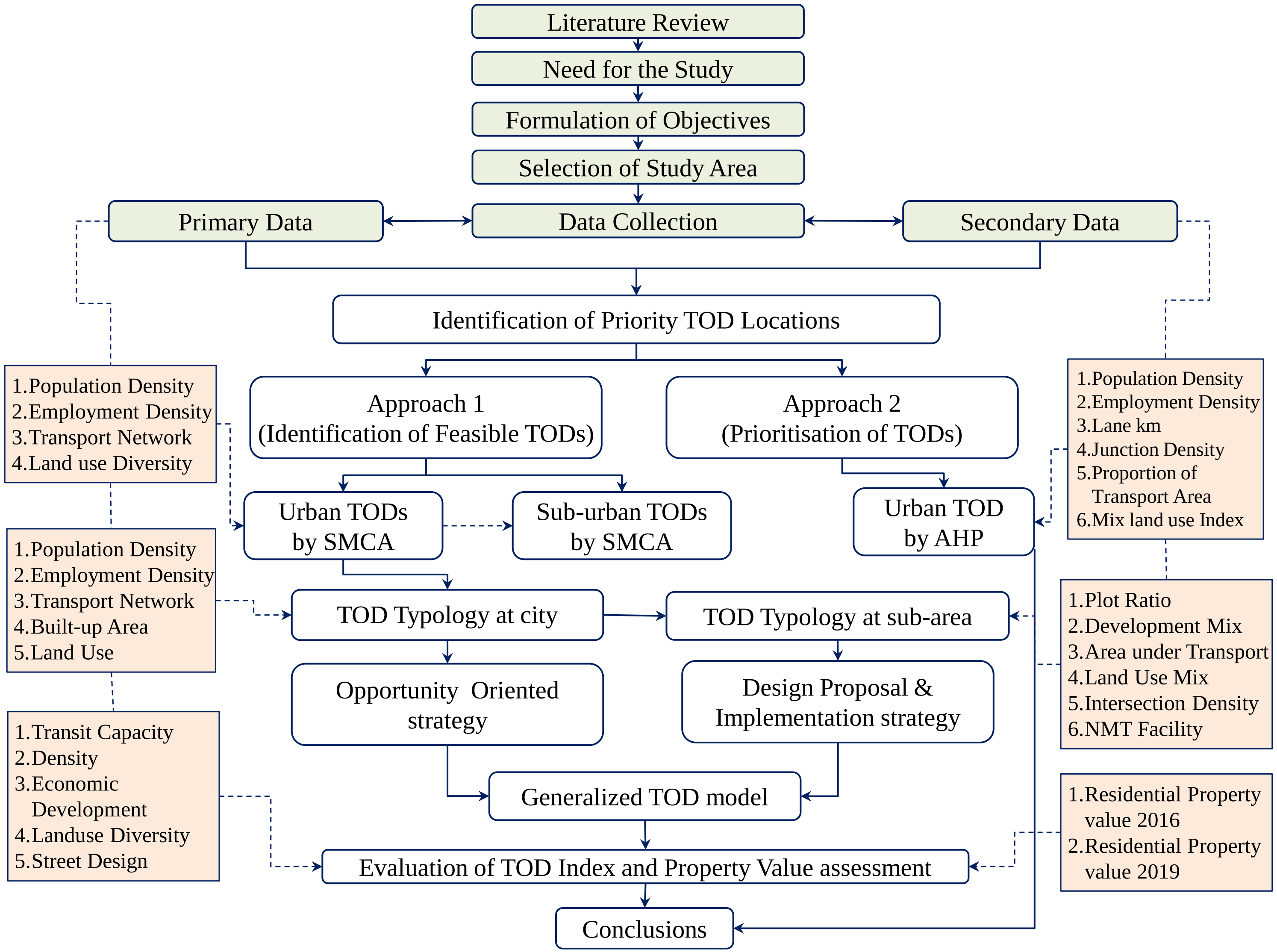


Figure 3.1: The study methodology flow chart

3.2 Identification of feasible and prioritization of TODs

Identification of feasible TOD locations is the first step in the framework. The identification process helps save time and money, so it is more appropriate in developing countries where the TOD concept is initially introduced. The other way of deciding on the selection of TODs is prioritization/ranking where TOD exists. Hence, two approaches are included in the proposed framework. The planning parameters like population, employment, transportation network, and land use of the study area are analyzed in the ArcGIS platform.

3.2.1 Identification of Feasible TODs using SMCA

Based on population and employment settlements across the study area, the study area is divided into urban and suburban areas. Firmly, the urban area is observed within Greater Hyderabad Municipal Corporation (GHMC), and the sub-urban area is the rest of HMA. It is more appropriate to analyze both areas separately. The rules are formed for both areas to identify feasible TOD locations using SMCA, as explained below.

Urban TODs

SMCA method using ArcGIS is adopted to identify feasible urban TODs. The analysis is carried out by selecting four criteria. Criteria one is the transit network layer with MRTS, MMTS track details, the second one is the road network layer with the attribute of traffic flow speeds, the third criteria is the bus route network layer with frequency attribute, and the fourth one is land-use layer with frequency attribute all details. For each layer, a particular rule is formed to identify the feasible location. Likewise, one after the other layer is analyzed, and appropriate locations are identified. At the end of the fourth layer, a cumulative number of feasible TOD locations are obtained. The following are the rules formed for each criterion. A detailed flow chart for identifying the Urban TOD using SMCA is given in **Figure 3.2.**

Rule 1: Interchange transit stations of MMTS, MRTS and intercity terminals are considered high priority and end stations of the transit corridor.

Rule 2: Areas where a transit network (MRTS/MMTS) is not present, a bus route network with high frequency is considered.

Rule 3: Road network with a traffic flow speed of more than 25km/his considered.

Rule 4: Crowded local economic activity areas and residential pockets are identified and taken into account for TOD selection.

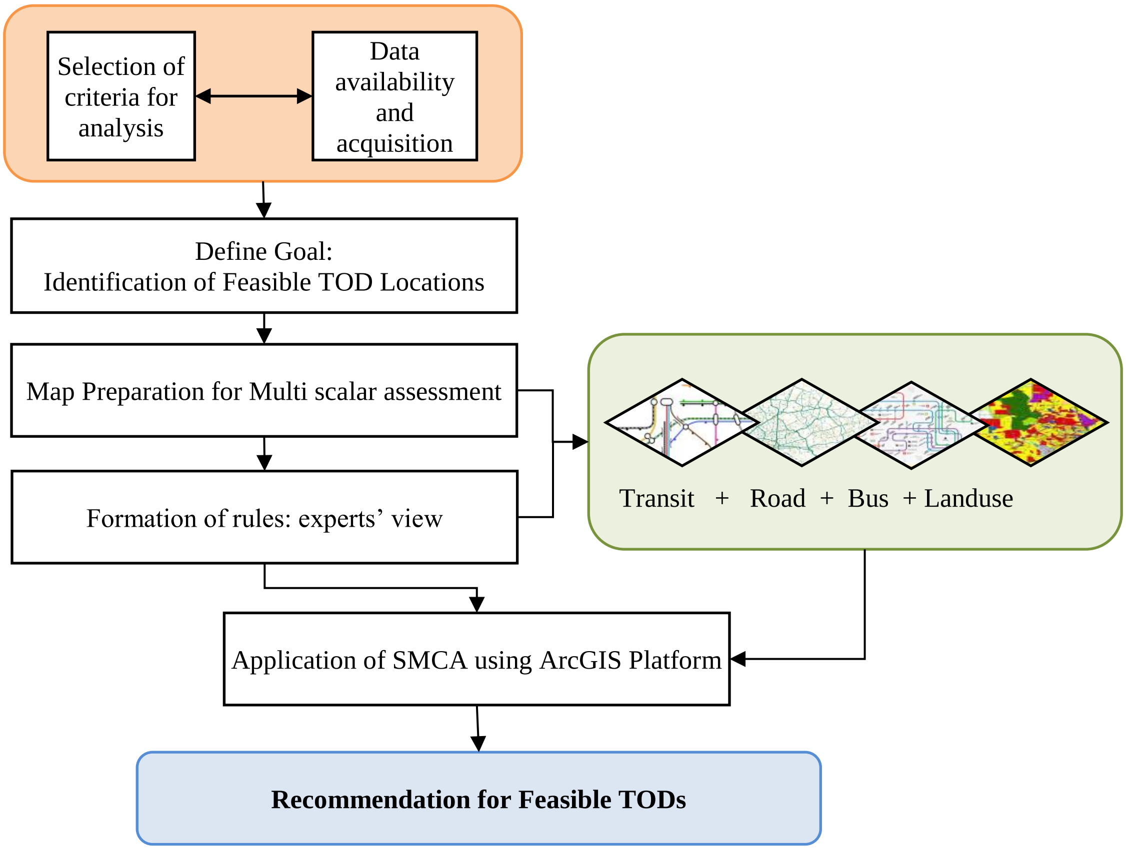


Figure 3.2: Spatial layer used for SMCA

Sub-Urban TODs

Similarly, the same approach (Figure 3.2) is followed for the Sub-urban area, but the criteria and rules are changed accordingly to suit sub-urban requirements. The first criteria would be forming a grid upon that an arterial road network and rail network (intercity)are considered other criteria, from which feasible TODs are identified based on the rules mentioned below.

Rule 1: Grid analysis is carried out to have uniform urban sprawl across the study area. Assuming the grid size of 4 km X 4 km for this study area, and the maximum distance between each TOD considered is about 8 km is considered.

Rule 2: Population and employment settlements are considered.

Rule 3: National Highways, State Highways with vehicle speed more than 40 km/h are considered.

3.2.2 Prioritisation using Analytical Hierarchy Process (AHP)

Multi-Criteria Decision Making (MCDM) is considered for the prioritization process. AHP is the most widely used MCDM technique. The fundamentals of AHP are found in the literature (Gass, 1985; Harker, 1987; Saaty, 1977). Thomas Saaty (1980) introduces the AHP method. It is found to be an efficient tool for dealing with multifaceted decision-making. The decision-maker may get the benefit of making the best optimal decision upon a set of alternatives. The complexity of the decision will come down by finding out the weights of the chosen criteria. For this, a series of pairwise comparisons are done, followed by normalizing the values. AHP is performed for both qualitative and quantitative aspects. Further, AHP also checks the consistency of the decision maker's assessment, thus assuring the reduction in bias (Pawel, 2010). AHP follows three significant steps: 1) Computing criteria weight; 2) Computing composite score and ranking, and 3) Consistency check.

Computing criteria weights

The procedure to compute criteria weights is given in **Figure 3.3**. The selection of appropriate parameters is the first and foremost step. To calculate the criteria weights, initially, a *pairwise comparison matrix* C is created. Matrix C is a $n \times n$real matrix, where n is the number of evaluation criteria considered. The importance of the j^{th} criterion relative to the kth criterion for each entry of $c_{jk}$is given in matrix C.

$$C=\begin{bmatrix} C_{11} & \cdots & C_{1n} \\ \vdots & \ddots & \vdots \\ C_{n1} & \cdots & C_{nn} \end{bmatrix} \tag{3.1}$$

If $c_{jk}> 1$, then the j^{th} criterion is more important than the kth criterion.

If $c_{jk}< 1$, then the k^{th} criterion is more important than the jth criterion.

If $c_{jk} = 1$, then j^{th} and k^{th} (two criteria) are equally important.

However, c_{jk} and c_{kj} satisfy the following constraint:

$$c_{jk} \times c_{kj} = 1 \tag{3.2}$$

Evidently, $c_{jj}= 1$ for all j. The relative importance between the two criteria is measured on a numerical scale from 1 to 9 (9 being more important). The jth criterion is assumed to be equally or more important than the kth criterion. This helps in converting the relative importance of the criteria to numbers. There may be slight inconsistencies in the ratings though these may not show a severe impact on AHP.

Then, C_{norm}matrix is obtained from matrix C by making equal to 1 the sum of the entries on each column. C_{norm}matrix for each entry of $\bar{c}_{jk}$is given by

$$\bar{c}_{jk} = \frac{c_{jk}}{\sum_{i=1}^{n} c_{ik}} \tag{3.3}$$

Finally, $\boldsymbol{w}$ the criteria weight vector (n-dimensional column vector) is built by averaging the entries on each row of C_{norm}, and is given by

$$w_j = \frac{\sum_{i=1}^{n} \bar{c}_{ji}}{n} \tag{3.4}$$

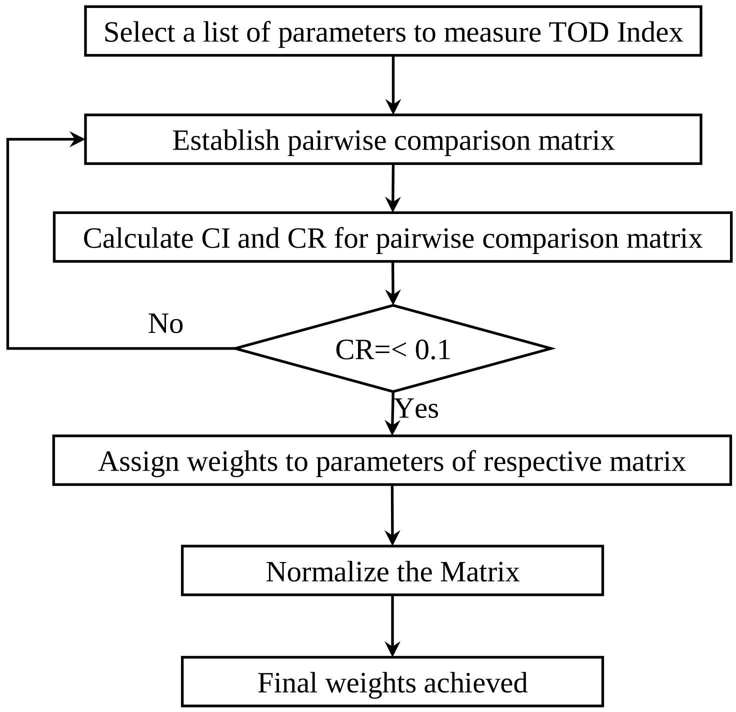


Figure 3.3: Procedure for computing criteria weights

Computing composite score and ranking

The next step is to calculate the composite scores by multiplying weights (w_j) with the rating of criteria of each variable adopted. In this study, each variable is categorized into seven levels based on the actual values. Seven levels are given a rating from 7 to 1 and said to be excellent, very good, good, average, fair, satisfactory, and poor. Then multiplying each parameter weightage (from step 1) with rated value (from step 2, i.e., 7 to 1) will give the composite score. Thus, composite scores are calculated, and final rankings for alternatives are given by arranging them chronologically. The sequential procedure for finding the final ranking is presented in **Figure 3.4.**

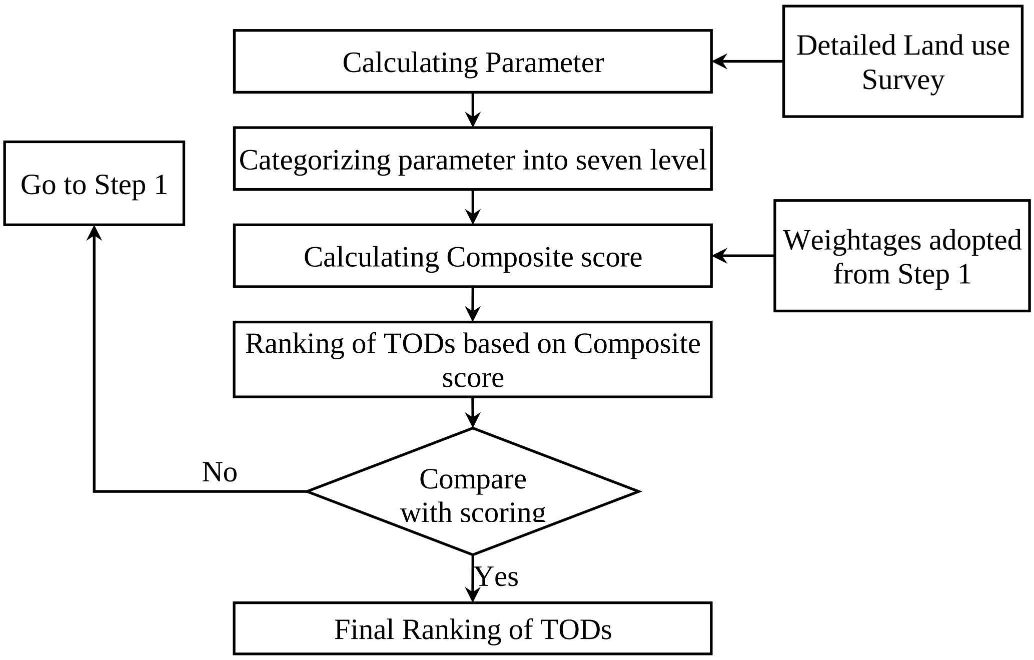


Figure 3.4: Procedure for final ranking

Consistency check

In AHP, there is a possibility for inconsistency issues due to pairwise comparisons. For example, inconsistency may arise if the decision-maker gives more weightage to the first criterion than the second criterion and similarly gives more importance to the third than the second criterion, where the third is given lower importance. To resolve such issues consistency check is carried out. An effective technique used by AHP to check the consistency of the pairwise comparisons given by the decision-maker to form the matrix C is Consistency Index (CI) and is obtained by using the formula given in eq.3.5. CI is computed as the scalar *x* as the average of the elements of the vector whose j_{th} element is the ratio of the j_{th} element of the vector $C{\cdot}w$to the corresponding element of the vector ***w***.

$$CI = \frac{x-n}{n-1} \tag{3.5}$$

The consistency is said to be perfect if *CI*=0. However, small values of inconsistencies may be tolerable. AHP obtains reliable results based on the tolerance of the inconsistency. *RI* is the *Random Index,* i.e., the consistency index when the entries of *C* are entirely random. The values of *RI* for minor problems have been given by Saaty (1980); The Consistency Ratio (CR) is given in eq.3.6, and the inconsistency is said to be tolerable if CR<0.1.

$$CR = \frac{CI}{RI} < 0.1 \tag{3.6}$$

A traditional scoring method is also considered for proof check of the AHP analysis.

3.3 TOD typology at city and sub-area level

3.3.1 Typology at City level

A city-level typology is proposed to elevate the opportunity of TODs having the potential to implement with priority. To plan any concept related to urban planning, one must understand several challenges such as land use, traffic and transportation facilities, social issues, environmental impacts, economic considerations, urban morphology, and political pressures.

SMCA is adopted and performed at four stages, one after the other, as shown in **Figure3.5**. In **Stage 1**, Urban Morphology is considered to delineate the study area into categories based on population and employment density, such as Core Urban (U1), Urban (U2), and Suburban (U3). Population and employment densities are calculated as given in eq.3.7 and eq. 3.8 respectively.

$$\boldsymbol{Density_{pop}} = \frac{\boldsymbol{Population\ of\ zone\ i}}{\boldsymbol{Area\ of\ Zone\ i}} \qquad (3.7)$$

$$\boldsymbol{Density_{emp}} = \frac{\boldsymbol{Employment\ of\ zone\ i}}{\boldsymbol{Area\ of\ Zone\ i}} \qquad (3.8)$$

Stage 2 is crucial to select the most appropriate TOD locations. In this stage, the entire city's transportation network (Transit and Road Network) is considered. The development proposals are based on the transportation facility available like Expressways (T1), Mass Rapid Transit Systems-MRTS (T2), Light Rail Transit (T3), Mono Rail (T4). Before performing this analysis, rules are made to choose the eligible Transportation network. The Transit network is thoroughly considered, and the road network with a speed of more than 25 km/h within the urban area is considered. In addition to this, suburban area grid analysis is performed, and TOD locations are selected based on the existing settlements and available road network. Further, Density and Design parameters can be organized more appropriately at this level.

Stage 3 deals with the built-up environment along the finalized TODs in stage 2. This stage is crucial for the development of proposals. The analysis is carried out for urban areas only, as densities are low in a suburban area. TOD area is considered within 500 m of the transit station. The percentage of land availability is calculated, as shown in eq.3.9. Based on available land, development proposals may be categorized into High (B1), Moderate (B2), and Low (B3).

$$\%\ \boldsymbol{of\ Land\ Available} = \frac{\boldsymbol{Open\ Land\ Area\ with\ in\ TOD_i}}{\boldsymbol{TOD_i\ Area}} \qquad (3.9)$$

stage 4, the percentage of land use is calculated category-wise at each selected location for urban TOD. Based on the predominant type of land use, typology is proposed. Diversity measures such as Residential (L1), Commercial (L2), Institutional (L3), and Mixed (L4) are considered.

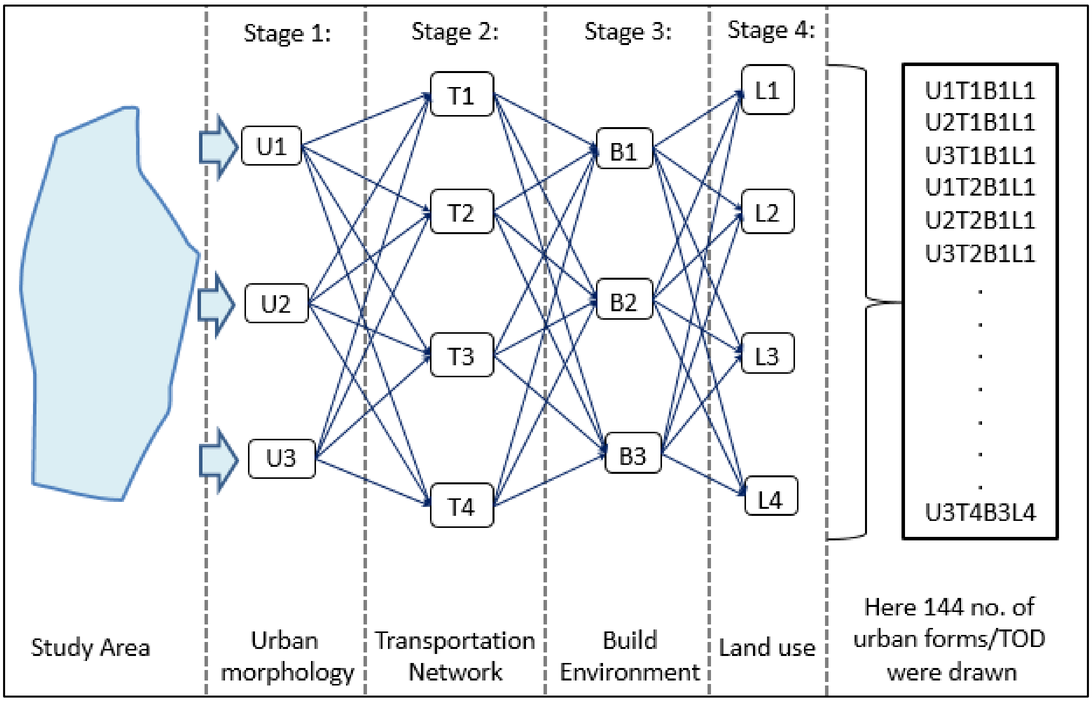


Figure 3.5: SMCA for typology

3.3.2. TOD Typology at Sub-area level

Gachibowli Hi-tech city Area (GHA) is considered to perform Sub-area level typology. Cluster analysis is carried out using the K-Means clustering technique, which helps group similar characteristics into one. The success of typology depends on the selection of effective parameters. A variety of relevant parameters helps in understanding the completeness of TOD, thus giving a precise typology. Hence, parameters considered based on 3D law as indices for carrying out cluster analysis are Density (plot ratio), Diversity (land use mix, development mix), and Design (proportion of transportation area and intersection density), as shown in **Table 3.1.**

Table 3.1: Parameters considered for Cluster Analysis

S.No	TOD Component	Parameters
1	Density	Plot Ratio
2	Diversity	Land use Mix
		Development Mix
3	Design	% of Transportation Area
		Intersection Density

K-Means Cluster analysis is considered in the present study for the classification of data. The main aim is to categorize n objects into k number of clusters (k > 1) by using p variables (p > 1). Euclidian distances are found in the K-Means clustering to find the distances of the objects from the centroids. Grouping is done by minimizing the Sum of Square Distance between data and the corresponding cluster centroid, given by eq.3.10.

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \left\| x_i^j - c_j \right\|^2 \qquad (3.10)$$

Where x_i is the data point of the j^{th} cluster and C_j is the centroid of the j^{th} cluster

3.4 Evaluation of TOD

Evaluation is the most critical segment in any project, where success or failure is based on this analysis. In the present study, evaluation is performed in two different ways; 1) measuring TOD and 2) Impact assessment of TOD.

3.4.1 Measuring TOD Index

Measuring TOD is to understand the TOD characteristics for planning or evaluation at a given site. This can be achieved by calculating the TOD index as an essential step. TOD index is to know how TOD is behaving and fulfilling its goals, on a scale of about 0-100. For this analysis, the selection of criteria plays a significant role. The criteria are selected in two steps. The first step is a thorough literature survey, and the second is preferences observed by planning authorities. Thus, five main criteria have been selected to measure TOD: Transit node capacity, Density, Economic development, Land use diversity, and Street design. These criteria cover different aspects of TOD sufficiently while being measurable and quantifiable at the same time. Criteria and their indicators considered in the present study are listed below.

1. Criteria: Transit node Facility
    a. Transit mode
    b. Connectivity
    c. Docking Stations
2. Criteria: Density
    a. Population Density
    b. Employment Density
3. Criteria: Economic Development
    a. Plot Ratio
4. Criteria: Land use Diversity
    a. Mixed Index
    b. Development Mix
5. Criteria: Street Design
    a. Percentage of Transportation Area
    b. Intersection Density
    c. Foot Path

d. Bicycle Lanes

e. Parking Facility

For each criterion, the indicators are assigned by weightage based on making the place into TOD. Then each criterion is estimated based on the on-site visit (or survey conducted), in case of future TOD values are estimated based on design proposals. After that, each indicator (S) is converted to 0-1 scaling: each indicator in the data set is recalculated as given in eq. 3.11

$$S_{xn} = \frac{V_x - \min(V_x)}{\max(V_x) - \min(V_x)} \qquad (3.11)$$

Where,

S_x = Scale value of the 'x' Indicator of TOD component

n = No. of TODs in the data set

V = Value of the indicator

This method allows variables to have different means and standard deviations but equal ranges. In this case, there is at least one observed value at 0 and 1 endpoints. After achieving the 'S' value, the final TOD index is obtained by multiplying 'S' with the assigned weights.

3.4.2 TOD Impact Assessment

Hedonic Price Method

The hedonic method is a regression technique used to estimate the prices of qualities or models that are not available in the market for particular periods but whose prices are needed to construct price relatives.

A hedonic price model is developed to estimate the impact of the metro on residential property values. In order to achieve a hedonic price model, influential factors such as building size, number of floors, and distance from the station are considered. Two models are developed for two individual stations. Each model is expressed in semi-log linear form and given by eq.3.12

$$\log(P) = \beta 0 + \beta 1*(NF) + \beta 2*(AB) + \beta 3*(DM) + \beta 4*(DS) + \beta 5*(FQ) \qquad (3.12)$$

Where P = Property Value

NF = Number of floors/storied residential property

AB = Gross area of the Building in sq.m

DM = Radial / Network distance from the property to Metro station in meters

DS = Network distance from the property to school in meters

FQ = frequency of metro train in minutes

Property Value Assessment

To estimate the impact of TOD, how property values have changed over a period during the project period is studied. In this study, residential property value has been considered before and after the construction of metro rail at four locations to observe the differences.

3.5 Summary

In this chapter, a detailed research methodology is discussed. The whole framework is broadly segmented into several steps and explained in detail. Step 1) Identification of feasible TOD locations: Spatial Multi-Criteria Analysis and Analytical Hierarchy Process (AHP- ranking approach) are adopted to identify the most critical/feasible TOD locations to simplify the implementation process for the authorities; Step 2) Deriving TOD typology: Here, TOD typology is proposed in two different levels, one is at the city level, and other is at sub-area level, for better understanding of exiting built-environment conditions; Further, measuring of TOD Index is explained for the evaluation process to know how TOD is performing before and after the design proposal. Finally, the impact assessment method is explained through the Hedonic Price method and property value assessment.

Chapter 4

Study Area and Data Collection

4.1 General

Transit-Oriented Development (TOD) is the concept of future urban living conditions. It is a new trend and technique which has gained popularity to implement all around the world. Already, developed countries have well implemented and witnessed the success of TOD through sustainable measures. Being a developing country, India is also looking forward to adopting these models to their cities. In this line, Hyderabad Metropolitan Area (HMA) is considered as the study area to carry out the present research work.

4.2 Study Area

HMA is one of the most emerging cities in India. It is ranked 6th in population and 3rd in the area among the metropolitan cities in India. HMA population is about 10 million as of 2019 and is expected to be 19 million by 2041 (CTSHMA, 2013). HMA has an area of 7,200 Sq Km. Initially, the study area is commissioned by the Municipal Corporation of Hyderabad (MCH); as growth occurred and urban sprawl increased tremendously, then it is converted to the Greater Municipal Corporation of Hyderabad (GHMC). Further, in 2008, with extended area Hyderabad Municipal Development Authority (HMDA) is formed, as represented in **Figure 4.1**.

Registered vehicles in HMA are 28.2 lakhs (the year 2017), with a growth rate of 11% per year. Road length is 5,500 km, which includes Outer Ring Road (ORR) with a length of 158 km, Inner Ring Road (IRR), and a radial road of 33 numbers. Authorities had the vision to form the ring and radial concept for HMA. Aside, the average journey speeds in the core area in peak hours are less than 20 kmph. All major arterial roads face traffic congestion with volume capacity ratios varying from 0.9 to 1.3 (CTSHMA, 2011). However, with the increase in travel demand in an urban area, HMA faces several problems such as traffic congestion, poor quality of the environment, and poor access to public transportation. To mitigate these problems, authorities have planned for Mass-Rapid Transit System (MRTS) with 72 km. In addition to this, HMA has other transit systems known as Multi-Modal Transport System (MMTS), which is present since 2003, with 44 km and 36 stations. As MRTS is introduced recently, it is an excellent opportunity to study and explore the implantation of TOD to make the city more sustainable for future generations.

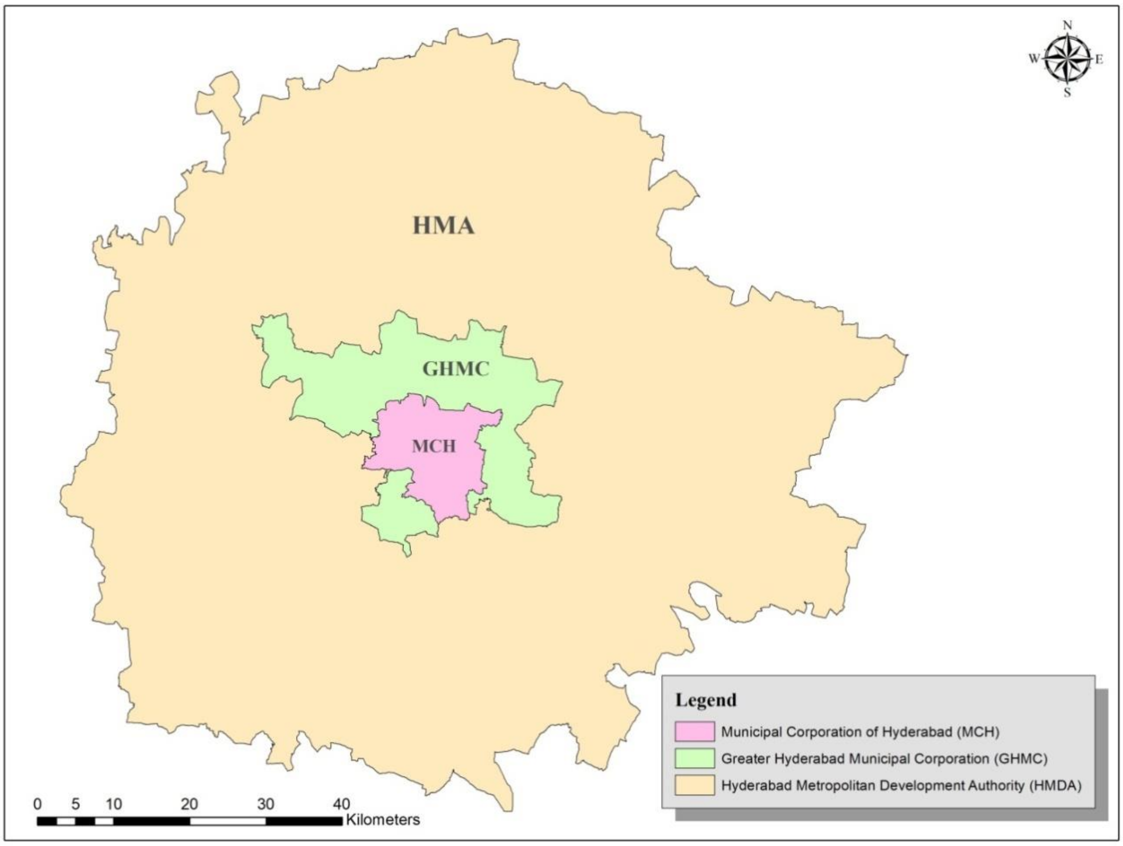


Figure 4.1: Jurisdiction boundaries of HMA

4.2.1 Data collection of HMA

Data required, such as Road network inventory, public transportation network data, and land use data for the study area (HMA), is collected from HMDA. The data is in shapefile format (.shp), which supports analyzing the ArcGIS platform. The complete road network of HMA is identified and delineated by links and nodes. A unique number for its identity notes each node, and the link is to be connected from and to the node. After data collection, data is attached to respective links by adding attributes to each link, as shown in **Figure 4.2**. Public transportation network data like bus route network details, MMTS, and MRTS are presented in **Figure 4.3.** Detailed existing land use map is collected and represented in **Figure 4.4**.

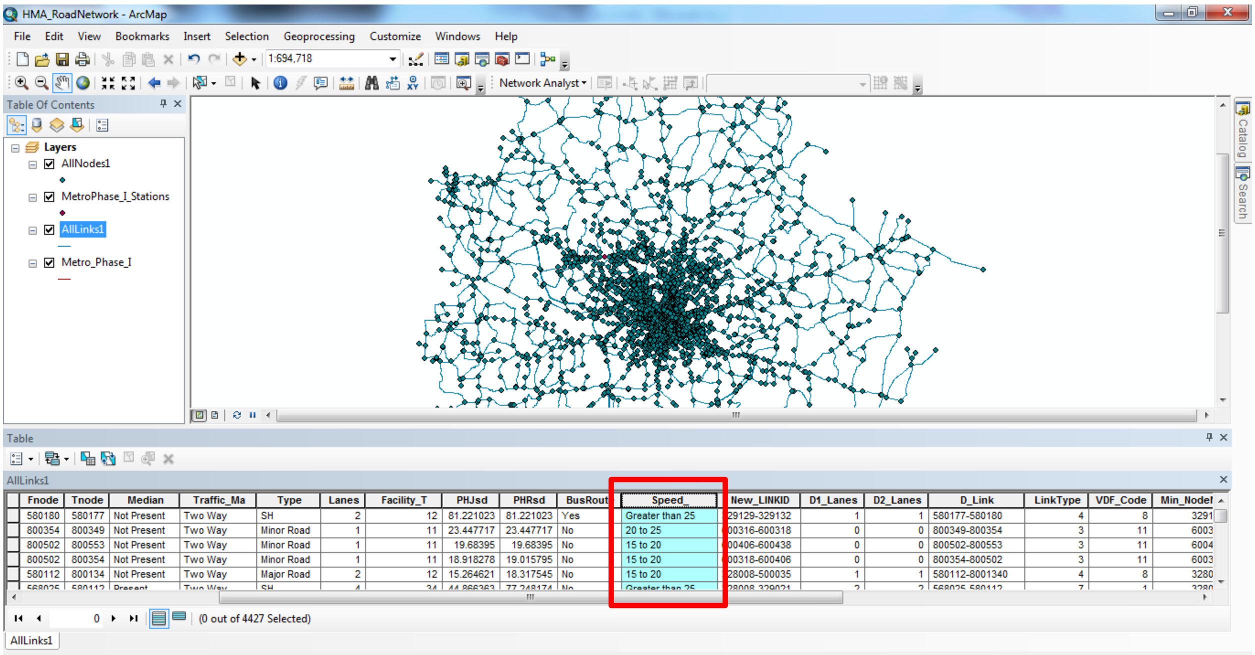


Figure 4.2: Road Network Inventory data of HMA

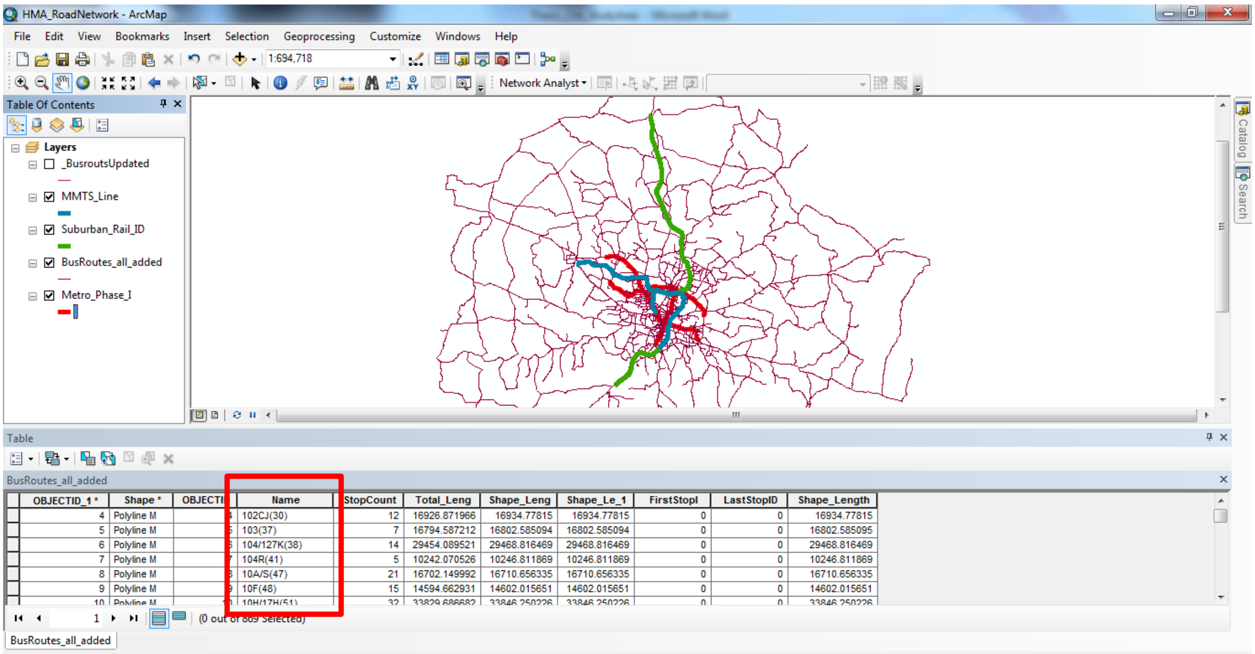


Figure 4.3: Public Transportation Network data of HMA

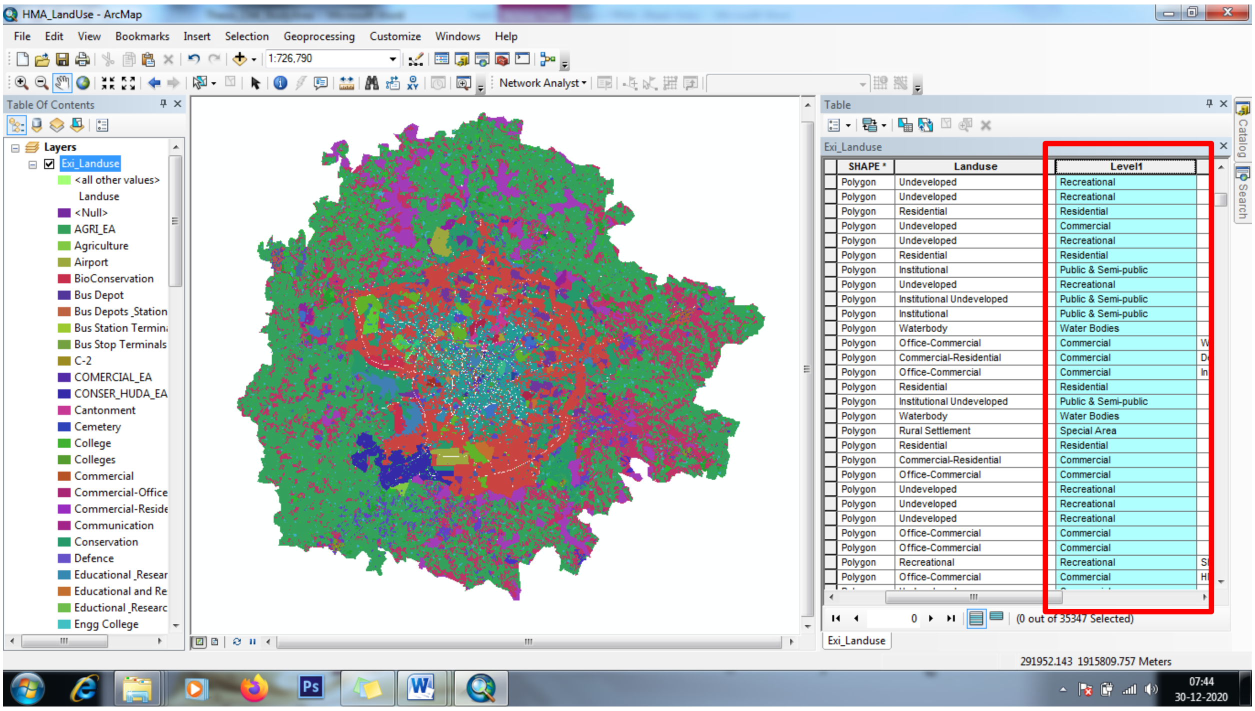


Figure 4.4: Land use details of HMA

4.2.2 Demographical Features of HMA

It is necessary to understand the demographical features like population, employment before proceeding with planning efforts. **Figures 4.5 and 4.6** show the population and employment settlements distribution in HMA; it is observed that within GHMC, the densities are higher than that of the rest of HMA. The maximum and average population densities within GHMC are about 700 and 260 persons per hectare, respectively. Whereas in the rest of HMA, an average population density is eight persons per hectare only.

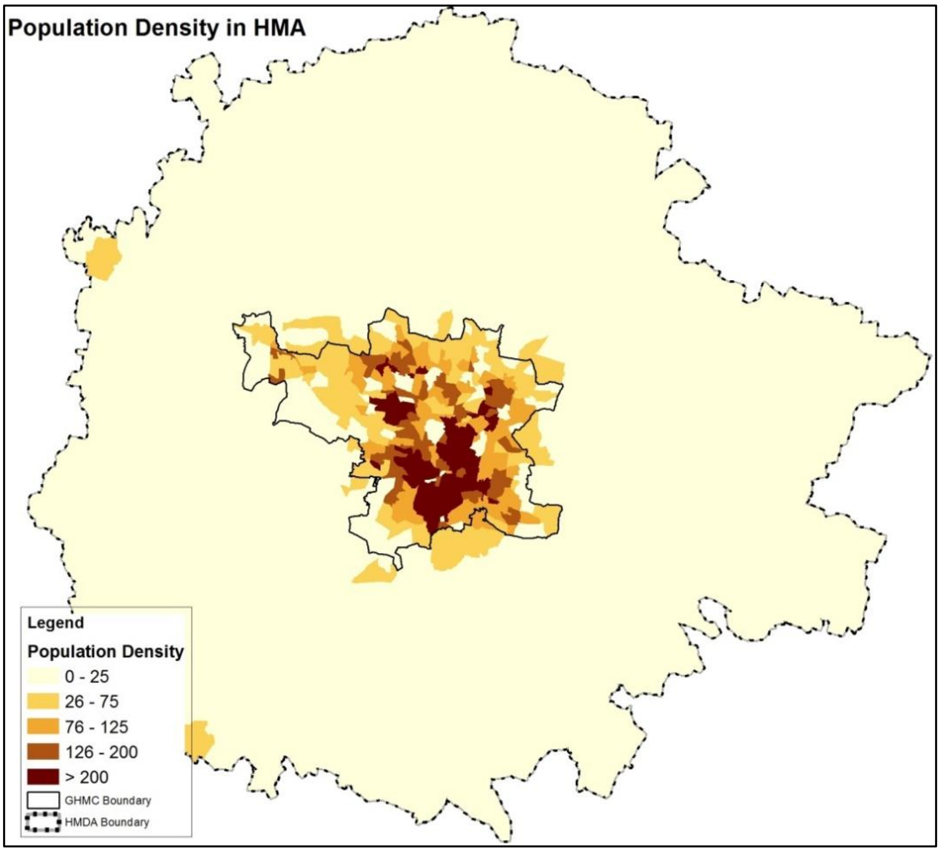


Figure 4.5: Population Distribution across Study Area

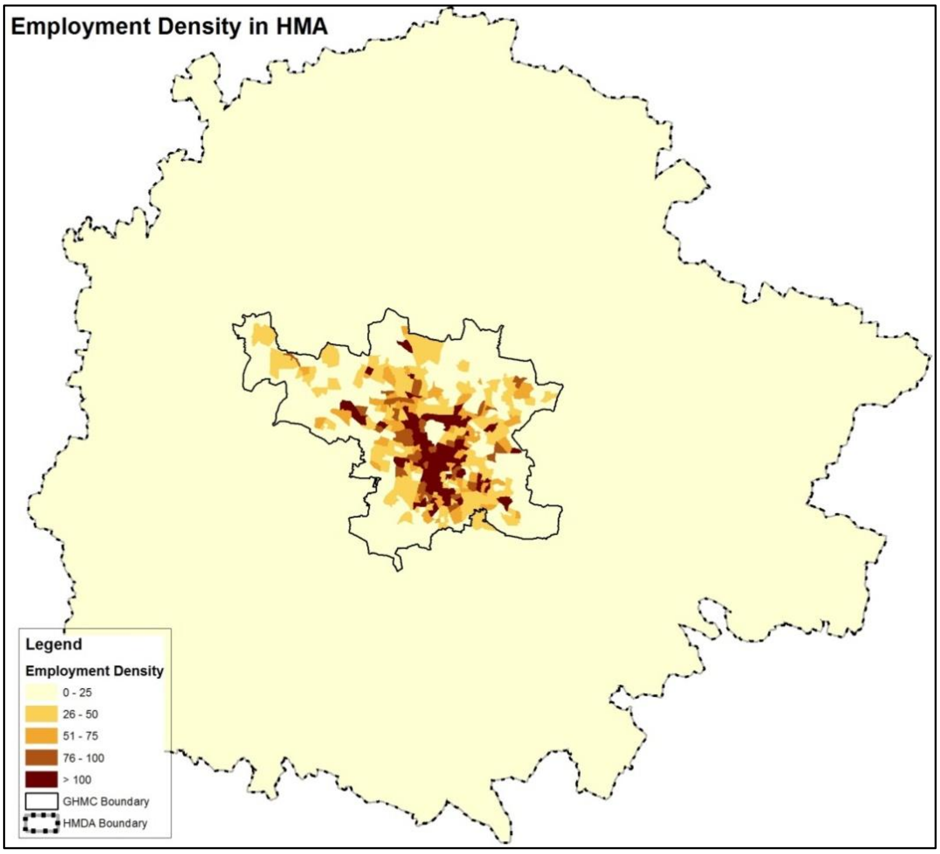


Figure 4.6: Employment Distribution across Study Area

4.2.3 Transportation Systems in HMA

Road Network

HMA road network comprises of different categories of roads viz. Expressways, National Highways, State Highways, Major District Roads, Other District Roads, and Village roads. The city has a radial and orbital form of the road network. Three National Highways, NH-65 (connecting Vijayawada on the eastern side and Mumbai in the west), NH-44 (connecting Bangalore in the south and Nagpur in the north), and NH-163 (Hyderabad to Warangal), pass through the CBD of the city. Five State Highways starts from the city center and diverge radially, connecting several towns and district headquarters within the State in all directions. The road network of Hyderabad consists of an Outer Ring Road (ORR) with an 8-lane expressway and an Inner Ring Road (IRR) with a 6-lane configuration, as shown in **Figure 4.7**.

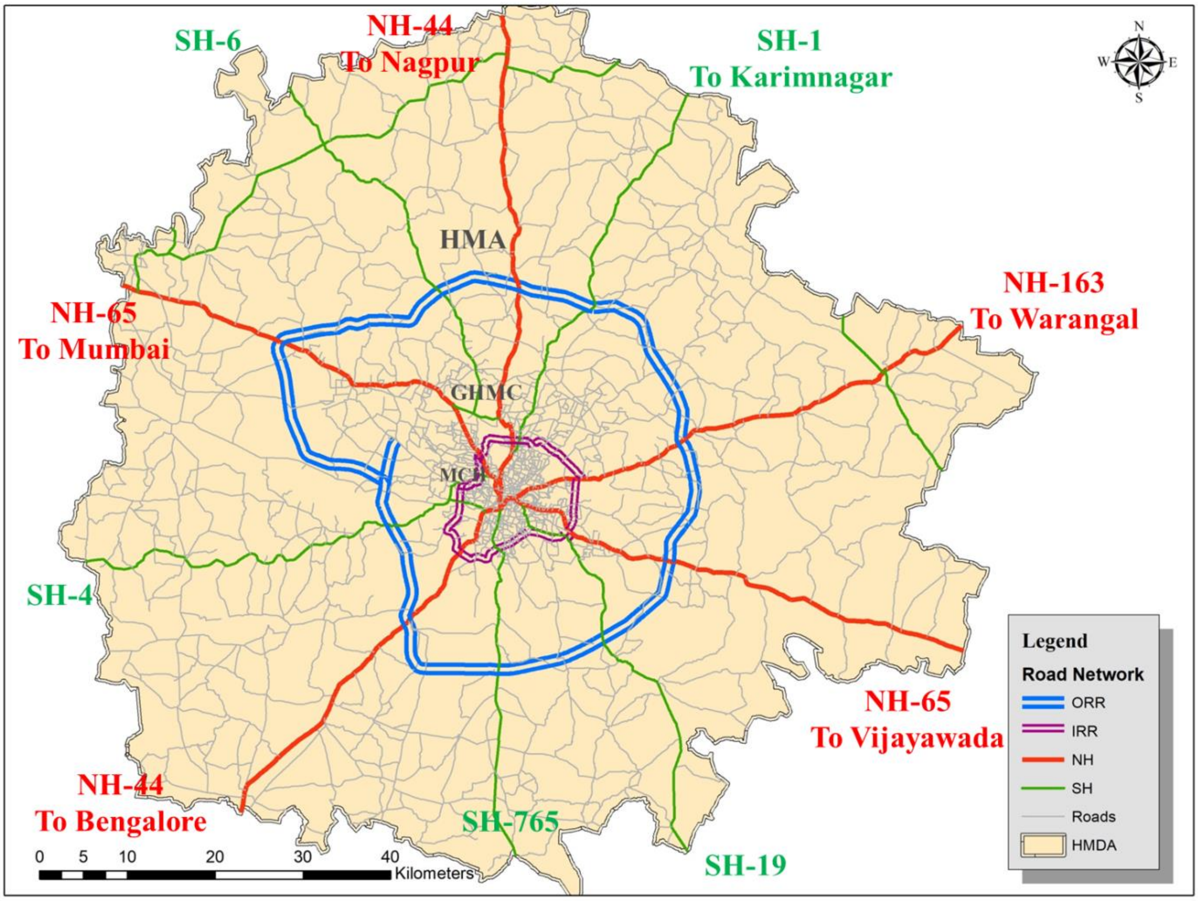


Figure 4.7: Transportation Road Network of HMA

Public Transport Network

At present, three types of public transport systems are operating in HMA. The first one is the bus system being exclusively operated by the State Government (TSRTC). More than 1200 bus services are provided on the roads. HMA has the densest bus network in the country, with a fleet of more than 3000 buses. The second one is MMTS, with 44km, operating on existing intercity rail tracks itself. MMTS is gaining popularity in terms of capturing demand, year by year, from the year 2003. The third one is MRTS, which is under construction now, and few tracks are operating and running successfully. Currently, MRTS has three corridors; 1) Miyapur-LB Nagar (29 km long) with 27 stations, 2) JBS-Falaknuma (15 km long) with 15 stations, and 3) Nagole-Raidurg (28 km long) with 24 stations. As of now, the share of public transportation in HMA is about 40%, and it is targeted to 75% by 2041, according to the study conducted by HMDA (CTSHMA, 2011). The public transportation network is represented in **Figure 4.8**.

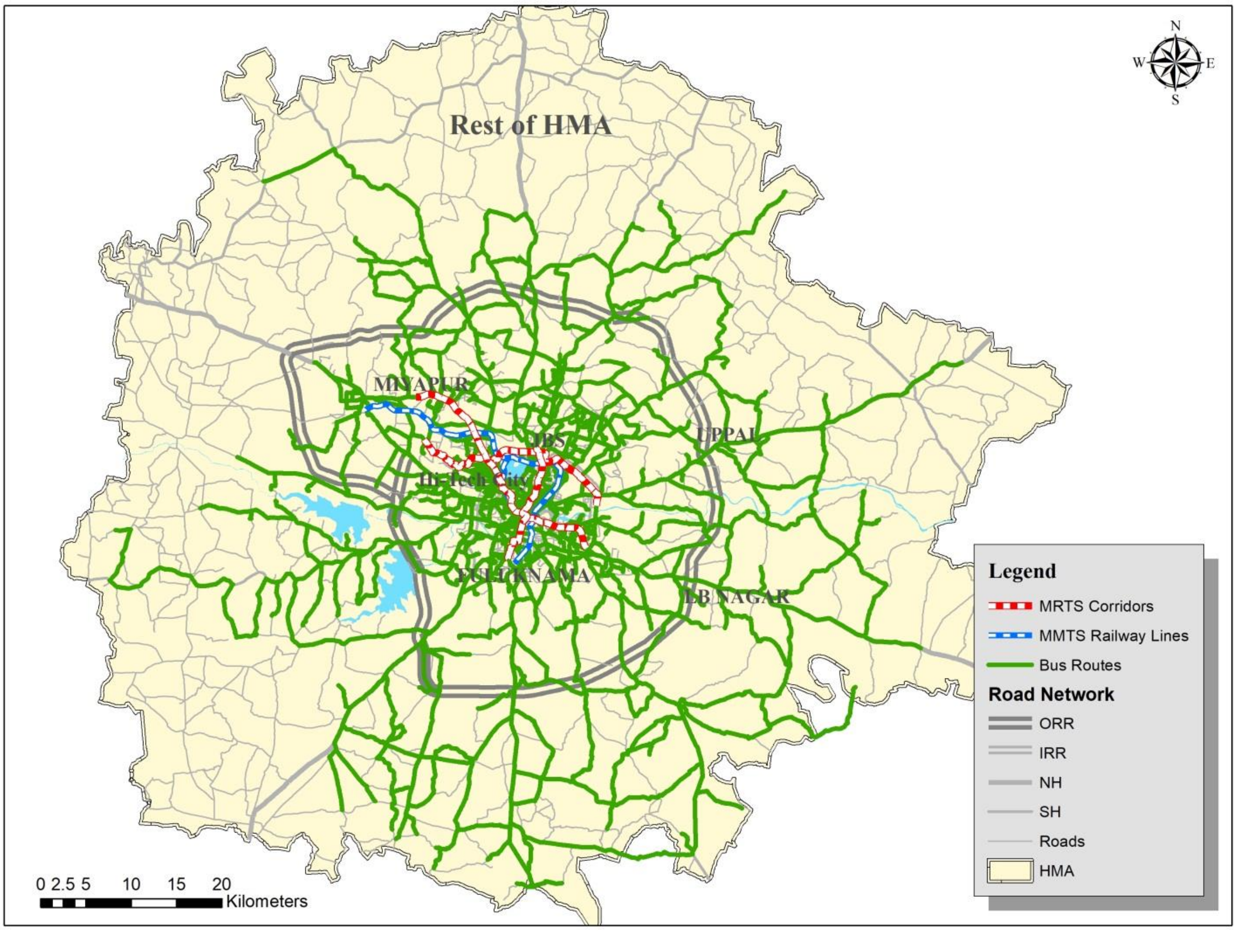


Figure 4.8: Public Transportation Network of HMA

4.3 Sub-Area: Gachibowli – Hi-Tech city Area (GHA)

The purpose of considering Sub-area is to carry out in-depth analysis and understanding of ground realities for better TOD planning strategies. For this area, detailed and complete data has been collected related to and influencing the TOD characteristics regarding land use and transportation network. Gachibowli-Hitech city Area (GHA) is a part of HMA located on the northwest side, and the area measured is about 46 sq.km, as shown in **Figure 4.9**. GHA is the fastest growing area in HMA and has compact building densities, and is connected with a good network of transport facilities such as city buses, MMTS trains, and phase-1 metro facility. This offers much scope to study in TOD implementation because it contains nearly half of the vacant land for development, which is a perfect opportunity to develop the area as semi-green field development.

Gachibowli Financial District is one of the leading Information Technology, Engineering, Health informatics, and Bioinformatics hubs of India situated in Hyderabad, Telangana. Cyber Towers, L&T Infocity, HICC, Mindspace IT Park, Ascendas IT Park, RMZ Futura IT Park, Tech Mahindra Campuses, Microsoft Hyderabad Campus, Facebook Hyderabad, The TCS Deccan Park Campus, IIIT Hyderabad, Hardware Park, etc. offices are in this area. The area has emerged as a symbolic heart of Cosmopolitan Hyderabad.

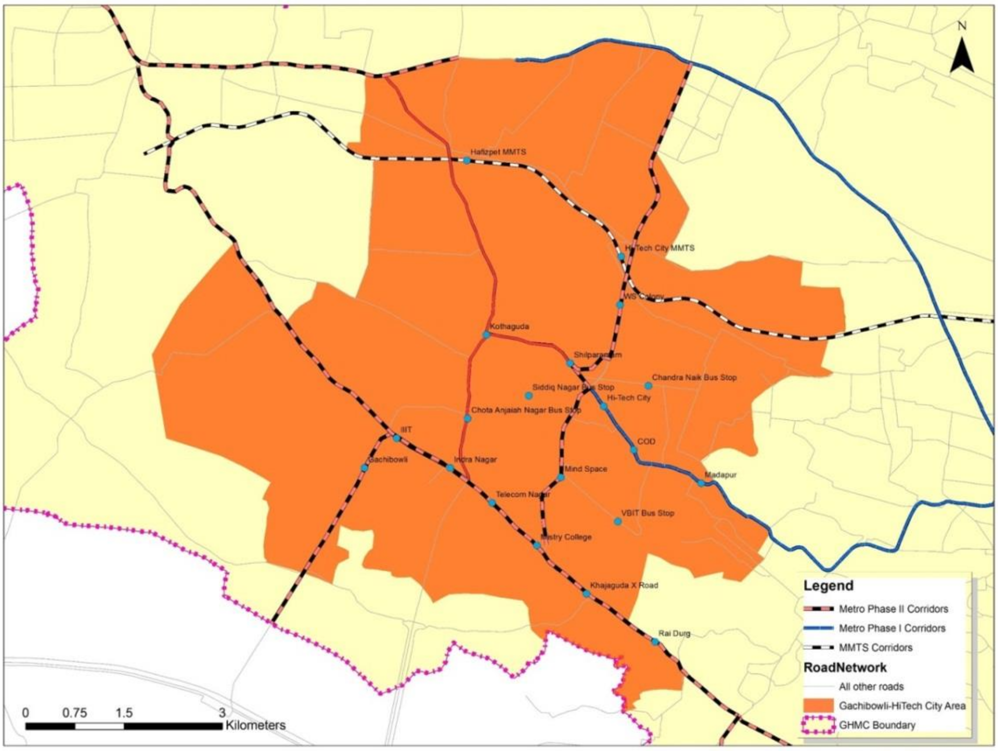


Figure 4.9: Location map of GHA

From the reconnaissance survey of the study area, the transportation corridors are identified, and 20 transit stations or TOD nodes are selected. Most of them are well developed and offer much further scope through vast vacant space. Some are proposed in consideration of future scope. The identified TOD nodes and their location on transit corridors are presented in **Table 4.1.**

Table 4.1: List of Location of TODs in GHA

Node Type and Location	TOD ID	TOD Name
Nagole – Shilparamam (Phase - 1 Metro Line)	1	Madhapur Metro Station
	2	COD Metro Station
	3	Hi-Tec City Metro Station
	4	Shilparamam Metro Station
JNTU – Gachibowli (Phase - 2 Metro Line)	5	WS Colony Metro Station
	6	Mind Space Metro Station
Gachibowli–Lakdikapul (Phase - 2 Metro Line)	7	Gachibowli Metro Station
	8	IIIT Metro Station
	9	Indra Nagar Metro Station
	10	Telecom Nagar Metro Station
	11	Mistry College Metro Station
	12	Khajaguda X Road Metro Station
	13	Raidurgam Metro Station
Bus Stops	14	VBIT Bus Stop
	15	SiddiqNagar Bus Stop
	16	ChotaAnjaiahNagar Bus Stop
	17	Chandra Naik Bus Stop
	18	Kothaguda Bus Stop
MMTS Stations	19	Hi-Tec City MMTS Station
	20	Hafeezpet MMTS Station

4.3.1 Data collection of GHA

For sub-area (GHA), data required for collection is categorized into two methods viz., land use survey and road network inventory. The methods are explained in detail in this section. The other data, like the number of intersections, is collected through 'Google earth.' Data collection techniques for GHA are presented in **Table 4.2.**

Table 4.2: Data collection technique

Sl. No.	Description of Parameter	Source
1	Land Use Data	Primary Survey – Land Use Survey
2	Plot Ratio	Primary Survey – Land Use Survey
3	The proportion of Transportation Area	Primary Survey – Road Network Inventory
4	Intersection Density	Secondary Source – Google Earth
5	Footpaths	Primary Survey – Road Network Inventory
6	Bicycle Lanes	Primary Survey – Road Network Inventory
7	Population Data	Secondary Source – CTS Hyderabad-2011
8	Employment Data	Secondary Source – CTS Hyderabad-2011
9	TOD Node	Secondary Source – Hyderabad Metro

Land Use** S**urvey

Land Use data provides an opportunity to evaluate the amount of brownfield area available, the size of each building, vacant space, unutilized spaces, water bodies, parks, etc. Land use is one of the critical parameters for defining TOD.

Before conducting the survey, the land use classification is done based on several comprehensive traffic and transportation survey, comprehensive mobility plans, and CMP tool kit reports. There are Residential, Commercial, Office, Public, and Semi-Public amenities, Institutional and Mixed Land Use. After categorizing, the land uses are marked in google earth, and for these corresponding areas, data is collected from the field with the help of enumerators. The template of the land-use survey is presented in Annexure - I. From this survey, compactness or densities of buildings, their use, plot ratio, parking criteria adopted in the area, etc., are observed. Improvement in the transport system leads to economic development and hence affects the land value. It is observed that about 40-50% of the undeveloped area is available in GHA. Land Use data is presented in **Table 4.3**.

Table 4.3: Land use details in GHA

Sl.No.	TOD Name	RA (%)	CA (%)	IA (%)	ML (%)	Off (%)	PASP (%)	BA (%)
1	Madhapur Metro Station	16.11	8.71	2.12	2.15%	6.83	0.95	36.87
2	COD Metro Station	30.06	7.46	2.37	2.81	9.33	1.09	53.13
3	Hi-Tec City Metro Station	13.19	4.56	6.25	0.66	19.38	1.52	45.56
4	Shilparamam Metro Station	6.28	2.96	0.1	0.5	4.97	1.54	16.34
5	WS Colony Metro Station	0.32	1.63	0	0.19	0.14	0.25	2.52
6	Mind Space Metro Station	14.55	1.31	0.09	0.23	24	0.16	40.33
7	Gachibowli Metro Station	17.82	0.76	2.93	0	0.46	1.98	23.96
8	IIIT Metro Station	18.7	2.81	8.64	0.28	18.23	2.62	51.28
9	Indra Nagar Metro Station	31.16	3.35	0.12	2.15	2.48	1.76	41.01
10	Telecom Nagar Metro Station	20.96	4.92	9.58	2.15	0.18	1.05	38.84
11	Mistry College Metro Station	27.52	5.31	3.33	0.79	3.45	0.83	41.22
12	Khajaguda X Road Metro	9.61	3.8	0.5	0.06	0.58	0.14	14.69
13	Raidurgam Metro Station	26	0.98	4.96	1.18	0.42	5.01	38.54
14	VBIT Bus Stop	31.92	1.1	0	0	16.7	0.55	50.26
15	SiddiqNagar Bus Stop	26.51	1.95	0	0	34.93	0.16	63.55
16	ChotaAnjaiahNagar Bus Stop	29.77	4.62	0.74	2.83	2.15	5.55	45.65
17	Chandra Naik Bus Stop	23	6.22	2.51	0.65	5.18	0.64	38.2
18	Kothaguda Bus Stop	31.11	4.22	0.09	2.04	3.78	2.82	44.06
19	Hi-Tec City MMTS Station	6.95	0.7	0.17	0.78	1.58	0.28	10.46
20	Hafeezpet MMTS Station	36.1	2.3	1.64	11.54	0.22	1.16	52.96
*RA- Residencial Area; CA- Commertial Area; IA- Institutional Area; ML- Mix Landuse; Off- Office; PASP- Public And Semi-Public; BA- Built-up Area								

Road Network Inventory Survey

The characteristics of the existing transport network system are obtained by conducting a road network inventory survey. A total of 165 km of road network data details are surveyed with the help of enumerators in GHA. Carriageway, median, footpaths, bicycle lanes, Right of Way

(ROW), type of intersections, bus route facilities, etc., details are collected from the field and furnished in **Table 4.4**. The survey template for the road network inventory survey is presented in Annexure-II.

Table 4.4: ROW details of each TOD

Sl.No.	TOD Name	Distribution of Road network (km) by Right of Way					Total Length (km)
		<10m	10-20m	20-30m	30-50m	≥50m	
1	Madhapur Metro Station	3.48	6.78	3.1	0	0	13.36
2	COD Metro Station	11.72	1.5	0	0.97	0	14.19
3	Hi-Tec City Metro Station	2.85	1.58	0	1.64	0	6.07
4	Shilparamam Metro Station	0.49	2.1	0	1.46	0	4.05
5	WS Colony Metro Station	0	0.11	1.01	0	0.344	1.46
6	Mind Space Metro Station	1.92	1.47	0	2.37	0	5.76
7	Gachibowli Metro Station	0	2.34	0.98	0.85	0	4.17
8	IIIT Metro Station	2.55	0.8	0	1.75	0	5.10
9	Indra Nagar Metro Station	5.71	2.74	0.48	0.97	0.81	10.71
10	Telecom Nagar Metro Station	7.89	0.39	0	0.34	0.54	9.16
11	Mistry College Metro Station	1.48	2.55	0.38	0.61	0.97	5.99
12	Khajaguda X Road Metro	3.39	0.91	0.53	1	0	5.83
13	Raidurgam Metro Station	5.7	0.47	0.82	0.18	0	7.17
14	VBIT Bus Stop	0.65	1.3	0	1.48	0	3.43
15	SiddiqNagar Bus Stop	6.95	0	2.84	0	0	9.79
16	ChotaAnjaiahNagar Bus Stop	9.3	3.33	0.47	0.9	0	14.00
17	Chandra Naik Bus Stop	9.21	4.01	0.95	0	0	14.17
18	Kothaguda Bus Stop	3.29	2.19	0.51	1.21	0	7.20
19	Hi-Tec City MMTS Station	2.91	1.51	1.34	0.9	0.7	7.36
20	Hafeezpet MMTS Station	10.167	1.15	0.15	0.87	0	12.34

The footpaths information on either side of streets in the road network is obtained by conducting the Road Network Inventory Survey in the field is presented in **Table 4.5**.

Table 4.5: Footpaths details in each TOD area

Sl.No.	TOD Name	Road Length (km)	Footpath Length (km)		FootpathLength (km)	Proportion of Footpath Length (%)
			LHS	RHS		
1	Madhapur Metro Station	13.36	1.51	0.65	2.16	8.09
2	COD Metro Station	14.18	0.00	0.00	0.00	0.00
3	Hi-Tec City Metro Station	6.08	1.54	1.54	3.08	25.34
4	Shilparamam Metro Station	4.05	1.12	1.12	2.24	27.66
5	WS Colony Metro Station	1.47	0.95	0.95	1.9	64.67
6	Mind Space Metro Station	5.76	1.53	1.53	3.06	26.58
7	Gachibowli Metro Station	4.18	2.07	0.85	2.92	34.97
8	IIIT Metro Station	5.09	1.29	1.29	2.58	25.33
9	Indra Nagar Metro Station	10.81	0.00	0.00	0.00	0.00
10	Telecom Nagar Metro Station	9.16	0.88	0.88	1.76	9.61
11	Mistry College Metro Station	5.99	0.61	0.00	0.61	5.09
12	Khajaguda X Road Metro	5.83	0.00	0.00	0.00	0.00
13	Raidurgam Metro Station	7.18	0.00	0.00	0.00	0.00
14	VBIT Bus Stop	3.42	0.55	0.55	1.1	16.06
15	SiddiqNagar Bus Stop	9.79	1.81	1.81	3.62	18.49
16	ChotaAnjaiahNBusStop	14.00	0.9	0.9	1.8	6.43
17	Chandra Naik Bus Stop	14.17	0.95	0.95	1.9	6.70
18	Kothaguda Bus Stop	7.21	0	0.53	0.53	3.68
19	Hi-Tec City MMTS Station	7.35	0.81	0.81	1.62	11.02
20	Hafeezpet MMTS Station	12.34	0.62	0.62	1.24	5.02

It is observed that COD Metro Station, Indra Nagar Metro Station, Khajaguda Metro Station, and Raidurgam station areas do not have any footpath facilities.

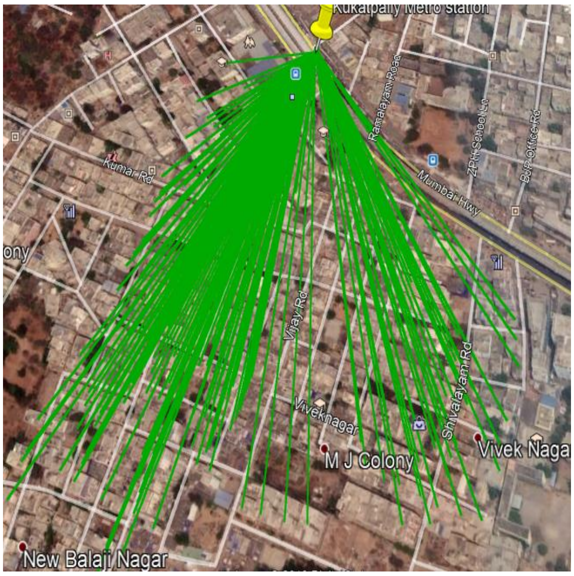
Intersection Density represents the network connectivity levels of an area. The number of intersections is counted using Google Earth and presented in **Table 4.6**.

Table 4.6No. of Intersections in each TOD

Sl. No.	TOD Name	Eff. TOD Area (ha)	No. of Intersections
1	Madhapur Metro Station	78.57	71
2	COD Metro Station	74.81	75
3	Hi-Tec City Metro Station	65.83	27
4	Shilparamam Metro Station	75.26	19
5	WS Colony Metro Station	72.41	2
6	Mind Space Metro Station	78.57	11
7	Gachibowli Metro Station	70.08	10
8	IIIT Metro Station	69.26	10
9	Indra Nagar Metro Station	70.37	57
10	Telecom Nagar Metro Station	77.85	51
11	Mistry College Metro Station	77.85	26
12	Khajaguda X Road Metro Station	78.57	45
13	Raidurgam Metro Station	78.57	45
14	VBIT Bus Stop	78.57	4
15	SiddiqNagar Bus Stop	74.51	74
16	ChotaAnjaiahNagar Bus Stop	74.39	73
17	Chandra Naik Bus Stop	72.91	85
18	Kothaguda Bus Stop	78.57	23
19	Hi-Tec City MMTS Station	72.41	52
20	Hafeezpet MMTS Station	78.57	79

Property value Assessment Survey

Data is collected through a questionnaire survey for the residential properties located within a 1000m radial distance from the station. Two hundred eight samples are collected at Ameerpet station, and 200 samples are collected at Kukatpally station. The distance of each property from the station is measured with the help of Google Earth Pro software, as shown in **Figures 4.10 and 4.11**. Also, the distance to CBD and distance to the nearest Park/School are measured, which are shown in **Figures 4.12 and 4.13**. The radial distance and network distance are measured, and the results are compared. The questionnaire format is given in Annexure -III. Sample data is presented in **Table 4.7**.



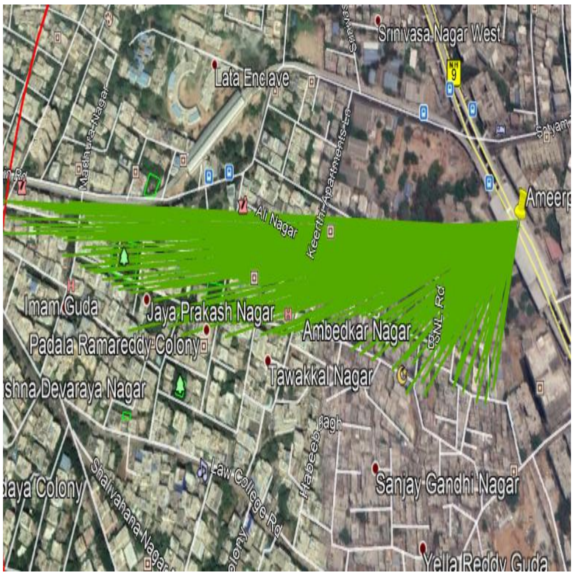


Figure 4.10: Distance from the metro station to properties in Kukatpally

Figure 4.11: Distance from the metro station to properties in Ameerpet

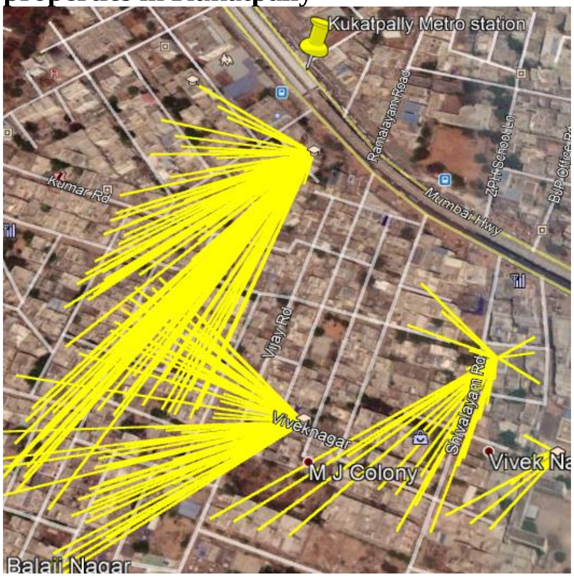


Figure 4.12: Distance to nearest school/Park for properties located in Kukatpally

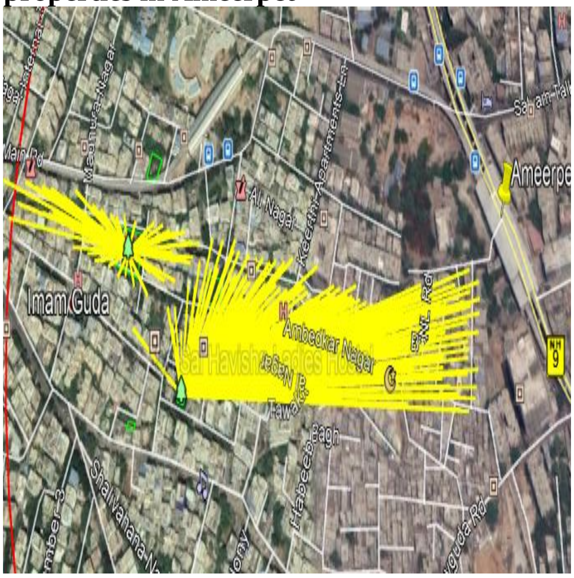


Figure 4.13: Distance to nearest school/Park for properties located in Ameerpet

Table 4.7: Sample data collected

Sl.no.	No.of floors	Age of building	Lot size (sq. Yd)	Distance to metro station (feet)	Distance to CBD (feet)	Distance to school/ park (feet)	No. of nearby stations	Frequency	Property value
1	2	10	491.18	319.24	15960.85	146.77	1	16	7367700
2	4	16	434.43	418.63	15978.74	116.78	1	16	6516450
3	5	18	682.40	422.91	15924.62	224.05	1	16	10236000
4	4	16	235.09	465.48	15878.82	215.01	1	16	3526350
5	4	16	514.43	498.88	15867.82	216.73	1	16	7716450
6	4	14	464.73	545.17	15849.66	239.37	1	16	6970950
7	1	16	264.20	529.40	15791.62	336.27	1	16	3963000

4.4 Summary

In this chapter, a brief explanation of the study area and data collection techniques is presented. A comprehensive view related to demographical features and transportation systems in the study is given. Road networks and public transportation networks are explained with the help of maps. For detailed analysis, a sub-area (GHA) is considered, and data is collected and furnished. Residential property values, along with distances, are collected for assessment purposes. Further, data analysis and planning strategies via typology are mentioned in chapter 5.

Chapter 5

TOD Planning and Typology

5.1 General

Transit-Oriented Development (TOD) concept and designs are successfully implemented in developed countries like United States, Australia, and the United Kingdom. Being motivated by them, developing countries are looking forward to adopting similar concepts. However, these TOD concepts are not directly transferable to developing countries due to demographic, social, economic, environmental, political, and urbanization, which plays a major role in planning and implementing new urban development concepts like TOD. Hence, the planning and implementation strategies have to be derived separately, at least at the national level. In this study, a framework is proposed for TOD implications. Hyderabad, India, is considered as a case study to execute the proposed framework. The first step in the framework is the identification of feasible TOD locations and prioritization of TODs. Then, the typology study is carried out for better planning and design.

5.2 TOD Planning Analysis Approach

In developing countries, long-term urban planning concepts like TOD will always be a constraint considering financial viability. Optimal plans will help the authorities to overcome this issue. So, the implementation of TOD at a specific location, which may potentially develop, is identified. Thus, the framework is proposed in two approaches; 1) Identification of feasible TODs and 2) prioritization of TODs.

5.2.1 Identification of feasible TODs

To find out feasible TOD locations, SMCA is used. As mentioned in chapter 3, the study area is bifurcated into two. One is core urban, and the other is sub-urban. In the subsequent sections, the analysis and outcomes of each area using the GIS platform are discussed.

5.2.1.1 Feasible Urban TODs

Transit Nodes in GHMC Area

GHMC (core urban area) majorly has three types of transit systems, namely MRTS (metro rail), MMTS (local trains), and road-based bus service systems. Metro rail consists of 3 corridors (with a length of 72 km) covering 66 transit stations. MMTS is another rail-based transit system, which operates on existing intercity rail tracks. MMTS track length is 43km with 27 transit stations. A road-based bus service system has a vast network of about 700km with more than 1200 route services. Among them, the routes with an average traffic stream speed of 25kmph are taken into consideration for TOD locations. Also, the market potential and placement of these locations to distribute across the peripheral of GHMC is considered. **Figure 5.1** shows all transit nodes considered for analysis, and the list is presented in **Table 5.1**.

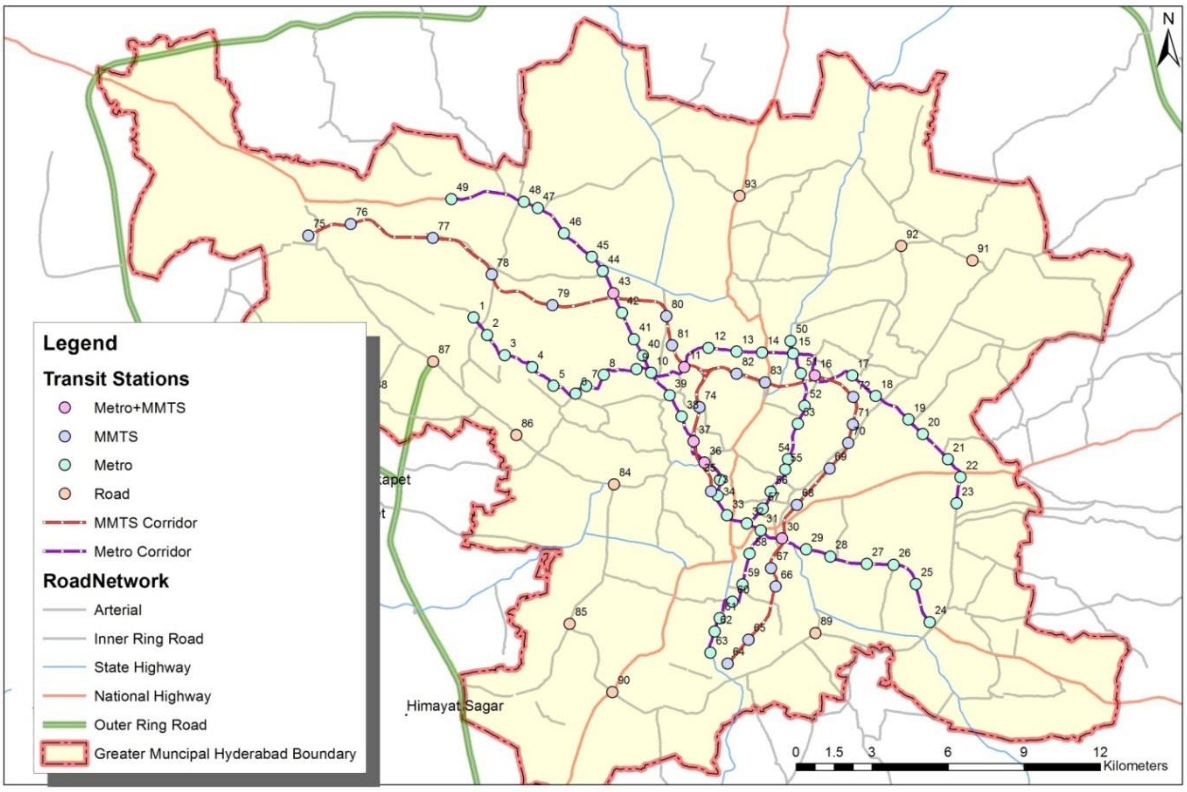


Figure 5.1: Transit Nodes considered in GHMC area

Table 5.1: List of Transit stations in GHMC

S.No	Transit Station	S.No	Transit Station	S.No	Transit Station	S.No	Transit Station
1	Shilparamam	26	Chaitanyapuri	51	SecunderabadM	76	Chandanagar
2	Hitech city	27	Dilsukhnagar	52	Gandhi hospital	77	Hafeezpet
3	COD	28	Musarambagh	53	Musheerabad	78	Hitec city
4	Madhapur	29	New market	54	Rtc x roads	79	Borabanda
5	Peddamma temple	30	Malakpet	55	Chikkadpally	80	Fatehnagar
6	Jubileecheck post	31	Mgbs	56	Narayanguda	81	Nature cure
7	Road no.5	32	OU medical college	57	Sultan bazaar	82	Sanjeev park
8	Yusufguda	33	Gandhi bhavan	58	Salarjungmuseum	83	James street
9	Madhuranagar	34	Nampally	59	Charminar	84	Retibowli
10	Ameerpet	35	Assembly	60	Shalibanda	85	Chintalmet
11	Begumpet	36	Lakdikapul	61	Shamsheergunj	86	Shaikpet
12	Prakash nagar	37	Khairatabad	62	Jangammet	87	Gachibowli x rd
13	Rasoolpura	38	Erummazil	63	FalaknumaM	88	Wipro juntion
14	Paradise	39	Panjagutta	64	Falaknuma	89	Owaisi hospital
15	Parade ground	40	Srnagar	65	Huppuguda	90	Aramghar
16	Secunderabad RS	41	ESI hospital	66	Yakutpura	91	Kapra
17	Mettuguda	42	Erragadda	67	Dabirpura	92	Neredmet
18	Tarnaka	43	Bharat nagar	68	Kachiguda	93	Suchitra
19	Habsiguda	44	Moosapet	69	Vidyanagar		
20	NGRI	45	Balanagaryjn	70	Jamaiosmania		
21	Survey of India	46	Kukatpally	71	Arts college		
22	Uppal	47	Kphb colony	72	Sitafalmandi		
23	Nagole	48	JNTU	73	Hyderabad		
24	LBNagar	49	Miyapur	74	Necklace road		
25	Victoria memorial	50	Jubilee bus station	75	Lingampalli		

Application of SMCA using ArcGIS

The analysis is carried out using SMCA in several steps. Initially, organizing the data collected (Transportation network data and Land use Data) from secondary sources is crucial. Transportation Network data, including transit lines (MMTS and MRTS), Bus route network, and road network, are collected. The transport network data is converted to a spatial layer with appropriate parameters to understand the study area well. Also, the land use layer is considered at the final stage to have a comprehensive idea of the study area.

The next step is defining the goal; in this study, identifying feasible TOD locations for urban areas is the goal. According to the goal, criteria are formulated and applied on each spatial map for assessment. Four spatial criteria are considered in this analysis, and each criterion is explained in detail with the help of figures (Maps) in the steps below.

Step1: A length of 116 km is considered, including MRTS (Metro) and MMTS (local trains). MMTS tracks are operating since 2003 on existing intercity railway tracks, whereas MRTS is the new transit system in the study area. The MRTS tracks are constructed based on the corridors where travel demand is high. In developing countries, converting all transit nodes to TODs will burden authorities, so to identify most feasible TODs, in this study, a criterion is formed such that the end stations and interchange stations are considered more important than the rest of the stations. Interchange stations are more crowded as passengers switch their direction of travel to reach the destination. The end stations are also important as they have more potential to develop. In the present study, most of the end stations are residential neighborhoods. The map with transit lines and highlighted locations of interchange and end stations are shown in **Figure 5.2.** List of selected TODs are presented in **Table 5.2**

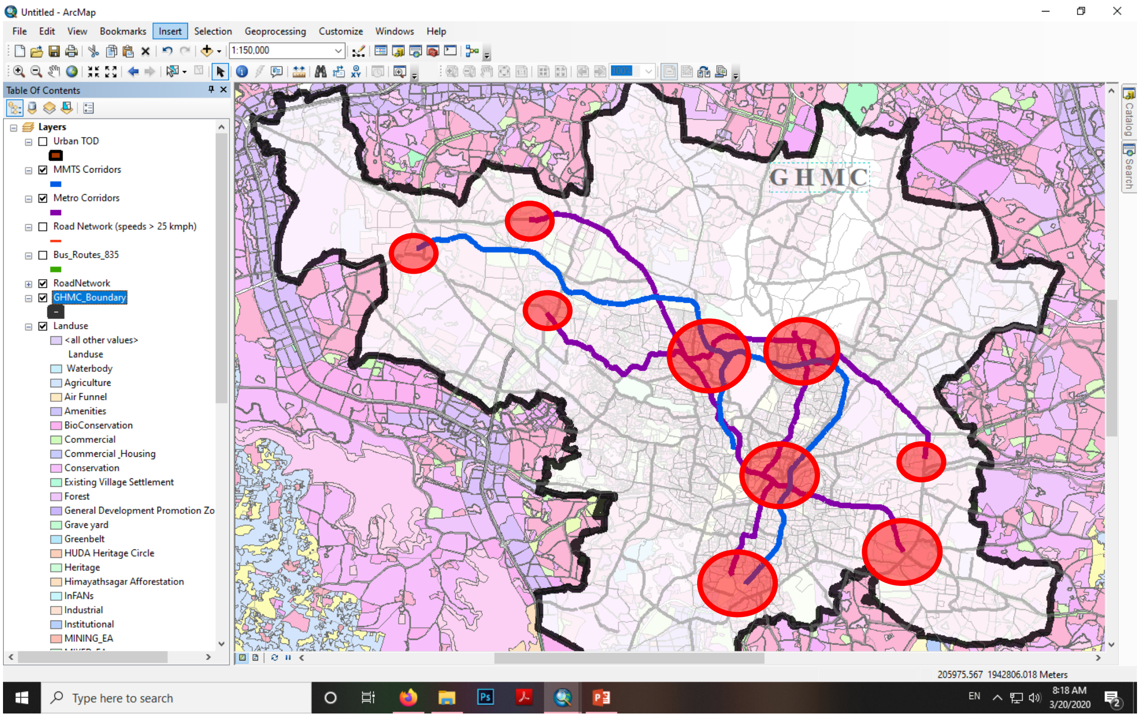


Figure 5.2: Application of Criteria 1 in SMCA

Table 5.2: List of TODs selected through Criteria 1

Urban TOD No	Location Name	Characteristics	Criteria
U-1	Falaknuma MMTS	End station, Residential Neighbourhood	1
U-2	Falaknuma Metro	End station, Residential Neighbourhood	1
U-3	MGBS	Interchange Sation, Integrated with Intercity Bus Terminal	1
U-5	Kachiguda	Interchange Sation, Integrated with Intercity Rail Terminal	1
U-8	Lingampalli	End station, Residential Neighbourhood, Commercial	1
U-9	Bharatnagar	Interchange between MMTS and MRTS	1
U-10	Begumpet	Interchange between MMTS and MRTS	1
U-11	Secunderabad	Interchange Sation, Integrated with Intercity Rail Terminal	1
U-12	Nampally	Interchange between MMTS and MRTS	1
U-13	Lakdikapul	Interchange between MMTS and MRTS	1
U-14	Malakpet	Interchange between MMTS and MRTS	1
U-15	Miyapur	End station, Residential Neighbourhood, Proposed Bus Terminal	1
U-16	Ameerpet	Interchange between MRTS lines	1
U-17	Parade Ground	Interchange between MRTS lines	1
U-18	Jubilee Bus Station	Interchange Station, Integrated with Intercity Bus Terminal	1
U-20	Uppal	End station, Residential Neighbourhood	1
U-21	LB Nagar	End station, Residential Neighbourhood	1
U-23	Shilparamam	End Station, Commercial, Retail, Office uses	1

Step2: The bus route network is considered as the second criterion. The rules are established to pick up appropriate locations, where transit system does not exist and have potential demand for future transit corridor. A prominent location is identified by considering the expert view, i.e., old Bombay road (old NH-7), which connects from Mehdipatnam to Gachibowli as shown in **Figure 5.3.**

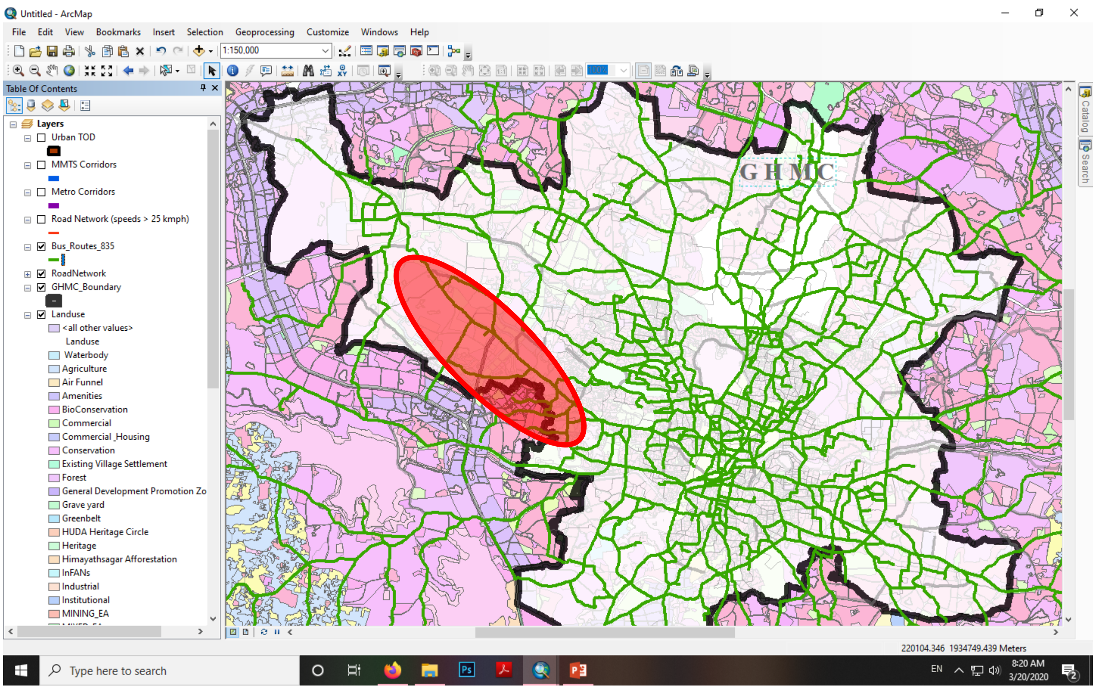


Figure 5.3: Application of Criteria 2 in SMCA

List of selected TODs identified through criteria two along with their characteristics are presented in **Table 5.3**

Table 5.3: List of TODs selected through Criteria 2

Urban TOD No	Location Name	Characteristics	Criteria
U-25	Rethibowli	High Frequency Bus Route, ROW>36m, Speed >25kmph	2
U-26	Rajendernagar	Potential Demand Corridor, ROW>36m, Speed >25kmph	2
U-27	ShaikpetDarga	High Frequency Bus Route, ROW>36m, Speed >25kmph	2
U-28	Gachibowli	ORR Connectivity, Potential for Commercial Development ROW>36m, Speed >25kmph	2

Step3: The reason for considering criteria 3 is to cover all the urban area parts spatially. The rules are formed based on road network characteristics like traffic flow speed and Right of way (ROW). These details are taken from the network inventory survey (CTSHMA, 2011). Locations are identified based on the conditions where the traffic flow speed is more than 25 kmph and ROW is more than 36. Two locations are identified and highlighted, as shown in **Figure 5.4.**

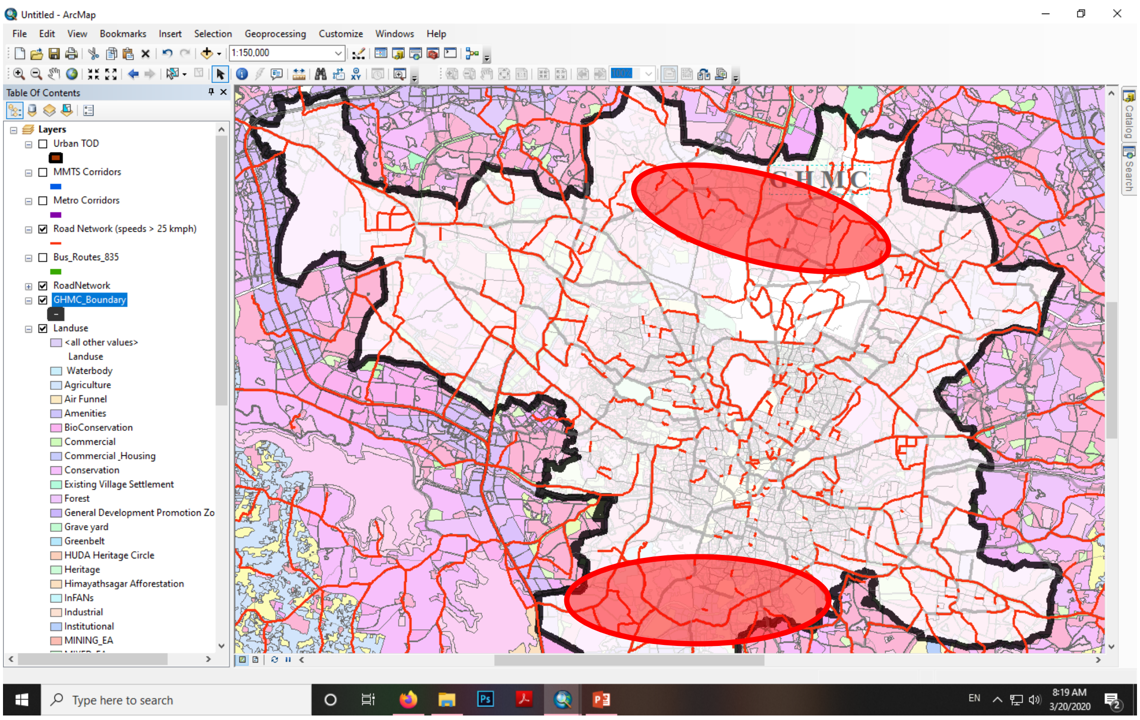


Figure 5.4: Application of Criteria 3 in SMCA

List of selected TODs through criteria three along with their characteristics are presented in **Table 5.4**

Table 5.4: List of TODs selected through Criteria 3

Urban TOD No	Location Name	Characteristics	Criteria
U-30	OwasiBusstop	Potential Demand Corridor, ROW>36m, Speed >25kmph	3
U-31	Aramgarh	Potential Demand Corridor, ROW>36m, Speed >25kmph	3
U-32	ECIL	Potential Demand Corridor, ROW>36m, Speed >25kmph	3
U-33	Neredmet	Potential Demand Corridor, ROW>36m, Speed >25kmph	3
U-34	Dairyform Road on Old NH7	Potential Demand Corridor, ROW>36m, Speed >25kmph	3

Step4: Finally, at a glance, land use characteristics are considered for criteria 4. The rule is set to find the predominant land use activities like commercial, retail, and office. Based on this analysis, **Figure 5.5** shows the most likely busy locations across the study area. **Table 5.5**lists the identified locations of criteria 4.

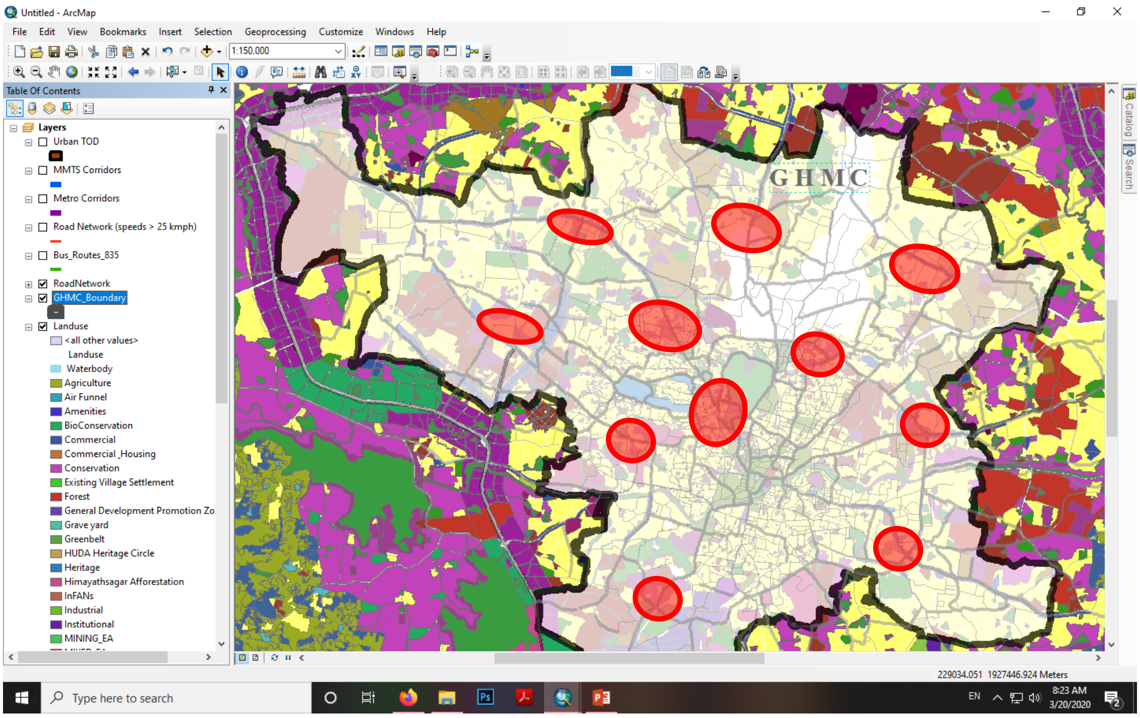


Figure 5.5: Application of Criteria 4 in SMCA

Table 5.5: List of TODs selected through Criteria 4

Urban TOD No	Location Name	Characteristics	Criteria
U-4	Arts College	Near Osmania University Campus (Institutional)	4
U-6	Sanjeevaiah Park	On Necklace road, Recreational Center	4
U-7	Necklace Road	On Necklace road, Recreational Center	4
U-19	Mettuguda	Immediate Neighbourhood to Secunderabad	4
U-22	Habsiguda	On Arterial Road, Core Commercial and Residential Neighbourhood	4
U-24	Jubilee Check post	Core Economic Activity	4
U-29	Gachibowli-Wipro Junction	Economic Activity, Gachibowli Financial District	4

By considering all the above criteria, cumulatively, a total of 34 urban TOD locations are identified. The criteria are considered to pick up the TOD locations and spread the locations across the study area so that the travel patterns in the city will change abruptly to make the city sustainable. On the other hand, change in the urban form of the city will occur with the implementation of identified TODs. These proposed TODs can address urban sprawl.34 urban TODs are shown in **Figure 5.6**and listed in **Table 5.6**.

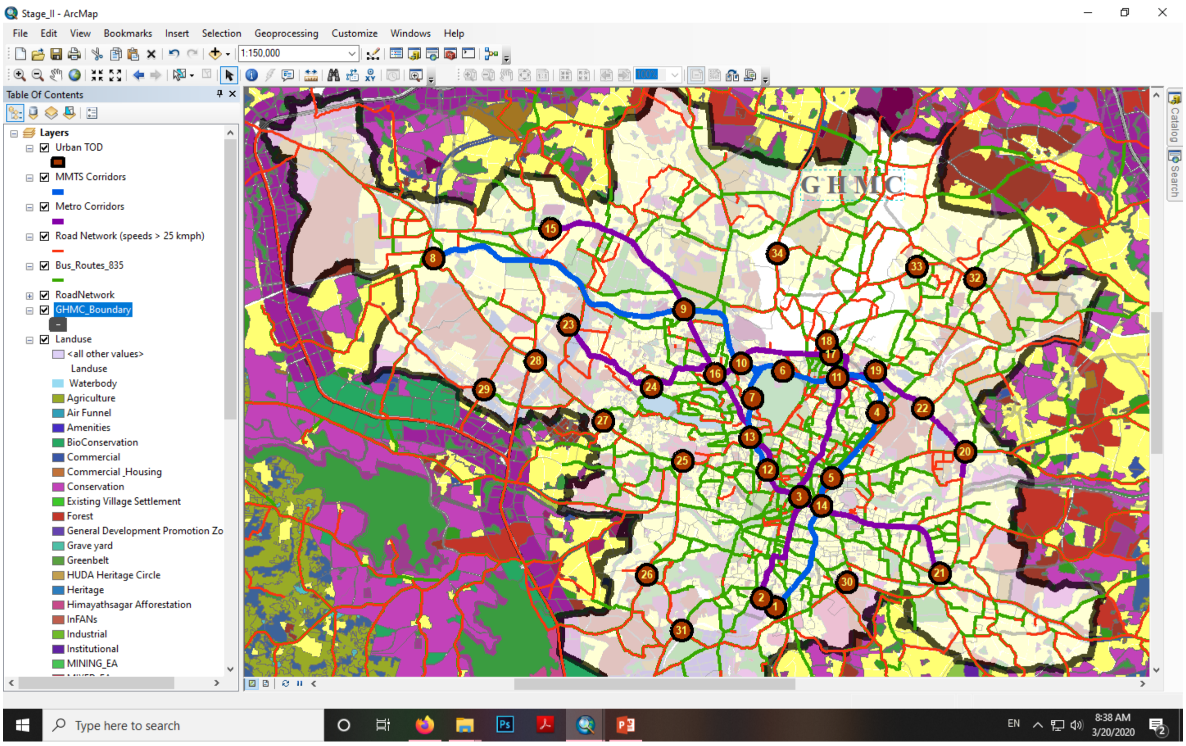


Figure 5.6: Selected feasible 34 Urban TODs location map

Table 5.6: Identified Urban TODs

Urban TOD No	Location Name	Urban TOD No	Location Name	Urban TOD No	Location Name
U-1	Falaknuma MMTS	**U-13**	Lakdikapul	**U-25**	Rethibowli
U-2	Falaknuma Metro	**U-14**	Malakpet	**U-26**	Rajendernagar
U-3	MGBS	**U-15**	Miyapur	**U-27**	ShaikpetDarga
U-4	Arts College	**U-16**	Ameerpet	**U-28**	Gachibowli
U-5	Kachiguda	**U-17**	Parade Ground	**U-29**	Gachibowli-Wipro Junction
U-6	Sanjeevaiah Park	**U-18**	Jubilee Bus Station	**U-30**	OwasiBusstop
U-7	Necklace Road	**U-19**	Mettuguda	**U-31**	Aramgarh
U-8	Lingampalli	**U-20**	Uppal	**U-32**	ECIL
U-9	Bharatnagar	**U-21**	LB Nagar	**U-33**	Neredmet
U-10	Begumpet	**U-22**	Habsiguda	**U-34**	Dairyform Road on Old NH7
U-11	Secunderabad	**U-23**	Shilparamam		
U-12	Nampally	**U-24**	Jubilee Check post		

5.2.1.2 Feasible Sub-Urban TODs

Other than urban areas (GHMC), the rest of HMA is considered to be suburban. The area of the sub-urban region is about 6500 sq.km. An attempt is made to propose the future TODs as sub-urban TODs. At present, there is no transit facility available in a sub-urban area other than intercity rail. So, to identify future TODs, criteria considered are population and employment density, arterial road network, and spatial spread.

The first criterion is establishing a 4km x 4km grid size to maintain a uniform distance between the TODs. The reason for considering 4km is, the rest of GHMC covers more than 90% of the study area (about 6,550 Sq.km). To plan and cover the complete area for future TOD, an assumption is made that a 4km x 4km grid must be formed to place the future TOD at a decent distance along with the significant hierarchical network. According to the existing practice, the transit stations are placed within 1 km in an urban area. In order to extend this assumption from urban to sub-urban, the distance is doubled, and thus a radius of 2km is considered for future TOD to cover a vast area. Accordingly, placing the TOD station with a 2km radius represents a distance of 4km between each TOD. By considering this, a grid has been formed to carry out the further steps.

Then, the second criterion is computing the densities of population and employment. The final criterion is to consider the arterial road network, i.e., Outer Ring Road (ORR), National Highways (NH), and State Highways (SH). By careful consideration of all the three criteria, a total of 35 sub-urban TODs are identified by adopting SMCA using ArcGIS, as shown in **Figure 5.7**and **Table 5.7.**

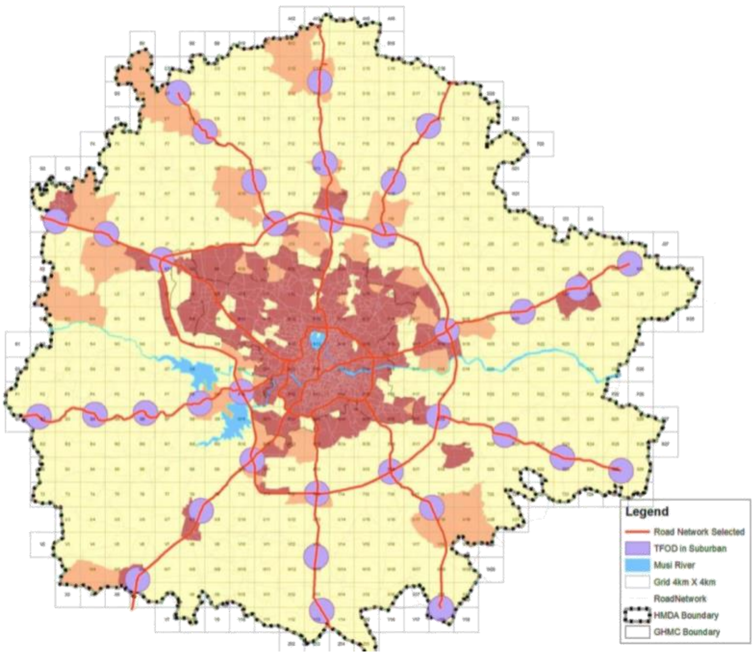


Figure 5.7: Identified feasible 35Sub-urban TODs location map

Table 5.7: Identified Sub-urban TODs

Sub-Urban TFOD No	Location Name	Network Characteristics
S-1	DomaraPocham Pally	ORR+Outer cordon
S-2	Kandlakoya	ORR+Outer cordon
S-3	Shameerpet	ORR+Outer cordon
S-4	Ghatkesar	ORR+Outer cordon
S-5	PeddaAmberpet	ORR+Outer cordon
S-6	Bongulur	ORR+Outer cordon
S-7	Tukkuguda	ORR+Outer cordon
S-8	Shamshabad	ORR+Outer cordon
S-9	Himayatsagar	ORR+Outer cordon
S-10	Patanchervu	ORR+Outer cordon
S-11	Shapur Nagar	State Highway
S-12	Narsapur	State Highway
S-13	Reddypalli	State Highway
S-14	Yellampet	National Highway
S-15	Tupran	National Highway
S-16	Turkapalli	State Highway
S-17	Mulugu	State Highway
S-18	Bibinagar	National Highway
S-19	Bhongiri	National Highway
S-20	Rayagiri	National Highway
S-21	Chotuppal	National Highway
S-22	Toopranpet	National Highway
S-23	Koyalagudem	National Highway
S-24	Ibrahimpatnam	State Highway
S-25	Yacharam	State Highway
S-26	Tummalur	State Highway
S-27	Kadthal	State Highway
S-28	Timmapur	National Highway
S-29	Shadnagar	National Highway
S-30	Moinabad	State Highway
S-31	Appareddyguda	State Highway
S-32	Chevella	State Highway
S-33	Mirjaguda	State Highway
S-34	Koulampet	National Highway
S-35	Sangareddy	National Highway

5.2.2 Prioritisation of TODs using AHP

Prioritization is the process of ranking among all the available transit nodes, and bus stops, those having the potential to translate into TOD.

5.2.2.1 Selection of TOD planning variable

The GHMC region information is gathered in layers and stored in a database file using ArcGIS. Based on the TOD components, viz., Density, Diversity, and Design, the potentiality of the location to promote as TOD can be said. So, the variables are selected carefully to understand the existing conditions of transit stations. Variables considered are Population Density (PD) and Employment Density (ED) for density component, Mix land use Index (MI) variable as diversity component and Proportion of Transport Area (PTA), Lane Kilometre (LK), and Junction Density (JD) variables as design components. The Spatial Data Analysis tool (in ArcGIS) is used to compute these variables.

For the selected 93 TOD locations, 500m buffer is taken as the radius to create the TOD influence area. The parameters considered are calculated as described below.

MI is calculated using eq.5.1 (Cervero, 1988). Land Use Mix is a heterogeneity index, ranging from 0 to 1. 0 represents the single-use, and 1 represents the maximally mixed-use.

$$MI = \frac{-\sum_i^k (Pi \times \ln(Pi))}{\ln(k)} \qquad (5.1)$$

Where P_i is the proportion of land use in type i; k stands for the number of land-use types; i stands for land use type

PTA is land allocated for transportation activities, including bus stop area, terminal area, etc. LK is said to be an area of the carriageway which allows the traffic for movement. It is calculated by multiplying the length of the road network by the number of lanes. JD is calculated by comparing the number of intersections present in the TOD influence area to the TOD influence area. All six variables are considered in the present study to understand the transit stations, and the calculated variable values are presented in **Table5.8**.

Table 5.8: Calculated variable values for all 93 transit stations

TOD ID	TOD Name	Variables					
		MI (Index)	PTA (%)	PD (Pop/ha)	ED (Emp/ha)	LK (km)	JD (No's)
1	Shilparamam	0.76	0.1	47.47	105.81	13.54	2.35
2	Hitech City	0.55	0.11	66.98	599.99	13.47	1.01
3	Cod	0.44	0.08	68.99	128.67	9.93	1.77
4	Madhapur	0.38	0.08	49.8	26.76	9.02	1.28
5	Peddamma Temple	0.38	0.09	59.17	88.1	11.61	3.27
6	Jubilee Hills Check Post	0.52	0.1	47.35	73.75	13.09	1.35
7	Road No.5 Jubilee Hills	0.32	0.08	153.02	64.42	10.42	2.17
8	Yusufguda	0.39	0.07	337.04	57.51	9.69	0.95
9	Madhura Nagar	0.37	0.12	216.49	84.53	15.49	1.48
10	Ameerpet	0.44	0.15	167.72	205.36	20.93	2.52
11	Begumpet	0.56	0.11	110.88	113.58	14.48	1.13
12	Prakash Nagar	0.46	0.09	94.42	77.64	12.93	1.93
13	Rasoolpura	0.62	0.08	82.34	101.64	11	3.19
14	Paradise	0.79	0.16	98.34	168.21	22	2.11
15	Parade Ground	0.72	0.25	152.04	228.97	33.58	2.31
16	Secunderabad Station	0.54	0.14	114.11	223.19	17.29	3.33
17	Mettuguda	0.46	0.09	100.45	30.95	12.94	0.56
18	Tarnaka	0.54	0.1	82.97	30.5	14.17	1.56
19	Habsiguda	0.55	0.1	93.87	37.57	13.62	1.34
20	Ngri	0.69	0.09	89.19	54.6	11.94	0.67
21	Survey Of India	0.75	0.11	105.96	83.02	14.71	1.12
22	Uppal	0.64	0.19	72.85	35.35	24.7	2.13
23	Nagole	0.77	0.09	59.03	16.34	10.93	2.05

TOD ID	TOD Name	Variables					
		MI (Index)	PTA (%)	PD (Pop/ha)	ED (Emp/ha)	LK (km)	JD (No’s)
24	Lb Nagar	0.18	0.19	145.5	70.44	25.26	0.34
25	Victoria Memorial	0.29	0.1	180.57	25.75	12.69	1.95
26	Chaitanyapuri	0.4	0.11	226.27	111.93	14.54	2.17
27	Dilsukhnagar	0.38	0.14	269.29	131.61	15.49	2.48
28	MusaramBagh	0.39	0.2	233.39	44.18	24.95	3
29	New Market	0.38	0.18	221.05	95.89	20.77	2.21
30	Malakpet	0.27	0.17	255.17	87.91	18.96	2.79
31	Mgbs	0.48	0.14	141.56	178.6	18.13	2.63
32	Osmania Medical College	0.62	0.16	193.81	226.62	21.74	2.21
33	Gandhi Bhavan	0.82	0.16	221.36	255.15	21.13	2.66
34	Nampally	0.83	0.13	179.28	269.07	15.61	3.56
35	Assembly	0.72	0.13	147.35	269.14	16.86	2.67
36	Lakdikapul	0.78	0.14	167	170.8	20.95	2.51
37	Khairatabad	0.59	0.12	172.89	169.23	16.29	2.06
38	ErumMazil	0.59	0.08	147.72	276.64	11.45	2.61
39	Panjagutta	0.53	0.17	145.64	205.54	22.36	2.08
40	Sr Nagar	0.45	0.12	226.27	174.73	16.12	1.34
41	Esi Hospital	0.38	0.09	292.84	89.9	11.97	1.72
42	Erragadda	0.62	0.09	221.33	74.29	13.57	1.56
43	Bharat Nagar	0.56	0.08	178.97	56.52	10.08	1.42
44	Moosapet	0.72	0.16	117.89	40.04	22.02	0.82
45	Balanagar Y- Junction	0.63	0.11	106.42	35.76	13.99	1.43
46	Kukatpally	0.5	0.09	145.94	36.68	11.21	1.26
47	Kphb Colony	0.35	0.11	154.34	110.71	14.37	1.86
48	Jntu	0.49	0.13	141.49	124.39	15.54	1.75
49	Miyapur	0.46	0.08	47.03	7.14	10.06	0.99
50	Jubilee Bus Station	0.77	0.17	91.4	88.14	21.96	1.87
51	Secunderabad R. S.	0.7	0.17	215.78	390.24	20.99	3
52	Gandhi Hospital	0.6	0.12	243.3	46.2	14.29	2.59
53	Musheerabad	0.37	0.13	425.46	57.49	16.59	3.57
54	Rtc X Roads	0.64	0.11	289.31	130.59	15.03	2.5
55	Chikkadpally	0.38	0.12	277.27	139	15.29	2.27
56	Narayanguda	0.73	0.16	252.31	124.1	21.63	3.06
57	Sultan Bazaar	0.74	0.18	199.57	223.04	24.67	2.44
58	Salarjung Museum	0.45	0.14	259.88	158.99	16.82	2.13
59	Charminar	0.28	0.12	300.76	201.57	14.77	2.29
60	Shalibanda	0.21	0.15	429.46	117.87	18.32	2.27
61	Shamsheergunj	0.16	0.08	411.32	106.04	10.55	1.86
62	Jangammet	0.57	0.09	366.44	75.09	13.04	1.97
63	Falaknuma	0.54	0.09	326.88	61.96	11.83	3.96
64	Falaknuma	0.42	0.05	259.32	63.96	6.46	6.76
65	Huppuguda	0.2	0.08	345.62	66.05	8.46	1.96
66	Yakutpura	0.13	0.08	555.53	173.96	9.33	1.9
67	Dabirpura	0.16	0.1	452.14	29.84	11.14	2.12
68	Kachiguda	0.63	0.08	263.89	124.5	11.87	3.09
69	Vidyanagar	0.44	0.14	282.13	63.42	17.84	3.65
70	Jamai Osmania	0.5	0.11	242.14	31.29	15.38	2.47
71	Arts College	0.49	0.09	324.63	59.83	10.95	1.74
72	Sitafalmandi	0.46	0.05	238.87	41.49	5.99	2.95
73	Hyderabad	0.76	0.1	194.03	207.58	12.97	3.2
74	Necklace Road	0.48	0.07	77.71	110.37	9.72	1.05
75	Lingampalli	0.31	0.06	36.05	23.28	9.22	1.3
76	Chandanagar	0.21	0.01	63.36	22.66	0.92	4.35
77	Hafeezpet	0.29	0.15	54.66	10.99	20.21	1.25
78	Hitec City	0.71	0.14	70.84	21.66	20.83	2.1
79	Borabanda	0.17	0.03	156.89	45.87	4.8	1.25

TOD ID	TOD Name	Variables					
		MI (Index)	PTA (%)	PD (Pop/ha)	ED (Emp/ha)	LK (km)	JD (No's)
80	Fatehnagar	0.58	0.09	149.62	64.67	11.97	1.69
81	Nature Cure Hospital	0.42	0.07	178.95	75.28	7.59	0.84
82	Sanjeevaiah Park	0.52	0.04	39.11	59.79	6.27	0.96
83	James Street	0.74	0.16	190.88	190.49	23.44	2.58
84	RetiBowli	0.27	0.14	203.17	93.29	18.33	0.94
85	Chintalmet	0.26	0.16	71.74	15.92	20.9	0.96
86	Shaikpet	0.34	0.09	40.75	8.11	10.93	1.04
87	Gachibowli X Rd	0.46	0.2	34.7	48.18	22.93	0.97
88	Wipro Juntion	0.69	0.08	7.08	36.37	11.23	0.99
89	Owaisi Hospital	0.67	0.11	234.17	91.79	14.79	2.44
90	Aramghar	0.72	0.18	57.92	17.23	23.34	1.07
91	Kapra	0.44	0.12	107.74	51.46	16.57	1.9
92	Neredmet	0.41	0.1	126.45	27.71	13.71	1.9
93	Suchitra	0.74	0.13	81.48	17.35	14.12	0.99

5.2.2.2 Process of AHP

A schematic diagram of the AHP method is presented in **Figure 5.8**. As explained in the earlier section, the first step is to fix the objective, i.e., ranking all 93 transit stations. The second is to derive criteria weights of six variables, namely MI, PTA, PD, ED, LK, and JD. The final step is to compute the composite score and designate the ranks for each alternative.

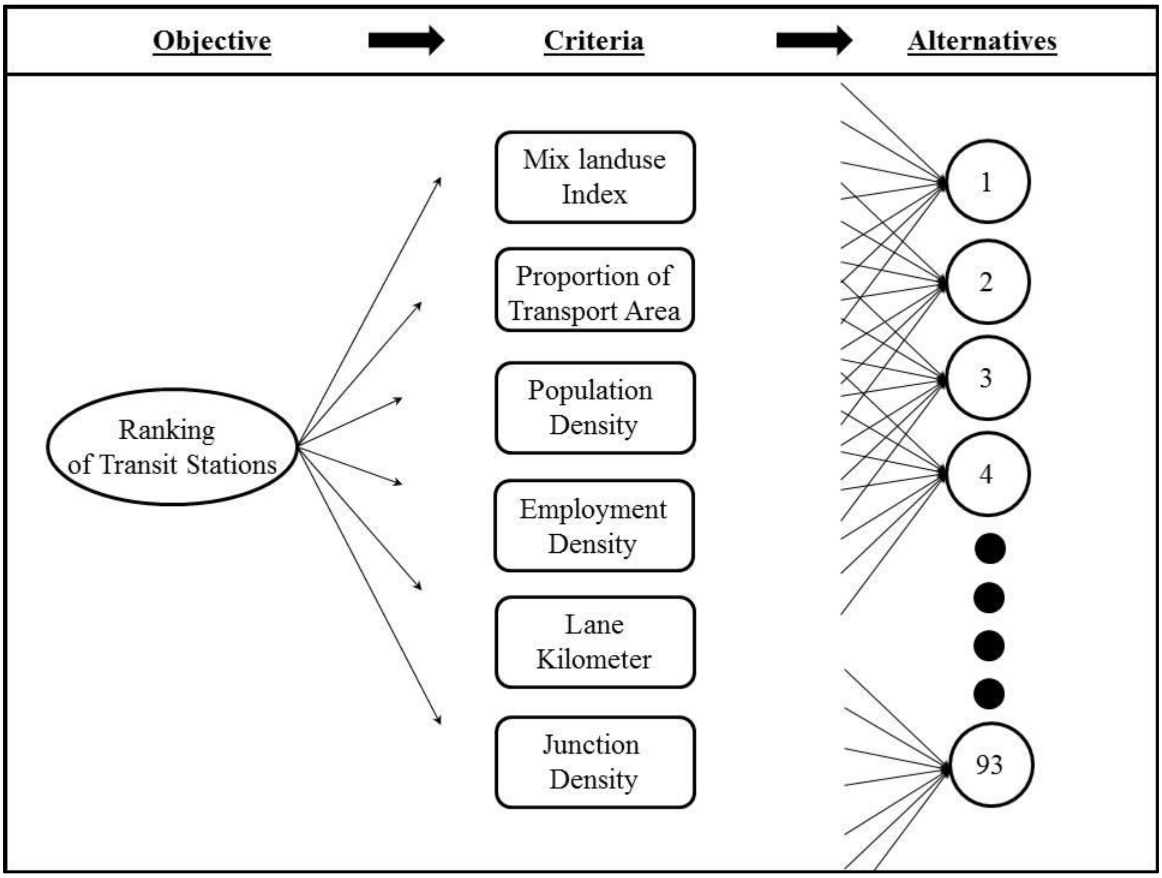


Figure 5.8: Schematic Representation of the AHP approach for ranking of Transit stations

5.2.2.3 Criteria weights

Among the six criteria, decision-making is a complex situation. To ease this, Saaty (1980) has proposed a pairwise comparison matrix. In this process, the importance of one criterion upon other criteria is noted on a scale from 1 to 9 for the upper diagonal matrix, and the values of the lower diagonal matrix are reciprocal. For example, if criteria MI is important than criteria PTA, it is given as 2, whereas criteria PTA compared with criteria MI is given as ½=0.5 (reciprocal). If a criterion JD is given a value of 6implies criteria, MI is strongly more critical than JD. Thus a pairwise comparison matrix C is obtained as given below. An expert opinion survey is conducted to obtain the pair-wise comparison matrix. Data is collected from Government officials, private bodies of the Transportation sector, and survey format in Annexure IV. The summary of the data collected is presented in Annexure V. Next, matrix C is normalized by dividing the summation of each column with each element in the respective column. The Normalised pairwise comparison matrix C_{norm} is presented below.

Pairwise comparison matrix C=

	MI	PTA	PD	ED	LK	JD
MI	1	2	4	4	6	6
PTA	0.5	1	2	2	4	4
PD	0.25	0.5	1	1.5	2.5	4
ED	0.25	0.5	0.67	1	2	4
LK	0.17	0.25	0.4	0.5	1	2
JD	0.17	0.25	0.25	0.25	0.5	1
Sum	**2.33**	**4.5**	**8.32**	**9.25**	**16**	**21**

Normalized pairwise comparison matrix c_{norm}=

	MI	PTA	PD	ED	LK	JD
MI	0.43	0.44	0.48	0.43	0.38	0.29
PTA	0.21	0.22	0.24	0.22	0.25	0.19
PD	0.11	0.11	0.12	0.16	0.16	0.19
ED	0.11	0.11	0.08	0.11	0.13	0.19
LK	0.07	0.06	0.05	0.05	0.06	0.1
JD	0.07	0.06	0.03	0.03	0.03	0.05

The weights of each criterion are obtained by taking the averages of each row. The weights obtained by the AHP process are presented in **Table 5.9**.

Table 5.9: Criteria weights obtained from AHP

S.No	Criteria	Weightage
1	Mix Index (MI)	0.41

2	Proportion of Transport Area (PTA)	0.22
3	Population Density (PD)	0.14
4	Employment Density (ED)	0.12
5	Lane-Kilometer (LK)	0.06
6	Junction Density (JD)	0.04

5.2.2.4 Consistency Ratio

As explained in the earlier section, consistency ratio is important to check the analysis's perfectness. This is a logical check to predict the human error occurring while building the pairwise comparison matrix. The results related to this are mentioned below.

Count (n)	6.00
λ-max (x)	6.142
CI	0.028
Constant (RI)	1.24
CR	0.023

Here CR value is observed to be 0.023. CR value less than 0.1 is acceptable. If it is not, the exercise is to be repeated.

5.2.2.5 Final Ranking by AHP

The Criteria chosen for ranking have been categorized into seven levels based on the values obtained. The value range of each criterion has been distributed equally by seven-level categories. Seven level category is rated as excellent, very good, good, average, fair, satisfactory, and poor with a score of 7, 6, 5, 4, 3, 2, and 1, respectively, as shown in **Table 5.10**. Then, the Composite scores are computed by multiplying the rating of each criterion and weightage obtained (from **Table 5.9**). The composite scores are placed in ascending order to rank the transit stations. The highest composite score is given rank 1, and the lowest composite score is given rank 93, and so on and is presented in **Table 5.11**.

Table 5.10: Seven level categorization of Criteria

Rating	Criteria					
	Mix Landuse Index (MI)	The proportion of Transport Area (PTA)	Population Density (PD)	Employment Density (ED)	Lane Kilometer (LK)	Junction Density (JD)
Excellent (7)	>0.75	>0.20	>450.00	>500.00	>30.00	>6.00
Very Good (6)	0.74 - 0.65	0.19 - 0.16	449.99 - 380.00	499.99 - 420.00	29.99 - 25.00	5.99 - 5.10
Good (5)	0.64 - 0.55	0.15 - 0.12	379.99 - 300.00	419.99 - 340.00	24.99 - 20.00	5.09 - 4.20
Average (4)	0.54 - 0.45	0.11 - 0.08	299.99 - 220.00	339.99 - 260.00	19.99 - 15.00	4.19 - 3.30
Fair (3)	0.44 - 0.35	0.07 - 0.04	219.99 - 200.00	259.99 - 180.00	14.99 - 10.00	3.29 - 2.40
Satisfactory (2)	0.34 - 0.25	0.03 – 0.01	199.99 - 120.00	179.99 - 100.00	9.99 - 5.00	2.39 - 1.50
Poor (1)	0.24 – 0.00	0.01-0.00	119.99 - 0.00	99.99 - 0.00	4.99 - 0.00	1.49 –0.00

Table 5.11: Ranking of 93 transit stations by AHP

Rank	TOD ID	TOD Name	Criteria												Composite Score
			Mix Landuse Index (MI)		Proportion of Transport Area (PTA)		Population Density (PD)		Employment Density (ED)		Lane Kilometer (LK)		Junction Density (JD)		
1	33	Gandhi Bhavan	Ex	(0.82)	Good	(0.16)	Avg	(221)	Fair	(255)	Good	(21)	Fair	(3)	**5.34**
2	51	Secunderabad R. S.	V.Good	(0.7)	V.Good	(0.17)	Fair	(216)	Good	(390)	Good	(21)	Fair	(3)	**5.25**
3	34	Nampally	Ex	(0.83)	Good	(0.13)	Satis	(179)	Avg	(269)	Avg	(16)	Avg	(4)	**5.17**
4	15	Parade Ground	V.Good	(0.72)	Ex	(0.25)	Satis	(152)	Fair	(229)	Ex	(34)	Satis	(2)	**5.16**
5	56	Narayanguda	V.Good	(0.73)	V.Good	(0.16)	Avg	(252)	Satis	(124)	Good	(22)	Fair	(3)	**5.03**
6	14	Paradise	Ex	(0.79)	V.Good	(0.16)	Poor	(98)	Satis	(168)	Good	(22)	Satis	(2)	**4.97**
7	36	Lakdikapul	Ex	(0.78)	Good	(0.14)	Satis	(167)	Satis	(171)	Good	(21)	Fair	(3)	**4.94**
8	57	Sultan Bazaar	V.Good	(0.74)	V.Good	(0.18)	Satis	(200)	Fair	(223)	Good	(25)	Fair	(2)	**4.87**
9	50	Jubilee Bus Station	Ex	(0.77)	V.Good	(0.17)	Poor	(91)	Poor	(88)	Good	(22)	Satis	(2)	**4.85**
10	73	Hyderabad	Ex	(0.76)	Avg	(0.1)	Satis	(194)	Fair	(208)	Fair	(13)	Fair	(3)	**4.72**
11	35	Assembly	V.Good	(0.72)	Good	(0.13)	Satis	(147)	Avg	(269)	Avg	(17)	Fair	(3)	**4.71**
12	83	James Street	V.Good	(0.74)	Good	(0.16)	Satis	(191)	Fair	(190)	Good	(23)	Fair	(3)	**4.65**
13	1	Shilparamam	Ex	(0.76)	Avg	(0.1)	Poor	(47)	Satis	(106)	Fair	(14)	Satis	(2)	**4.41**
14	32	Osmania Medical College	Good	(0.62)	V.Good	(0.16)	Satis	(194)	Fair	(227)	Good	(22)	Satis	(2)	**4.41**
15	44	Moosapet	V.Good	(0.72)	V.Good	(0.16)	Poor	(118)	Poor	(40)	Good	(22)	Poor	(1)	**4.39**
16	90	Aramghar	V.Good	(0.72)	V.Good	(0.18)	Poor	(58)	Poor	(17)	Good	(23)	Poor	(1)	**4.39**
17	89	Owaisi Hospital	V.Good	(0.67)	Avg	(0.11)	Avg	(234)	Poor	(92)	Fair	(15)	Fair	(2)	**4.35**
18	23	Nagole	Ex	(0.77)	Avg	(0.09)	Poor	(59)	Poor	(16)	Fair	(11)	Satis	(2)	**4.29**
19	78	Hitec City	V.Good	(0.71)	Good	(0.14)	Poor	(71)	Poor	(22)	Good	(21)	Satis	(2)	**4.22**
20	2	Hitech City	Good	(0.55)	Avg	(0.11)	Poor	(67)	Ex	(600)	Fair	(13)	Poor	(1)	**4.14**
21	54	Rtc X Roads	Good	(0.64)	Avg	(0.11)	Avg	(289)	Satis	(131)	Avg	(15)	Fair	(2)	**4.12**
22	93	Suchitra	V.Good	(0.74)	Good	(0.13)	Poor	(81)	Poor	(17)	Fair	(14)	Poor	(1)	**4.05**

Rank	TOD ID	TOD Name	Criteria												Composite Score
			Mix Landuse Index (MI)		Proportion of Transport Area (PTA)		Population Density (PD)		Employment Density (ED)		Lane Kilometer (LK)		Junction Density (JD)		
23	22	Uppal	Good	(0.64)	V.Good	(0.19)	Poor	(73)	Poor	(35)	Good	(25)	Satis	(2)	**4.03**
24	62	Jangammet	Good	(0.57)	Avg	(0.09)	Good	(366)	Poor	(75)	Fair	(13)	Satis	(2)	**4.03**
25	38	ErumMazil	Good	(0.59)	Avg	(0.08)	Satis	(148)	Avg	(277)	Fair	(11)	Fair	(3)	**4.02**
26	39	Panjagutta	Avg	(0.53)	V.Good	(0.17)	Satis	(146)	Fair	(206)	Good	(22)	Satis	(2)	**4.00**
27	52	Gandhi Hospital	Good	(0.6)	Avg	(0.12)	Avg	(243)	Poor	(46)	Fair	(14)	Fair	(3)	**3.94**
28	28	MusaramBagh	Fair	(0.39)	Ex	(0.2)	Avg	(233)	Poor	(44)	Good	(25)	Fair	(3)	**3.90**
29	42	Erragadda	Good	(0.62)	Avg	(0.09)	Avg	(221)	Poor	(74)	Fair	(14)	Satis	(2)	**3.89**
30	58	Salarjung Museum	Avg	(0.45)	Good	(0.14)	Avg	(260)	Satis	(159)	Avg	(17)	Satis	(2)	**3.88**
31	68	Kachiguda	Good	(0.63)	Fair	(0.08)	Avg	(264)	Satis	(125)	Fair	(12)	Fair	(3)	**3.84**
32	20	NGRI	V.Good	(0.69)	Avg	(0.09)	Poor	(89)	Poor	(55)	Fair	(12)	Poor	(1)	**3.83**
33	21	Survey Of India	V.Good	(0.75)	Avg	(0.11)	Poor	(106)	Poor	(83)	Fair	(15)	Poor	(1)	**3.83**
34	37	Khairatabad	Good	(0.59)	Avg	(0.12)	Satis	(173)	Satis	(169)	Avg	(16)	Satis	(2)	**3.79**
35	87	Gachibowli X Rd	Avg	(0.46)	Ex	(0.2)	Poor	(35)	Poor	(48)	Good	(23)	Poor	(1)	**3.79**
36	53	Musheerabad	Fair	(0.37)	Good	(0.13)	V.Good	(425)	Poor	(57)	Avg	(17)	Avg	(4)	**3.73**
37	63	Falaknuma	Avg	(0.54)	Avg	(0.09)	Good	(327)	Poor	(62)	Fair	(12)	Avg	(4)	**3.72**
38	16	Secunderabad Station	Avg	(0.54)	Good	(0.14)	Poor	(114)	Fair	(223)	Avg	(17)	Avg	(3)	**3.68**
39	31	Mgbs	Avg	(0.48)	Good	(0.14)	Satis	(142)	Satis	(179)	Avg	(18)	Fair	(3)	**3.65**
40	13	Rasoolpura	Good	(0.62)	Avg	(0.08)	Poor	(82)	Satis	(102)	Fair	(11)	Fair	(3)	**3.64**
41	29	New Market	Fair	(0.38)	V.Good	(0.18)	Avg	(221)	Poor	(96)	Good	(21)	Satis	(2)	**3.63**
42	71	Arts College	Avg	(0.49)	Avg	(0.09)	Good	(325)	Poor	(60)	Fair	(11)	Satis	(2)	**3.62**
43	80	Fatehnagar	Good	(0.58)	Avg	(0.09)	Satis	(150)	Poor	(65)	Fair	(12)	Satis	(2)	**3.61**
44	88	Wipro Juntion	V.Good	(0.69)	Fair	(0.08)	Poor	(7)	Poor	(36)	Fair	(11)	Poor	(1)	**3.61**
45	48	Jntu	Avg	(0.49)	Good	(0.13)	Satis	(141)	Satis	(124)	Avg	(16)	Satis	(2)	**3.6**
46	70	Jamai Osmania	Avg	(0.5)	Avg	(0.11)	Avg	(242)	Poor	(31)	Avg	(15)	Fair	(2)	**3.59**
47	11	Begumpet	Good	(0.56)	Avg	(0.11)	Poor	(111)	Satis	(114)	Fair	(14)	Poor	(1)	**3.54**

Rank	TOD ID	TOD Name	Criteria												Composite Score
			Mix Landuse Index (MI)		Proportion of Transport Area (PTA)		Population Density (PD)		Employment Density (ED)		Lane Kilometer (LK)		Junction Density (JD)		
48	27	Dilsukhnagar	Fair	(0.38)	Good	(0.14)	Avg	(269)	Satis	(132)	Avg	(15)	Fair	(2)	**3.52**
49	69	Vidyanagar	Fair	(0.44)	Good	(0.14)	Avg	(282)	Poor	(63)	Avg	(18)	Avg	(4)	**3.45**
50	10	Ameerpet	Fair	(0.44)	Good	(0.15)	Satis	(168)	Fair	(205)	Good	(21)	Fair	(3)	**3.42**
51	19	Habsiguda	Good	(0.55)	Avg	(0.1)	Poor	(94)	Poor	(38)	Fair	(14)	Poor	(1)	**3.42**
52	45	Balanagar Y- Junction	Good	(0.63)	Avg	(0.11)	Poor	(106)	Poor	(36)	Fair	(14)	Poor	(1)	**3.42**
53	43	Bharat Nagar	Good	(0.56)	Fair	(0.08)	Satis	(179)	Poor	(57)	Fair	(10)	Poor	(1)	**3.34**
54	59	Charminar	Satis	(0.28)	Good	(0.12)	Good	(301)	Fair	(202)	Fair	(15)	Satis	(2)	**3.26**
55	55	Chikkadpally	Fair	(0.38)	Avg	(0.12)	Avg	(277)	Satis	(139)	Avg	(15)	Satis	(2)	**3.25**
56	72	Sitafalmandi	Avg	(0.46)	Fair	(0.05)	Avg	(239)	Poor	(41)	Satis	(6)	Fair	(3)	**3.25**
57	30	Malakpet	Satis	(0.27)	V.Good	(0.17)	Avg	(255)	Poor	(88)	Avg	(19)	Fair	(3)	**3.21**
58	40	Sr Nagar	Fair	(0.45)	Avg	(0.12)	Avg	(226)	Satis	(175)	Avg	(16)	Poor	(1)	**3.20**
59	26	Chaitanyapuri	Fair	(0.4)	Avg	(0.11)	Avg	(226)	Satis	(112)	Fair	(15)	Satis	(2)	**3.19**
60	46	Kukatpally	Avg	(0.5)	Avg	(0.09)	Satis	(146)	Poor	(37)	Fair	(11)	Poor	(1)	**3.15**
61	41	Esi Hospital	Fair	(0.38)	Avg	(0.09)	Avg	(293)	Poor	(90)	Fair	(12)	Satis	(2)	**3.07**
62	12	Prakash Nagar	Avg	(0.46)	Avg	(0.09)	Poor	(94)	Poor	(78)	Fair	(13)	Satis	(2)	**3.06**
63	18	Tarnaka	Avg	(0.54)	Avg	(0.1)	Poor	(83)	Poor	(31)	Fair	(14)	Satis	(2)	**3.06**
64	64	Falaknuma	Fair	(0.42)	Fair	(0.05)	Avg	(259)	Poor	(64)	Satis	(6)	Ex	(7)	**3.04**
65	6	Jubilee Hills Check Post	Avg	(0.52)	Avg	(0.1)	Poor	(47)	Poor	(74)	Fair	(13)	Poor	(1)	**3.01**
66	17	Mettuguda	Avg	(0.46)	Avg	(0.09)	Poor	(100)	Poor	(31)	Fair	(13)	Poor	(1)	**3.01**
67	9	Madhura Nagar	Fair	(0.37)	Avg	(0.12)	Fair	(216)	Poor	(85)	Avg	(15)	Poor	(1)	**2.94**
68	60	Shalibanda	Poor	(0.21)	Good	(0.15)	V.Good	(429)	Satis	(118)	Avg	(18)	Satis	(2)	**2.93**
69	91	Kapra	Fair	(0.44)	Good	(0.12)	Poor	(108)	Poor	(51)	Avg	(17)	Satis	(2)	**2.93**
70	8	Yusufguda	Fair	(0.39)	Fair	(0.07)	Good	(337)	Poor	(58)	Satis	(10)	Poor	(1)	**2.88**
71	74	Necklace Road	Avg	(0.48)	Fair	(0.07)	Poor	(78)	Satis	(110)	Satis	(10)	Poor	(1)	**2.85**
72	49	Miyapur	Avg	(0.46)	Fair	(0.08)	Poor	(47)	Poor	(7)	Fair	(10)	Poor	(1)	**2.79**

Rank	TOD ID	TOD Name	Criteria												Composite Score
			Mix Landuse Index (MI)		Proportion of Transport Area (PTA)		Population Density (PD)		Employment Density (ED)		Lane Kilometer (LK)		Junction Density (JD)		
73	92	Neredmet	Fair	(0.41)	Avg	(0.1)	Satis	(126)	Poor	(28)	Fair	(14)	Satis	(2)	**2.79**
74	84	RetiBowli	Satis	(0.27)	Good	(0.14)	Fair	(203)	Poor	(93)	Avg	(18)	Poor	(1)	**2.75**
75	85	Chintalmet	Satis	(0.26)	V.Good	(0.16)	Poor	(72)	Poor	(16)	Good	(21)	Poor	(1)	**2.75**
76	3	Cod	Fair	(0.44)	Avg	(0.08)	Poor	(69)	Satis	(129)	Satis	(10)	Satis	(2)	**2.71**
77	5	Peddamma Temple	Fair	(0.38)	Avg	(0.09)	Poor	(59)	Poor	(88)	Fair	(12)	Fair	(3)	**2.7**
78	67	Dabirpura	Poor	(0.16)	Avg	(0.1)	Ex	(452)	Poor	(30)	Fair	(11)	Satis	(2)	**2.67**
79	24	Lb Nagar	Poor	(0.18)	V.Good	(0.19)	Satis	(146)	Poor	(70)	V.Good	(25)	Poor	(0)	**2.54**
80	77	Hafeezpet	Satis	(0.29)	Good	(0.15)	Poor	(55)	Poor	(11)	Good	(20)	Poor	(1)	**2.53**
81	66	Yakutpura	Poor	(0.13)	Fair	(0.08)	Ex	(556)	Satis	(174)	Satis	(9)	Satis	(2)	**2.51**
82	82	Sanjeevaiah Park	Avg	(0.52)	Satis	(0.04)	Poor	(39)	Poor	(60)	Satis	(6)	Poor	(1)	**2.51**
83	47	Kphb Colony	Satis	(0.35)	Avg	(0.11)	Satis	(154)	Satis	(111)	Fair	(14)	Satis	(2)	**2.5**
84	81	Nature Cure Hospital	Fair	(0.42)	Fair	(0.07)	Satis	(179)	Poor	(75)	Satis	(8)	Poor	(1)	**2.46**
85	61	Shamsheergunj	Poor	(0.16)	Fair	(0.08)	V.Good	(411)	Satis	(106)	Fair	(11)	Satis	(2)	**2.43**
86	25	Victoria Memorial	Satis	(0.29)	Avg	(0.1)	Satis	(181)	Poor	(26)	Fair	(13)	Satis	(2)	**2.38**
87	4	Madhapur	Fair	(0.38)	Fair	(0.08)	Poor	(50)	Poor	(27)	Satis	(9)	Poor	(1)	**2.32**
88	86	Shaikpet	Satis	(0.34)	Avg	(0.09)	Poor	(41)	Poor	(8)	Fair	(11)	Poor	(1)	**2.19**
89	7	Road No.5 Jubilee Hills	Satis	(0.32)	Fair	(0.08)	Satis	(153)	Poor	(64)	Fair	(10)	Satis	(2)	**2.16**
90	65	Huppuguda	Poor	(0.2)	Fair	(0.08)	Good	(346)	Poor	(66)	Satis	(8)	Satis	(2)	**2.11**
91	75	Lingampalli	Satis	(0.31)	Fair	(0.06)	Poor	(36)	Poor	(23)	Satis	(9)	Poor	(1)	**1.91**
92	76	Chandanagar	Poor	(0.21)	Satis	(0.01)	Poor	(63)	Poor	(23)	Poor	(1)	Good	(4)	**1.42**
93	79	Borabanda	Poor	(0.17)	Satis	(0.03)	Satis	(157)	Poor	(46)	Poor	(5)	Poor	(1)	**1.36**

* Ex - Exellent; Avg - Average; V.Good - Very Good; Satis - Satisfactory

5.2.3 Application of Scoring Method

A spreadsheet is prepared to develop the final rankings by employing the experience and expert opinion survey for given criteria. Criteria MI is considered the utmost important variable and assigned the weightage of a maximum of 6, followed by a PTA of 4 according to the Survey. The density criteria, PD, and ED are observed equally in weightage of 2. The other two network variables are assigned equal weights of 1.

The formulae are given: $\boldsymbol{s_i} = \sum \boldsymbol{w_j x_{ij}}$(i = 1-93 and j = 1-6) (5.2)

where: s_i= score of the i^{th} transit station;

x_{ij}=score assigned to the j^{th} variable of the i^{th} transit station; and

w_i= weight assigned to the j^{th} variable.

For each criterion, a score is assigned based on the value obtained from Table 5.8. The highest value of each criterion is assigned by '1', and the score increases as the value reduce. For example, MI values are obtained by the formula given in eq.5.1varying from 0 to 1. Transit stations that are having similar characteristics of land use are given the same number. So not surprisingly, there are 53 unique MI values. Precisely, for this reason, the same number appears more than once for variable MI. In the same manner, PTA and JD have 20 and 78 unique numbers, respectively. Whereas PD, ED, and LK have all unique numbers (93). Weights considered for variables are MI-6, PTA-4, PD-2, ED-2, LK-1, and JD-1. The composite score is obtained by applying Eq 5.2. The resulting data for 93 transit stations are presented in decreasing their ranking as given in **Table 5.12**.

Table 5.12: Ranking of 93 transit stations by the Scoring method

Rank	TOD ID	TOD Name	Criteria Score						Composite Score
			Mix Landuse Index (MI)	Proportion of Transport Area (PTA)	Population Density (PD)	Employment Density (ED)	Lane Kilometer (LK)	Junction Density (JD)	
1	33	Gandhi Bhavan	2	6	29	6	15	17	**138**
2	34	Nampally	1	9	40	5	35	6	**173**
3	57	Sultan Bazaar	8	4	35	10	5	27	**186**
4	51	Secunderabad R. S.	12	5	33	2	16	13	**191**
5	56	Narayanguda	9	6	21	29	14	12	**204**
6	83	James Street	8	6	38	15	6	21	**205**
7	15	Parade Ground	10	1	49	7	1	29	**206**
8	36	Lakdikapul	4	8	45	19	17	23	**224**
9	73	Hyderabad	6	12	36	11	59	9	**246**
10	35	Assembly	10	9	52	4	29	16	**253**
11	32	Osmania Medical College	17	6	37	8	13	32	**261**
12	14	Paradise	3	6	66	21	11	36	**263**
13	54	Rtc X Roads	15	11	13	25	41	24	**275**
14	68	Kachiguda	16	14	17	27	66	11	**317**
15	89	Owaisi Hospital	14	11	25	40	42	27	**327**
16	50	Jubilee Bus Station	5	5	69	42	12	46	**330**
17	16	Secunderabad Station	24	8	60	9	28	7	**349**
18	39	Panjagutta	25	5	54	12	9	38	**349**
19	37	Khairatabad	19	10	43	20	33	39	**352**
20	58	Salarjung Museum	31	8	18	22	30	34	**362**
21	38	ErumMazil	19	14	51	3	69	19	**366**
22	10	Ameerpet	32	7	44	13	18	22	**374**
23	62	Jangammet	21	13	6	49	58	41	**387**

Rank	TOD ID	TOD Name	Criteria Score						Composite Score
			Mix Landuse Index (MI)	Proportion of Transport Area (PTA)	Population Density (PD)	Employment Density (ED)	Lane Kilometer (LK)	Junction Density (JD)	
24	31	Mgbs	29	8	56	16	26	18	**394**
25	52	Gandhi Hospital	18	10	22	67	48	20	**394**
26	27	Dilsukhnagar	37	8	16	24	37	25	**396**
27	69	Vidyanagar	32	8	14	57	27	4	**397**
28	63	Falaknuma	24	13	9	58	67	3	**400**
29	40	Sr Nagar	31	10	27	17	34	58	**406**
30	55	Chikkadpally	37	10	15	23	40	31	**409**
31	1	Shilparamam	6	12	86	36	55	28	**411**
32	21	Survey Of India	7	11	64	46	44	64	**414**
33	42	Erragadda	17	13	30	50	54	53	**421**
34	59	Charminar	44	10	11	14	43	30	**427**
35	29	New Market	37	4	31	38	21	32	**429**
36	44	Moosapet	10	6	59	71	10	75	**429**
37	28	MusaramBagh	36	2	26	69	3	13	**430**
38	53	Musheerabad	38	9	4	62	31	5	**432**
39	60	Shalibanda	47	7	3	30	25	31	**432**
40	22	Uppal	15	3	75	76	4	34	**442**
41	26	Chaitanyapuri	35	11	27	32	45	33	**450**
42	30	Malakpet	45	5	20	44	23	15	**456**
43	13	Rasoolpura	17	14	72	37	73	10	**459**
44	48	Jntu	28	9	57	28	36	49	**459**
45	2	Hitech City	23	11	79	1	56	68	**466**
46	11	Begumpet	22	11	61	31	46	63	**469**
47	70	Jamai Osmania	27	11	23	77	39	26	**471**

Rank	TOD ID	TOD Name	Criteria Score						Composite Score
			Mix Landuse Index (MI)	Proportion of Transport Area (PTA)	Population Density (PD)	Employment Density (ED)	Lane Kilometer (LK)	Junction Density (JD)	
48	78	Hitec City	11	8	77	86	20	37	**481**
49	71	Arts College	28	13	10	59	74	50	**482**
50	90	Aramghar	10	4	83	88	7	65	**490**
51	41	Esi Hospital	37	13	12	41	63	51	**494**
52	80	Fatehnagar	20	13	50	54	63	52	**495**
53	64	Falaknuma	33	17	19	56	89	1	**506**
54	9	Madhura Nagar	38	10	32	45	37	54	**513**
55	45	Balanagar Y- Junction	16	11	63	75	51	55	**522**
56	93	Suchitra	8	9	73	87	50	69	**523**
57	43	Bharat Nagar	22	14	41	63	79	56	**531**
58	47	Kphb Colony	39	11	47	33	47	47	**532**
59	66	Yakutpura	52	14	1	18	84	45	**535**
60	20	Ngri	13	13	70	64	65	76	**539**
61	23	Nagole	5	13	82	89	75	40	**539**
62	72	Sitafalmandi	30	17	24	70	91	14	**541**
63	84	RetiBowli	45	8	34	39	24	73	**545**
64	91	Kapra	32	10	62	65	32	45	**563**
65	12	Prakash Nagar	30	13	67	47	61	44	**565**
66	61	Shamsheergunj	51	14	5	35	77	47	**566**
67	8	Yusufguda	36	15	8	61	83	72	**569**
68	19	Habsiguda	23	12	68	72	53	58	**577**
69	87	Gachibowli X Rd	30	2	92	66	8	70	**582**
70	3	Cod	32	14	78	26	81	48	**585**
71	65	Huppuguda	48	14	7	53	87	42	**593**

Rank	TOD ID	TOD Name	Criteria Score						Composite Score
			Mix Landuse Index (MI)	Proportion of Transport Area (PTA)	Population Density (PD)	Employment Density (ED)	Lane Kilometer (LK)	Junction Density (JD)	
72	6	Jubilee Hills Check Post	26	12	87	51	57	57	**594**
73	18	Tarnaka	24	12	71	79	49	53	**594**
74	5	Peddamma Temple	37	13	81	43	68	8	**598**
75	46	Kukatpally	27	13	53	73	71	61	**598**
76	74	Necklace Road	29	15	74	34	82	66	**598**
77	24	Lb Nagar	49	3	55	52	2	78	**600**
78	81	Nature Cure Hospital	33	15	42	48	88	74	**600**
79	88	Wipro Juntion	13	14	93	74	70	69	**607**
80	7	Road No.5 Jubilee Hills	41	14	48	55	78	33	**619**
81	67	Dabirpura	51	12	2	80	72	35	**625**
82	92	Neredmet	34	12	58	81	52	45	**627**
83	17	Mettuguda	30	13	65	78	60	77	**655**
84	25	Victoria Memorial	43	12	39	83	62	43	**655**
85	82	Sanjeevaiah Park	26	18	90	60	90	71	**689**
86	77	Hafeezpet	43	7	84	91	22	62	**720**
87	85	Chintalmet	46	6	76	90	19	71	**722**
88	49	Miyapur	30	14	88	93	80	69	**747**
89	4	Madhapur	37	14	85	82	86	60	**758**
90	79	Borabanda	50	19	46	68	92	62	**758**
91	76	Chandanagar	47	20	80	85	93	2	**787**
92	86	Shaikpet	40	13	89	92	75	67	**796**
93	75	Lingampalli	42	16	91	84	85	59	**810**

5.2.4 Comparison between AHP and Scoring Methods

Both methods have followed different approaches, and the results obtained for the top 20 ranks are analyzed. In both methods, four transit stations are common in the top 5 ranks. Say 80% of the results are the same and confirm their significance. Whereas 14 transit stations are common in the top 20 ranks, which is equal to 70% of the data, which is common in both the methods and is presented in **Table 5.13**. This shows the reliability of the ranking method by AHP for promoting the transit station as TOD.

Table 5.13: Comparison of results between AHP and Scoring Method

TOD ID	TOD Name	Analytic Hierarchy Process		Scoring Method	
		Composite Score	Rank	Composite Score	Rank
33	Gandhi Bhavan	5.14	1	138	1
51	Secunderabad R. S.	5.04	2	191	4
34	Nampally	4.96	3	173	2
15	Parade Ground	4.94	4	206	7
56	Narayanguda	4.82	5	204	5
14	Paradise	4.76	6	263	12
36	Lakdikapul	4.74	7	224	8
57	Sultan Bazaar	4.66	8	186	3
50	Jubilee Bus Station	4.64	9	330	16
73	Hyderabad	4.54	10	246	9
35	Assembly	4.52	11	253	10
83	James Street	4.46	12	205	6
1	Shilparamam	4.24	13	411	31
32	Osmania Medical College	4.22	14	261	11
44	Moosapet	4.2	15	429	36
90	Aramghar	4.2	16	490	50
89	Owaisi Hospital	4.18	17	327	15
23	Nagole	4.12	18	539	61
78	Hitec City Mmts	4.04	19	481	48
2	Hitech City Metro	4	20	466	45

5.3 TOD Typology Analysis

TOD typology is performed for two different conditions. One is performed at the city level (GHMC) by Spatial Multi-Criteria Analysis to obtain its opportunity-oriented strategy. The second one is at the local level by the K-Mean clustering technique to draw the design-oriented strategies via resulted typology.

5.3.1 TOD typology at the city level

The most feasible urban TODs identified in the earlier step are considered for deriving typology at the city level. Criteria such as transportation network, built environment, and predominant land use types are considered in the analysis. To make a similar set of characteristics, each criterion is categorized as follows: Transportation network is divided into four subcategories based on the type of facility, say T1 (MMTS), T2 (MRTS), T3 (MMTS+MRTS), and T4 (Road); Built-environment is sub-categorized into three based on the percentage of open land available (Built-up land) say B1 (>40%), B2 (20%-40%) and B3 (<20%); Predominant land use is classified into four namely L1(Residential), L2(Commercial), L3(Institutional) and L4(Mixed). Combining these criteria leads to forming a common set of urban forms (grouping similar sets into one), say T1-B1-L1, T1-B1-L2.., etc. In the same manner, 34 transit stations are analyzed, and finally, 23 urban forms are observed and presented in **Table 5.14**.

Table 5.14: Achieved TOD Typology at City level

Urban TOD No	Location Name	Criteria 1: UM	Criteria 2: TF	Criteria 3: BE	Criteria 4: LU	TOD Typology
7	Necklace Road	U1	T1	B1	L2	U1-T1-B1-L2
6	Sanjeevaiah Park	U1	T1	B1	L4	U1-T1-B1-L4
1	Falaknuma MMTS	U1	T1	B2	L1	U1-T1-B2-L1
8	Lingampalli	U1	T1	B2	L4	U1-T1-B2-L4
4	Arts College	U1	T1	B3	L3	U1-T1-B3-L3
5	Kachiguda	U1	T1	B3	L4	U1-T1-B3-L4
15	Miyapur	U1	T2	B1	L1	U1-T2-B1-L1
23	Shilparamam	U1	T2	B1	L2	U1-T2-B1-L2
24	Jubilee Check post	U1	T2	B2	L1	U1-T2-B2-L1
3	MGBS	U1	T2	B2	L4	U1-T2-B2-L4
20	Uppal	U1	T2	B2	L4	U1-T2-B2-L4
22	Habsiguda	U1	T2	B2	L4	U1-T2-B2-L4
2	Falaknuma Metro	U1	T2	B3	L1	U1-T2-B3-L1
19	Mettuguda	U1	T2	B3	L1	U1-T2-B3-L1
16	Ameerpet	U1	T2	B3	L3	U1-T2-B3-L3
17	Parade Ground	U1	T2	B3	L4	U1-T2-B3-L4
18	Jubilee Bus Station	U1	T2	B3	L4	U1-T2-B3-L4
21	LB Nagar	U1	T2	B3	L4	U1-T2-B3-L4
9	Bharatnagar	U1	T3	B2	L1	U1-T3-B2-L1
10	Begumpet	U1	T3	B3	L2	U1-T3-B3-L2
13	Lakdikapul	U1	T3	B3	L2	U1-T3-B3-L2
11	Secunderabad	U1	T3	B3	L4	U1-T3-B3-L4
12	Nampally	U1	T3	B3	L4	U1-T3-B3-L4
14	Malakpet	U1	T3	B3	L4	U1-T3-B3-L4

28	Gachibowli	U1	T4	B1	L2	U1-T4-B1-L2
27	ShaikpetDarga	U1	T4	B1	L4	U1-T4-B1-L4
34	DairyformRoad NH7	U1	T4	B1	L4	U1-T4-B1-L4
26	Rajendernagar	U1	T4	B2	L1	U1-T4-B2-L1
29	Gachibowli-Wipro Junction	U1	T4	B2	L2	U1-T4-B2-L2
31	Aramgarh	U1	T4	B2	L4	U1-T4-B2-L4
30	OwasiBusstop	U1	T4	B3	L1	U1-T4-B3-L1
33	Neredmet	U1	T4	B3	L1	U1-T4-B3-L1
25	Rethibowli	U1	T4	B3	L4	U1-T4-B3-L4
32	ECIL	U1	T4	B3	L4	U1-T4-B3-L4
*UM - Urban Morphology; TF - Transportation Facility; BE - Built Environment; LU - Land Use						

TOD Investment Strategy for Priority Stations

Assessing the priority stations is undoubtedly an essential step for the TOD investment strategy. This part of the analysis is helpful for authorities or stakeholders to have an implementation strategy more appropriately in terms of investment. Based on early investigations of the city level typology, the criteria Transit facility (T), Land availability (B), and Predominant Land use (L) against High, Medium, and Low TOD priority are analyzed for investment on TOD. For instance, transit facility T2 and T3 (MRTS and MRTS+MMTS) have an excellent opportunity to invest in TOD because of high-capacity nodes. Similarly, B1(land availability is >40%), L1 (Residential), and L4 (Mixed) have high potential in the development of TOD. Accordingly, the rest of the criteria are segregated to medium and low based on their characteristics. The complete picture of priority TOD via its investment opportunity is presented in **Figure 5.9.** It is observed that three types of TODs are formed via., upper diagonal, along the diagonal, and below the diagonal. The resulting three types are named via high, medium, and low priority TODs, as represented in **Table 5.15.**

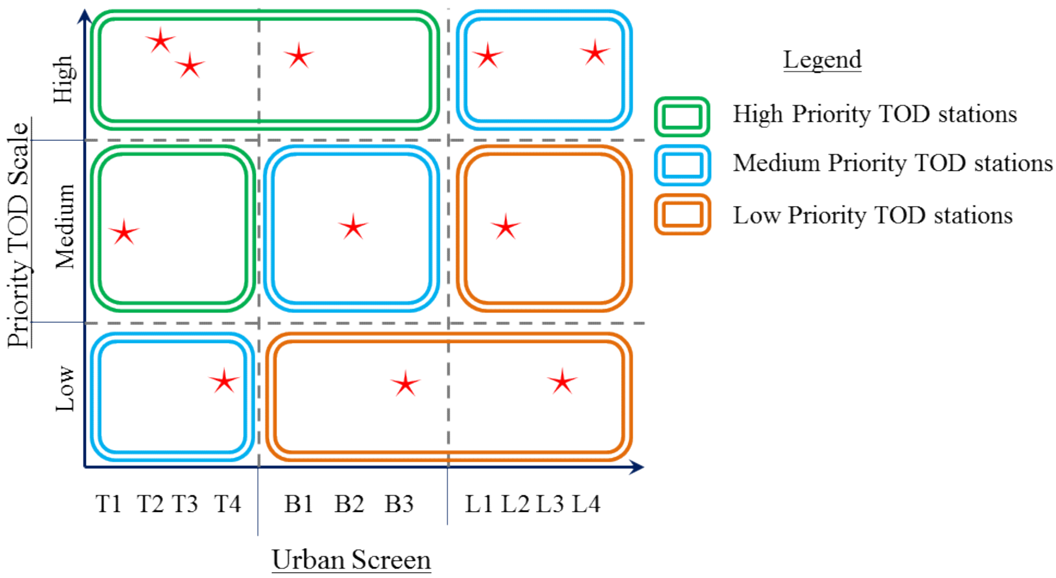


Figure 5.9: A schematic representation of the TOD Opportunity

For example, the Necklace road is TI-B1-L2 and noted as a high priority. As mentioned in Figure 5.9, T1 belongs to medium and falls in upper diagonal (Green box area), B1 also falls under upper diagonal, whereas L2 is under medium priority. Overall, on average, it falls under the upper diagonal, representing the High opportunity TOD category in the schematic representation of TOD opportunity.

Table 5.15: Opportunity oriented TOD Typology

High Opportunity	Medium Opportunity	Low Opportunity
10 No's	**15 No's**	**9 No's**
1. Necklace Road 2. Sanjeevaiah Park 3. Miyapur 4. Shilparamam 5. Parade Ground 6. Jubilee Bus Station 7. LB Nagar 8. Secunderabad 9. Nampally 10. Malakpet	1. Lingampalli 2. Kachiguda 3. Jubilee Check post 4. MGBS 5. Uppal 6. Habsiguda 7. Ameerpet 8. Begumpet 9. Lakdikapul 10. ShaikpetDarga 11. Dairy form Road on Old NH7 12. Rajendernagar 13. Aramgarh 14. Rethibowli 15. ECIL	1. Falaknuma MMTS 2. Arts College 3. Falaknuma Metro 4. Mettuguda 5. Bharatnagar 6. Gachibowli 7. Gachibowli-Wipro Junction 8. OwasiBusstop 9. Neredmet

5.3.2 TOD typology at sub-area level

GHA is considered to perform sub-area level TOD typology. A total of 20 TODs are identified. Land use and network inventory data are collected to analyze the TOD area. To understand the characteristics of each TOD, parameters considered are Land Use Mix, Plot Ratio, Proportion of Transport Area, Development Mix, and Intersection Density. The computing of each parameter is described below.

5.3.2.1 Calculation of Parameters

Land use Mix Index (MI)

MI represents the diversity of land use in the TOD area. MI is calculated using eq. 5.1. Data is collected through a Land use survey, as presented in Table 4.3. The obtained MI is given in **Table 5.16**.

Table 5.16: Mix Index value for TODs in GHA

Sl. No.	TOD Name	MI
1	Madhapur Metro Station	0.76
2	COD Metro Station	0.66
3	Hi-Tec City Metro Station	0.77
4	Shilparamam Metro Station	0.76
5	WS Colony Metro Station	0.67
6	Mind Space Metro Station	0.49
7	Gachibowli Metro Station	0.44
8	IIIT Metro Station	0.73
9	Indra Nagar Metro Station	0.46
10	Telecom Nagar Metro Station	0.63
11	Mistry College Metro Station	0.54
12	Khajaguda X Road Metro Station	0.47
13	Raidurgam Metro Station	0.50
14	VBIT Bus Stop	0.53
15	SiddiqNagar Bus Stop	0.60
16	ChotaAnjaiah Nagar Bus Stop	0.59
17	Chandra Naik Bus Stop	0.60
18	Kothaguda Bus Stop	0.52
19	Hi-Tec City MMTS Station	0.56
20	Hafeezpet MMTS Station	0.49

Plot Ratio (PR)

Plot ratio data is obtained by conducting a land-use survey in the study area. The plot ratio is the ratio of the total gross floor area to the total plot area. It represents the building density or compact form. **Table 5.17** presents the Plot Ratio data.

Table 5.17: Observed Plot Ratio data for TODs in GHA

Sl. No.	TOD Name	Total Gross Floor Area (Sq.m)	Total Plot Area (Sq.m)	Plot Ratio
1	Madhapur Metro Station	593259.35	289728.78	2.05
2	COD Metro Station	1159883.76	397445.96	2.02
3	Hi-Tec City Metro Station	825997.37	299915.83	2.75
4	Shilparamam Metro Station	306280.01	122973.11	2.49
5	WS Colony Metro Station	27204.12	18218.20	1.49
6	Mind Space Metro Station	1018430.63	316872.69	3.21
7	Gachibowli Metro Station	339002.98	167888.26	2.02
8	IIIT Metro Station	751672.33	355162.80	2.12
9	Indra Nagar Metro Station	623999.60	288607.11	2.16
10	Telecom Nagar Metro Station	706077.72	302394.54	2.33
11	Mistry College Metro Station	939148.71	320913.51	2.93
12	Khajaguda X Road Metro Station	158403.40	115446.51	1.37
13	Raidurgam Metro Station	390629.61	302821.28	1.29
14	VBIT Bus Stop	1837467.37	394937.02	4.65
15	SiddiqNagar Bus Stop	1098073.36	473501.42	2.32
16	ChotaAnjaiahNagar Bus Stop	877283.29	339541.78	2.58
17	Chandra Naik Bus Stop	597732.73	278522.48	2.15
18	Kothaguda Bus Stop	1133730.83	346199.57	3.27
19	Hi-Tec City MMTS Station	123729.51	75767.49	1.63
20	Hafeezpet MMTS Station	440537.96	416110.45	1.06

Proportion of Transport Area (PTA)

PTA is the area under transportation facility. Transportation area includes the area covered by the road network, rail network, bus stops, parking lots, and terminals. PTA is calculated by the formula given in eq. 5.3 and values are presented in **Table 5.18**

$$PTA = \frac{Area\ under\ Transportation}{effective\ TOD\ Area} \quad (5.3)$$

Development Mix Index (DMI)

A development mix is adapted to control each stations' role as either an employment center or a neighborhood. Based on station areas' development mix, interaction potential is calculated between people and the pool of jobs, jobs, and people pool. However, there might be some disparity between present and future population and employment that may result from planning the TOD concept around new stations. However, the variable as specified may provide an assessment of existing conditions designed to serve as a benchmark for potential policy interventions. DMI is a statistic ranging between 0 to 1, reflects the balance between population and employment in a station area. It is calculated by using the formula given in eq. 5.4. DMI calculations are presented in **Table 5.19.**

$$DMI = \frac{Employment}{Employment + Population} \quad (5.4)$$

Table 5.18: PTA calculation for TODs in GHA

Sl.No.	TOD Name	Effective TOD Area(Sq.m)	Road Area(Sq.m)	Railway Area(Sq.m)	Rail+Road Area (Sq.m)	Proportion of Road Network (%)	Proportion of Transportation Area (%)
1	Madhapur Metro Station	785714.3	198240.0		198240.0	25.23	25.23
2	COD Metro Station	748083.3	150178.7		150178.7	20.08	20.08
3	Hi-Tec City Metro Station	658342.5	99747.6		99747.6	15.15	15.15
4	Shilparamam Metro Station	752598.0	83221.5		83221.5	11.06	11.06
5	WS Colony Metro Station	724150.3	48423.3	24050.0	72473.3	6.69	10.01
6	Mind Space Metro Station	785714.3	135859.2		135859.2	17.29	17.29
7	Gachibowli Metro Station	700790.1	81822.7		81822.7	11.68	11.68
8	IIIT Metro Station	692619.8	96775.9		96775.9	13.97	13.97
9	Indra Nagar Metro Station	703712.3	176205.3		176205.3	25.04	25.04
10	Telecom Nagar Metro Station	778522.7	104917.9		104917.9	13.48	13.48
11	Mistry College Metro Station	778522.7	143810.8		143810.8	18.47	18.47
12	Khajaguda X Road Metro Station	785714.3	93839.9		93839.9	11.94	11.94
13	Raidurgam Metro Station	785714.3	68690.7		68690.7	8.74	8.74
14	VBIT Bus Stop	785714.3	79963.6		79963.6	10.18	10.18
15	Siddiq Nagar Bus Stop	745083.1	121946.7		121946.7	16.37	16.37
16	ChotaAnjaiah Nagar Bus Stop	743868.4	161154.0		161154.0	21.66	21.66
17	Chandra Naik Bus Stop	729089.7	168782.0		168782.0	23.15	23.15
18	Kothaguda Bus Stop	785714.3	114920.1		114920.1	14.63	14.63
19	Hi-Tec City MMTS Station	724150.3	149615.2	81693.0	231308.3	20.66	31.94
20	Hafeezpet MMTS Station	785714.3	135640.4	67570.0	203210.5	17.26	25.86

Table 5.19: DMI Values for TODs in GHA

Sl. No	TOD Name	Population 2011	Employment2011	DMI
1	Madhapur Metro Station	4051	3749	0.48
2	COD Metro Station	5504	12515	0.69
3	Hi-Tec City Metro Station	5051	47416	0.90
4	Shilparamam Metro Station	3635	5358	0.60
5	WS Colony Metro Station	316	164	0.34
6	Mind Space Metro Station	2798	6628	0.70
7	Gachibowli Metro Station	1431	1806	0.56
8	IIIT Metro Station	3035	3116	0.51
9	Indra Nagar Metro Station	3017	3914	0.56
10	Telecom Nagar Metro Station	2698	3816	0.59
11	Mistry College Metro Station	1605	2065	0.56
12	Khajaguda X Road Metro	496	214	0.30
13	Raidurgam Metro Station	1051	439	0.29
14	VBIT Bus Stop	2268	6603	0.74
15	Siddiq Nagar Bus Stop	4777	8391	0.64
16	ChotaAnjaiah Nagar Bus Stop	4090	5600	0.58
17	Chandra Naik Bus Stop	4973	3808	0.43
18	Kothaguda Bus Stop	3549	3891	0.52
19	Hi-Tec City MMTS Station	5521	1678	0.23
20	Hafeezpet MMTS Station	4291	859	0.17

Junction Density (JD)

Junction Density is the number of intersections located within a unit area of the buffer. Junction Density represents the network connectivity levels of an area. It is positively associated with the walkability aspect of the TOD area.

$$JD = \frac{No.of\ Intersections}{Effective\ TOD\ Area} \quad (5.5)$$

By using eq. 5.5, JD for TOD areas are calculated and presented in **Table 5.20**.

All the input parameters computed above are compiled and presented in **Table 5.21**.

Table 5.20: Intersection Density for TOD area

Sl. No.	TOD	No. of Intersections	Eff. TOD Area (ha)	Junction Density (No. of Intersections/ha)
1	Madhapur Metro Station	71	78.57	0.90
2	COD Metro Station	75	74.81	1.00
3	Hi-Tec City Metro Station	27	65.83	0.41
4	Shilparamam Metro Station	19	75.26	0.25
5	WS Colony Metro Station	02	72.41	0.03
6	Mind Space Metro Station	11	78.57	0.14
7	Gachibowli Metro Station	10	70.08	0.14
8	IIIT Metro Station	10	69.26	0.14
9	Indra Nagar Metro Station	57	70.37	0.81
10	Telecom Nagar Metro Station	51	77.85	0.66
11	Mistry College Metro Station	26	77.85	0.33
12	Khajaguda X Road Metro	45	78.57	0.57
13	Raidurgam Metro Station	45	78.57	0.57
14	VBIT Bus Stop	4	78.57	0.05
15	Siddiq Nagar Bus Stop	74	74.51	0.99
16	ChotaAnjaiah Nagar Bus Stop	73	74.39	0.98
17	Chandra Naik Bus Stop	85	72.91	1.17
18	Kothaguda Bus Stop	23	78.57	0.29
19	Hi-Tec City MMTS Station	52	72.41	0.72
20	Hafeezpet MMTS Station	79	78.57	1.01

Table 5.21: Parameters Calculated for Clustering Process

Sl. No	TOD	MI	PR	PTA	DM	JD
1	Madhapur Metro Station	0.76	2.05	0.25	0.48	0.90
2	COD Metro Station	0.66	2.02	0.20	0.70	1.00
3	Hi-Tec City Metro Station	0.77	2.75	0.15	0.90	0.41
4	Shilparamam Metro Station	0.76	2.49	0.11	0.60	0.25
5	WS Colony Metro Station	0.67	1.49	0.07	0.34	0.03
6	Mind Space Metro Station	0.49	3.21	0.11	0.70	0.14
7	Gachibowli Metro Station	0.44	2.02	0.12	0.56	0.14
8	IIIT Metro Station	0.73	2.12	0.14	0.51	0.14
9	Indra Nagar Metro Station	0.46	2.16	0.25	0.57	0.81
10	Telecom Nagar Metro Station	0.63	2.34	0.14	0.59	0.66
11	Mistry College Metro Station	0.54	2.93	0.19	0.56	0.33
12	Khajaguda X Road Metro Station	0.47	1.37	0.12	0.30	0.57
13	Raidurgam Metro Station	0.50	1.29	0.09	0.29	0.57
14	VBIT Bus Stop	0.53	4.65	0.10	0.74	0.05
15	Siddiq Nagar Bus Stop	0.60	2.32	0.16	0.64	0.99
16	ChotaAnjaiah Nagar Bus Stop	0.59	2.58	0.22	0.58	0.98
17	Chandra Naik Bus Stop	0.60	2.15	0.23	0.43	1.17
18	Kothaguda Bus Stop	0.52	3.28	0.15	0.52	0.29
19	Hi-Tec City MMTS Station	0.56	1.63	0.32	0.23	0.72
20	Hafeezpet MMTS Station	0.49	1.06	0.26	0.17	1.01

5.3.2.2 Procedure for K-Means Clustering using SPSS

Table 5.21 is the input data for the analysis in SPSS. Here, the detailed procedure is explained for the K-Means clustering technique. K-means clustering technique is the most widely used concept among all the other techniques in various disciplines. The advantages of adopting K-means clustering are that it is suitable for large data sets, relatively simple to use, convergence is more appropriate, random positions of the initial centroids, and generalizes the cluster shapes and sizes.

Firstly, classify option is selected in analyze menu bar, and K – Means Clustering option is picked up as shown in **Figure5.10**. After selecting the K – Means clustering option, the variables are marked and sent to the variables box. The Label Cases box is used for entering a string variable. The number of desired clusters is entered in the Number of Clusters box; in the present study, it is five, and then iteration is carried out, and the information is classified for successive iterations and final clustering to be carried out as shown in**Figure5.11.** In the Iterate option, criteria for updating cluster centers are selected. The maximum Iterations number can be given up to 999. The Convergence Criterion decides the stopping of the iteration process. Save option enables saving the new variables in the data set file, representing the cluster membership and the distance of each object (**Figure 5.12**). The requirement, displaying additional statistics such as initial cluster centers, ANOVA table, and cluster information for each case is selected as shown in **Figure5.13.** Finally, the output of the clustering is obtained by clicking OK.

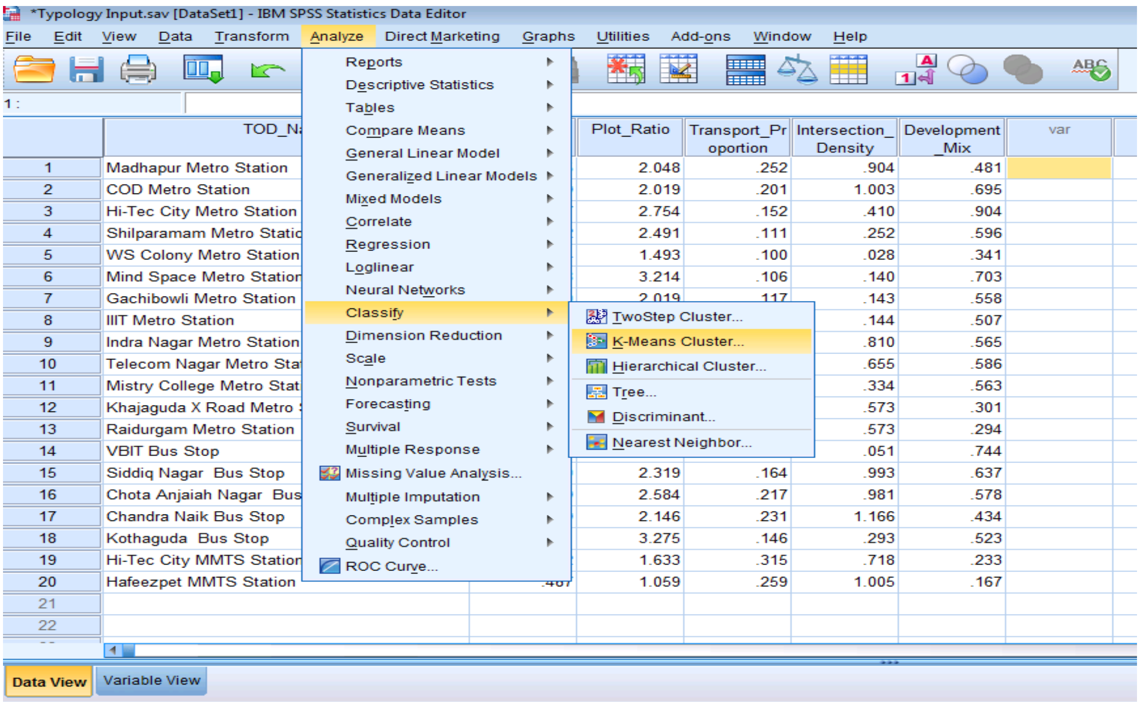


Figure 5.10: Selecting K – Means Clustering in SPSS

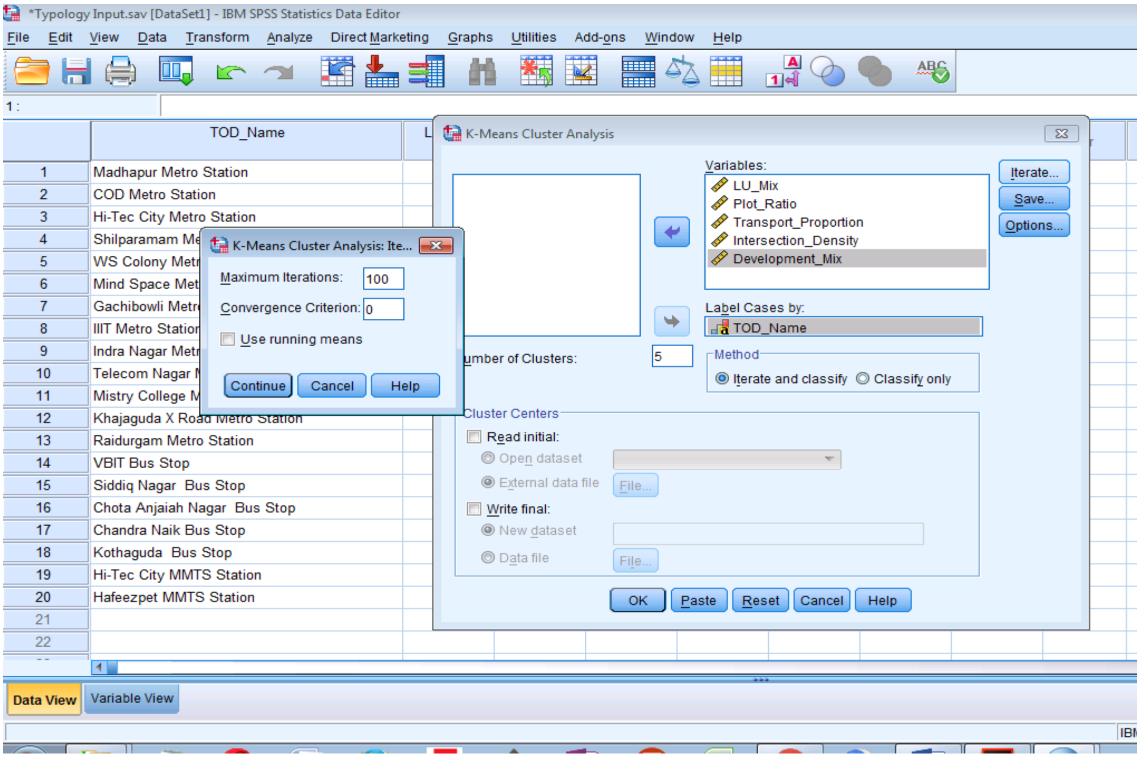


Figure 5.11: Selecting Iterations criteria in SPSS

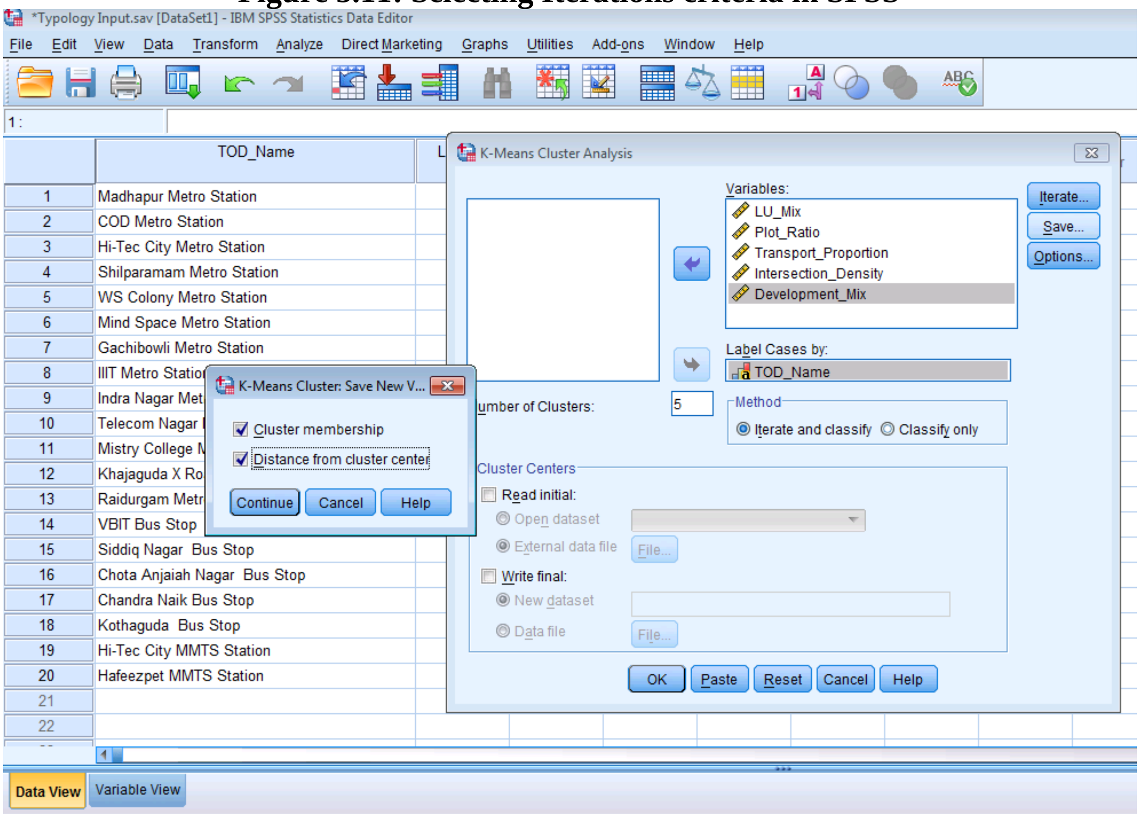


Figure 5.12: Selection of Cluster Membership pattern

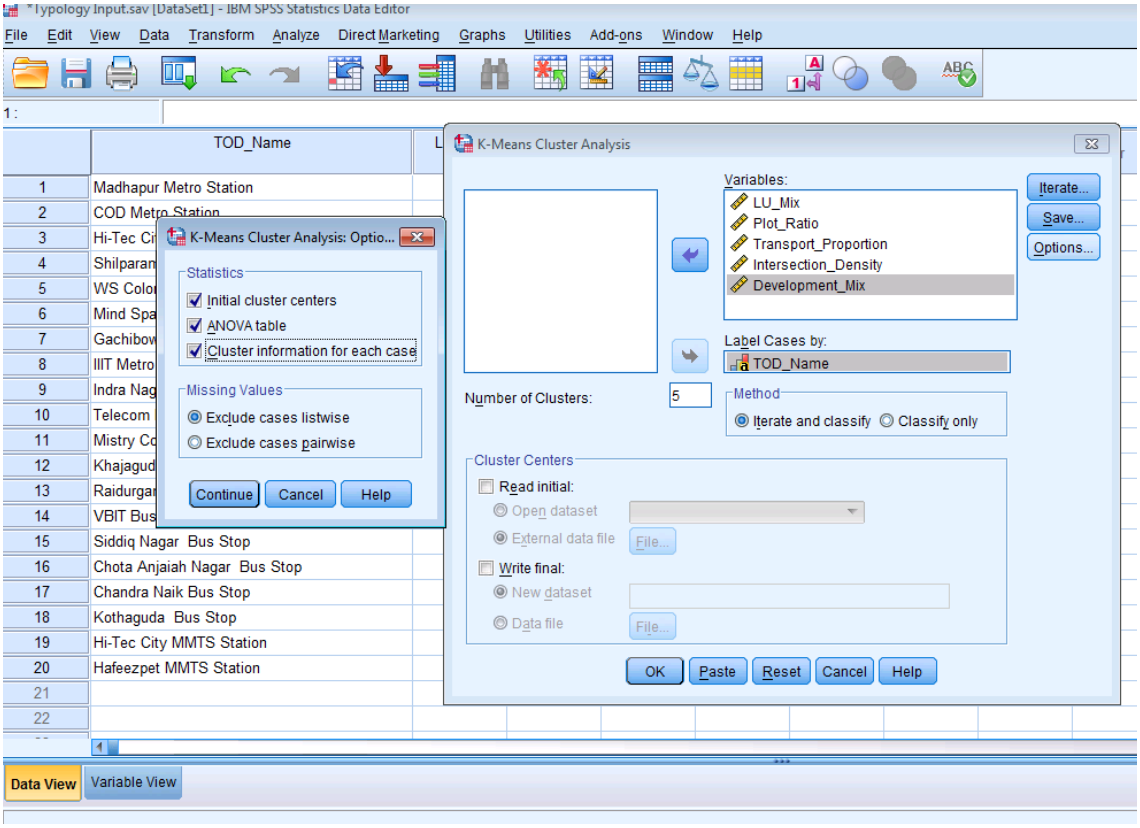


Figure 5.13: Selection of Output Statistical Options

Based on the analysis mentioned above, five cluster groups are formed and named by observing the cluster characteristics in detail. The five-cluster output along with corresponding TODs are given in **Figure 5.14**.

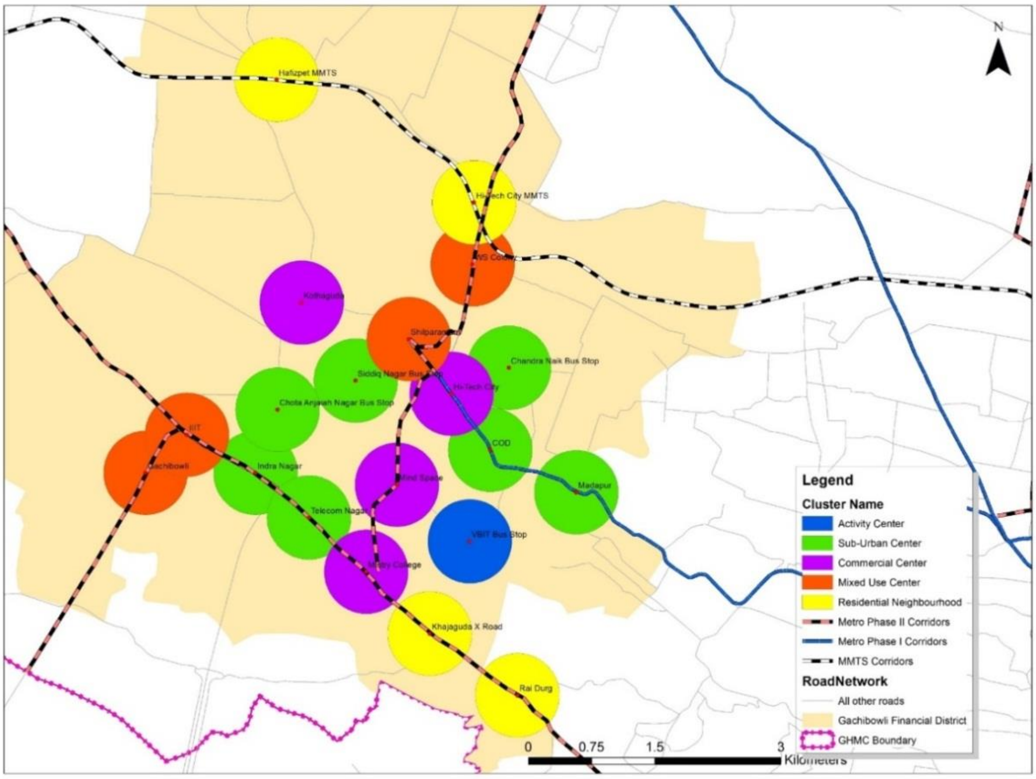


Figure 5.14: Sub-area level TOD Typology

Table 5.22: Final Output of K-Means Clustering

Cluster Number (Name)	TOD Name
C – 1 (Activity Center)	VBIT Bus Stop
C – 2 (Balanced TOD)	Madhapur Metro Station
	COD Metro Station
	Indra Nagar Metro Station
	Telecom Nagar Metro Station
	Siddiq Nagar Bus Stop
	ChotaAnjaiah Nagar Bus Stop
	Chandra Naik Bus Stop
C – 3 (Commercial TOD)	Hi-Tec City Metro Station
	Mind Space Metro Station
	Mistry College Metro Station
	Kothaguda Bus Stop
C – 4 (Mixed TOD)	Shilparamam Metro Station
	WS Colony Metro Station
	Gachibowli Metro Station
	IIIT Metro Station
C – 5 (Residential TOD)	Khajaguda X Road Metro Station
	Raidurgam Metro Station
	Hi-Tec City MMTS Station
	Hafeezpet MMTS Station

TOD typology is an integral part of the planning process, which plays a vital role in evaluating existing transit stations and detecting a common set of issues on a metropolitan scale. Consequently, the typology will be supporting the identification of general development potentials and necessary future adoptions for the whole class or within classes. Based on the results obtained for five clusters and looking into the existing site-specific conditions (details mentioned in chapter 6), clusters have been named activity-based TOD, Balanced TOD, Commercial TOD, Mixed TOD, and Residential TOD, as given in **Table 5.22.**

5.4 Summary

In this chapter, analysis of feasible TODs identification, prioritizing of TODs, and TOD typology is carried out. A total number of 34 and 35 feasible TODs are identified for urban and sub-urban areas, respectively. Prioritization of all transit nodes within GHMC is done using the AHP method, and results are compared with the traditional scoring method. TOD typology study is carried out for city and sub-area levels separately. Twenty-three types of urban forms are observed from the city-level typology study. For the sub-area level, detailed analysis is carried from the land use and network inventory survey for 20 transit stations. By using these details, the K-Means clustering technique is adopted to reach the five cluster group typology. Further, detailed design proposals and strategies based on derived typology are discussed in chapter 6.

Chapter 6

Design Proposals and Implementation Strategies

6.1 General

Transit-Oriented Development (TOD) is one of the most efficient ways of creating a sustainable city. The main objective is to draw the implementation strategies. Each state or country should have its strategies. In developed countries, strategies have been drawn, and TOD is implemented successfully. To draw strategies, it is necessary to understand the ground-level deficiencies concerning sustainable measures. According to the sub-area level typology results, an attempt is made here to draw implementation strategies based on issues identified and analysed and design proposals. Also, a generalized TOD model is developed to help the planning authorities for an easy implementation process.

6.2 Design Proposals

Design of each element with care and proper enforcement actions would yield significant positive results. However, designing each TOD at the micro-level is a tedious and complex procedure. Hence, designing the TOD areas in terms of cluster-level, i.e., macro level, would save much time. So, derived TOD Typology (from chapter 5) is considered for design proposals, as shown in **Table 6.1**. Then, the design aspects for each cluster level TODs are proposed. The present study highlights the considerations of implementing successful TOD areas in accordance with the Indian guidelines and international case studies. Design proposals have been suggested for quantitative as well as qualitative variables in the following sections. The quantitative variables are further analyzed to the evaluation process to witness the impact of design proposals.

Table 6.1: Naming of Cluster of TODs

Sl. No.	Cluster	Proposed Scenario
1	C - 1	Activity Center (Recreational) TOD
2	C - 2	Balanced (Residential + Employment) TOD
3	C - 3	Commercial TOD
4	C - 4	Mixed TOD
5	C - 5	Residential Neighborhood TOD

6.2.1 Design Proposal of Quantitative variables

Land Use Scenario

An optimal mix of residential, commercial uses, incomes, and services needs to be planned in the influence area to reduce dependency on private vehicles and shift travel patterns from private vehicles to walk, cycling, IPT, and public transport. In the Indian context, at least 30% residential, 20% commercial + Institutional use (min. 5% for each) of FAR is mandatory in every new/ redevelopment project within the influence zone (UTTIPEC, 2012). Cluster-wise existing land use scenario in terms of percentages is presented in **Table 6.2**.

Table 6.2: Existing Land Use Scenario for Clusters of TODs

Sl. No.	Land Use	C - 1	C - 2	C - 3	C - 4	C - 5
1	Residential Land Use	31.9%	25.4%	21.6%	10.8%	19.7%
2	Commercial Land Use	1.1%	5.3%	3.9%	2.0%	1.9%
3	Institutional Land Use	0.0%	2.5%	2.4%	2.9%	1.8%
4	Mixed Land Use	0%	1.8%	0.9%	0.2%	3.4%
5	Office Land Use	16.7%	8.7%	12.7%	5.9%	0.7%
6	Public & Semi Public Amenities	0.6%	1.6%	1.3%	1.6%	1.7%
7	Transportation Area	10.2%	20.7%	16.4%	11.7%	19.6%
8	Undeveloped Land	39.6%	34.0%	40.8%	64.8%	51.2%

In the present study, Inorbit mall is found in cluster one, a notable activity centre in the present and will also be an activity center in the future. Hence, the proposed land use for the activity center is 50%, and the rest of land use (50%) is distributed among others (i.e., residential, commercial, community). Similarly, all the clusters are analyzed, and proposed land use patterns are given based on international guidelines (TOD Guideline, Queensland, 2010), as presented in **Table 6.3**.

Table 6.3: Proposed Land Use Scenario for Clusters of TODs

Cluster Name	Proposed Landuse
Activity Centre TODs **(C – 1)**	1. Residential: >20%
	2. Commercial+Office+ Institution: 20%
	3. Community: 10%
	4. Activity Center: 50%
Balance TODs **(C – 2)**	1. Residential: 40%
	2. Commercial+Office+ Institution: 40%
	3. Community: 10%
	4. Activity: 10%
Commercial TODs **(C – 3)**	1. Residential: 30%
	2. Commercial+Office+ Institution: 60%
	3. Community: 5%
	4. Activity: 5%
Mixed TODs **(C – 4)**	1. Residential: 50%
	2. Commercial+Office+ Institution: 40%
	3. Community: 5%
	4. Activity: 5%
Residential TODs **(C – 5)**	1. Residential: 60%
	2. Commercial+Office+ Institution: 15%
	3. Community: 10%
	4. Activity: 15%

Floor Area Ratio Criteria

A higher floor area ratio (FAR) represents higher population and job density in the influence area. The minimum floor area ratio should be 3 to 5 and can be higher depending on city size (URDPFI, 2014). This may result in a higher concentration of people within the walking distances of transit nodes, thereby increasing public transit ridership and reducing own vehicle ride dependency. However, the FAR norms and proposed densities in the influence areas may vary across the city depending upon the available infrastructure, land use zoning, transit capacity, etc., for the study area. Currently, the GHMC development plan does not have specific FSI rules for buildings in Hyderabad. Specifically, high rises have free FAR (no limits on FAR) to encourage real estate growth in the city. However, as per AP Building rules, in some cases, such as stepped type, podium, and tower buildings are being at higher FAR of up to 5. The existing and proposed Floor Area Ratio for each cluster type is given in **Table 6.4.**

Table 6.4: Existing and Proposed FAR for TOD clusters

Cluster	Existing FAR	Proposed FAR
C - 1	4.65	5 to 8
C - 2	2.23	4 to 6
C - 3	3.04	4 to 6
C - 4	2.03	3 to 5
C - 5	1.34	3 to 5

Density Criteria

To make TOD more sustainable and facilitate the most efficient use of land in the TOD area and prevent sprawl, the population holding capacity of each station area is maximized. FAR < 3 should not be permitted for any redevelopment project. Higher FAR would not automatically result in densification as large dwelling units may defeat the critical purpose of densification. Hence the integration of FAR with the dwelling unit's density would be essential. It should be noted that higher density is much more important than increased FAR. The integration of FAR with density is a critical element of the TOD concept. Permissible FAR with a density of dwelling units are given in **Table 6.5**.

Table 6.5: Permissible FAR criteria with density

Gross FAR (Site)	**Minimum permissible density (with + 10% variation**	
	Residential dominated project (Residential FAR > 50%)	**Predominantly non - residential (Residential FAR < 30%)**
< 1	Under - Utilization of FAR (not permitted)	Under - Utilization of FAR (not permitted)
1.1 - 2.0	200- 400 du/ha*	100 - 200 du/ha
2.1 - 3.0	400 - 600 du/ha*	250 – 400 du/ha
>3.1	600 – 800 du/ha*	400 – 600 du/ha
*du/ha – Dwelling unit per hectare		

Transportation Area

Transportation area proportion represents the opportunity for developing transportation infrastructure facilities in an area. NMT, pedestrian, public transportation, and intermediate public transport should be given due priority compared to others. The proposed scenario of transportation area proportions is represented in **Table 6.6.**

Table 6.6: Proposed Transportation Areas

Cluster	**Proportion of Transport Area**	
	Existing	**Proposed**
C - 1	10.20%	15% - 20%
C - 2	20.71%	20% - 25%
C - 3	14.73%	20% - 25%
C - 4	11.70%	20% - 25%
C - 5	19.50%	20% - 25%

For service level benchmarking of urban transportation 'Ministry of Urban Development' suggested % Road area for Level of Service as given in **Table 6.7**

Table 6.7: Level of Service with respect to % of Road area

LOS	**% Road Area**
1	> 15
2	12 -15
3	10 - 12
4	< 10

Development Mix

Development Mix indicates a balance between residential and employment populations in an area. If the Development Mix is > 0.5, the station area is oriented to employment or residential activities. The proposed scenario of Development Mix (as per TOD Guidelines by DDA) is given in **Table 6.8**

Table 6.8: Proposed Development Mix for Clusters

Cluster	Existing Development Mix	Proposed Development Mix
C - 1	0.744	0.7-0.8
C - 2	0.568	0.6-0.75
C - 3	0.673	0.75-0.85
C - 4	0.501	0.4-0.6
C - 5	0.249	0.3-0.5

Street Network

The streets in TOD areas should be designed so that all age groups should use the streets conveniently and safely. The development in the influence zone should be in smaller blocks with a finer street network having provisions for pedestrians, bicyclists, and NMT users. Thus, this will produce a grid of small, traversable blocks and ensures the accessibility of transit stations by pedestrians and cyclists. Right of way (ROW) should not dictate the pedestrian circulation in the network; it should instead be designed based on the pedestrian volume and adjoining land use. If ROWs are smaller, it is preferable to go with "pedestrian and NMT only" or "one-way streets" so that pedestrian circulation is not compromised. The right of way for road types should follow the URDPFI guidelines, as given in **Table 6.9**. The minimum lane width for Urban Expressway, Arterial, Sub – Arterial, and Distributor/Collector lanes should be 3.0 to 3.5m, whereas, for Local streets and Access roads, it should be 2.75 to 3.0 m.

Table 6.9: Right of Way (ROW) Criteria for Urban Roads

Sl. No.	Road Type	Design Speed (kmph)	Space Standard (m)
1	Urban Expressway	80	50 – 60
2	Arterial Roads	50	50 – 80
3	Sub - Arterial Roads	50	30 – 50
4	Distributor/Collector Roads	30	12 – 30
5	Local Street	10 – 20	12 – 20
6	Access Streets	15	12 – 15

Source: URDPFI, 2014

Footpaths

It is desirable to have continuous and unobstructed footpaths of suitable widths on either side of the road. For arterial and sub-arterial road footpaths, the code specifies to provide guard rails for safety concerns. All the roads in the TOD area should contain footpaths on either side. The existing scenario of footpaths and bicycle lanes is presented in **Table 6.10**. IRC:103-2012 provides the guidelines for footpath widths as per adjacent land uses and is presented in **Table 6.11**.

Table 6.10: Existing Footpaths and Bicycle lanes lengths on cluster level

Cluster	Existing Proportion of Footpaths	Existing The proportion of Bicycle Lanes
C - 1	16.06%	0%
C - 2	7.04%	0%
C - 3	15.17%	0%
C - 4	38.16%	0%
C - 5	4.01%	0 %

Table 6.11: Required width of Footpath as per Adjacent Land Use given by IRC: 103 -2012

Adjacent Land Use	Required Footpath Width
Residential/Mixed Use Areas	1.8 m
Commercial Areas	2.5 m
Shopping Frontages	3.5-4.5m
Bus Stops	3 m
High-Intensity Commercial Areas	4 m
* Consider dead width of 0.5m in addition.	

Bicycle Lanes

IRC: 103-1962 specifies a minimum width of cycle track to be > 2m (2 lanes, each of 1m), and the code recommends a provision of 3m width if overtaking is permitted. It is desirable to have Bicycle lanes for all the street networks. If there is any ROW constraint, then bicycle lanes should be provided for all the roads of ROW > 10m.

Pedestrian Crossings

Pedestrian safety should be given the highest priority to make walking catchments of the TOD area. To avoid conflict issues of pedestrian crossings, the unsafe roads should be provided with a safe pedestrian crossing infrastructure. IRC: 103-2012 gives the guidelines of infrastructure facilities for pedestrian crossings as follows.

- Pedestrian Subways: 4.8 m width, 2.75 m vertical clearance, at least 50 lux lighting, and CCTV cameras.
- Pedestrian Foot Over Bridges: This is of least priority as walking length increases considerably. If provided should have 1.8 m width, one vertical to 5 horizontal slopes, 0.76 – 0.9 m guard rails. If a lift facility is provided at Foot Over Bridge ends, it should have 1.5 m x 1.5m internal dimensions.
- Cross Walks: The Zebra Crossings width should be 2 – 4 m.
- Pedestrian signals at intersections.

6.2.2 Design Proposal of Qualitative variables

Weaker Sections Housing

The cities should fix a minimum proportion (30% or higher) of allowed FSI for affordable housing (up to 60 sq.m. area) in all development/ redevelopment projects. 10-15% of the built-up area in the TOD influence zone should define for economically weaker sections (EWS). This should be provided by enforcement mandatory to take care of and provide incentives of additional FAR for EWS housing.

Traffic Calming Measures

Traffic calming measures promote a safe and secure environment for pedestrians and NMT users. Necessary considerations should be taken to slow down the speeds and reduce the volume of motorized traffic in the influence area. National TOD policy suggests that on streets primarily designed for the movement of pedestrian and NMT users and those are having ROW < 12m, the maximum speed limit should be restricted to 20 kmph, and for all other streets, in and around the influence zones, the speed should be limited to 40 kmph (NTOD, 2017). The streets having widths of less than 6m make streets of NMT lanes only, however, eligible for emergency vehicles. Ninety degrees' street network discourages motor vehicle movement.

Open Space Preservation

Open spaces such as amenity spaces, green spaces, playgrounds, parks, and natural areas should be preserved as part of the development of the transit area. URDPFI (2014) guidelines suggest 10-12 sq.m per person.

Multi-Modal Integration

Mass transportation options serving the TOD area should be well-integrated, and the pedestrians, NMT users, and feeder services, so that time spent for ingress and egress and modal transfers is reduced to the minimum. Modal transfers should be integrated spatially through smart ticketing and real-time information. Delhi Development Authority suggests the following norms for multi-modal integration in the TOD area, as shown in **Table 6.12**

Table 6.12: Distances of Facilities from Nodes

Distance from Node	Designated Facilities
Within 50 m	Bus Stops, Cycle - Rental Station
Within 100 m	High Occupancy Feeder Stop
Within 150 m	Cycle Rickshaw Stand, IPT/Auto Rickshaw Stand
Beyond 150 m	Private Car, Taxi drop - off Location, Public Toilets
Beyond 300 m	Validated car parking facility Park & Ride
Within 500 m	The interchange between any two Rapid Transit Station modes (e.g., Railway, Metro, RRTS, etc.)

Hierarchy of Station Area Access

The hierarchy of the facilities at the node is in the following order.

Pedestrians > Bicycle > Feeder Bus > Drop – Off facilities > Park and Ride facility

Last Mile Connectivity

Intermediate Public Transport (IPT), Non-Motorized Transport (NMT), and Feeder Buses will perform a key role in providing first and last-mile connectivity to the populace beyond the influence zone. The area around the transit station remains congestion-free, and to facilitate easy transfers, it is essential to provide adequate pick-up/drop–off facilities, adequate parking for the above modes at convenient, suitable locations at the stations and in the influence zone. To support TOD, park and ride facilities may be provided if needed. The facilities, with pricing, may deter private vehicle use, may be planned primarily at the terminal stations, and can variably decrease as per the requirement on the intermediate nodes.

Parking

The parking issues and solutions are listed here as

- On-street parking should be prohibited in the influence area; if necessary, it should be priced higher than off-street parking.
- The supply of parking must be reduced within the influence area and made it expensive to discourage the use of private vehicles and to manage to park.
- The use of parking spaces within the influence zone can be maximized by sharing spaces between uses that have demand during different times of the day. For example, parking requirements for office/work can be shared with the parking spaces for residences as their hours for demands do not coincide.
- TOD aims to promote NMT, which includes the use of bicycles. Therefore, bicycle parking facilities should be provided at regular intervals and suitable locations within the influence zone. Public bicycle sharing systems may also be planned to promote the use of bicycles.

To restrict unauthorized parking and to avoid congestion caused due to on-street parking, it is essential to have an enforcement mechanism in place. Cities should have a parking policy with a heavy penalty for unregulated parking in the influence zone and ensure that the same is implemented. Also, the parking should have price variations per time of day and duration of parking.

6.3 Implementation Strategies

It is certain that TOD is successful in many countries and is a very able technique of travel demand management and in promoting public transport use. However, considering the status of the transport sector, it's bearing on society, the complexity of the relationship between various stakeholders, and political motivation, it is imperative to address this concept in a new light. TOD should be primarily a tool for demand management rather than a source of finance. A few points need to be studied in detail and improved before implementing a smart growth tool which is practically possible. Otherwise, TOD will be part of reports and proposals and will never be a deserved success. Strategies are to be drawn as listed below

Strategy1: The transformation of streets towards a walkable environment

Strategy 2: Integration between street design and adjacent development

- Integration of land use with existing/new constructed transport infrastructure for good access
- Connectivity plans among the building (adjacent building access)
- Creation of space within a built environment for refreshment purposes

Strategy 3: Change of regulatory measures at the policy level to support TOD

Strategy 4: Projects completion

- Completion of existing projects to demonstrate the high quality of Transit
- Completion of short-term planning projects which directly support the transit system to enhance its ridership like junction improvement/corridor improvement/ pedestrian paths etc.
- Pedestrian safety projects such as minimizing the conflict areas between vehicular and pedestrian moments near station areas

Strategy 5: Zonal demarcation – traffic circulations

- Intense zone: (up to 150m)
    - No parking facilities are allowed
    - Pickup and drop-off only must be provided
    - Only through traffic is permitted (at least in peak periods)
    - Bicycle docking stations must be present
    - High importance to the pedestrians and NMT
- Standard zone: (150 – 400 m)
    - Off-street parking slots are provided based on market potential

- Equitable distribution of road space for NMT & Vehicular traffic
- The docking station is in a half number (compared to intense zone)

- Transition zone: (beyond 400m)
  - Provision of space for local markets (for daily needs)
  - Provision of IPT stands (Uber/Ola/Auto rickshaw.. etc.)

Strategy 6: Development Activity

- Green Field Development:
  - Vacant land or undeveloped land
- Brownfield development:
  - Redevelopment/Infill
  - Combining smaller land parcels into one
  - Green area communities
  - Provision for Economically Weaker Section housing (10-15%)

Strategy 7: Integration of other Transport services

- Feeder services shall be provided to improve first and last-mile connectivity with the existing available transport system
- Fare integration among all other transport services

Strategy 8: Finding of financial tools to encourage the development

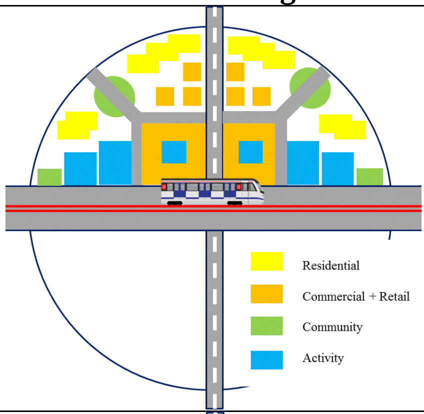
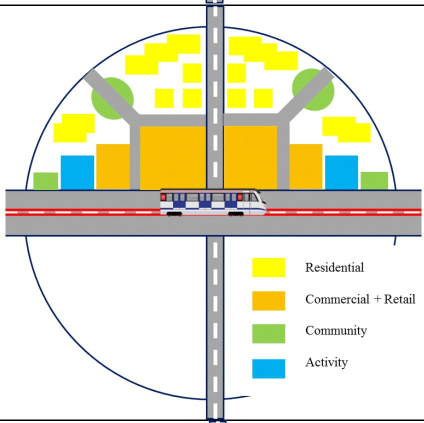
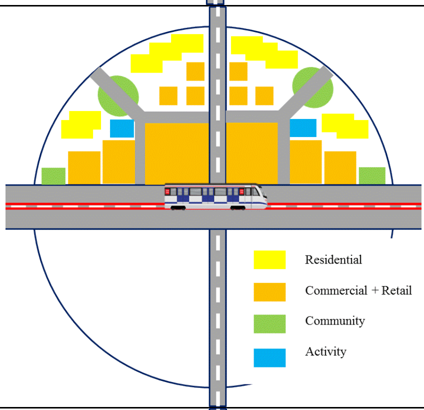
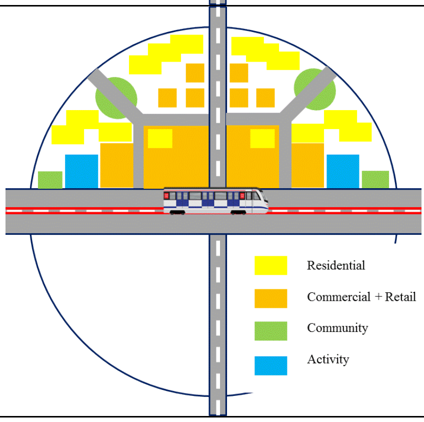
Strategy 9: Institutional setup - Authorities should have a separate TOD wing at the central level

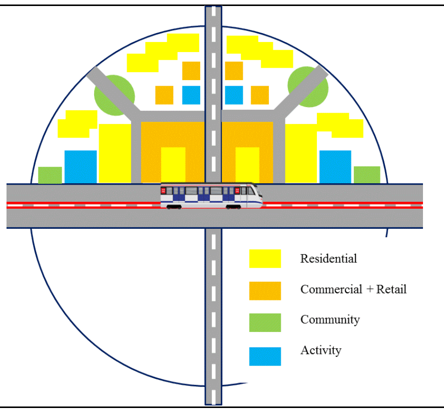
6.4 Generalised TOD model

6.4.1 Schematic Representation of Types of TOD

Based on present study proposals, a schematic representation of TODs for each cluster is drawn and presented in **Table 6.13**. Proposed land use characteristics for each cluster are mentioned. The four primary land use criteria are given in terms of percentages to represent the proposed type of cluster. These schematic diagrams are helpful to guide the authorities for the implementation process in the future.

Table 6.13: Cluster-Based Schematic Representation of TOD

Type of TOD	Schematic Diagram	Characteristics
Activity Centre TODs (C – 1)		1. Residential: >20% 2. Commercial+Retail: >20% 3. Community: 10% 4. Activity Center: 50%
Balance TODs (C – 2)		1. Residential: 40% 2. Commercial+Retail: 40% 3. Community: 10% 4. Activity: 10%
Commercial TODs (C – 3)		1. Residential: 30% 2. Commercial+Retail: 60% 3. Community: 5% 4. Activity: 5%
Mixed TODs (C – 4)		1. Residential: 50% 2. Commercial+Retail: 40% 3. Community: 5% 4. Activity: 5%

Residential TODs (C – 5)		1. Residential: 60% 2. Commercial+Retail: 15% 3. Community: 10% 4. Activity: 15%

6.4.2 A General Schematic TOD Model

A generalized TOD model is developed to suit the developing country's conditions and address the challenges they face in the success story of TOD. To develop the model, the design elements considered are land use orientation, traffic circulations, NMT facilities, traffic regulations, parking facilities, and local markets (roadside vendors/ hawkers). Regarding land use orientation, it is proposed that in the intense zone (i.e., up to 150 m from the station), high priority is given to core commercial and retail activity. Next, in the standard zone (i.e., 150-400 m), high mixed land use is suggested, and in the transverse zone (beyond 400m), residential, green area preservation is highly imposed. Further, the ground realities are addressed in traffic circulation, NMT facilities, parking, and local market allocation. For instance, local markets are proposed in the transverse zone because of highly occupied roadside vendors in an intense zone, which affects the proposed NMT facilities and leads to failure of designs. A schematic diagram is presented in **Figure 6.1**.

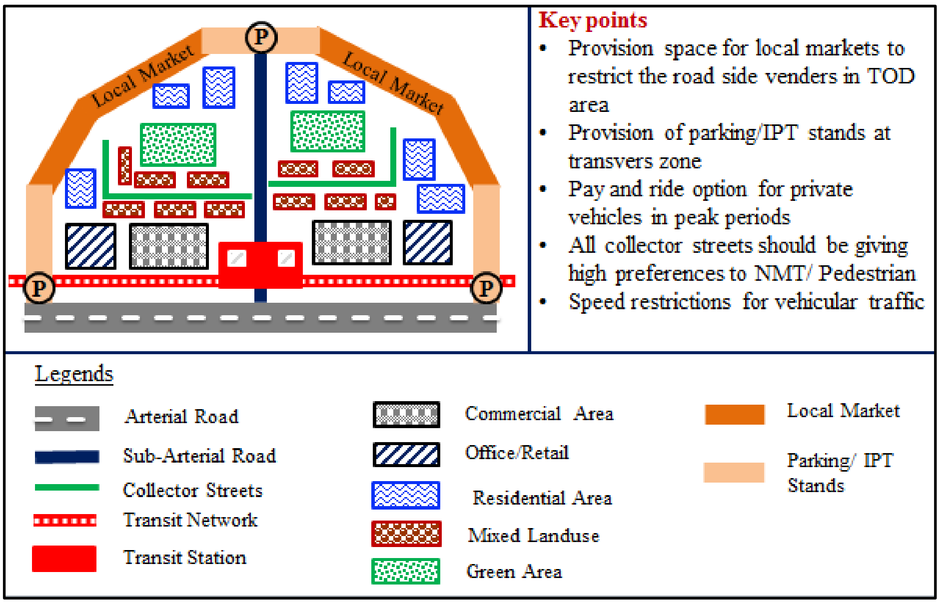


Figure 6.1: A schematic Generalised TOD Model

The existing TOD model is developed and implemented in only developed countries like the US, UK, Australia, etc., and is most suitable for greenfield development. Whereas the present study results in the TOD models based on existing land use and traffic scenarios. The study targeted to fit the TOD model with the current ground conditions. Accordingly, the proposed models are formed by not deviating much from the existing land-use scenarios and land cover. The study also included the elements related to traffic issues like parking and circulation plan within the TOD area.

6.5 Summary

The design aspects for each cluster of TODs are proposed by careful understanding of needs and targets for development. These guidelines will try to clarify necessities and priorities for the TOD area. The present guidelines recommend that they are intended to act as a basis for planners and development authorities and helps in the planning and development process, and reduce delay and conflict for all stakeholders. The zenith goal of these guidelines is to promote vibrant and liveable TOD areas that will benefit surrounding communities and use public Transit as primary means of transportation. Accordingly, the study developed a schematic generalized TOD model to address the identified challenges (viz., local markets, parking, traffic circulation, etc.) for the Indian dense cities context. Finally, Strategies are drawn for the implementation of TOD to make it more promising.

Chapter 7

Evaluation of TOD

7.1 General

The evaluation process is a critical step, where the success or failure of a project is determined. Around the world, most of the studies are done in the evaluation process for the completed TOD project only. Whereas, in the present framework, it is proposed that, before going for implementation, the evaluation process is included. Here, two approaches are followed; one is measuring the TOD index before and after design proposals, and the second one is the Impact assessment of TOD.

7.2 Measuring of TOD Index

Measuring TOD Index is the quantifying characteristic of TOD, ranging from '0' to '1', where '1' represents complete TOD and '0' represents the non-TOD region. TOD Index is calculated by considering the components such as transit node, density, economic development, land use diversity, and street design. These weights are assigned based on their role in making successful TOD. Hence, calculating the existing and future TOD index (with new design proposals) and observing the improvement gained is the method of witnessing.

7.2.1 Existing TOD Index

GHA area is considered to carry out the TOD Index for 20 TOD locations. TOD index is proposed based on representative site parameters to assess the existing TOD. For this analysis, significant criteria like transit node, density, economic development, land-use diversity, and street design are considered. A total of 12 indicators are incorporated to represent the selected criteria mentioned above, and each TOD component and their indicators with proposed weights are given in **Table 7.1.** These weights are assigned based on careful observation from the literature and expert opinion. It is observed that about 55% of weightage is allotted to land use diversity and street design criteria. These criteria will play a significant role in making successful TOD.

Table 7.1: TOD criteria and their indicators with weightages

Sl.No	TOD Criteria	Weightage	Indicators	Weightage
1	Transit Node	0.15	Mode	0.5
			Connectivity	0.3
			Docking Stations	0.2
2	Density	0.20	Population Density	0.5
			Employment Density	0.5
3	Economic Development	0.10	Plot Ratio	1.0
4	Land Use Diversity	0.30	Mix Index	0.5
			Development Mix	0.5
5	Street Design	0.25	% of Transport Area	0.3
			Intersection Density	0.1
			Foot Path	0.2
			Bicycle Lanes	0.2
			Parking Facility	0.2

TOD index is calculated for 20 TODs in the present study area and is given in **Table 7.2**.

Table 7.2 Existing TOD index along with criteria indices

TOD ID	TOD Name	Transit Node	Density	Economic Development	Land use Diversity	Street Design	TOD Index
1	Madhapur Metro	0.64	0.40	0.30	0.62	0.51	**0.52**
2	COD Metro	0.58	0.65	0.30	0.68	0.44	**0.56**
3	Hi-Tec City Metro	0.67	0.95	0.50	0.84	0.40	**0.69**
4	Shilparamam Metro	0.67	0.35	0.40	0.68	0.36	**0.50**
5	WS Colony Metro	0.37	0.00	0.10	0.51	0.27	**0.28**
6	Mind Space Metro	0.37	0.30	0.60	0.60	0.21	**0.41**
7	Gachibowli Metro	0.37	0.10	0.30	0.50	0.17	**0.30**
8	IIIT Metro	0.37	0.30	0.30	0.62	0.15	**0.37**
9	Indra Nagar Metro	0.37	0.30	0.30	0.51	0.28	**0.37**
10	Telecom Nagar Metro	0.37	0.30	0.40	0.61	0.14	**0.37**
11	Mistry College Metro	0.37	0.10	0.50	0.55	0.17	**0.33**
12	Khajaguda X Road Metro	0.37	0.00	0.10	0.39	0.11	**0.21**
13	Raidurgam Metro	0.37	0.05	0.10	0.40	0.11	**0.22**
14	VBIT Bus Stop	0.25	0.25	1.00	0.64	0.11	**0.41**
15	SiddiqNagarBusStop	0.25	0.55	0.40	0.62	0.23	**0.43**
16	ChotaAnjai Nagar BusStop	0.25	0.40	0.40	0.59	0.28	**0.40**
17	ChandraNaik Bus Stop	0.25	0.50	0.30	0.52	0.30	**0.40**
18	Kothaguda Bus Stop	0.25	0.35	0.60	0.52	0.13	**0.36**
19	Hi-Tec City MMTS	0.38	0.50	0.20	0.40	0.60	**0.45**
20	Hafeezpet MMTS	0.38	0.40	0.00	0.33	0.52	**0.37**

80% of TODs fall below the mid-point (0.5) of the TOD index, indicating the absence of TOD components. So the study recommends a detailed analysis of future TOD to improve the TOD index. Thus, the study framework suggests carrying out TOD typology in planning and implementation of TOD.

7.2.2 Future TOD Index

Design proposal and implementation strategies proposed in chapter 6 are positively influencing TOD. The same criteria given above are considered to evaluate the future TOD Index. The first criteria, Transit Node, depends upon it's indicators like mode of transit, connectivity, and bicycle docking stations. As per the proposals, transit mode is upgrading from bus to MRTS (for TOD ID -5 to 13) according to HMDA proposals. The implementation strategies 1, 2, 3, and 5 (given in Chapter 6.3) support the TOD area to better its connectivity. Similarly, Implementation strategy 5 (given in Chapter 6.3) recommends the docking stations in the TOD area. Similarly, for calculating density criteria (population and employment), proposed FAR values (see Table 6.4) are used to arrive at new density values. Then, they are converted to index values by using eq. 3.11. Likewise, the future TOD Index is calculated by considering all the design proposals and implementation strategies, as presented in **Table 7.3**. An average of 0.62 is achieved. At the Hi-tech city metro station, design components such as density, population, employment, and street design (viz., NMT facilities, parking) play a vital role in achieving the highest TOD index of 0.83.

Table 7.3: Future TOD index along with the criteria indices

TOD ID	TOD Name	Transit Node	Density	Economic Development	Land use Diversity	Street Design	TOD Index
1	Madhapur Metro	0.86	0.55	0.80	0.75	0.64	**0.70**
2	COD Metro	0.86	0.75	0.80	0.75	0.65	**0.75**
3	Hi-Tec City Metro	0.95	0.95	1.00	0.84	0.59	**0.83**
4	Shilparamam Metro	0.95	0.55	0.80	0.68	0.58	**0.68**
5	WS Colony Metro	0.77	0.70	0.30	0.51	0.73	**0.62**
6	Mind Space Metro	0.77	0.60	0.80	0.70	0.57	**0.67**
7	Gachibowli Metro	0.77	0.70	0.80	0.50	0.61	**0.64**
8	IIIT Metro	0.77	0.65	0.30	0.62	0.57	**0.60**
9	Indra Nagar Metro	0.77	0.45	0.50	0.70	0.63	**0.62**
10	Telecom Nagar Metro	0.77	0.45	0.50	0.75	0.62	**0.64**
11	Mistry College Metro	0.77	0.25	0.80	0.70	0.59	**0.60**
12	Khajaguda X Road Metro	0.77	0.35	0.50	0.39	0.61	**0.50**
13	Raidurgam Metro	0.77	0.45	0.30	0.40	0.61	**0.51**
14	VBIT Bus Stop	0.57	0.25	1.00	0.64	0.57	**0.57**
15	SiddiqNagarBusStop	0.57	0.60	0.30	0.75	0.64	**0.62**
16	ChotaAnjaiahBusStop	0.57	0.50	0.30	0.80	0.64	**0.62**
17	Chandra Naik Bus Stop	0.57	0.60	0.30	0.70	0.63	**0.60**
18	Kothaguda Bus Stop	0.57	0.65	0.50	0.70	0.58	**0.62**
19	Hi-Tec City MMTS	0.67	0.60	0.00	0.40	0.80	**0.54**
20	Hafeezpet MMTS	0.67	0.45	0.00	0.33	0.68	**0.46**

TOD Index is calculated for both existing and proposed conditions to observe the difference in improvement. On average, a 22% increase in the TOD index is observed for 20 stations. Also, the maximum improvement of the TOD Index is witnessed at the WS colony metro station by 34%. Existing and Future TOD Index values are given in **Table 7.4** and represented as shown in **Figure 7.1.**

Table 7.4:Existing and Future TOD Index values

TOD ID	Future TOD Index	Existing TOD Index	Future TOD Index
1	Madhapur Metro	0.52	0.70
2	COD Metro	0.56	0.75
3	Hi-Tec City Metro	0.69	0.83
4	Shilparamam Metro	0.50	0.68
5	WS Colony Metro	0.28	0.62
6	Mind Space Metro	0.41	0.67
7	Gachibowli Metro	0.30	0.64
8	IIIT Metro	0.37	0.60
9	Indra Nagar Metro	0.37	0.62
10	Telecom Nagar Metro	0.37	0.64
11	Mistry College Metro	0.33	0.60
12	Khajaguda X Road Metro	0.21	0.50
13	Raidurgam Metro	0.22	0.51
14	VBIT Bus Stop	0.41	0.57
15	SiddiqNagarBusStop	0.43	0.62
16	ChotaAnjaiahBusStop	0.40	0.62
17	Chandra Naik Bus Stop	0.40	0.60
18	Kothaguda Bus Stop	0.36	0.62
19	Hi-Tec City MMTS	0.45	0.54
20	Hafeezpet MMTS	0.37	0.46

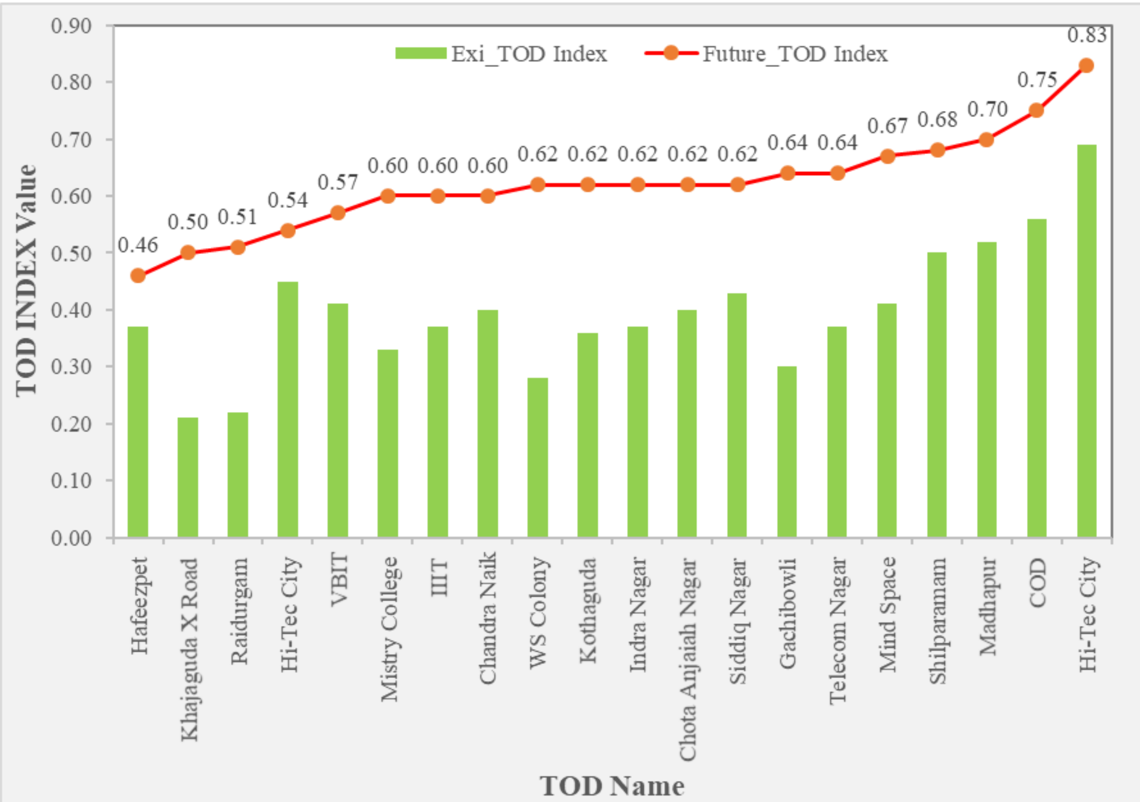


Figure 7.1: TOD Index before and after the proposal

7.3 Impact Assessment

7.3.1 Hedonic Price Method

Two metro stations, namely Ameerpet and Kukatpally, are considered to identify the impacts on residential property values and land use. The hedonic model is used to analyze the changes in the value of properties located within 1000m from metro station considering the distance to metro stations, area of the building, frequency of trains, distance to nearest school/park/hospital as the variables that influence the property value (PV). The results have shown a positive impact at Kukatpally metro station with a decrease in property value as the distance to the station increases, whereas at Ameerpet metro station, the values increase with an increase in distance.

PV Model Estimation for Ameerpet

For an individual station the model developed is given in eq.7.1

$$\log(PV) = \beta 0 + \beta 1*(NF) + \beta 2*(LS) + \beta 3*(DM) + \beta 4*(DS) \quad (7.1)$$

where,

$\beta 1$ = coefficient representing the effect of No. of floors on property value

$\beta 2$ = coefficient representing the effect of lot size on property value

$\beta 3$ = coefficient representing the effect of distance to metro station on property value

$\beta 4$ = coefficient representing the effect of distance to nearest school/Park on property value

PV = value of the residential property

Two models are developed comparing the radial distance with network distance. The results obtained are almost similar for both models. The model estimates or coefficients of variables are shown in **Table 7.5**.

Table 7.5: Regression model results for Ameerpet Station

Item	Radial distance model estimates			Network distance model estimates		
	Coefficients	Standard Error	t- Stat	Coefficients	Standard Error	t-Stat
Intercept	6.4068	0.046	139.7	6.4157	0.110	59.6
No. of Floors	0.0346	0.010	3.59	0.0365	0.010	3.74
Area of building (sq.m)	0.0010	0.000	12.64	0.001	0.000	12.8
Distance to Metro station (m)	0.0006	0.0001	6.54	0.0005	0.000	4.31
Distance to School/Park (m)	-0.0001	0.000	-2.03	-0.0001	0.000	-2.7
R^2	0.74			0.73		

The model explains over 74% of the variation in the log of property values. Three of the variables: No. of floors, Area of building, and Distance to school/park, are statistically significant with expected signs. The increase in floors increases the property value by 3.46% for an additional one floor. For every 100m increase in distance to school or park, property value reduces by 1%.

In the network model, the value of property increases by 5% for every 100m increase in the distance from the station. The coefficients of building and distance to the nearest school/park remain the same as in the radial model.

PV Model Estimation for Kukatpally

The regression model is developed for Kukatpally, as shown in eq.7.2 using radial distance, which explains 80% of the variation in the log of property value. In this model, only two variables are statistically significant with an appropriate sign. The no. of floors and building areas are significant with an expected sign, whereas the distance to the nearest school/park is not significant.

$$\log(PV) = \beta 0 + \beta 1*(NF) + \beta 2*(LS) + \beta 3*(DM) + \beta 4*(DS) \quad (7.2)$$

Here $\beta 0$,$\beta 1$,$\beta 2$,$\beta 3$,$\beta 4$ are the same as explained in eq.7.1

The radial distance model and network distance model developed have shown almost similar results, and the model estimates are as given in **Table 7.6**.

Table 7.6: Regression Model result for Kukatpally Station

Item	Radial distance model estimates			Network distance model estimates		
	Coefficients	Standard Error	t Stat	Coefficients	Standard Error	t Stat
Intercept	6.222	0.04	175.2	6.2381	0.04	167
No. of Floors	0.0288	0.01	4.09	0.0284	0.01	4.02
Area of building (sq.m)	0.0013	0	20.8	0.0013	0	20.6
Distance to Metro station (m)	-0.0003	0	-3.69	-0.0003	0	-3.6
Distance to School/Park (m)	0.0002	0	1.97	0.0001	0	1.98
R^2	0.8			0.79		

The model developed for Ameerpet and Kukatpally stations has an R^2 value of 0.74 and 0.80, respectively.

7.3.2 Property Value Assessment

Four locations are considered to assess the impact of development. Ameerpet, Kukatpally, Uppal, and Miyapur are the locations considered, and the residential property values for the years 2016 and 2019 are collected. Then the percentage of change in property value is calculated and plotted, as shown in **Figure 7.2.** At Ameerpet and Kukatpally, the percentage of change in property value is nominal when moving far from the stations as they are acting like CBD, and it is hardly a no-space for new development. Whereas Uppal and Miyapur are end stations, there is a vast scope for development, leading to increased property value even after 500m from the station area. The availability of land is also another consideration for the investors to invest their money on upcoming business in these areas.

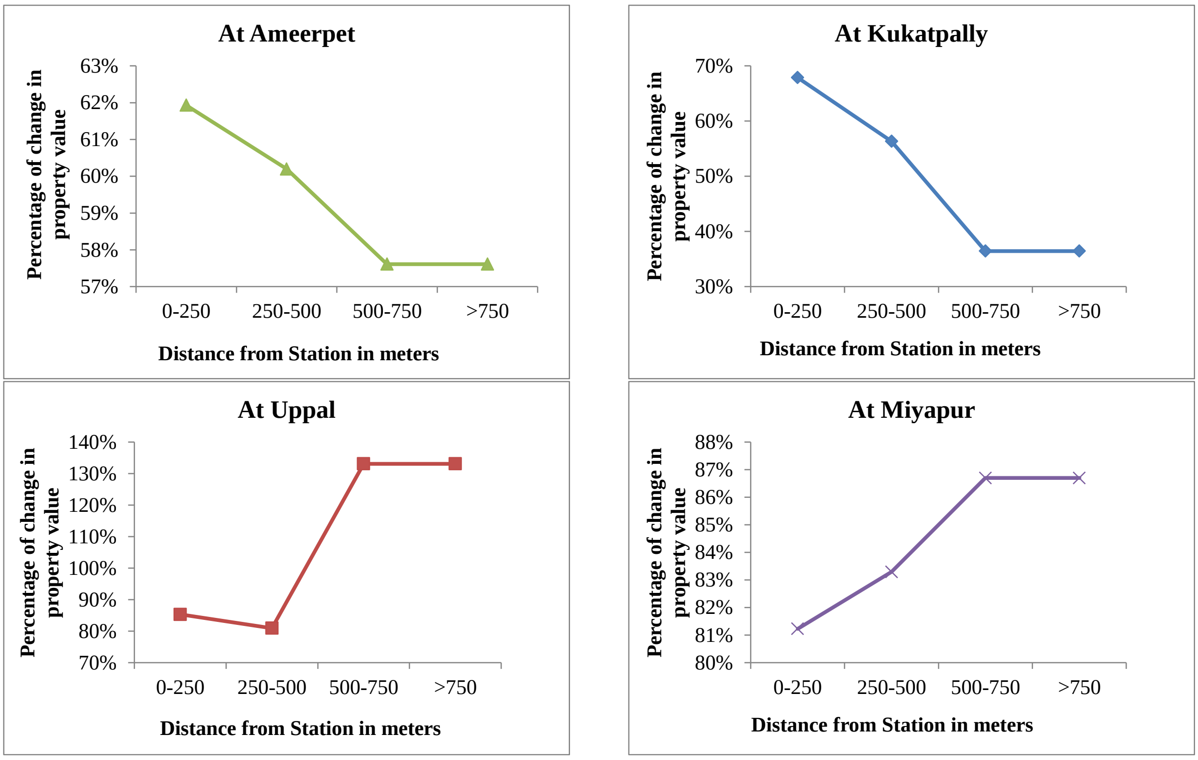


Figure 7.2: Percentage of Change in Property value at selected locations

7.4 Summary

In this chapter, the evaluation process is presented. The evaluation of TOD is done in two different approaches; 1) Measuring TOD Index and 2) Impact assessment. TOD Index for the GHA area is measured by considering before and after design proposals. So, the effect of design criteria on TOD is witnessed. Impact assessment is done by considering the residential property value assessment. Further, the conclusions of the present study are reported in the next chapter.

Chapter 8

Summary and Conclusions

8.1 General

In this chapter, a summary of the present study and conclusions drawn are presented in the following sections. The whole work is summarised, and each step of the framework is explained in brief along with the outcomes. Parameters considered and the method adopted are also summarised. Further, for each objective, the conclusions are drawn and presented subsequently. Study limitation of the present research work is presented. Finally, the scope of the future work is briefed.

8.2 Summary

The research work comprises of extensive literature review to understand the state of the art of TOD. This helps understand the TOD historical perception, concept, definitions, planning theories, and implementation strategies across the globe. Later research gaps are identified, and accordingly, objectives of the research work are established. The comprehensive goal of the research work is to establish a framework for TOD implementation. To achieve this, several steps are involved, explained in detail in research methodology (chapter 3). HMA is considered as the study area to apply the proposed framework.

Identification of feasible TODs is the initial step of the framework proposed. A total number of 34 and 35 feasible TODs are identified for urban (GHMC) and sub-urban (Rest of HMA) areas, respectively. Prioritization of TODs of the GHMC area is also performed to showcase the ranking procedure to the authorities for stage-wise implementation. Prioritization is done using the AHP method, and results are compared with the traditional scoring method. TOD typology study is carried out for city and sub-area levels separately. Twenty-three types of urban forms are observed from the city-level typology study. For the sub-area level, GHA is considered, and 20 transit stations are taken into consideration for the typology study. Parameters considered are plot ratio, development mix, the proportion of transport area, land use mix, and junction density. K-Means clustering technique is adopted to derive five cluster group typologies.

The design aspects for each cluster of TODs are proposed by careful understanding of needs and targets for development. These guidelines would clarify the necessities and priorities for the TOD area. The present guidelines are recommended, which act as a basis for planners and development authorities and help plan and develop processes to reduce delay and conflict for all stakeholders. The main goal of these guidelines is to promote vibrant and liveable TOD areas that will benefit surrounding communities and make use of public Transit as primary means of transportation. Accordingly, a schematic generalized TOD model is developed in this study to address the identified challenges (viz., local markets, parking, traffic circulation, etc.) for the Indian dense cities context.

The final step in the framework is the evaluation process. To know the impact of proposed designs and strategies, appropriate parameters are selected for assessment. Based on parameters selected TOD Index is measured for existing and future conditions of TOD where design proposals are witnessed. Also, an attempt is made to know the impact of TOD based on the percentage change in the residential property value. Key findings of the present study are as follows:

- A total of 34 Urban TODs are identified in the core area by the SMCA approach using ArcGIS
- A total of 35 sub-urban TODs are recognized based on the Gird Analysis using ArcGIS
- In the present study, a total of 93 TOD locations are ranked using AHP analysis
- The study concluded that the mixed land-use index, the proportion of transportation area, population and employment density, lane-kilometer and junction densities are more suitable criteria in the TOD ranking process
- By urban screen analysis, a total of 34 urban TODs are categorized into 10-High, 15-Medium, and 9-low TOD investment opportunities to propose the implementation process.

- In the present study, from the K-means cluster analysis, the local level TOD Typology is categorized into five groups, namely activity center, balanced, commercial, mixed-use, residential neighborhood TODs, which signifies the future TOD adaptation
- The study revealed that an average of 22% increase in TOD index is observed based on before and after design proposals

8.3 Conclusions

The following conclusions are drawn from the present study:

- Based on the framework developed, the most feasible TODs are identified to ensure sustainable urban development across the study area by considering the macro-level spatial data such as land use and transportation network
- Prioritization of TODs are explored by the Analytic Hierarchy Process (AHP), which is appropriate to rank the TODs and help the authorities to make decisions in the stage-wise implementation of process
- The study revealed that the city level opportunity based typology is significant enough for TOD implementation based on urban screen analysis through Transit facility, land availability, and predominant land-use type
- The present study concluded that the existing characteristics of place and node are essential in performing local level TOD typology to ensure the necessity of future adaptations for successful TOD
- The study concluded that parameters such as plot ratio, development mix, land use mix index, affordable housing, the proportion of transport area, NMT facilities, and open space preservation are appropriate to strengthen the TOD area through a cluster-based design implementation strategy
- The study developed a schematic generalized TOD model to address the identified challenges (viz., local markets, parking, traffic circulation, etc.) for Indian dense cities context
- The study also concluded that density (viz., population, employment) and street design (viz., NMT facilities, parking) are playing a vital role in achieving the highest TOD index at Hi-tech city metro station (0.83)

8.4 Limitations

The present study has the following limitations:

- In the process of identification of sub-urban TODs, settlement location, the activity center is not considered.
- Socio-economic factors are not considered for typology analysis
- As part of the TOD impact assessment, data collection of the property value at each unit level is not considered.

8.5 Scope for the future study

The present study targeted developing a framework for the implementation of TOD in developing countries. As part of this study, several analyses have been carried out and have much scope for various elements to strengthen more scientifically. Here are few points listed to carry out the future study.

- Sub-urban TODs can be further studied in detail to translate them into self-sustainable centers.
- A Corridor level Typology can be analyzed further based on the structure of urban morphology.
- Evaluation of the impact of TOD can be analyzed by understanding the changes in travel behavior patterns in the city.
- A hedonic price model can be done by considering each individual unit in the apartment for micro-level analysis.

REFERENCES

1. Al-Mosaind, M. A., Dueker, K. J., & Strathman, J. G. (1993). Light-rail transit stations and property values: a hedonic price approach. *Transportation Research Record* 1400: 90-94.
2. An Atlanta Report. (2013). An Equitable TOD Typology for the Atlanta Region: Atlanta Typology Memo, The Atlanta TOD Collaborative, Atlanta
3. Austin, M., Belzer, D., Sam, Z., and Lyman, A. (2010). *Performance-Based Transit-Oriented Development Typology Guidebook,* Center for TOD, California.
4. Bae, C.-H. C. Orenco Station, Portland, Oregon: a successful transit oriented development experiment. Transportation Quarterly, 2002, 56, No. 3, 9–18.
5. BART Report. (2003). Transit-oriented development Guidelines, San Francisco Bay Area Rapid Transit District.
6. Banai, R., (1998). Transit-oriented development suitability analysis by the analytic hierarchy process and a geographic information system: a prototype procedure. J. Public Transp. 2 (1), 43–65.
7. Belzer, D., and Aulter, G., (2002). Transit-Oriented Development: Moving from Rhetoric to Reality. Thr Brookings Institute Center for Urban and Metropolitan Policy and The Great American Station Foundation, Washington, D.C., USA.
8. Bertolini, L., (1996). Nodes and places: complexities of railway station redevelopment. Eur. Plan. Stud. 4 (3), 331–345.
9. Bertolini, L., (1999). Spatial development patterns and public transport: the application of an analytical model in the Netherlands. Plan. Pract. Res. 14 (2), 199–210.
10. Bertolini, L., Curtis, C., Renne, J., (2012). Station area projects in Europe and beyond: towards transit oriented development? Built Environ. 38 (1), 31–50
11. Bertolini, L., le Clercq, F., & Kapoen, L. (2005). Sustainable accessibility: a conceptual framework to integrate transport and land use plan-making. Two test-applications in the Netherlands and a reflection on the way forward. Transport policy, 12(3), pp 207-220.
12. Bernick, M., R. Cervero. (1997). The Transit Village in the 21st Century. McGraw-Hill, New York.
13. Boarnet M. and Crane R. (1998). Public finance and transitoriented planning: new evidence from southern California. *Journal of Planning Education and Research*, 17, No. 3, 206–219.
14. Boarnet, M. G. and Compin, N. S. Transit-oriented development in San Diego County: The Incremental Implementation of a Planning Idea. *Journal of the American Planning Association*, 1999, 65, No. 1, 80–95.

15. Bowes, D. R., & Ihlanfeldt, K. R. (2001). Identifying the impacts of rail transit stations on residential property values. *Journal of Urban Economics*, *50*(1), 1-25.
16. California Department of Transportation. (2002). State-wide Transit-Oriented Development Study Factors for Success in California: Final Report. California Department of Transportation, Sacramento, CA, USA.
17. Calthorpe, P., (1993). The Next American Metropolis. Ecology, Community and the American Dream. Princeton Architectural Press, New York.
18. Cervero, R., 1995. Sustainable new towns. Stockholm's rail-served satellites. Cities 12 (1), 41–51.
19. Cervero, R., Dai, D., (2014). BRT TOD: leveraging transit oriented development with bus rapid transit investments. Transp. Policy 36, 127–138
20. Cervero, R., Ferrell, C., and Murphy S. (2002). TCRP Research result digest: Transit oriented development and Joint development in the United States: A literature Review. Transportation Research Board of the National Academics, Number 52, pp. 1–144.
21. Cervero, R., and Kang, C. (2011). "Bus rapid transit impacts on land uses and values in Seoul, Korea." *Journal of Transport Policy*, 18, 102–116.
22. Cervero, R., Kockelman, K., (1997). Travel demand and the 3Ds: Density, diversity, and design. Transportation Research Part D: Transport and Environment Volume 2(3), pp 199-219.
23. Cervero R., Murphy S., Ferrell C., Goguts N., Tsai Y.-H., Arrington G. B., Borski J., Smith-Heimer J., Golem R., Peninger P., Nakajima E., Chui E., Dunphy R., Myers M., Mckay S. and Witenstein N. (2004). Transit-Oriented Development in the United States: Experiences, Challenges. Transportation Research Board, Washington, D.C., USA, Transit Cooperative Research Program Report 102.
24. Celik, H. & Yankaya, Ugur. (2006). The impact of rail transit investment on the residential property values in developing countries: The case of Izmir Subway, Turkey. *Property Management.* 24. 369-382.
25. Chen, X., Lin, L., (2015). The node-place analysis on the "hubtropolis" urban form: the case of Shanghai Hongqiao air-rail hub. Habitat Int. 49, 445–453
26. CTOD, (2010). Performance-Based Transit-Oriented Development Typology Guidebook.
27. CTSHMA, (2014). Comprehensive Transportation Study for Hyderabad Metropolitan Area. Hyderabad Metropolitan Development Authority.

28. Dittmar, H. and Poticha, S. (2004). Defining Transit-Oriented development: The New Reginal Building Block, in The New Transit Town - Best Practices in Transit Oriented Development, Dittmar, H., Ohland, Gloria., Editor Island Press, p. 19-39..
29. Dumbaugh, Eric. (2004). Overcoming Financial and Institutional Barriers to TOD: Lindbergh Station Case Study. Journal of Public Transportation, 7 (3): 43-69.
30. Evans, J.E., Stryker, A., Kuzmyak, R., and Pratt, R. H. (2007). Transit Oriented Development: traveller response to transportation system changes. Transit Cooperative Research Program (TCRP) Report 95. Transportation Research Board.
31. Ewing, R., Cervero, R., (2001). Travel and the built environment: a synthesis. Transportation Research Record 1780, 87–114.
32. Fard, P. (2013). Measuring TOD: Implementing a GIS-based analytical tool for measuring existing TOD levels, Master's thesis, University of Twente, Netherlands
33. Forouhar, A., & Hasankhani, M. (2018). The effect of Tehran metro rail system on residential property values: A comparative analysis between high-income and low-income neighbourhoods. *Urban Studies*, *55*(16), 3503-3524.
34. Galelo, A.; Ribeiro, A.; Martinez, L.M. (2014). Measuring and Evaluating the Impacts of TOD Measures–Searching for Evidence of TOD Characteristics in Azambuja Train Line, *Procedia-Social and Behavioral Sciences*, 111(5): 899-908
35. Gallo, M. (2018). The Impact of Urban Transit Systems on Property Values: A Model and Some Evidences from the City of Naples. *Journal of Advanced Transportation*, *2018*.
36. Gass, S. (1985). Decision making models and algorithm. John Wiley and Sons, New York, N.Y.
37. Global Platform for Sustainable Cities, (2018). TOD Implementation Resources & Tools. World Bank, Washington, D.C.
38. Groenendijk, L., Rezaei, J., Correia, G., (2018). Incorporating the travellers' experience value in assessing the quality of transit nodes: a Rotterdam case study. Case Stud. Transport Policy 6, 564–576
39. Guthrie, A., Fan, Y., (2016). Developers' perspectives on transit-oriented development. Transp. Policy 51, 103–114.
40. Huang, R., Grigolon, A., Madureira, M., Brussel, M., (2018). Measuring transit-oriented development (TOD) network complementarity based on TOD node typology. J. Transport Land Use 11 (1), 304–324
41. Harker, P., and Vargas, L. The theory of ratio scale estimation: Saaty's analytic hierarchy process. Manage. Sci., Vol.33, No.11, 1987, pp. 1383-1403.

42. Hasibuana, H.S.; Soemardia, T.P.; Koestoerb, R.; Moersidik, S. (2014). The Role of Transit Oriented Development in constructing urban environment sustainability, the case of Jabodetabek, Indonesia, *Procedia Environmental Sciences* 20: 622- 631.
43. Hess, D. B., & Almeida, T. M. (2007). Impact of proximity to light rail rapid transit on station-area property values in Buffalo, New York. *Urban studies*, *44*(5-6), 1041-1068.
44. Hong, C., Rufolo, A.M., and Kenneth, D. (1997) "Measuring the Impact of Light Rail Systems on Single Family Home Values: A Hedonic Approach with GIS Application". *Center for Urban Studies Publications and Reports*. 35.
45. Hickman, R., Hall, P. (2008). Moving the City East: explorations into contextual public transport-orientated development. Plan. Pract. Res. 23 (3), 323–339.
46. Higgins, C.D., Kanaroglou, P.S. (2016). A latent class method for classifying and evaluating the performance of station area transit-oriented development in the Toronto region. J. Transp. Geogr. 52, 61–72
47. Ibraeva, A., Correia, G.H.d.A., Silva, C., Antunes, A.P. (2020). Transit-oriented development: A review of research achievements and challenges. Transportation Research Part A, 132: 110–130.
48. Jacobs, J. (1996). The Death and Life of Great American Cities. Vintage, New York, NY, USA.
49. Jacobson, J. and Ann, J. (2008). Seven American TODs: Good Practices for Urban Design in Transit-Oriented Development Projects. Journal of Transport and Land Use. 1. 10.5198/jtlu.v1i2.67.
50. Kamruzzaman, M., D. Baker, S. Washington, and G. Turrell. (2014). Advance transit-oriented development typology: Case study in Brisbane, Australia. Journal of Transport Geography. 34:54–70.
51. Kim, S., Ulfarsson, G., and Hennessy, J. (2007). “Analysis of Light rail rider travel behavior: impacts of individual, built environment and crime characteristics on transit access”, *Transportation Research Board Part A*, 41(6), 511–522
52. Levine, J., Inam, A. (2004). The market for transportation-land use integration: do developers want smarter growth than regulations allow? Transportation 31, 409–427
53. Li, C. N., and Lai, T. Y., (2009). Why should cities change from DOT to TOD. Proceedings of Institute of Civil Engineers, Transport 162, Issue TR2, pp. 71-79.
54. Lin, J.J., Gau, C.C., (2006). A TOD planning model to review the regulation of allowable development densities around subway stations. Land Use Policy 23 (3), 353–360

55. Lund H. M., Cervero R. and Willson R. W. (2004). Travel Characteristics of Transit-Oriented Development in California. California Department of Transportation, Sacramento, CA, USA, Caltrans Transportation Grant Report FTA Section 5313 (b).
56. Lyu, G., Bertolini, L., Pfeffer, K. (2016). Developing a TOD typology for Beijing Metro Station Areas. J. Transp. Geogr. 55, 40–50.
57. Maryland Department of Transportation. (2000). Report to Governor Parris N. Glendening from the Transit-Oriented Development Task Force. Maryland Department of Transportation.
58. McIntosh, J., Trubka, R., Newman, P. (2014). Can value capture work in a car dependent city? Willingness to pay for transit access in Perth, Western Australia. Transp. Res. Part A: Policy Pract. 67, 320–339
59. McIntosh, J., Trubka, R., Newman, P., Kenworthy, J. (2017). Framework for land value capture from investment in transit in car-dependent cities. J. Transport Land Use
60. 10 (1), 155–185.
61. Mohammad, S. I., Graham, D. J., & Melo, P. C. (2015). The effect of the Dubai Metro on the value of residential and commercial properties. *Journal of Transport and Land Use*, *10*(1).
62. Monajem, S., Nosratian, F.E. (2015). The evaluation of the spatial integration of station areas via the node place model; an application to subway station areas in Tehran. Transp. Res. Part D 40, 14–27
63. Nahlik, M.J.; Chester, M.V. (2014). Transit-oriented smart growth can reduce lifecycle environmental impacts and household costs in Los Angeles, *Transport policy* 35: 21-30
64. Noland, R.B., Weiner, M.D., DiPetrillo, S., Kay, A.I. (2017). Attitudes towards transit-oriented development: resident experiences and professional perspectives. Journal of Transport Geography. 60, pp. 130–140.
65. NTOD (National Transit Oriented Development Policy) (2017). Ministry of Urban Development, New Delhi.
66. Pawel, C. (2010). Using the Analytic Hierarchy Process in Evaluating Decision Alternatives. Operations Research and Decisions.
67. Pojani, D., Stead, D. (2014). Dutch planning policy: the resurgence of TOD. Land Use Policy 41, 357–367.
68. Queensland Guide TOD Report, (2010). guide for practitioners in Queensland, *Queensland Government*, Queensland

69. Renne, J.L. (2009). Measuring the Success of Transit Oriented Development, in Transit Oriented Development: Making it Happen, Curtis, C., Renne, J.L., and Bertolini, L., Editors., Ashgate e-Book, p. 241-257.
70. Renne, J.L. (2007). Measuring the Performance of Transit Oriented Development in Western Australia, Planning and Transport Research Centre and Institute for Sustainability and Technology Policy, Murdoch University.
71. Renne, J.L., Wells, J.S. (2005). Research Results Digest 294 - Transit Oriented Development: developing a Strategy to Measure Success. Transport Research Board of the National Academies
72. Reusser, D.E., Loukopoulos, P., Stauffacher, M., Scholz, R.W. (2008). Classifying railway stations for sustainable transitions – balancing node and place functions. J. Transp. Geogr. 16 (3), 191–202
73. Saaty, T. (1977). A scaling method for priorities in hierarchical structures: Mathematical Psychology, Vol.15, pp. 234-281.
74. Saaty, T.L. (1980). The Analytic Hierarchy Process. McGraw-Hill, New York.
75. Salat, S., Ollivier, G. (2017). Transforming the Urban Space through Transit-Oriented Development: The 3V Approach. World Bank, Washington, D.C.
76. Salvesen, D. (1996). Promoting transit-oriented development. Urban Land, 37, No. 7, 31–35.
77. Schlossberg, M., and Brown, M. (2004). “Comparing Transit Oriented Development Sites by Walkability Indicators.” *Transportation Research Record,* 1887, 34-42.
78. Still, T. (2002).Transit-oriented development: reshaping America’s metropolitan landscape. On Common Ground, Winter, 44–47.
79. Searle, G., Darchen, S., Huston, S. (2014). Positive and negative factors for Transit-Oriented Development: case studies from Brisbane, Melbourne and Sydney. Urban Policy Res. 32 (4), 437–457
80. Serge, S., and Gerald, O. (2017). Transforming the urban space through TOD: The 3V approach. World Bank Group. Washington DC. USA.
81. Singh, Y.J., Fard, P., Zuidgeest, M., Brussel, M., Maarseveen, M. (2014). Measuring transit oriented development: a spatial multi criteria assessment approach for the city region Arnhem and Nijmegen. J. Transp. Geogr. 35, 130–143
82. Singh, Y. J., P. He, J. Flacke, and M.F.A.M.V. Maarseveen. (2015). Measuring TOD Over A Region Using Gis Based Multiple Criteria Assessment Tools. The SPA Journal of Planning and Architecture. 19(1-2):1-22.

83. Singh, Y. J., M. H. P. Zuidgeest, J. Flacke & M. F. A. M. van Maarseveen. A design framework for measuring transit oriented development. The Built Environment, Vol 128. Urban Transport XVIII 719
84. Suzuki, H., Cervero, R., Iuchi, K. (2013). Transforming Cities with Transit: Transit and Land-Use Integration for Sustainable Urban Development. World Bank, Washington, D.C.
85. Seo, K., Golub, A., & Kuby, M. (2014). Combined impacts of highways and light rail transit on residential property values: a spatial hedonic price model for Phoenix, Arizona. *Journal of Transport Geography*, *41*, 53-62.
86. Staricco, L., Brovarone, E.V. (2018). Promoting TOD through regional planning. A comparative analysis of two European approaches. J. Transp. Geogr. 66, 45–52
87. Sun, H., Wang, Y., & Li, Q. (2016). The impact of subway lines on residential property values in Tianjin: An empirical study based on hedonic pricing model. *Discrete Dynamics in Nature and Society*, *2016*.
88. Tan, W., Bertolini, L., Janssen-Jansenm, L.B. (2014). Identifying and conceptualising context specific barriers to transit-oriented development strategies: the case of the Netherlands. Town Plan. Rev. 85 (5), 639–663.
89. TCRP, (2002). Transit-Oriented Development and Joint Development in the Unites States: A Literature Review. Transportation Research Board, Transit Cooperative Research Program, Research Results Digest 52, Washington, DC.
90. TCRP, (2004). Transit-Oriented Development in the Unites States: Experiences, Challenges and Prospects. Transportation Research Board, Transit Cooperative Research Program, Report 102, Washington, DC.
91. TCRP, (2008). Effects of TOD on Housing, Parking, and Travel. Transportation Research Board, Transit Cooperative Research Program, Report 128, Washington, DC.
92. Thomas, R., Bertolini, L. (2017). Defining critical success factors in TOD implementation using rough set analysis. J. Transport Land Use 10 (1), 139–154.
93. Thomas, R., Pojani, D., Lenferink, S., Bertolini, L., Stead, D., Van Der Krabben, E. (2018). Is transit-oriented development (TOD) an internationally transferable policy concept? Reg. Stud. 52 (9), 1201–1213.
94. The City of Calgary, (2004). Transit- Oriented Development : Best Practices Handbook, The City of Calgary.
95. Todd, L., & David, B. (2006) Issues in sustainable transportation. International Journal of Global Environmental Issues. 6(4). 331-347.

96. Transit Oriented Development: Developing a Strategy to Measure Success, (2009). Transport Research Board (TRB).
97. United Nations (UN). (2019). Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). New York: United Nations.
98. Urban and Regional Development Plans Formulation and Implementation (URDPFI). (2014). Guidelines, Ministry of Urban Development, Government of India, Vol. 1.
99. Vichiensan, V., & Miyamoto, K. (2010). Influence of Urban Rail Transit on House Value. *Journal of the Eastern Asia Society for Transportation Studies, 8*, 986-996.
100. Wang, L. (2010). Impact of urban rapid transit on residential property values: An empirical analysis of the Shanghai housing market. *Chinese Economy*, *43*(2), 33-52.
101. Xiangnan, L. (2011). "Analysis of TOD categories according to the differences of Land Uses." *International Conference on Technology and Education,* Chengdu, China.
102. Yan, S., Delmelle, E., & Duncan, M. (2012). The impact of a new light rail system on single-family property values in Charlotte, North Carolina. *Journal of Transport and Land Use*, *5*(2), 60-67.
103. Yang, J., Chen, J., Le, X., Zhang, Q. (2016). Density-oriented versus development-oriented transit investment: decoding metro station location selection in Shenzhen. Transp. Policy 51, 93–102.
104. Zemp, S., Stauffacher, M., Lang, D., and Scholz, R. (2011). Classifying railway stations for strategic transport and land use planning: Context matters!. Journal of Transport Geography. Vol 19(4), Pages 670-679.
105. Zhang, X., & Jiang, Y. (2014). An empirical study of the impact of metro station proximity on property value in the case of Nanjing, China. *Asian Development Policy Review*, *2*(4), 61-71.
106. Zhao, J. (2008). Study on planning methodology of TOD for Chinese cities. Master's thesis. Tsinghua University, Beijing, China.
107. Zimbabwe, S. and Anderson, A. (2011) TOD 204 Planning for TOD at Regional Scale: The Big Picture, The Center for Transit-Oriented Development.
108. Zou, M., Lin, X., Mao, C., Zhang, K., Li, M. (2014). Review on the theory and planning principle of TransitOriented Development. In CICTP 2014: Safe, Smart, and Sustainable Multimodal Transportation Systems, 3532-3547.

ANNEXURE – I

LAND USE SURVEY TEMPLATE

LAND USE SURVEY

Name of the Enumerator: **Shift No:** **Date:**

Weather (Sunny/ Cloudy/ Rainy): **Sheet No:** **TOD Name:**

Sl.No.	Zone	Building No.	Building	Address	Land Use	Floors	Parking	Status	Remarks

ANNEXURE – II

ROAD NETWORK INVENTORY SURVEY TEMPLATE

Road Network Inventory Survey																		
Name of Enumerator :							Shift No :									Date :		
Weather (Sunny/ Cloudy/ Rainy):							Sheet No:									Day:		
Link	No. of Lanes	Right of way width (m)	Divided/ Undivided 1way/ 2way	Carriage Way Width (m) (Curb to Median)			Service Lanes width (m)		Bicycle Lanes (m)		Footpaths		On Steet Parking Length (m)		Any Auto/Taxi Stand	Is it a Bus Route (Y,No)	Junction Details	
				LHS Width (m)	Median Width (m)	RHS Width (m)	LHS Width (m)	RHS Width (m)	LHS Width (m)	RHS Width (m)	LHS Width (m)	RHS Width (m)	LHS	RHS	(On Street/ Off Street)		Type (Sig/Unsig)	

ANNEXURE - III

Table 3.1: Questionnaire format for the study

NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL TRANSPORTATION ENGINEERING								
Date:						**Place:**		
Description:	The survey is done to create a model for the impact of metro on property values							
Property Value	**No. of floors**	**Age of Building**	**Area of building (sq.m)**	**Distance to Metro**	**Distance to CBD**	**Distance to nearest school/College/Park**	**No. of nearby stations**	**Frequency of trains**

ANNEXURE – IV

Expert Opinion Survey Format for AHP

In the following sheet, express your opinion in order to select amongst the alternatives. The pair wise comparison scale is used to express the importance of one criteria over another

Explanation	Numeric values
if criteria 1 and 2 are equally important: *round*	1
if criteria 1 is moderately more important than criteria 2: *round*	3
if criteria 1 is strongly more important than criteria 2: *round*	5
if criteria 1 is very strongly more important than criteria 2: *round*	7
if criteria 1 is extremely more important than criteria 2: *round*	9
even values for intermediate judgements: *round*	2, 4, 6, 8

Criteria 1	extremely		very strongly		strongly		moderately		equally		moderately		strongly		very strongly		extremely	Criteria 2
Mixed Landuse	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Proportion of Transportation Area**
Mixed Landuse	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Population Density**
Mixed Landuse	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Employment Density**
Mixed Landuse	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Lane Kilometer**
Mixed Landuse	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Junction Density**
Proportion of Transportation Area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Population Density**
Proportion of Transportation Area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Employment Density**
Proportion of Transportation Area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Lane Kilometer**
Proportion of Transportation Area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Junction Density**
Population Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Employment Density**
Population Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Lane Kilometer**
Population Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Junction Density**
Employment Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Lane Kilometer**
Employment Density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Junction Density**
Lane Kilometer	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Junction Density**

ANNEXURE – V

Expert Opinion Survey Data

In the following sheet, express your opinion in order to select amongst the alternatives. The pair wise comparison scale is used to express the importance of one criteria over another

Criteria 1	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10	Expert 11	Expert 12	Expert 13	Expert 14	Expert 15	Criteria 2
Mixed Landuse	2	2	3	2	2	2	2	3	2	2	2	2	1	1	2	Proportion of Transportation Area
Mixed Landuse	3	3	3	5	2	5	3	5	7	7	3	5	3	3	3	Population Density
Mixed Landuse	3	2	3	3	3	5	5	3	5	3	7	7	3	5	3	Employment Density
Mixed Landuse	5	7	9	5	5	5	7	7	3	3	9	9	5	5	7	Lane Kilometer
Mixed Landuse	7	5	5	9	5	7	5	7	9	3	3	7	5	9	5	Junction Density
Proportion of Transportation Area	2	3	1	3	1	3	1	3	1	3	3	2	3	2	3	Population Density
Proportion of Transportation Area	3	2	3	1	3	1	3	1	3	3	1	3	2	2	3	Employment Density
Proportion of Transportation Area	5	3	3	3	5	2	7	5	3	7	3	3	3	3	5	Lane Kilometer
Proportion of Transportation Area	3	2	7	3	3	5	5	3	5	3	3	7	3	5	3	Junction Density
Population Density	1	1	1	1	1	3	1	1	3	1	1	3	1	3	1	Employment Density
Population Density	2	3	3	1	5	3	3	1	3	2	3	3	1	3	2	Lane Kilometer
Population Density	3	5	3	3	3	5	2	7	5	7	3	5	3	3	3	Junction Density
Employment Density	3	2	3	3	3	1	1	1	3	3	1	3	3	2	2	Lane Kilometer
Employment Density	5	3	2	3	3	5	3	5	3	7	3	3	5	3	7	Junction Density
Lane Kilometer	2	3	2	1	1	3	3	1	3	2	3	3	1	3	2	Junction Density

List of Publications

International Journal Publications

1. **Lokku, P.S**., Prasad, C.S.R.K., Bala Krishna K. (2020). "A Local level Transit-Oriented Development Typology: Using Two-Step Clustering Technique". Transportation Research, Lecture Notes in Civil Engineering, volume 45, Pages 39-50. Springer, Singapore.
2. **Lokku, P.S**., and Prasad, C.S.R.K. (2019). "Prioritization of Transit Stations to Promote as Transit-Oriented Development Using Analytic Hierarchy Process", Trends in Transport Engineering and Applications, Volume 6-2, Pages 14-29.
3. **Lokku, P.S**., and Prasad, C.S.R.K., "Frame Work for Establishing Feasible Transit Oriented Development Locations: A Case Study in Hyderabad, India", International Journal for Traffic and Transport Engineering, Volume 8, Issue-2 (2018), Pages 228-240.
4. **Lokku, P.S**., and Prasad, C.S.R.K., "Travel Demand Estimation through Corridor Analysis for Hyderabad Metro Rail", International Journal of Engineering & Technology, Volume 7, Issue-2.23 (2018), Pages 323-327.
5. **Lokku, P.S**., Swetha, Y. and Prasad, C.S.R.K., "Hedonic Price Modeling to Measure the Residential Property Value in TOD Area, Hyderabad Metro Rail", Suranaree Journal of Science and Technology. (Under Review).

International / National Conference

6. **Lokku, P.S**., Prasad, C.S.R.K., "Measuring Transit-Oriented Development (TOD): Towards Assessment, Planning and Evaluation", Transportation Research Board Annual Meeting, 25-29 January 2021.
7. **Lokku, P.S**., and Prasad, C.S.R.K., "Implementation Strategies to Make Cities Sustainable Through emphasizing TOD concept: Indian Context", 26th ITS World Congress, Singapore, 21-25 October 2019.
8. **Lokku, P.S**., Chandrasekhar, Y., Prasad C.S.R.K., Abhigna, D., "Analysing the Travel behaviour for compact and sprawl Area", Innovative Trends in Civil Engineering for Sustainable Development (ITCSD), NIT Warangal, 13-15 September 2019.
9. Chandra Kumar Y. J., Kumar. M., **Lokku, P.S**., Prasad CSRK, "Role of Transit Oriented Growth Centres in Transformation of the Urbanization Process for Hyderabad

Metropolitan Region", Innovative Trends in Civil Engineering for Sustainable Development (ITCSD - 2019), NIT Warangal, 13-15 September 2019.

10. **Lokku, P.S**., and Prasad, C.S.R.K., "An Exploratory Analysis for successful TOD with respect to Design Aspects based on existing scenario", All India Seminar on Transit Oriented Development in Urban Areas, The Institute of Engineers (India), 19-20 January2018.
11. **Lokku, P.S**., Prasad, C.S.R.K., and Balakrishna, K. "Transit Oriented Development Typology", 4th Conference of Transportation Research Group of India (CTRG), Indian Institute of Technology Bombay, Mumbai, 17-20 December 2017.
12. **Lokku, P.S**., and Prasad, C.S.R.K., "Planning of TOD Implication for Dense Cities in Indian Context", World society for Transport & Land Use Research (WSTLUR), Brisbane, Australia, 3-6 July 2017
13. **Lokku, P.S**., Suhas, T., and Prasad, C.S.R.K., "Implementation Plan based on TOD Typology by Spatial Analysis using GIS for Dense Cities", 12th Transportation Planning and Implementation Methodologies for Developing Countries (TPMDC), Indian Institute of Technology Bombay, Mumbai, 19-21 December 2016.
14. **Lokku, P.S**., and Prasad, C.S.R.K., "Issues and Challenges in Implementing Transit Oriented Development", Indian National Group of IABSE, Seminar, Visakhapatnam, 21-22 October 2016.

Brief CV

Name: **Prashanth Shekar Lokku**
Address: 2-4-454/1, Ramnagar,
Hanamkonda,
Warangal-500056
Mobile: **+91-9177140004**
e-mail: LPS.LOKKU@gmail.com
prashanth.lokku@student.nitw.ac.in

Profile

Mr Prashanth Shekar Lokku is currently pursuing Doctor of Philosophy (PhD) in Civil Engineering with Transportation Engineering specialisation at NITW. He has a total of 10 years' experience including 5 years in industry and 5 years in research. His research interests are Transit-Oriented Development, Urban and Regional Transportation Planning, Road Safety, GIS for Transportation, Travel Demand Modelling, Sustainable Transportation and Traffic Engineering. He has published more than 10 papers in international journals and conferences. He visited Australia and Singapore for presenting the research work in conferences during PhD. As a Transportation Engineer in the industry, he has involved in various kinds of projects such as Transport Planning, Travel Demand Modelling, Developing Route Choice and Mode Choice Models, Design of At-Grade and Grade Separated Intersections, Micro/Macro Simulation and Highway projects (DPR/DFR).

Software skills

EMME, LIMDEP, VISSUM, VISSIM, ArcGIS, SQLserver (DataBase Management), SPSS Statistics, Stata, AutoCAD, Adobe Photoshop, AutoCAD Civil 3D, and MS-Office

Education Qualification

Role	University/Organisation	Year
Research Scholar (PhD)	National Institute of Technology, Warangal	2015 - Till date
Post-Graduation (Transportation Engineering)	National Institute of Technology, Warangal	2007 - 2009
Graduation (Civil Engineering)	Osmania University, Hyderabad	2003 - 2007

Professional Career

Role	University/Organisation	Year
Transportation Engineer/ Planner	Lea Associates South Asia Pvt. Ltd.	2011 - 2014
Transportation Engineer	Egis India Consulting Engineers Pvt. Ltd.	2010 - 2011
Engineer	Indian Road Survey Management Pvt. Ltd./ Australian Road Research Board (ARRB)	2009 - 2010